

SNC2D - The nine planetary boundaries project

Background

The idea that the planet has nine boundaries that humanity must live within to ensure a safe living space is an idea that was first thought of in 2009 by the Stockholm Resilience Centre in Stockholm, Sweden. It has been updated in 2015 with data that reflects the current situation in all of the nine boundaries. The idea of the nine boundaries is that crossing any one or more of them may be catastrophic for Earth and humanity and trigger major environmental changes. The report has given a quantitative limit or upper threshold for seven of the nine, and reports on the current values around the world. Climate change is one of them.

Resources:

- Visit <http://www.stockholmresilience.org/research/planetary-boundaries.html> for information on their [Stockholm Resilience's research](#).
- Visit <https://www.ecologyandsociety.org/vol14/iss2/art32/> to read the [full study](#).
- Visit <https://www.youtube.com/watch?v=RgqtrlixYR4> to watch a [TED Talk](#). (18 mins)
- Visit <http://www.stockholmresilience.org/research/planetary-boundaries/planetary-boundaries-data.html> to view [the study's data and figures](#).
- Visit <http://www.stockholmresilience.org/research/planetary-boundaries/planetary-boundaries/about-the-research/the-nine-planetary-boundaries.html> for a [summary of each boundary](#).

Activity

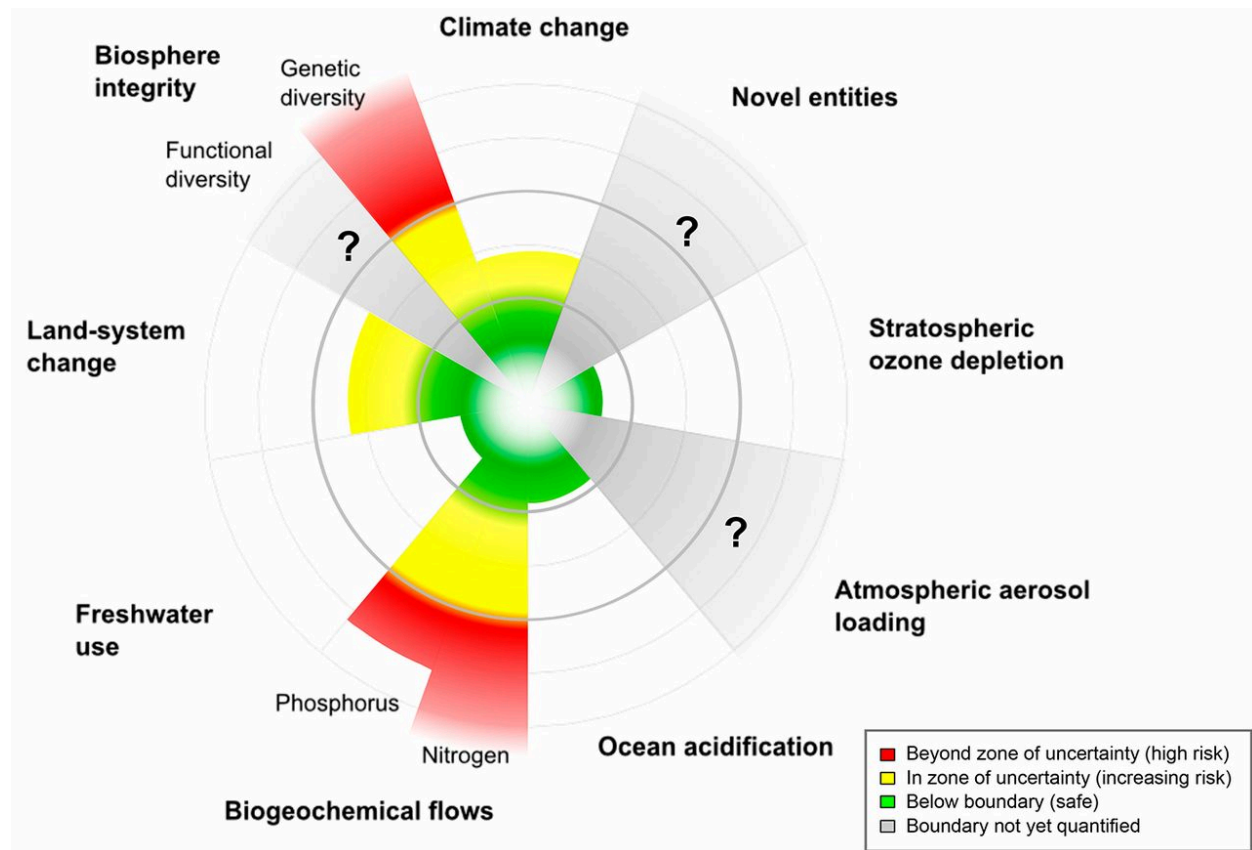
To introduce the topic to the students briefly share with them what the Nine Planetary Boundaries are, then expose the students to aspects of the report and the figures and graphics from the website that show how each of the Nine Planetary Boundaries are being approached or crossed already. Ask the students questions to get them engaged and thinking.

Since there are Nine Planetary Boundaries, make nine groups of students in your class (2-3 students per group), and assign one of the Nine Planetary Boundaries for them to become familiar with and research then present their ideas to the class. The Nine Planetary Boundaries have been summarized for you on the following nine pages (big numbers in the top left corner). Give one page per group.

Timeline (1-2 periods)

1. On the first day, share the information, handouts and discuss with them what the Nine Planetary Boundaries are. (10-15 min)
2. Break the students into the nine groups, and assign one of the Nine Planetary Boundaries (one of the handouts attached) and ask them to become “experts” on the subject (20-30 min).
3. On the second day have your class arrange their desks in a horseshoe or other way that is conducive to a debate/discussion (so that everyone is facing each other). Have each group (the Nine Planetary Boundaries) share their information with the class (this can be done orally, using technology, or whatever means you/they choose). As the two or three students are presenting the one Planetary Boundary, remind the rest of the students that they should be taking notes for themselves, as well as asking questions/making other statements with the group. Ultimately you are trying to engage a healthy debate and dialogue among students.

