Planetary boundaries & sustainability transition

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Planet Earth: Complex system, interactions
Non-linear responses

state 2

state 1
A safe operating space for humanity

Identifying and quantifying planetary boundaries that must not be transgressed could help prevent human activities from causing unacceptable environmental change, argue Johan Rockström and colleagues.

Although Earth has undergone many periods of significant environmental change, the planet's environmental systems have been relatively stable for the past 5,000 to 10,000 years. This period of stability — known as the Holocene — has seen human civilizations arise, develop and flourish. Such stability may now be under threat, since the Industrial Revolution, a new era has arisen, the Anthropocene, in which human activities have become the main driver of global environmental change. "This is not an accidental change," says Rockström. "The consequences that are discussed of even small changes to the Earth system are enormous and would have serious implications for large parts of the world."

During the Holocene, environmental changes occurred naturally and Earth's regulatory capacity maintained the conditions that enabled human development. Regular temperatures, freshwater availability and biogeochemical flows all carried within a relatively narrow range, largely because of a relatively strong influence on land, ocean and biological systems. Since the Industrial Revolution, however, human activities have caused the Earth system to move away from its Holocene equilibrium. The result could be irreversible, in some cases, abrupt environmental change, leading to a state that is difficult or impossible to maintain. Without substantial human intervention, the Holocene is expected to continue for at least several thousands of years.

**Planetary boundaries**

To meet the challenge of maintaining the MES, we propose a framework based on "planetary boundaries". These boundaries define the safe operating space for humanity with respect to the Earth system and are associated with the planet's biophysical subsystems or processes. Although there are thresholds in many processes or systems that represent a particular limit or capacity beyond which the system may be considered to have crossed, thresholds are most important when they result in critical transitions to other states. Such thresholds have been widely identified, such as the thermal limits of life or the critical loss of biodiversity. However, many such limits are not well defined, and their identification is crucial to understanding the stability of the Earth system.

**Summary**

- New approach proposed for defining conditions for human development
- Identifying and quantifying planetary boundaries could prevent human activities from causing unacceptable environmental change
- Planetary boundaries are thresholds that define the safe operating space for humanity, and are associated with the planet's biophysical subsystems or processes
- Human activities have caused the Earth system to move away from its Holocene equilibrium, leading to a state that is difficult or impossible to maintain without substantial human intervention
- Without human intervention, the Holocene is expected to continue for at least several thousands of years.

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![Diagram](https://example.com/diagram.png)

**Figure 1**: In the boundary framework, transgressing planetary boundaries means moving beyond the safe operating space for humanity. The boundaries are thresholds that define the safe operating space for humanity, and are associated with the planet's biophysical subsystems or processes. Transgressing these thresholds could lead to critical transitions in the Earth system, such as the extinction of species or the collapse of ecosystems.
Safe operating space for humanity
Critical transitions or regime shifts
Valuable Ecosystem Services (Desirable)  

1. coral dominance  
   - clear water  
   - grassland  

2. overfishing, coastal eutrophication  
   - phosphorous accumulation in soil and mud  
   - fire prevention

3. disease, hurricane  
   - flooding, warming, overexploitation of predators  
   - good rains, continuous heavy grazing

Loss of ecosystem services (Undesirable)  

4. algal dominance  
   - turbid water  
   - shrub-bushland
Regime shifts in the Earth system; then humanity’s period of grace – the last 10,000 years

Planetary Boundaries

Climate Change
< 350 ppm CO₂ < 1W m²
(350 – 500 ppm CO₂ ;
1-1.5 W m²)

Ozone depletion
< 5 % of Pre-Industrial 290 DU
(5 - 10%)

Atmospheric Aerosol Loading
To be determined

Ocean acidification
Aragonite saturation ratio > 80 % above pre-industrial levels
(> 80% - > 70 %)

Global Freshwater Use
<4000 km³/yr
(4000 – 6000 km³/yr)

Biogeochemical loading: Global N & P Cycles
Limit industrial fixation of N₂ to 35 Tg N yr⁻¹ (25 % of natural fixation)
(25%-35%)
P < 10× natural weathering inflow to Oceans
(10× – 100×)

Rate of Biodiversity Loss
< 10 E/MSY
(< 10 - < 1000 E/MSY)

Land System Change
≤15 % of land under crops (15-20%)

Chemical Pollution
Plastics, Endocrine Desruptors, Nuclear Waste Emitted globally
To be determined
Rate of biodiversity loss  
Avoid large scale irreversible loss of functional diversity and ecological resilience

• Local and regional biodiversity changes can have pervasive effects on Earth System functioning
• Biodiversity plays a key role for functional diversity and thereby ecosystem resilience
• Humans have increased the rate of species extinction by 100-1,000 times the background rates
• Average global extinction rate projected to increase another 10-fold, to 1,000-10,000 extinctions per $10^6$ species-years this century
• Safe planetary boundary: extinction rate within an order of magnitude of natural background rate (10 \ E/MSY)
Land change

• Main processes:
  – Agricultural expansion
  – Deforestation
  – Urbanization
  – Land use intensification

• Impacts on:
  – Climate (albedo, CO₂...)
  – Hydrology, water quality
  – Soil degradation
  – Biodiversity
  – Ecosystem goods & services
  – Vulnerability of places
• Land: a natural resource that will soon become scarce

• Increasing competition between food, fuel, fiber, living space, green space

• Asian agricultural companies encouraged to buy land abroad

• Offshore land acquisition by oil-rich but food-poor countries
Land full by ± 2030

**In 2000:**
- Cropland: 1,510 Mha
- Land reserve: <700 Mha (neither rainforests, nor protected areas)

**By 2030:**
- Cropland needed: 200 Mha
- Industrial forestry: 25 Mha
- Bioenergy: 300 Mha (250 - 600)
- Land loss to urbanization: 50 Mha
- Land degradation: 150 Mha

Total 725 Mha < 700 Mha

> 50% new cropland expansion in natural forests
Bad governance: a leading cause of land degradation and tropical deforestation

- Misguided policies, policy failure
- Poor enforcement of land use regulations and property rights
- Illegal timber trade
Mix of good policies, economic reforms and cultural changes can restore forests and spare land

« Forest transition »

China, India, Vietnam, Bhutan, Costa Rica, El Salvador, Dominican Republic, Panama...
Reforestation in Vietnam
Growing timber imports

• Increase in processed wood imports

• Increasing imports of illegal timber

From EIA / Telapak
Sustainability transition

Implementing planetary stewardship
reorienting the society-biosphere relationship
action plan to address planetary boundaries

Global environmental governance

Global land architecture

Geoengineering
Environmental information?

Motivations to modify land use practices?

Capacity to adopt new land use practices?
Reversal of environmental degradation

- Widespread perception of an ecological crisis triggers a reaction

- Policy intervention promotes a more rational natural resource management

- Reforms implemented at an acceptable social cost thanks to technological innovations and new economic opportunities

**information - motivation - capacity**
Social heterogeneity

- Altruists (<20%)
- Conditional cooperators (60%)
- Free riders (>20%)

  - social models
  - 7% richests = 50% global CO₂ emissions
We have a personal interest to preserve nature’s integrity because human happiness closely depends on natural environments.
Conclusions

- Non-negotiable boundaries to human activities
- Biodiversity: boundary already exceeded
- Interactions between boundaries: biodiversity, land, climate
- Synergies between policies on biodiversity, land, climate
- Avoid displacement between sectors and regions
- Sustainability transition, planetary stewardship: reconnect people with nature to create motivation for behavioural change