

# A PLANET ON THE EDGE

Maintaining the planet's stable climate would seem like a good idea. Scientists have now identified what they think are the nine Earth systems that do just that. But it looks like we have already crossed three of the boundaries that keep us a safe distance from dangerous thresholds.

In September, Johan Rockström from the Stockholm Resilience Centre and colleagues published an article in the journal *Nature* entitled 'A safe operating space for humanity'.

Rockström argued that our civilisation has thrived on environmental stability: as long as society knew what was coming up it could plan for the future. This easy predictability allowed agriculture to develop then flourish. This helped the global population to swell to six billion people. And it has enabled us to tame our environment. We make the environment work for us on a global scale. In short, we rely on environmental stability to support our society and the economy.

The best available evidence says this stability, which we know has lasted 11,000 years, is now in jeopardy. During this stable period – the Holocene – a range of globally-important biogeochemical parameters fluctuated within a narrow band. In the distant past, large shifts in some of these parameters have been associated with planetary-scale environmental change.

Now, our own burgeoning civilisation is overwhelmingly responsible for pushing some

of these parameters beyond the narrow range required to remain in a similar stable state. But how far can we push before we subject ourselves to a catastrophic shift on a global scale? Without humans, the planet's climate would likely stay in this stable state for a few thousand years before slipping into the next ice age. This now looks unlikely. When you look at the problem from this point of view, says Rockström and colleagues, it becomes apparent that the Holocene climate is the desired state for society and the economy.

## Stepping out

But we are moving outside of the Holocene envelope. In an astonishingly short period – 250 years – civilisation has generated the capacity to rock the global Earth system in a way it has not been pushed for millions of years. Does our society have the mechanisms to rein this in? Not yet, but the starting point must be to establish what the Holocene's boundaries are, where their limits lie, and then to estimate how close we are to those limits.

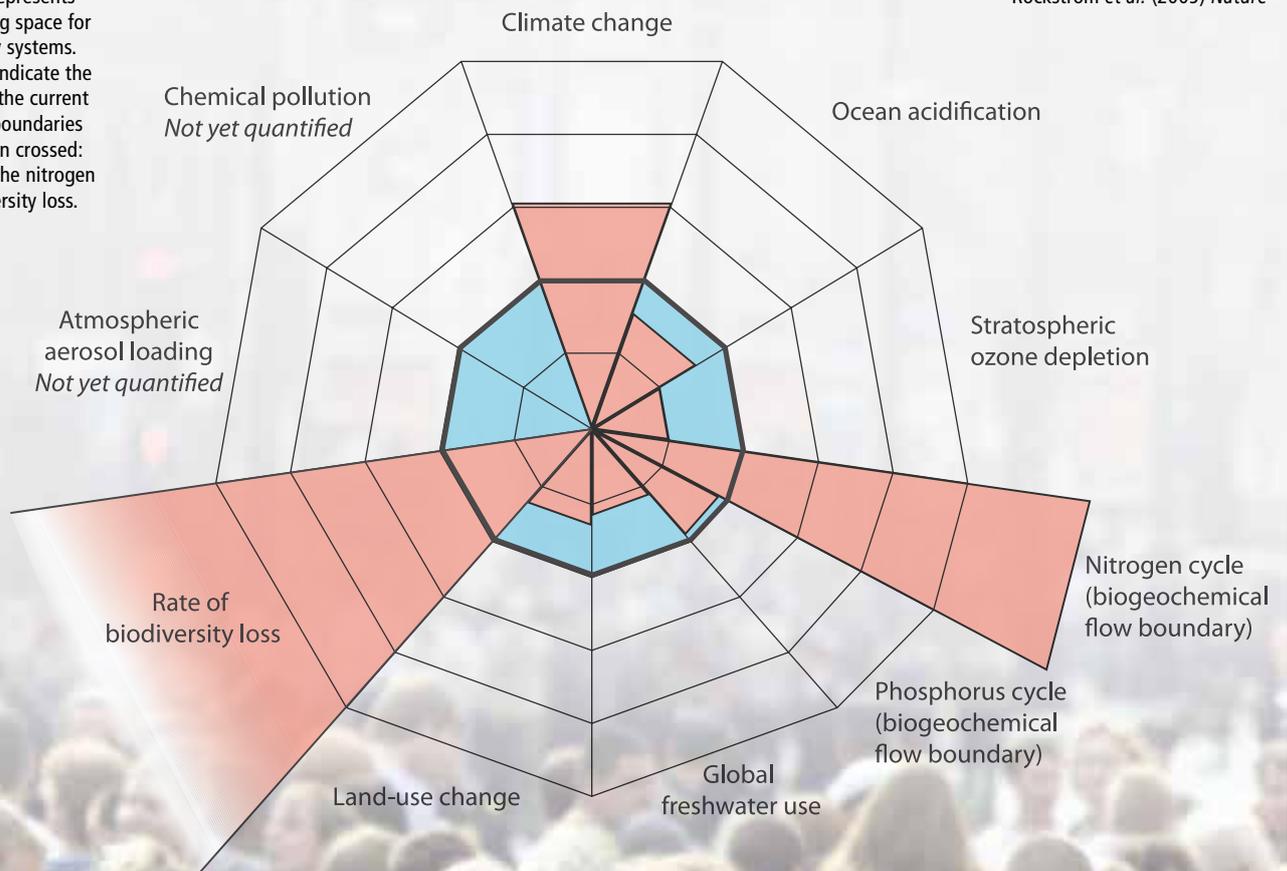
The planetary-boundaries concept has been gestating for

