Planetary boundaries & sustainability transition

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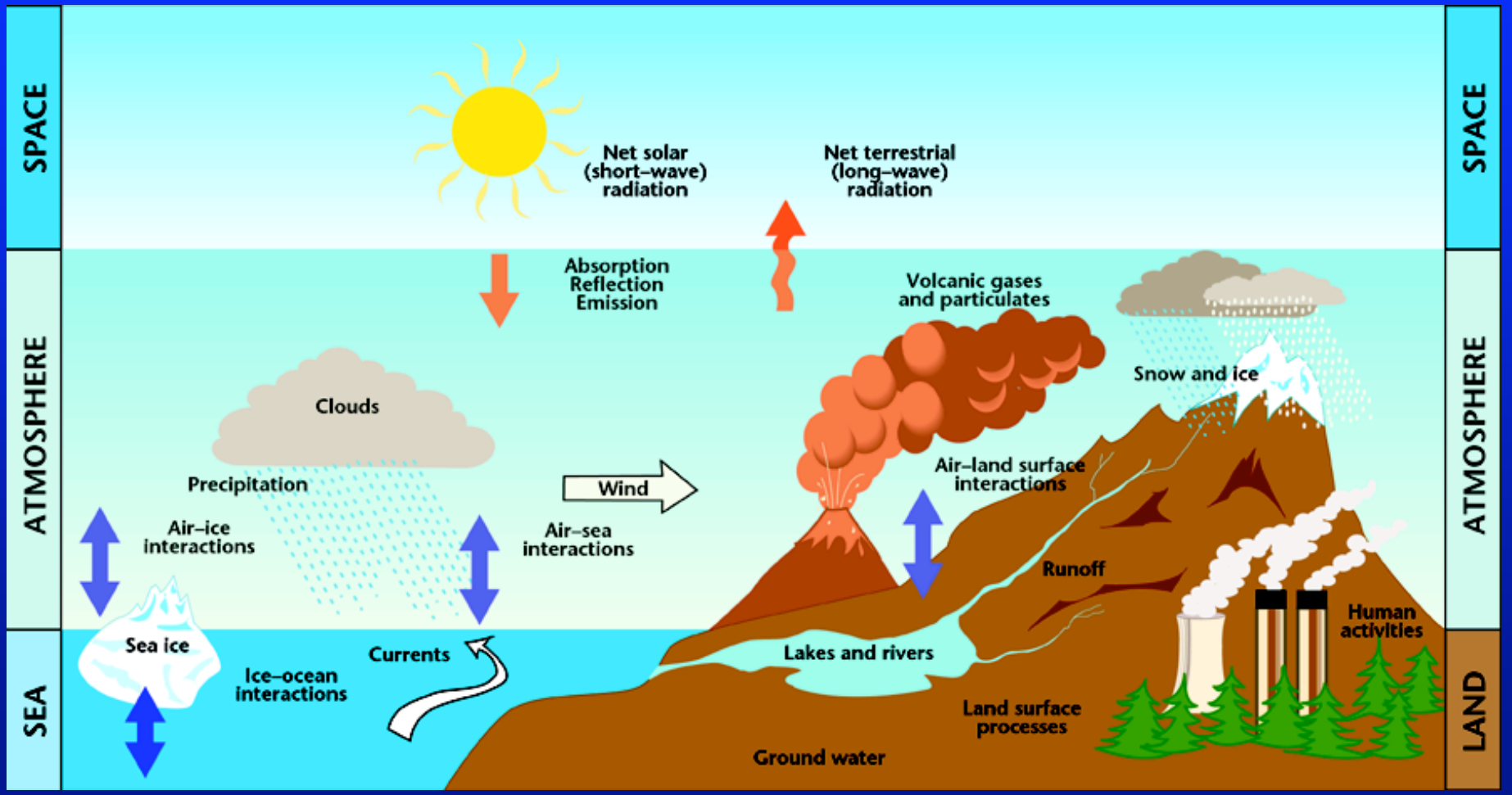
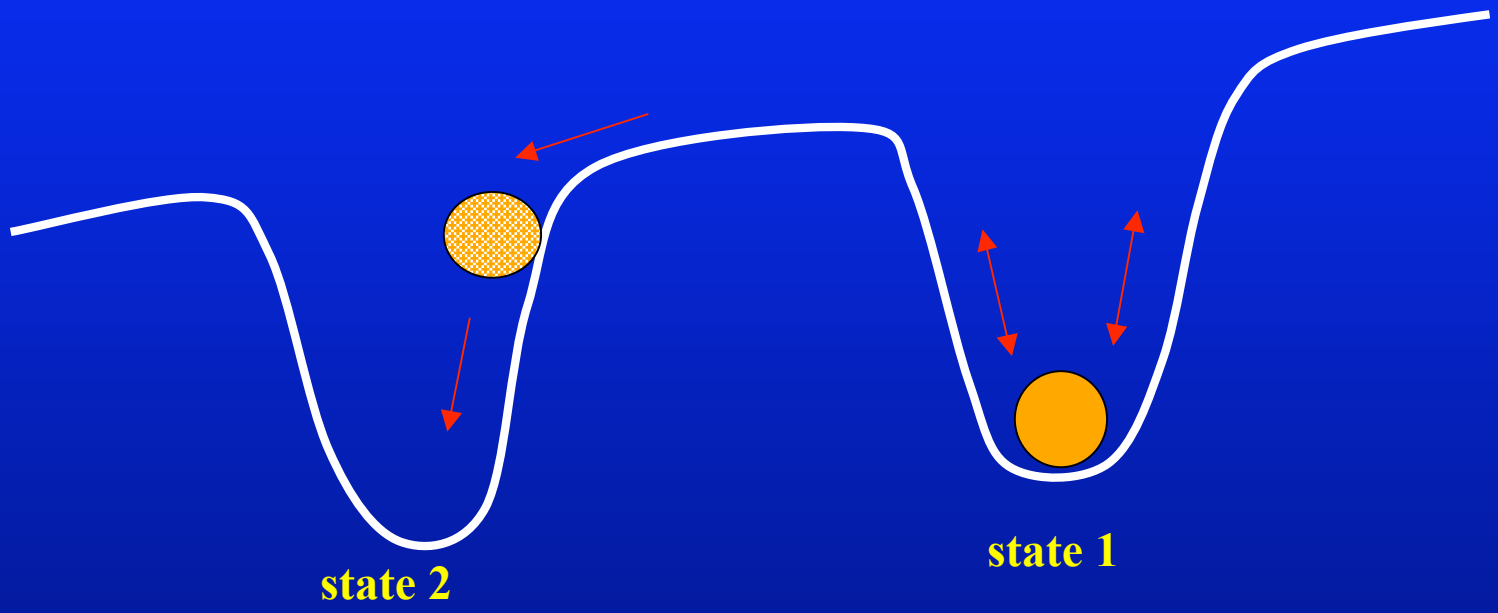
Planet Earth: Complex system, interactions



