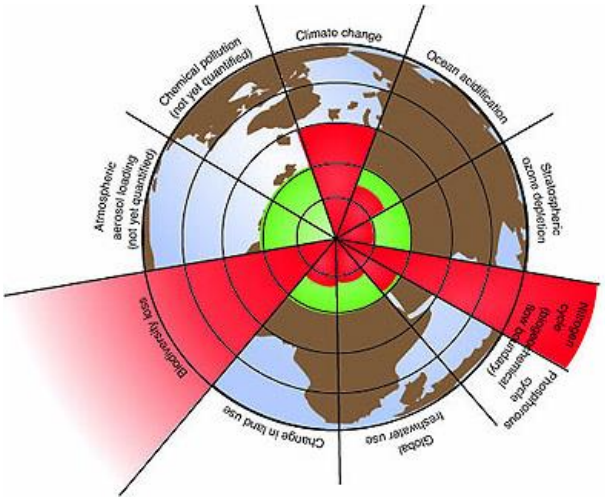

Planetary Boundaries[1]

Planetary boundaries and population

The concept of 'planetary boundaries' serves to define the limits of a safe environmental space for human development on Earth by determining the risk of threshold effects of biophysical processes and identifying the key drivers that could lead to them.[1,2]

The overarching goal of identifying the planetary boundaries is to develop a plan for human development on a planet that has limits, rather than simply focussing on minimising the individual environmental insults of greenhouse gas emissions and biodiversity loss.[1]

A total of nine planetary boundaries, or nine biophysical processes, have been identified, suggesting that human development is primarily dependent on these nine processes, and the threshold limits defined by these boundaries mark the 'safe environmental space'.

Concept of planetary boundaries

The planetary boundaries approach is based on three major scientific principles. The first principle is to establish a safe global level for the depletion of non-renewable fossil resources, such as coal, oil and gas. The second is to address the need to ensure a safe global level of use of the living biosphere, and to establish limits to the exploitation of ecosystems and consumption of renewable resources. Thirdly, it asserts the need to determine a safe global level for Earth's capacity to absorb and dissipate human waste flows, including carbon, nitrogen, phosphorous, and toxic chemicals such as pesticides.[2]

Based on these three scientific principles, the nine planetary boundaries identified are:[1,2]

1. **Climate Change** (atmospheric CO_2 concentration of <350 ppm)
2. **Ocean Acidification** (mean surface seawater saturation state with respect to aragonite <80 per cent)
3. **Stratospheric Ozone** (<5 per cent decrease in ozone concentration from preindustrial level of 290 Dobson units)
4. **Biochemical Nitrogen Cycle** (limitation of industrial and agricultural nitrogen fixation to 35 Tg N $year^{-1}$) **and Phosphorous Cycle** (annual inflow of phosphorous into oceans not to exceed ten times the natural background weathering of phosphorous)
5. **Global Freshwater Use** (<4000 km^3 $year^{-1}$ of consumptive use of run-off resources)
6. **Land System Change** (<15 per cent of ice-free land surface area under crop land)
7. **Change in Biosphere Integrity** (<10 per cent annual rate of extinctions per million species)

8. **Introduction of Novel Entities** (organic pollutants, radioactive materials and micro-plastics)
9. **Atmospheric Aerosol Loading** (microscopic particles in the atmosphere that affect climate and living organisms)

These nine planetary boundaries differ in character, yet are interdependent, and the approach builds on the approaches of 'limits-to-growth', 'safe minimum standards', 'the precautionary principle', and 'tolerable windows'.

These boundaries possess self-regulating capacity: crossing over the defined threshold limits of any boundary means triggering non-linear changes in the functioning of the Earth system. In a way, the boundaries represent a 'planetary playing field' or dynamic biophysical space on the Earth, the crossing of which would challenge socio-ecological resilience at regional as well as global levels. Contrary to the general assumption, the concept of planetary boundaries is not intended to put a cap on human development: rather it provides a 'safe space' for technology, development and growth in an increasingly-populated world.