several years. Nine of the paper's authors are closely linked to IGBP, including two former executive directors, Kevin Noone and Will Steffen and a former vice chair, Paul Crutzen. IGBP's executive director Sybil Seitzinger and chair Carlos Nobre have also been involved in discussions and workshops. Rockström asked scientists from many disciplines – climatologists, ecologists, oceanographers, land-use specialists, hydrologists and others – "which Earth-system processes must we be stewards of to remain within the desired state?"

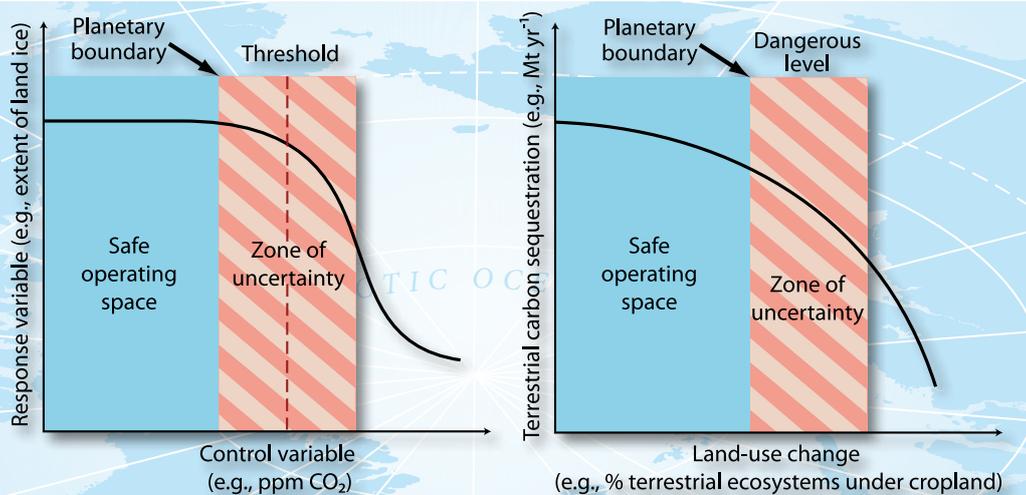
The experts identified just nine boundaries: climate change, biodiversity loss, interference with the nitrogen and phosphorus cycles, stratospheric ozone depletion, ocean acidification, global freshwater use, change in land use, chemical pollution and atmospheric aerosol loading. The boundaries are interlinked and the authors suggest we have overstepped three of them: atmospheric carbon dioxide concentration, biodiversity loss and the nitrogen cycle. We are close to the boundaries of a further three: land use, fresh water and ocean acidification.