Student Sheet



Before: Review this graphic, and review material shared with you by your teacher as well as all your class notes on climate change.

During: Take notes during your classmates' presentations. Consider how we, as a society, can change so Earth stays within the boundaries.

Ask yourself:

- What stands out to you?
- What are you surprised or shocked about?
- What doesn't surprise you at all?
- What is new here? What didn't you know before?
- What does this make you think about now?

After: Reflection

After you have listened to all the presentations from your class, consider the following questions.

1. Reflect on all the information you just heard today in class. What information sticks with you the most? What were you really shocked about?
2. What information was 'new' to you today? What hadn't you previously known before about the state of the environment of the planet that you now do?
3. Of all the Nine Planetary Boundaries which one do you think is the most pressing or the one that seems the most severe of all them all?
4. Which one do you feel you have the ability to have a positive impact on (in other words: reducing the effect)? Describe how you could lessen your impact on environment. What actions would you take?

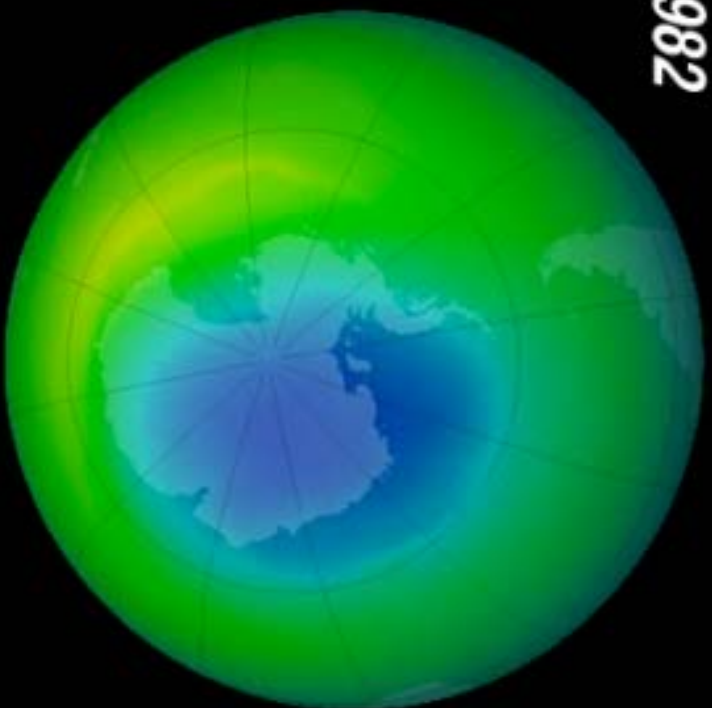
1 Stratospheric ozone depletion

Planetary boundary name	Summary	Where we were in 2015
Stratospheric ozone depletion	Less than 5 % below pre-industrial level of about 290 Dobson Units (DU) (One DU is 0.01 mm thick at standard temperature and pressure and relates to how thick the ozone layer would be if it were compressed in the Earth's atmosphere).	Still safely inside the boundary except over Antarctica during the spring, when levels drop to 200 DU.

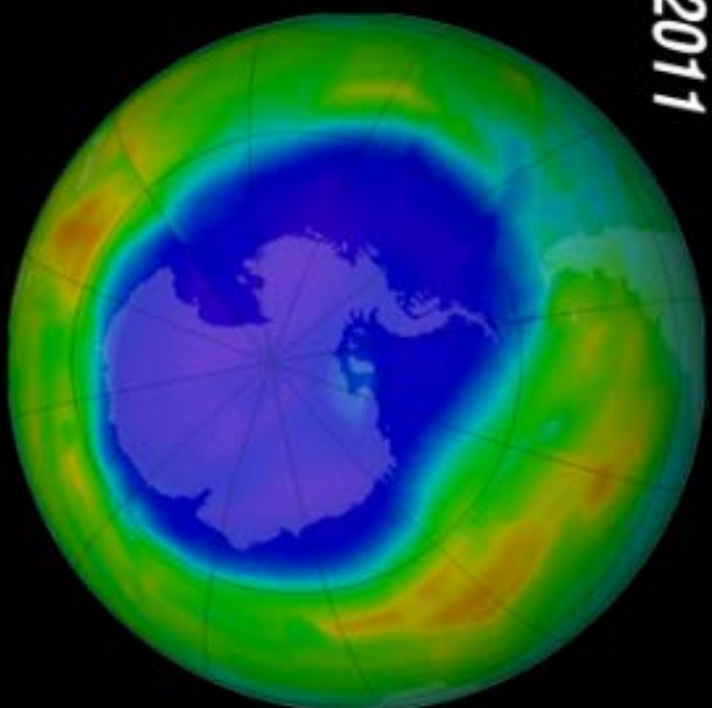
The stratospheric ozone layer in the atmosphere filters out ultraviolet (UV) radiation from the sun. If this layer decreases, increasing amounts of UV radiation will reach ground level. This can cause a higher incidence of skin cancer in humans as well as damage to terrestrial and marine biological systems. The appearance of the Antarctic ozone hole was proof that increased concentrations of anthropogenic ozone-depleting chemical substances, interacting with polar stratospheric clouds, had passed a threshold and moved the Antarctic stratosphere into a new regime. Fortunately, because of the actions taken as a result of the Montreal Protocol, we appear to be on the path that will allow us to stay within this boundary.