Non-linear responses



FEATURE

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.

SUMMARY

- New approach proposed for defining preconditions for human development
- Crossing certain biophysical thresholds could have disastrous consequences for humanity
- Three of nine interlinked planetary boundaries have already been overstepped

Although Earth has undergone many periods of significant environmental change, the planet's environment has been unusually stable for the past 10,000 years[1–3]. This period of stability — known to geologists as the Holocene — has seen human civilizations arise, develop and thrive. Such stability may now be under threat. Since the Industrial Revolution, a new era has arisen, the Anthropocene[4], in which human actions have become the main driver of global environmental change[5]. This could see human activities push the Earth system outside the stable environmental state of the Holocene, with consequences that are detrimental or even catastrophic for large parts of the world.

During the Holocene, environmental change occurred naturally and Earth's regulatory capacity maintained the conditions that enabled human development. Regular temperatures, freshwater availability and biogeochemical flows all stayed within a relatively narrow range. Now, largely because of a rapidly growing reliance on fossil fuels and industrialized forms of agriculture, human activities have reached a level that could damage the systems that keep Earth in the desirable Holocene state. The result could be irreversible and, in some cases, abrupt environmental change, leading to a state less conducive to human development[4]. Without pressure from humans, the Holocene is expected to continue for at least several thousands of years[3].

Planetary boundaries

To meet the challenge of maintaining the Holocene state, 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 Earth's complex systems sometimes respond smoothly to changing pressures, it seems that this will prove to be the exception rather than the rule. Many subsystems of Earth react in a nonlinear, often abrupt, way, and are particularly sensitive around threshold levels of certain key variables. If these thresholds are crossed, then important subsystems, such as a monsoon system, could shift into a new state, often with deleterious or potentially even disastrous consequences for humans[6,7].