**We have overstepped three boundaries.**

The inner circle represents the safe operating space for the key planetary systems. The red wedges indicate the best estimate of the current situation. Three boundaries have already been crossed: climate change, the nitrogen cycle and biodiversity loss.



Credit: Istockphoto



Two types of boundary are identified. On the left is a boundary marking the safe limit to avoid crossing a threshold in the Earth system that would cause, for example, ice-sheet collapse. On the right, there is no known threshold but crossing the boundary will lead to large-scale effects of serious global concern.

Rockström *et al.* (2009) *Nature*

## Early days

The nine boundaries and their suggested limits define a “safe operating space for humanity”. The authors stress that this work is still preliminary, some of the thresholds need closer investigation to improve estimates, and two, aerosols and chemical pollution, have no limits yet imposed. There is simply too little information to make estimates.

The estimates for seven of the boundaries are possible because of the tremendous effort by the international research community over the last few decades to understand the planet’s biogeochemical cycles and how these cycles have changed throughout Earth’s history.

One upshot of this research is the knowledge that the planet’s response to major changes is non-linear. Take glaciers, for example. As atmospheric carbon dioxide levels increase they react in a relatively limited way for a long time before reaching a threshold, then they can melt rapidly. The exact position of a threshold is extremely difficult, if not impossible, to pinpoint. So, a planetary boundary is the safe level, based on the best available evidence, beyond which you don’t want to transgress for fear of crossing the threshold. “We have put this

**If you are heading for an abyss wearing a blindfold, you should stop the car.**

boundary at the lower edge of the uncertainty level around this threshold,” says Rockström.

The *Nature* feature concludes, “The evidence so far suggests that, as long as thresholds are not crossed, humanity has the freedom to pursue long-term social and economic development.”

But the conclusion drawn from the longer paper in *Ecology and Society*, upon which the *Nature* paper is based, is bleaker. The complexities and interconnectedness of the dynamic Earth system makes it remarkably resilient to external pressure, even the massive pressure we now exert. But this is lulling us into a false sense of security. “Incremental change can lead to the unexpected crossing of thresholds that drive the Earth system, or significant sub-systems, abruptly into states deleterious or even catastrophic to human well-being.”

## Some critics

The idea of interlinked boundaries when framing the planetary-scale challenges facing humanity is an interesting and powerful concept that changes how policymakers can address the problem. But it is not without its critics.

Setting boundaries for policymakers can allow potentially indefinite slow degradation,

argues William Schlesinger from the Cary Institute of Ecosystem Studies in New York. Schlesinger also says the cap on phosphorus is too lenient. “If we cross a threshold for phosphorus that leads to deep-oceanic anoxia, we risk a truly dire situation.”

The land-use boundary – no more than 15 percent of the global ice-free land surface should be converted to cropland – has also come under fire. Stephen Bass from the International Institute for Environment and Development in London suggests a limit on soil degradation or soil loss would be a more useful boundary because there is a big difference between intensive and more sustainable farming techniques. But Rockström *et al.* argue that land-use change can trigger rapid continental-scale changes. For example, IGBP chair Carlos Nobre and colleagues believe there is strong evidence that as more of the Amazon rainforest is turned over to cultivation and grazing, eventually a threshold will be crossed that transforms the basin to semi-arid savannah (see news page 7). This would likely have consequences for the Earth’s climate system. So, perhaps soil degradation should be an additional boundary.

Setting the climate boundary at 350 parts per million CO<sub>2</sub> is arguably the most contentious. Myles Allen from the University of Oxford argued in *Nature*, and at a recent IGBP/Royal Swedish Academy of Sciences Stockholm symposium, that this boundary misses the point. CO<sub>2</sub> should be viewed as a non-renewable resource. To avoid dangerous climate change we should stop emitting carbon to the atmosphere once we reach one trillion tonnes. Michael Raupach from the Global Carbon Project points out on page 24 that, if this is the limit, we have just passed peak CO<sub>2</sub>.