Source: [The Stockholm Resilience Project - The Nine Planetary Boundary](http://www.stockholmresilience.org/research/planetary-boundaries/planetary-boundaries/about-the-research/the-nine-planetary-boundaries.html)
<http://www.stockholmresilience.org/research/planetary-boundaries/planetary-boundaries/about-the-research/the-nine-planetary-boundaries.html>.

1982



2011



Ozone (Dobson Units)



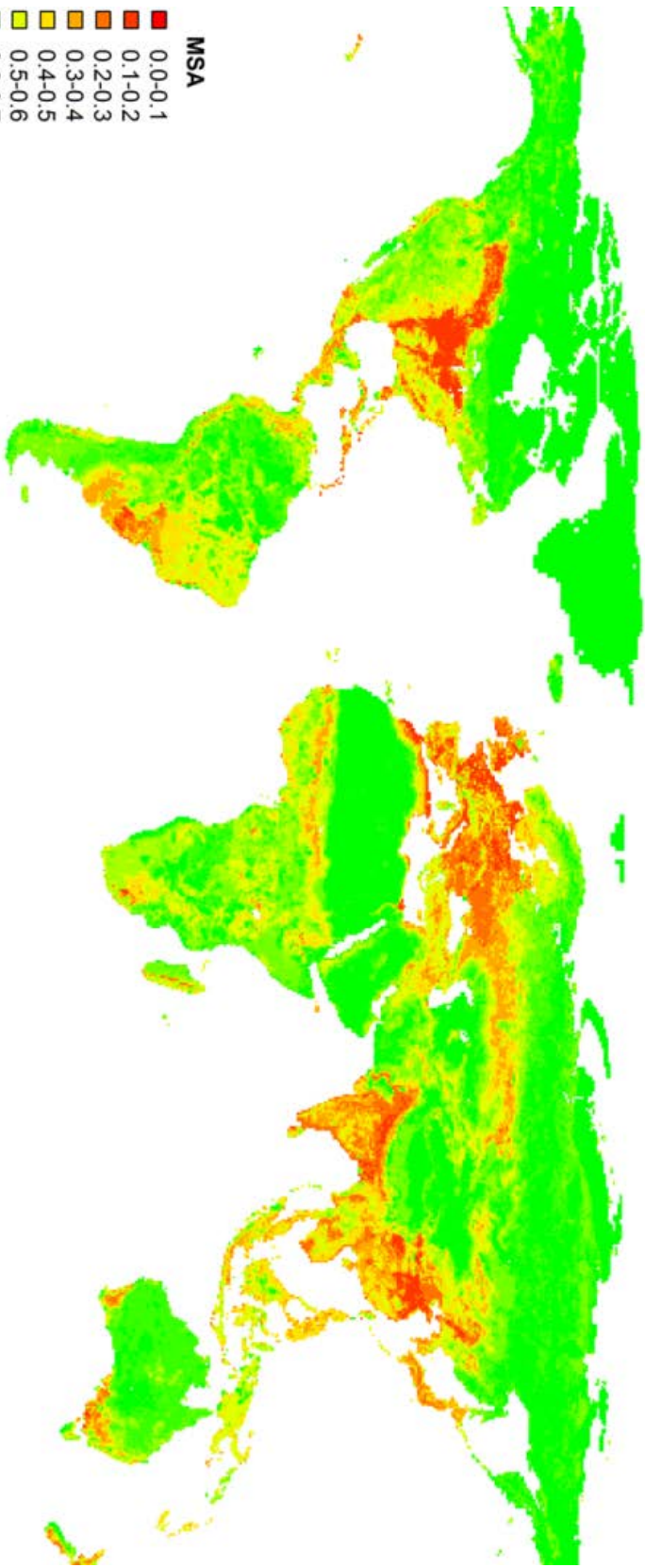
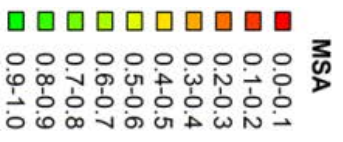
2 Loss of biosphere integrity

Planetary boundary Name	Summary	Where we were in 2015
Loss of biosphere integrity. (Extinctions)	Maintain 90% of biodiversity.	Biodiversity has dropped to 84% in parts of the world such as Africa.

(The global distribution of combined relative mean species abundance of original species (MSA) is an approximation of the aggregated human pressure on the terrestrial biosphere.)

The Millennium Ecosystem Assessment of 2005 concluded that changes to ecosystems due to human activities were more rapid in the past 50 years than at any time in human history, increasing the risks of abrupt and irreversible changes. The main drivers of change are the demand for food, water, and natural resources, causing severe biodiversity loss and leading to changes in ecosystem services. These drivers are either steady, showing no evidence of declining over time, or are increasing in intensity. The current high rates of ecosystem damage and extinction can be slowed by efforts to protect the integrity of living systems (the biosphere), enhancing habitat, and improving connectivity between ecosystems while maintaining the high agricultural productivity that humanity needs. Further research is underway to improve the availability of reliable data for use as the 'control variables' for this boundary.

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<http://www.stockholmresilience.org/research/planetary-boundaries/planetary-boundaries/about-the-research/the-nine-planetary-boundaries.html>.



3 Chemical pollution and the release of novel entities

Planetary boundary name	Summary	Where we were in 2015
Chemical pollution and the release of novel entities.	Dumping of organic pollutants, radioactive materials, nanomaterials, micro-plastics, and other man-made substances into the environment. The effect is unknown.	Still unknown.

Emissions of toxic and long-lived substances such as synthetic organic pollutants, heavy metal compounds and radioactive materials represent some of the key human-driven changes to the planetary environment. These compounds can have potentially irreversible effects on living organisms and on the physical environment (by affecting atmospheric processes and climate). Even when the uptake and bioaccumulation of chemical pollution is at sub-lethal levels for organisms, the effects of reduced fertility and the potential of permanent genetic damage can have severe effects on ecosystems far removed from the source of the pollution.