Most of these thresholds can be defined by a critical value for one or more control variables, such as carbon dioxide concentration. Not all processes or subsystems on Earth have well-defined thresholds, although human actions that undermine the resilience of such processes or subsystems — for example, land and water degradation — can increase the risk that thresholds will also be crossed in other processes, such as the climate system.

We have tried to identify the Earth-system processes and associated thresholds which, if crossed, could generate unacceptable environmental change. We have found nine such processes for which we believe it is necessary to define planetary boundaries: climate change; rate of biodiversity loss (terrestrial and marine); 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 (see Fig. 1 and Table).

In general, planetary boundaries are values for control variables that are either at a 'safe' distance from thresholds — for processes with evidence of threshold behaviour — or at dangerous levels — for processes without

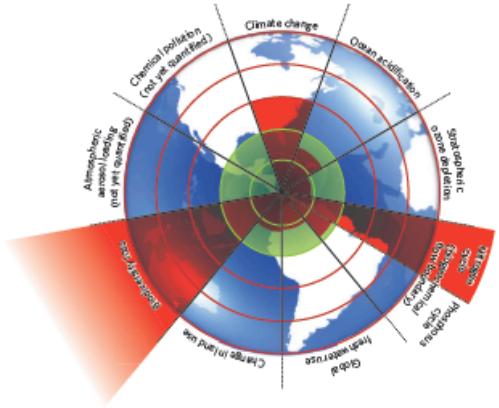


Figure 1| Beyond the boundary. The inner green shading represents the proposed safe operating space for nine planetary systems. The red wedges represent an estimate of the current position for each variable. The boundaries in three systems (rate of biodiversity loss, climate change and human interference with the nitrogen cycle), have already been exceeded.


