Planetary boundaries

In the latest issue of *Nature*, a group of leading academics argue that humanity must stay within defined boundaries for a range of essential Earth-system processes to avoid catastrophic environmental change (*Nature* **461**, 472–475; 2009). In proposing the concept of 'planetary boundaries', Johan Rockström of the Stockholm Resilience Centre and co-authors present a new framework for measuring stress to the Earth system and define a safe operating space for human existence on this planet.

Rockström and co-authors suggest preliminary boundaries for the following indicators of environmental change: climate, ocean acidification, stratospheric ozone depletion, freshwater use, biodiversity, the global cycles of nitrogen and phosphorus, and land-use change. They propose that for three of these — the nitrogen cycle, the rate of loss of species and anthropogenic climate change — the maximum acceptable limit has already been transgressed. In addition, they say that humanity is fast approaching the boundaries for freshwater use, for converting forests and other natural ecosystems to cropland and urban areas, and for acidification of the oceans. Crossing even one of these planetary boundaries would risk triggering abrupt or irreversible environmental changes that would be very damaging or even catastrophic for society. Furthermore, if one boundary is transgressed, then there is a more serious risk of breaching the other boundaries.

In this series of Commentaries, seven renowned experts respond to the planetary boundaries concept. Though collectively they represent a broad spectrum of interests across Earth and environmental sciences, each author brings specific expertise to evaluating one aspect of the proposed framework. They ask whether we can currently define, even roughly, the acceptable upper bounds for indicators of environmental degradation, and whether doing so would ultimately help or hinder efforts to protect the planet.

Thresholds risk prolonged degradation

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For nitrogen deposition as for other pollution, waiting until we approach the limits of environmental degradation merely allows us to continue our bad habits until it's too late to change them.

Thresholds are comforting for decision-makers. There is no controversy when a high-jumper makes the bar, in contrast to a figure-skater who wins based on form and execution. When the skater doesn't make the grade, there is endless debate about whether the judges were too harsh and what revisions are needed in scoring procedures.

In personal health, as long as we are alive we can be pretty sure we haven't crossed a threshold of dire consequence. But in many cases, identifying and waiting for thresholds also allows misbehaviour that might be better nipped in the bud. Humans don't die of the first cigarette they inhale, but the slow cumulative effects of smoking can hasten the journey towards one's ultimate personal threshold.

Ecologists believe there are numerous thresholds in nature (*Nature* **413,** 591–596; 2001). As we see anthropogenic changes in the Earth system, we need to decide whether we want to allow human activities to disrupt Earth's life-support processes, or whether to begin now to sustain something that is pleasant and potentially more healthful for humans and the other species that share this planet with us. Ongoing changes in global chemistry should alarm us about threats to the persistence of life on Earth, whether or not we cross a catastrophic threshold anytime soon.

Rockström *et al.* (*Nature* **461,** 472–475; 2009) guess that an acceptable human impact on the global nitrogen cycle should not exceed 25 per cent of the current anthropogenic transfer of nitrogen from the atmosphere to the land surface. This threshold for nitrogen seems arbitrary and might just as easily have been set at 10 per cent or 50 per cent. Since nitrogen can also be denitrified by soil bacteria and ecosystem remediation is theoretically possible, greater human impacts might potentially be tolerated with proper management (*Proc. Natl Acad. Sci. USA* **106,** 203–208; 2009).

But is a threshold really a good idea at all? In areas of excess nitrogen deposition from the atmosphere — for example, in pastures in Great Britain — species decline linearly as a function of increasing nitrogen inputs to the land (*Science* **303,** 1876 –1879; 2004). Some experimental studies with nitrogen fertilizer show a greater loss of species at low levels of excess nitrogen deposition, with diminishing incremental effects thereafter (*Nature* **451,** 712–715; 2008). Waiting to cross the threshold allows much needless environmental degradation.

Rockström *et al.* set a lenient limit for acceptable human perturbation of the global phosphorus cycle, suggesting it should not exceed ten times the background weathering of phosphorus. But if we cross a threshold for phosphorus that leads to deep oceanic anoxia, we risk a truly dire situation. And lower levels of phosphorus input have well-documented effects on fresh water, which led regulators to set limits on the phosphorus content of detergents nearly 40 years ago.

Moreover, the background value for phosphorus is difficult to estimate. Rivers now carry an estimated 22×10^{12} grams of phosphorus per year (gP yr^{-1}) to the sea, but an unknown fraction of that is derived from human activities (*Treatise on Geochemistry* Vol. 8, 585–643; Elsevier, 2005). Not all phosphorus in rivers is reactive; most is bound to iron and aluminium minerals and is rapidly deposited in marine sediments. The current human contribution to reactive phosphorus in river waters (about