For example, persistent organic compounds have caused dramatic reductions in bird populations and impaired reproduction and development in marine mammals. There are many examples of additive and synergic effects from these compounds, but these are still poorly understood scientifically. At present, we are unable to quantify a single chemical pollution boundary, although the risk of crossing Earth system thresholds is considered sufficiently well-defined for it to be included in the list as a priority for precautionary action and for further research.

Source: [The Stockholm Resilience Project - The Nine Planetary Boundary](http://www.stockholmresilience.org/research/planetary-boundaries/planetary-boundaries/about-the-research/the-nine-planetary-boundaries.html)
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Bioaccumulation in Action

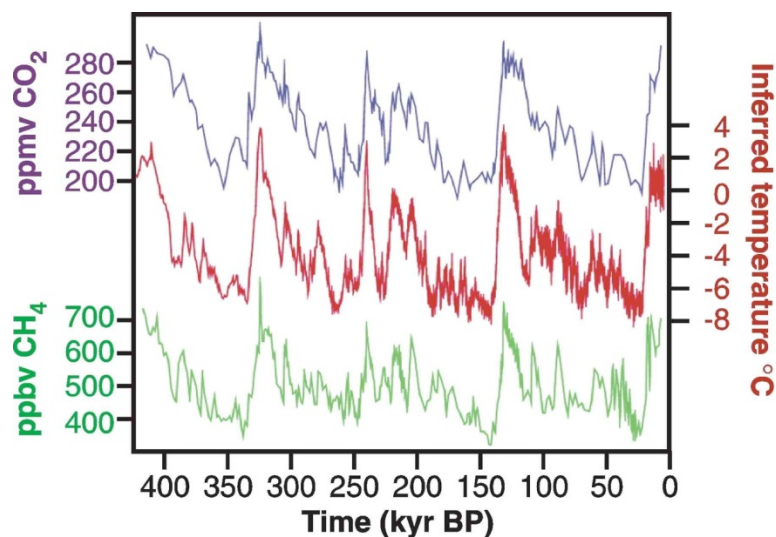


4 Climate change

Planetary boundary Name	Summary	Where we were in 2015
Climate change	Atmospheric concentrations of carbon dioxide at no more than 350ppm. (ppm = parts per million)	Carbon dioxide levels are at 400ppm and climbing.

Recent evidence suggests that the Earth, now passing 390 ppmv CO₂ in the atmosphere, has already transgressed the planetary boundary and is approaching several Earth system thresholds. We have reached a point at which the loss of summer polar sea-ice is almost certainly irreversible. This is one example of a well-defined threshold above which rapid physical feedback mechanisms can drive the Earth system into a much warmer state with sea levels metres higher than present. The weakening or reversal of terrestrial carbon sinks, for example through the on-going destruction of the world's rainforests, is another potential tipping point, where climate-carbon cycle feedbacks accelerate Earth's warming and intensify the climate impacts. A major question is how long we can remain over this boundary before large, irreversible changes become unavoidable.

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<http://www.stockholmresilience.org/research/planetary-boundaries/planetary-boundaries/about-the-research/the-nine-planetary-boundaries.html>.



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5 Ocean acidification

Planetary boundary Name	Summary	Where we were in 2015
Ocean acidification	When the oceans become acidic enough that the minerals sea creatures need and use to make shells (e.g. aragonite CaCO_3) begin to dissolve due to high levels of acidity.	Still within the boundary, this won't be crossed if we can stay within the climate boundary of 350ppm of CO_2 in the atmosphere.

Aragonite is a mineral used by sea creatures to form shells. They can't grow their shells if the water becomes too acidic, because the shell dissolves.

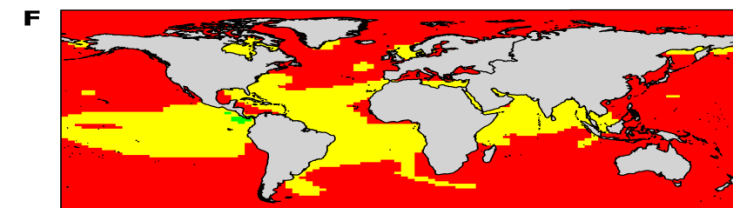
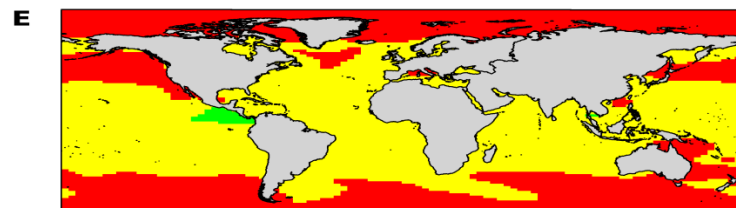
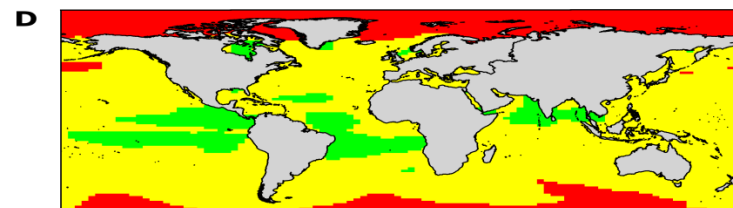
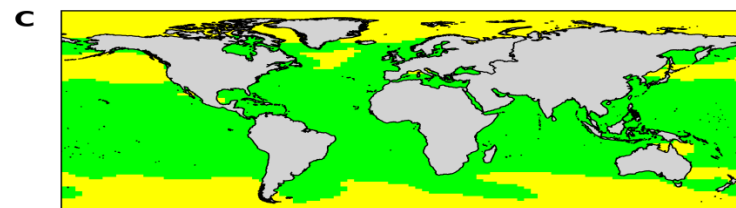
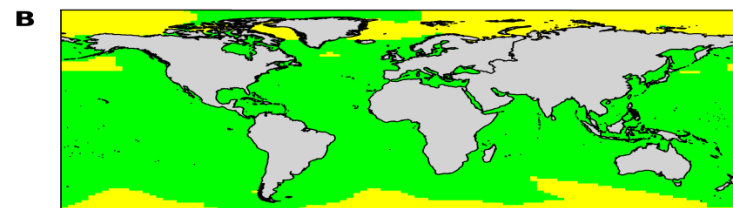
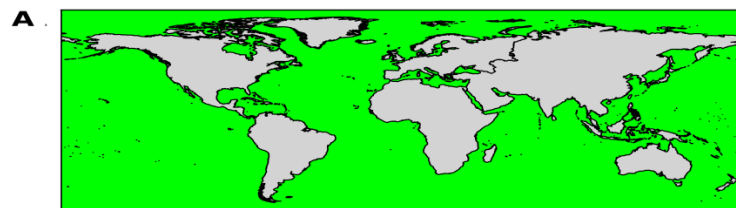