Safe operating
space for
humanity
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Visions of Earth
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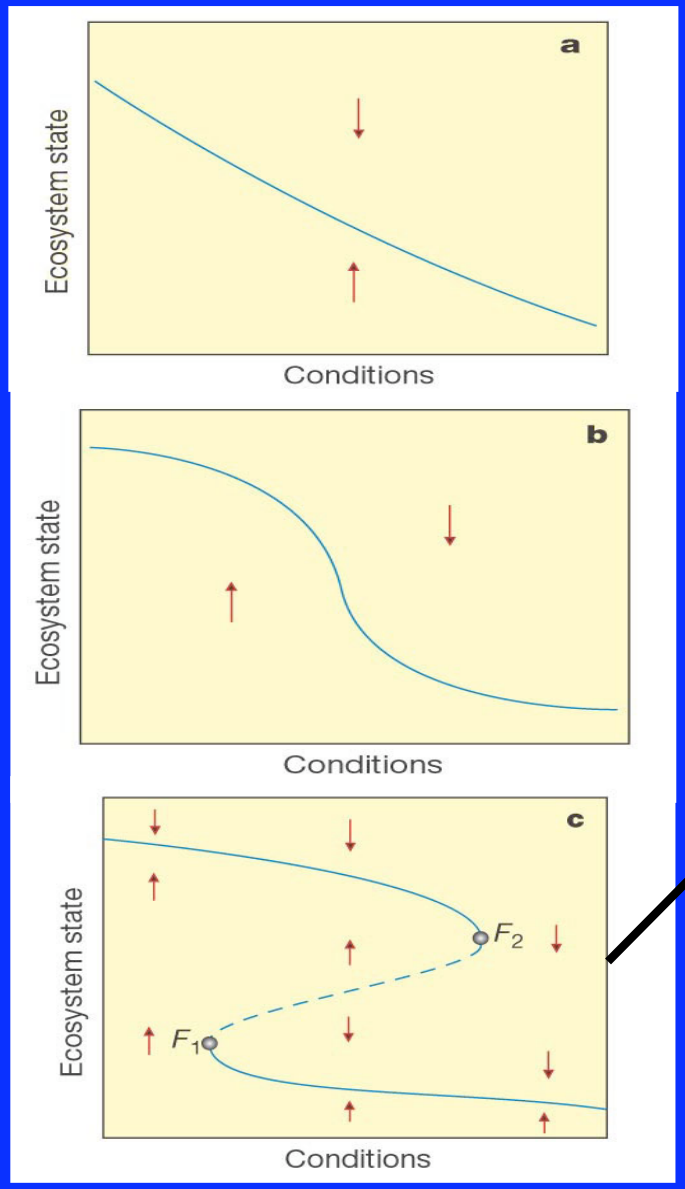
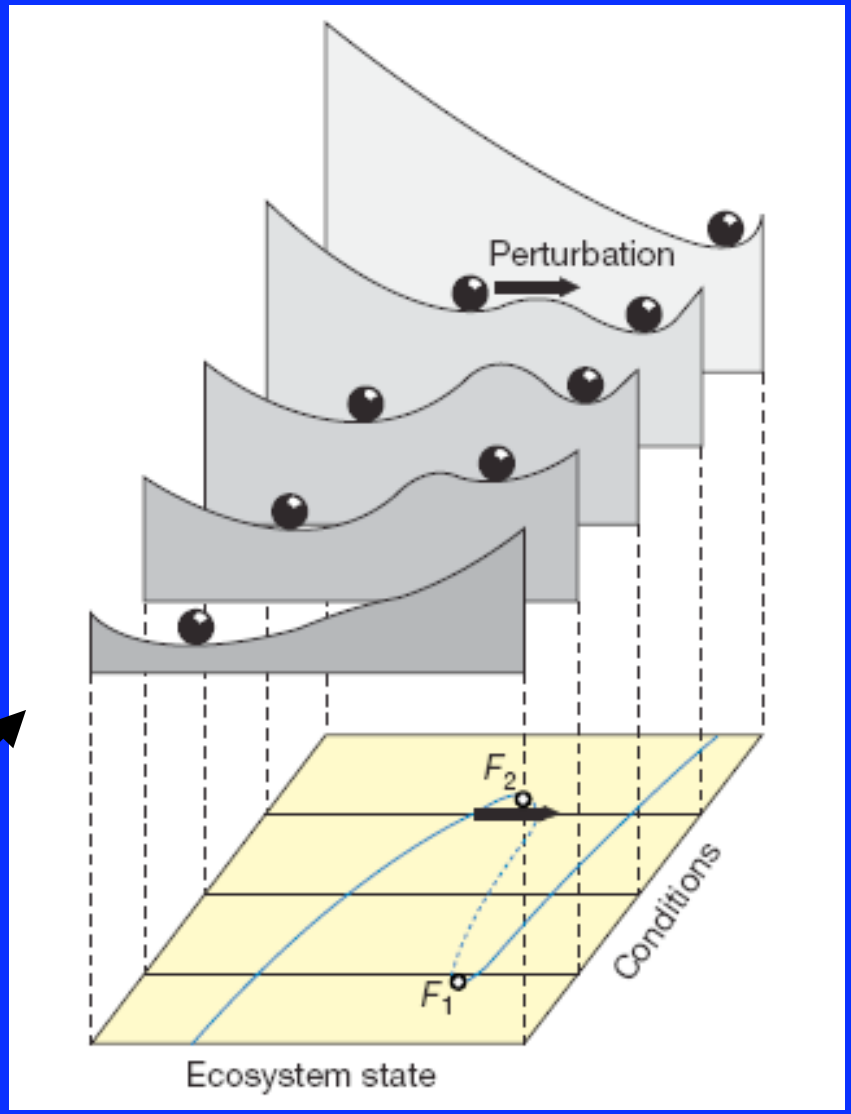
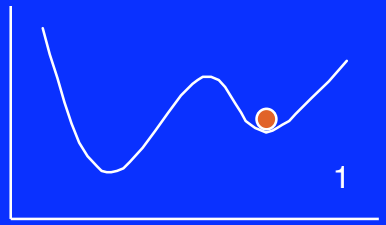
Critical transitions or regime shifts





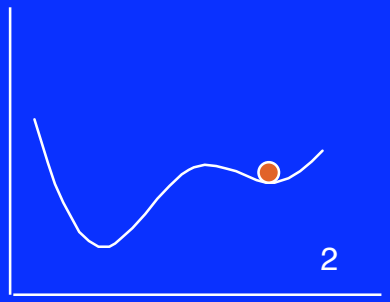
Valuable Ecosystem Services (Desirable) → Loss of ecosystem services (Undesirable)



