Planetary Boundaries

Amy Wesolowski

Climate Change Seminar
University of Minnesota

14 October 2009

Abstract

Rockström *et al.*, **Planetary Boundaries: Exploring the safe operating space for humanity**, *Ecology and Society, In Press 14th September 2009.*

Anthropogenic pressures on the Earth System have reached a scale where abrupt global environmental change can no longer be excluded. We propose a new approach to global sustainability in which we define planetary boundaries within which we expect that humanity can operate safely. Transgressing one or more planetary boundaries may be deleterious or even catastrophic due to the risk of crossing thresholds that will trigger non-linear, abrupt environmental change within continental- to planetary-scale systems.

New Challenges Require New Thinking on Global Sustainability

- Focus on the biophysical processes of the Earth System that determine the self-regulating capacity of the planet
- The set of boundaries represent the dynamic biophysical 'space' of the Earth System within which human has evolved and thrived.
- Offering a new approach to global sustainability that looks at key indicators of welfare for humanity.
- Assesses the risks of pushing outside of Earth System boundaries.

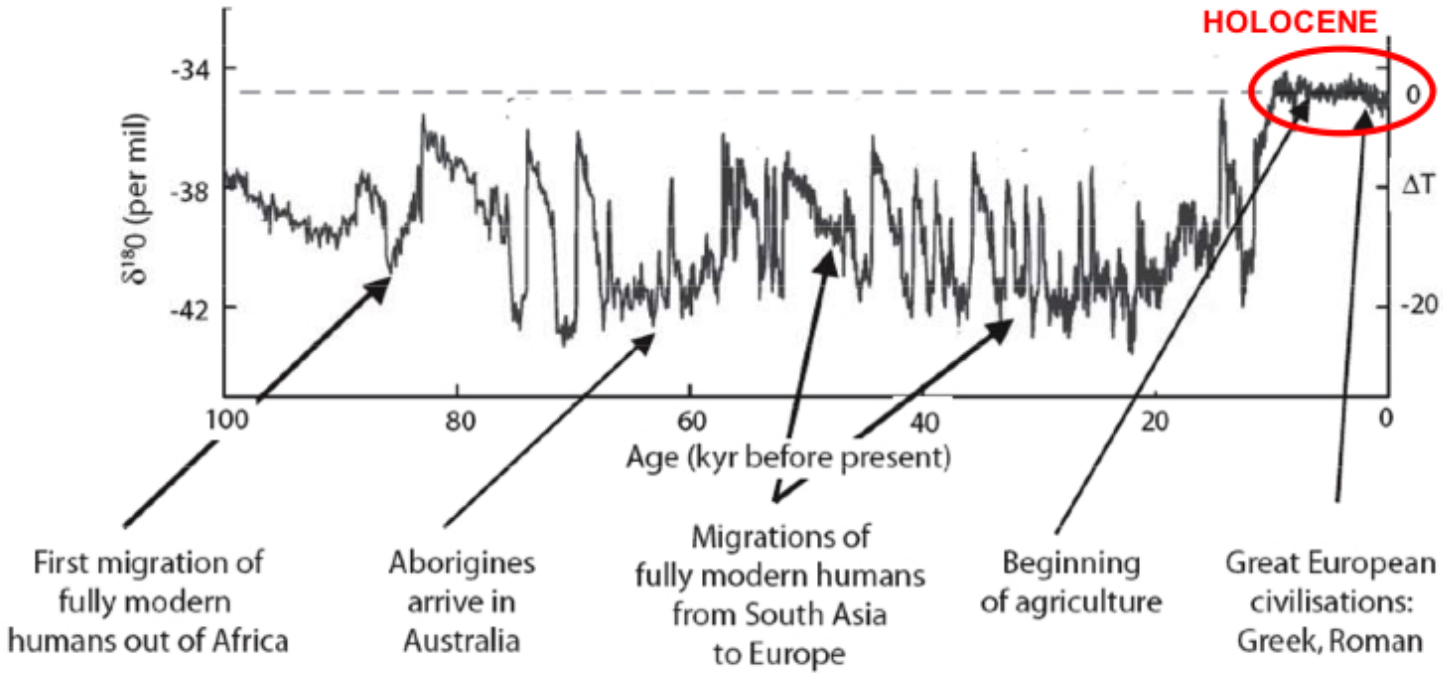


Figure 1. The last glacial cycle of 18O (an indicator of temperature) and selected events in human history. The Holocene is the last 10,000 years. Adapted from Young and Steffen (2009).