Around a quarter of the CO_2 that humanity emits into the atmosphere is ultimately dissolved in the oceans. Here it forms carbonic acid, altering ocean chemistry and decreasing the pH of the surface water. This increased acidity reduces the amount of available carbonate ions, an essential 'building block' used by many marine species for shell and skeleton formation. Beyond a threshold concentration, this rising acidity makes it hard for organisms such as corals and some shellfish and plankton species to grow and survive. Losses of these species would change the structure and dynamics of ocean ecosystems and could potentially lead to drastic reductions in fish stocks. Compared to pre-industrial times, surface ocean acidity has already increased by 30 percent. Unlike most other human impacts on the marine environment, which are often local in scale, the ocean acidification boundary has ramifications for the whole planet. It is also an example of how tightly interconnected the boundaries are, since atmospheric CO_2 concentration is the underlying controlling variable for both the climate and the ocean acidification boundaries, although they are defined in terms of different Earth system thresholds.

Source: [The Stockholm Resilience Project - The Nine Planetary Boundary](http://www.stockholmresilience.org/research/planetary-boundaries/planetary-boundaries/about-the-research/the-nine-planetary-boundaries.html)

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The maps below show: The ocean acidification boundary: values of the control variable, aragonite saturation state (a) 280 (pre-industrial state); (b) 380; (c) 400 (approximately current state); (d) 450; (e) 500; and (f) 550 ppm atmospheric CO₂ concentrations.



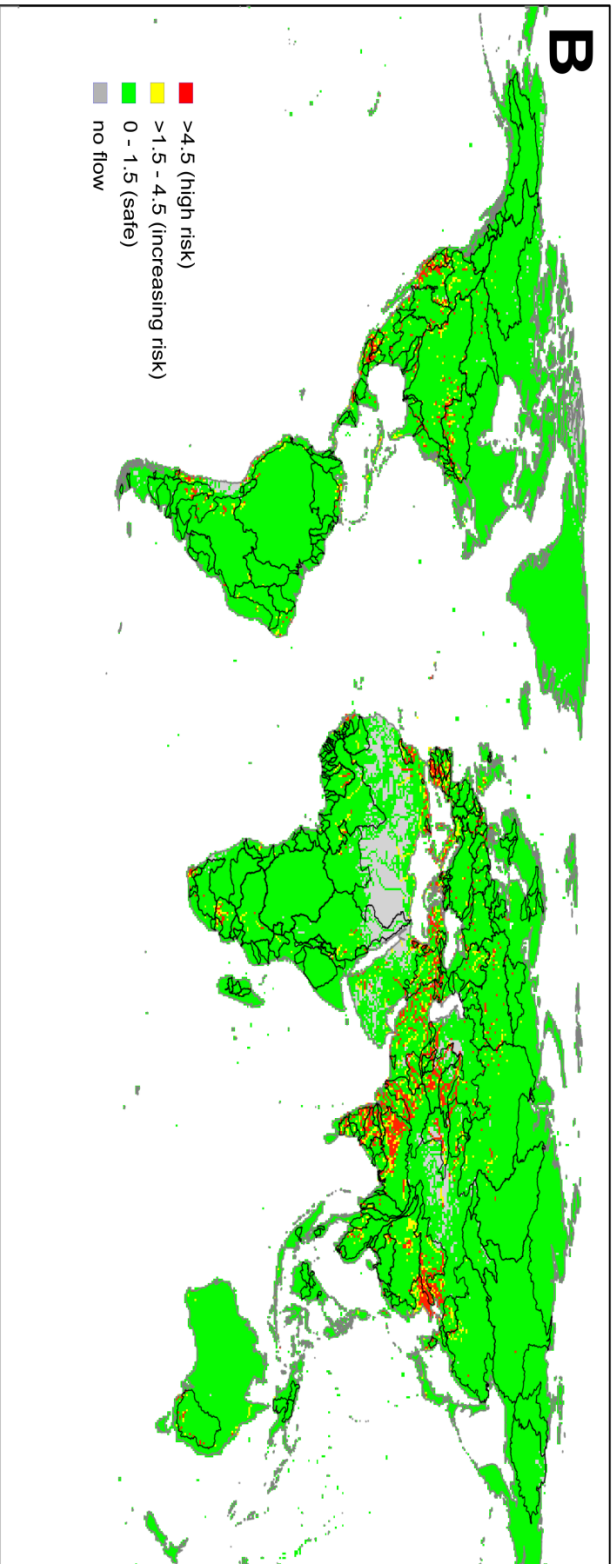
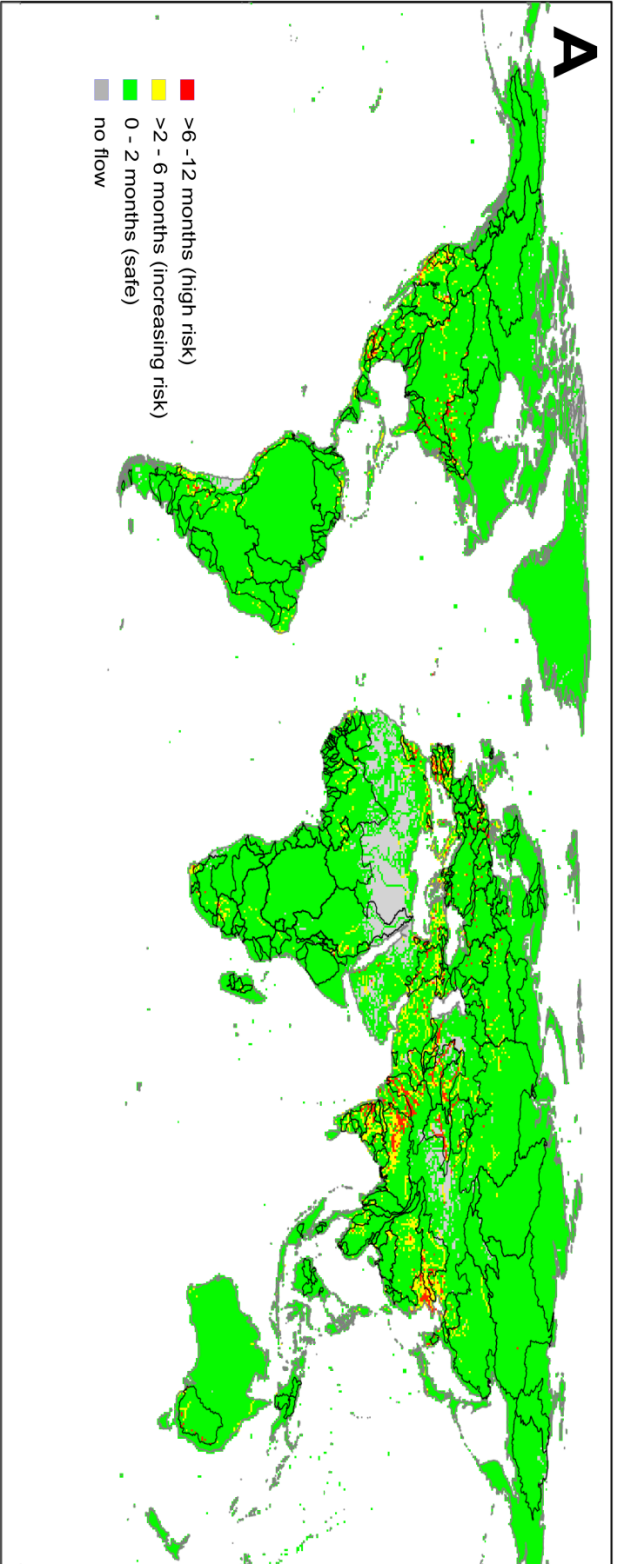
6 Freshwater consumption and the global hydrological cycle