Why the concept of planetary boundaries is crucial for a sustainable future

We have entered a new geological era, the Anthropocene, in which humans are the largest geological force on Earth, wherein our consumption patterns have a greater impact than natural biophysical and geological processes. We have increased our ecological footprint to one-and-a-half times what the earth produces and, as a result, have jeopardised our future by putting innumerable species, including our own, at significant risk.[3] As the developing countries with high population growth seek to catch up with the developed countries in the areas of technology, human capital, income and infrastructure, their consumption patterns are set to increase within a system with continuously declining resources. With an ever-increasing demand for resources, the concept of planetary boundaries is intended to safeguard our future by setting limits to our consumption, emissions and modification of the biosphere. These boundaries and their threshold limits are necessary to arrest, if not reduce, the current increase in greenhouse gas emissions, melting of snow caps, rising atmospheric temperature, extinction of species and loss of biodiversity. More importantly, the concept provides a shared global framework for ensuring a sustainable future, thus overcoming the failures of national policies of individual countries to acknowledge mitigation strategies.

Limits to planetary boundaries

According to recent research, four of the nine planetary boundaries have already been crossed as a result of human activity. These four boundaries are: **climate change**, **change in biosphere integrity**, **land system change**, and **altered biochemical nitrogen and phosphorous cycles**. The suggested boundary of 350 ppm CO_2 was crossed several years ago, and the current level is around 400 ppm.[4] According to certain estimates, the planet was ice free at a CO_2 concentration above 450 ppm.[4] Thus, we will jeopardise our future if we do not take necessary steps to mitigate the increasing level of CO_2. With

the currently-increasing CO_2 levels, there is already an increase in the shift in weather patterns, wherein drier regions are becoming even drier as a consequence of extreme weather. Similarly, water availability and food security are already a problematic issue in several regions. Ocean acidification and biochemical nitrogen and phosphorus cycle inflows into the oceans are reducing these carbon sinks' capacity to absorb the rising levels of CO_2. Thus, climate change, ocean acidification and the biochemical nitrogen and phosphorous cycle are considered as three different, yet interdependent, planetary boundaries.

The limit to stratospheric ozone is important, because it protects marine biodiversity and human health by filtering the ultraviolet radiation from the sun. The increase in the concentration of anthropogenic ozone-depleting substances like chlorofluorocarbons is responsible for ozone holes and the overall depletion of the ozone layer. Since the advent of the Anthropocene, the rate of species extinction has out-paced the rate of speciation, and, as a result, loss of species is the primary driver of catastrophic changes to biodiversity. Likewise, global anthropogenic manipulations of freshwater resources has resulted in the drying of an estimated 25 per cent of the world's river basins before reaching the ocean.[5] The land system change that occurs primarily as a result of agricultural expansion and intensification contributes to global environmental change, and impedes any progress towards a sustainable future. The implementation of the land-system boundary will halt the conversion of tropical rainforests into grassland, help to avoid soil erosion, ensure sufficient groundwater levels and availability of natural resources, and protect diversity. The threshold limits for introduction of novel entities and aerosol loading is not defined: however, they have a direct influence on climate change as well as human health at a regional and global scale. The increase in aerosol loading is responsible for rising incidences of cardiopulmonary diseases, crop damage and changes in global precipitation patterns. Similarly, the increasing concentration of chemical pollutants as novel entities in the atmosphere results in deleterious consequences in the food chain and climate.

Population and planetary boundaries

Although population is not one of the nine planetary boundaries, the rising level of human population undermines our efforts to limit human development to the above-mentioned nine planetary boundaries. The rate of the world's population growth has slowed down; however, according to the UN population projections, the absolute number of people added each year will not begin to fall until mid-century.[6] The higher the population, the higher the risk of climate change through overconsumption of resources, increased greenhouse gas emission, land-use change and chemical pollution. It is thus evident that achieving population stabilisation is central to our attempts to restrict human development to within the nine planetary boundaries. Efficient family planning services, voluntary fertility reduction, adequate access to healthcare services, education, poverty alleviation and promotion of smaller families are some of the necessary measures to minimise population growth.

Conclusion

It is clear that planetary boundaries offer a common global framework to reduce, minimise and neutralise the anthropogenic manipulations of the natural environment, in support of our hope to have a sustainable future. Although more research is needed to ascertain the severity of the defined threshold effects of the nine planetary boundaries, it is clear that immediate measures must be taken at the regional and global scale to repair our relationship with planet Earth.

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