The Concept of Planetary Boundaries

- **Thresholds** are defined as non-linear transitions in the functioning of coupled human-environmental systems. Thresholds are intrinsic features of Earth Systems (such as the ice-albedo feedback in the case of sea ice). These are determined through current scientific understanding.
- **Boundaries** are human-determined values of the control variable set at a 'safe' distance from a dangerous level (for processes without known thresholds at the continental to global scales) or from its global threshold. These boundaries are set using normative judgments of how societies choose to deal with risk and uncertainty.

Criteria and Process for Identifying Planetary Boundaries

- Selection is determined from the definition of what constitutes unacceptable human-induced global environmental change.
- Overall, the position of the boundary is a function of the degree of risk the global community is willing to take. It also takes into account the social and ecological resilience of the impacted societies.
- Boundaries are identified by the time needed to trigger an abrupt irreversible change.

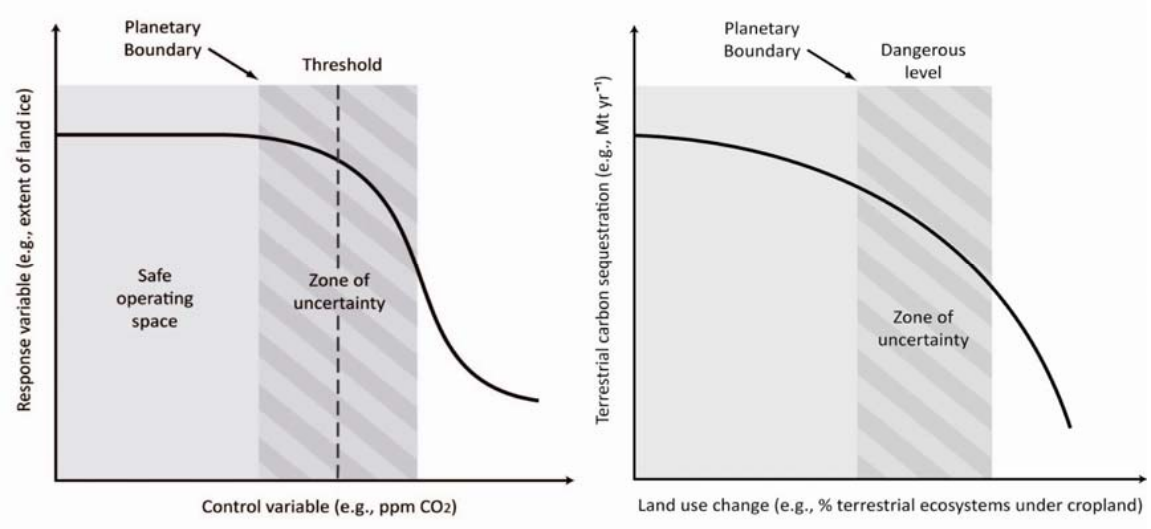


Figure 2a b. Conceptual description of planetary boundaries. In (a) the boundary is designed to avoid the crossing of a critical continental to global threshold in an Earth System process. Insufficient knowledge and the dynamic nature of the threshold generate a zone of uncertainty about its precise position, which informs the determination of where to place the boundary. In (b) there is no global threshold effect as far as we know, but exceeding the boundary level will lead to significant interactions with regional and global thresholds, and/or may cause a large number of undesired threshold effects at the local to regional scale which on aggregate add up to a serious global concern for humanity.

List of Planetary Boundaries

- Climate Change
- Ocean Acidification
- Stratospheric Ozone Depletion
- Atmospheric Aerosol Loading
- Biogeochemical Flows: Inference with P and N Cycles
- Global Freshwater Use
- Land System Change
- Biodiversity Loss
- Chemical Pollution

Table 1. Categories of Planetary Boundaries.