Planetary boundary name	Summary	Where we were in 2015
Freshwater consumption and the global hydrological cycle	We can use up to 4,000 km ³ of freshwater a year	We use around 2,600 km ³ of freshwater per year.

The freshwater cycle is strongly affected by climate change and its boundary is closely linked to the climate boundary, yet human pressure is now the dominant driving force determining the functioning and distribution of global freshwater systems. The consequences of human modification of water bodies include both global-scale river flow changes and shifts in vapour flows arising from land use change. These shifts in the hydrological system can be abrupt and irreversible. Water is becoming increasingly scarce - by 2050 about half a billion people are likely to be subject to water-stress, increasing the pressure to intervene in water systems. A water boundary related to consumptive freshwater use and environmental flow requirements has been proposed to maintain the overall resilience of the Earth system and to avoid the risk of 'cascading' local and regional thresholds.

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The maps on the next page demonstrate the allowed monthly water withdrawals (by the Energy-Water-Food Nexus) with how much they exceed their allowance. Areas in yellow and red (the top two levels) are the highest risk, and found in the greatest areas of population around the world.



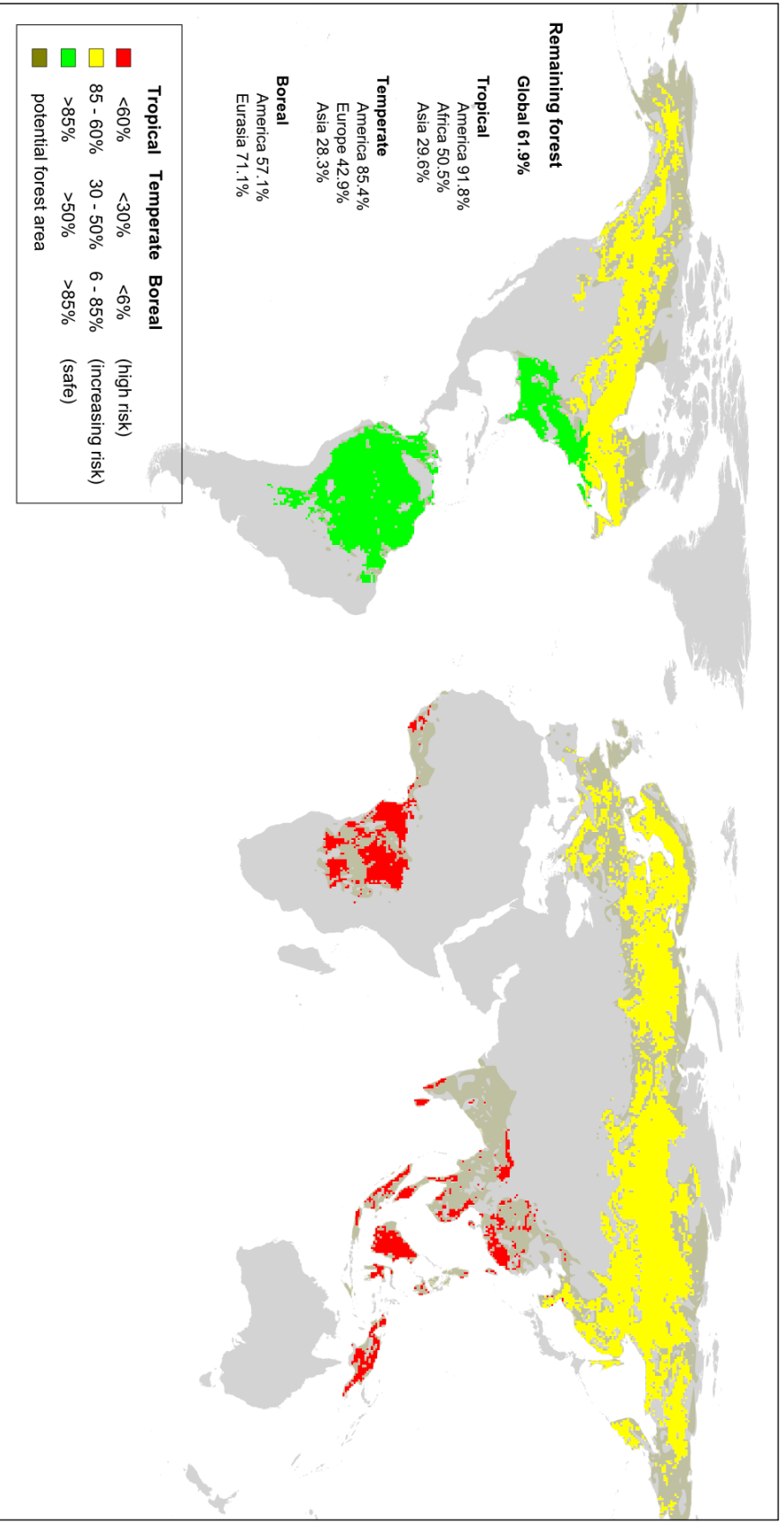
7 Land system change

Planetary boundary name	Summary	Where we were in 2015