The annual freshwater consumption boundary of 4000 cubic kilometres could well be too high. More consensus is needed on

extinction rates, set at ten species per million per year. And the chemical pollution boundary may prove impossible to figure out – there are up to 100,000 chemicals on the global market.

While researchers have been critical of the detail, the boundaries concept has had a positive reception, particularly regarding consequences for policy. Bass says, the “paper has profound implications for future governance systems.” He argues it offers some of the wiring needed to link global and national economic governance with governance of natural resources.

### Inadequate governance

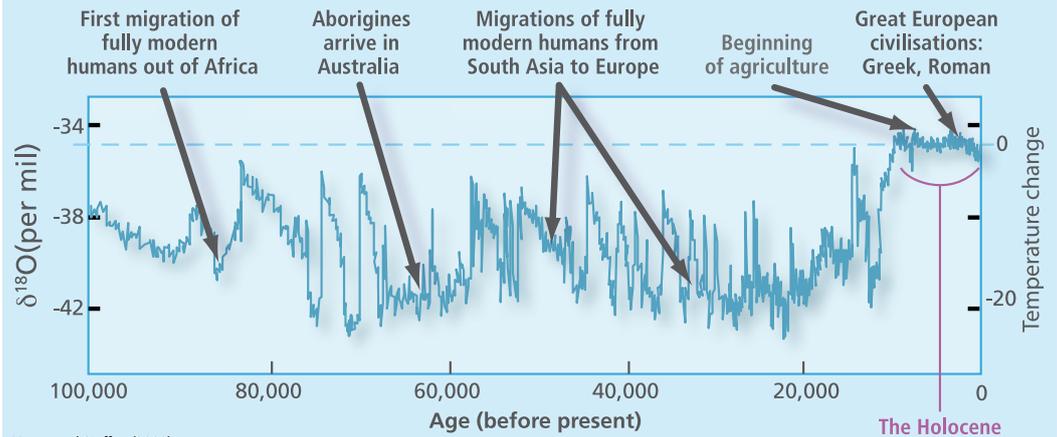
In recent years, the environmental science community at all levels has been asked to make its outputs more policy relevant. An upshot of this, for example, has been a major drive on climate-change research focused on local-to-regional space scales and timescales of days to decades. Policy, it is believed, works more effectively at these scales.

But the boundaries concept appears, on the face of it, to take us back to the global. The authors say current governance systems are often oblivious to or lack a mandate to act on planetary risks, despite evidence that pressures on biophysical processes of the Earth systems are accelerating.

If the planetary-boundaries concept proves sound – further analysis from a larger community is required – it throws down the gauntlet to policymakers. The paper suggests in no uncertain terms that governance systems are inadequate to address the scale of the problem, not just at a planetary level, but also at regional and local scales. This is why the planetary boundaries concept may prove so attractive: governments prefer dealing with boundaries than uncertainties.

UN Secretary-General Ban Ki-moon told the World Climate

## HUMAN DEVELOPMENT AND GLACIAL-INTERGLACIAL CYCLING



Young and Steffen (2009)

## 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	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 <sub>2</sub> 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 <sup>3</sup> per year)	4000	2600	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 disruptors, heavy metals and nuclear waste in the global environment, or the effects on ecosystem and functioning of the Earth system	to be determined		

Boundaries for processes in red have been crossed. Data source: Rockström *et al.* (2009) *Nature*

Conference in Geneva in August that we have our foot on the accelerator and we are heading for an abyss. At the IGBP symposium in September, Rockström responded that if you are heading for an abyss wearing a blindfold, you should stop the car. ■

Written by OWEN GAFFNEY.

**Governments prefer dealing with boundaries.**

### Further information

[www.nature.com/news/specials/planetaryboundaries/index.html](http://www.nature.com/news/specials/planetaryboundaries/index.html)

### Video

Johan Rockström's presentation at the IGBP-KVA symposium Planet Under Pressure [www.igbp.net](http://www.igbp.net)

Johan Rockström

[www.stockholmresilience.org](http://www.stockholmresilience.org)