Boundary character / Scale of process	Processes with global scale thresholds	Slow processes without known global scale thresholds
Systemic processes at planetary scale	Climate Change	
	Ocean Acidification	
		Stratospheric Ozone
Aggregated processes from local/regional scale	Global P and N cycles	
	Atmospheric Aerosol Loading	
	Freshwater Use	
	Land Use Change	
	Biodiversity Loss	
	Chemical Pollution	

Climate Change

Boundary Goal: Avoid crossing the critical thresholds that separate qualitatively different climate system states.
Data Used: Atmospheric CO_2 and radiative forcing as global-scale control variables. Used to calculate the equilibrium sensitivity of the climate system to greenhouse gas forcing, behavior of polar ice sheets, and current behavior of the climate system.
Boundary: Boundary value of 350 ppm CO_2 and 1 W m^{-1} above pre-industrial level.

Ocean Acidification

Boundary Goal: Maintain the ocean's ability to function as a CO_2 sink, maintain and reduce the depletion of aragonite-forming organisms, and maintain coral reefs and associated ecosystems.
Data Used: Ocean aragonite saturation state.
Boundary: Maintain ocean aragonite saturation state at 80% the average global pre-industrial surface seawater of 3.44.

Stratospheric Ozone Depletion

Boundary Goal: Reduce the thinning of extra-polar stratospheric ozone.
Data Used: Tropospheric concentrations of ozone-depleting gases.
Boundary: Less than 5% decrease in column ozone levels for any particular latitude w/r/t 1964-1980 values.

Nitrogen and Phosphorus Cycles

Boundary Goal: Reduce the effect of eutrophication due to human-induced influxes of N and P. (P) Reduce the risk of global-scale ocean anoxic events (OAE).
Data used: (N) Human fixation of N_2 from the atmosphere.
Boundary: (N) Set at 24% of its current value.

Biodiversity Loss

Boundary Goal: Reduce biodiversity loss to increase ecosystem resilience to disturbances and maintain ecosystems' ability to respond to and adapt to change in physical and biotic conditions. Decrease the annual rate of extinction.
Data Used: Using extinction rate as a proxy for the regulation rate of biodiversity.
Boundary: Extinction rate of 10 per million species per year.