Land system change	Maintain 75 per cent of the planet's original forests.	Down to 62 per cent.

Land is converted to human use all over the planet. Forests, grasslands, wetlands and other vegetation types have primarily been converted to agricultural land. This land-use change is one driving force behind the serious reductions in biodiversity, and it has impacts on water flows and on the biogeochemical cycling of carbon, nitrogen and phosphorus and other important elements. While each incident of land cover change occurs on a local scale, the aggregated impacts can have consequences for Earth system processes on a global scale. A boundary for human changes to land systems needs to reflect not just the absolute quantity of land, but also its function, quality and spatial distribution. Forests play a particularly important role in controlling the linked dynamics of land use and climate, and are the focus of the boundary for land system change.

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The map below shows the area of forest cover remaining in the world's major forest biomes compared to the potential forest cover, colour-coded to show the position of the control variable (area of forest land remaining) with respect to the boundary.



8 Nitrogen and phosphorus flows to the biosphere and oceans

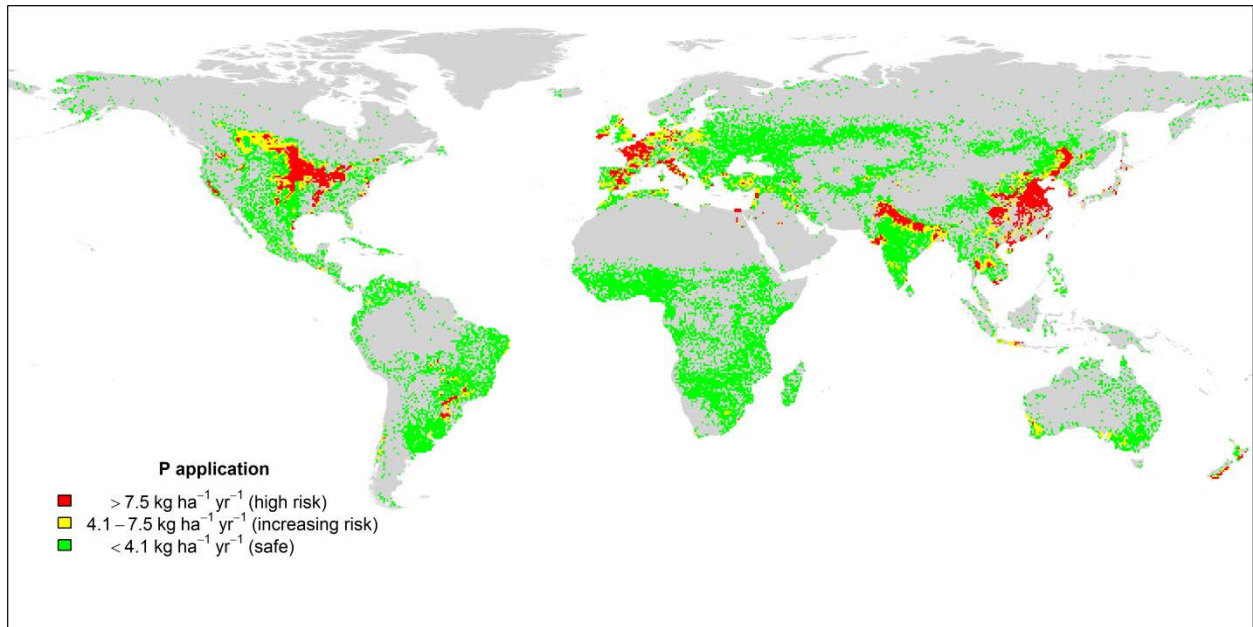
Planetary boundary name	Summary	Where we were in 2015
Nitrogen and phosphorus flows to the biosphere and oceans	Worldwide use per year of about 11 teragrams (Tg) of phosphorous and 62 Tg of nitrogen.	Up to about 22 Tg per year of phosphorous and 150 Tg of nitrogen.

The biogeochemical cycles of nitrogen and phosphorus have been radically changed by humans as a result of many industrial and agricultural processes. Nitrogen and phosphorus are both essential elements for plant growth, so fertilizer production and application is the main concern. Human activities now convert more atmospheric nitrogen into reactive forms than all of the Earth's terrestrial processes combined. Much of this new reactive nitrogen is emitted to the atmosphere in various forms rather than taken up by crops. When it is rained out, it pollutes waterways and coastal zones or accumulates in the terrestrial biosphere.

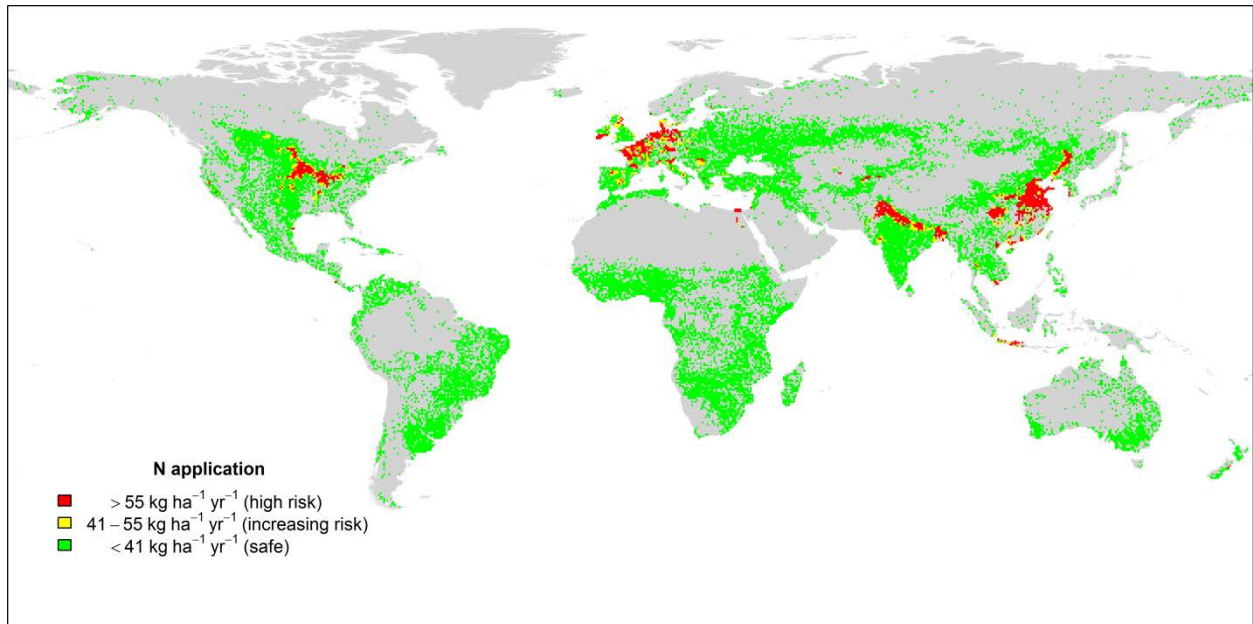
Similarly, a relatively small proportion of phosphorus fertilizers applied to food production systems is taken up by plants; much of the phosphorus mobilized by humans also ends up in aquatic systems. These can become oxygen-starved as bacteria consume the blooms of algae that grow in response to the high nutrient supply. A significant fraction of the applied nitrogen and phosphorus makes its way to the sea, and can push marine and aquatic systems across ecological thresholds of their own. One regional-scale example of this effect is the decline in the shrimp catch in the Gulf of Mexico's 'dead zone' caused by fertilizer transported in rivers from the US Midwest.

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The first map shows where most of the phosphorous is applied on the planet.



The second map shows where most of the nitrogen is applied on the planet.



9 Atmospheric aerosol loading

Planetary boundary name	Summary	Where we were in 2015
Atmospheric aerosol loading	Global boundary is UNKNOWN, but regional effects (such as on the South Asian Monsoon) occur when Aerosol Optical Depth (AOD) is more than 0.25. (An AOD of less than 0.1 means a crystal clear sky with maximum visibility while a value of 1 means a hazy sky with limited visibility)	Up to 0.30 AOD over South Asia, but probably well inside (or below) the boundary over most of the globe.

An atmospheric aerosol planetary boundary was proposed primarily because of the influence of aerosols on Earth's climate system. Through their interaction with water vapour, aerosols play a critically important role in the hydrological cycle affecting cloud formation and global-scale and regional patterns of atmospheric circulation, such as the monsoon systems in tropical regions. They also have a direct effect on climate, by changing how much solar radiation is reflected or absorbed in the atmosphere. Humans change the aerosol loading by emitting atmospheric pollution (many pollutant gases condense into droplets and particles), and also through land-use change that increases the release of dust and smoke into the air.

Shifts in climate regimes and monsoon systems have already been seen in highly polluted environments, giving a quantifiable regional measure for an aerosol boundary. A further reason for an aerosol boundary is that aerosols have adverse effects on many living organisms. Inhaling highly polluted air causes roughly 800,000 people to die prematurely each year. The toxicological and ecological effects of aerosols may thus relate to other Earth system thresholds. However, the behaviour of aerosols in the atmosphere is extremely complex, depending on their chemical composition and their geographical location and height in the atmosphere. While many relationships between aerosols, climate and ecosystems are well established, many causal links are yet to be determined.

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