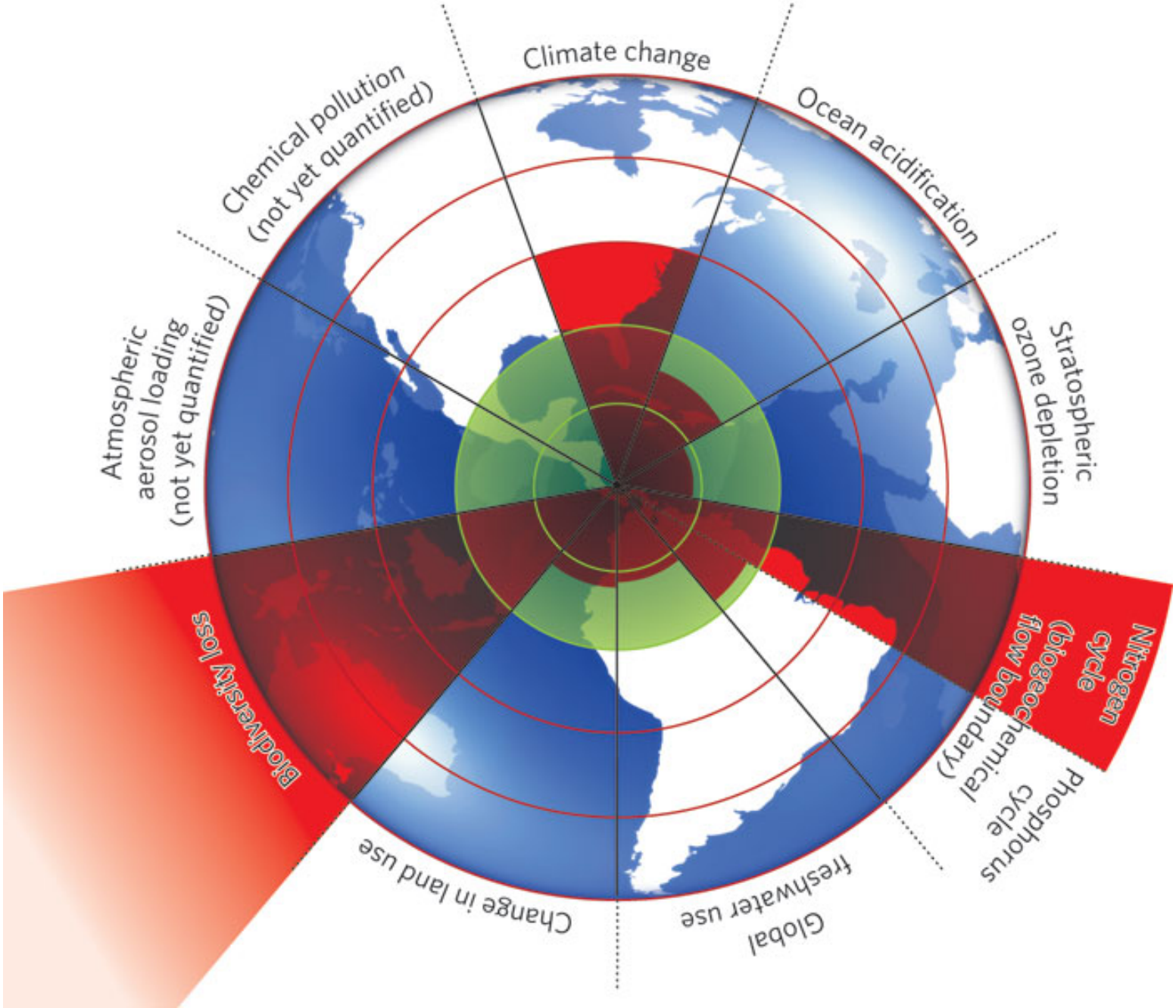
Global Freshwater Use

Boundary Goals: Maintain the current availability of freshwater to maintain biodiversity, food and health security, and ecological functioning. Reduce the threat to human livelihood in terms of soil moisture resources, available potable water, and precipitation patterns.
Data Used: Runofff depletion in the form of consumptive runoff or blue water use as a proxy.
Boundary: 4,000 km^3 yr^{-1} of consumptive blue water use.

Land System Change

Boundary Goals: Maintain our current production of food, regulation of freshwater flows, and ecosystem functioning services.
Data Used: Land use coverage.
Boundary: Less than 15% of global ice-free land surfaced converted to cropland. Moreover, cropland should be only allocated to high-productivity land and agricultural systems should mimic natural processes.

Aerosol Loading and Chemical Pollution


Climate change
Ocean acidification
Stratospheric ozone depletion
Nitrogen cycle (biogeochemical flow boundary)
Phosphorus cycle
Global freshwater use
Change in land use
Biodiversity loss
Atmospheric aerosol loading (not yet quantified)
Chemical pollution (not yet quantified)

PLANETARY BOUNDARIES

Earth-system process	Parameters	Proposed boundary	Current status	Pre-industrial value
Climate change	(i) Atmospheric carbon dioxide concentration (parts per million by volume)	350	387	280
	(ii) Change in radiative forcing (watts per metre squared)	1	1.5	0
Rate of biodiversity loss	Extinction rate (number of species per million species per year)	10	>100	0.1–1
Nitrogen cycle (part of a boundary with the phosphorus cycle)	Amount of N_2 removed from the atmosphere for human use (millions of tonnes per year)	35	121	0
Phosphorus cycle (part of a boundary with the nitrogen cycle)	Quantity of P flowing into the oceans (millions of tonnes per year)	11	8.5–9.5	~1
Stratospheric ozone depletion	Concentration of ozone (Dobson unit)	276	283	290
Ocean acidification	Global mean saturation state of aragonite in surface sea water	2.75	2.90	3.44
Global freshwater use	Consumption of freshwater by humans (km^3 per year)	4,000	2,600	415
Change in land use	Percentage of global land cover converted to cropland	15	11.7	Low
Atmospheric aerosol loading	Overall particulate concentration in the atmosphere, on a regional basis		To be determined	
Chemical pollution	For example, amount emitted to, or concentration of persistent organic pollutants, plastics, endocrine disrupters, heavy metals and nuclear waste in, the global environment, or the effects on ecosystem and functioning of Earth system thereof		To be determined	

Boundaries for processes in red have been crossed. Data sources: ref. 10 and supplementary information

Arguments Against Planetary Boundaries

- This research is using existing data sets that are not robust, out of date, have high error bars, and are poor proxies
- Setting targets is not useful for science or policy makers
- Uses blunt instruments as measurement tools that are inaccurate
- Ignores important aspects of the Earth System
- Ignores societal dynamics
- Does not take into account population dynamics