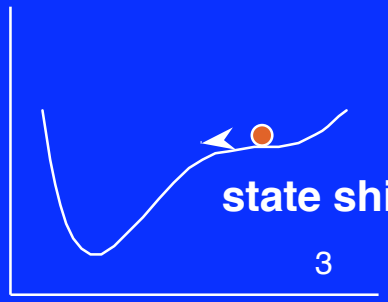
coral dominance

clear water

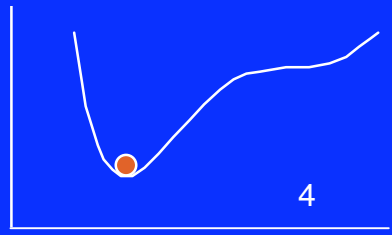
grassland



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



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

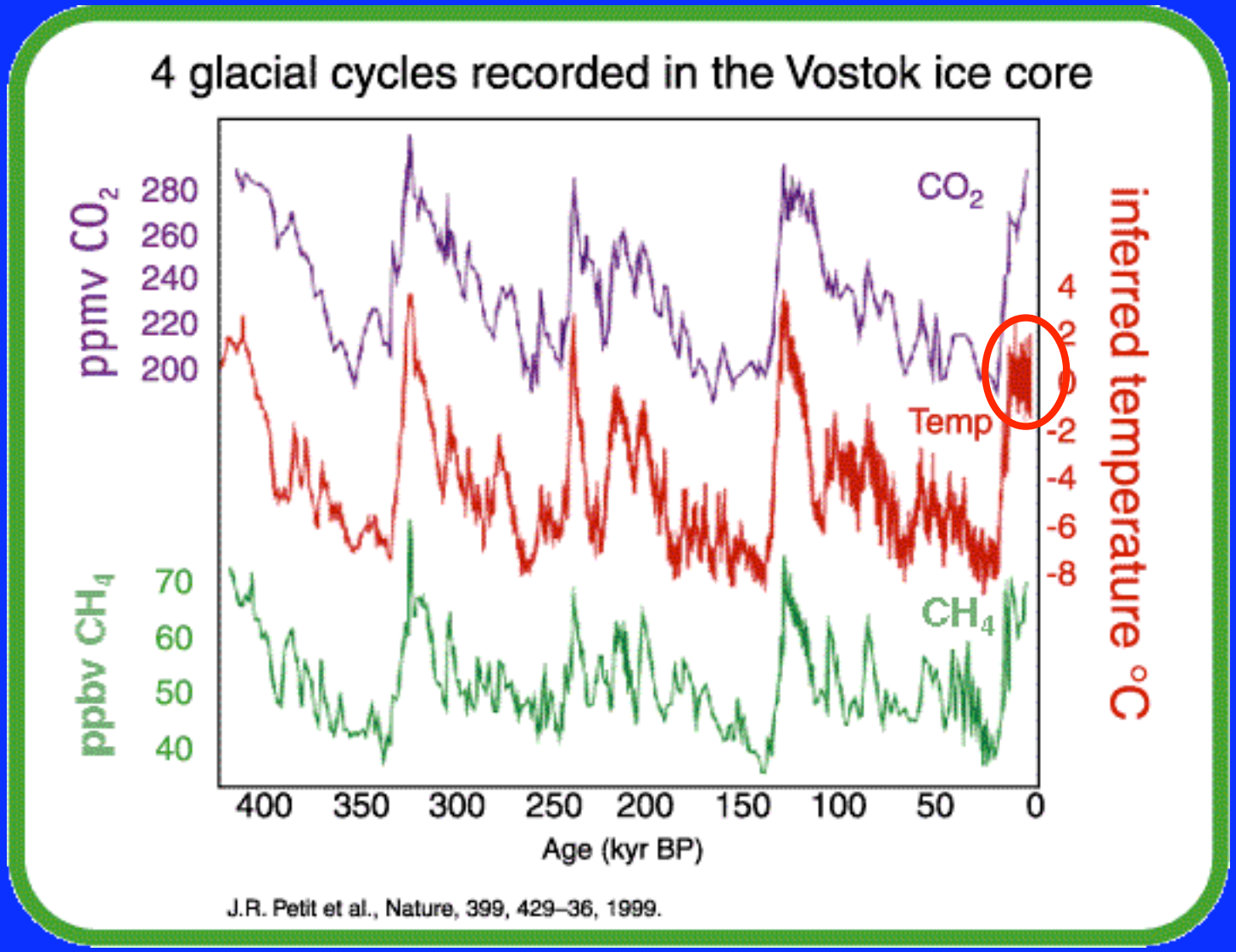


algal dominance

turbid water

shrub-bushland

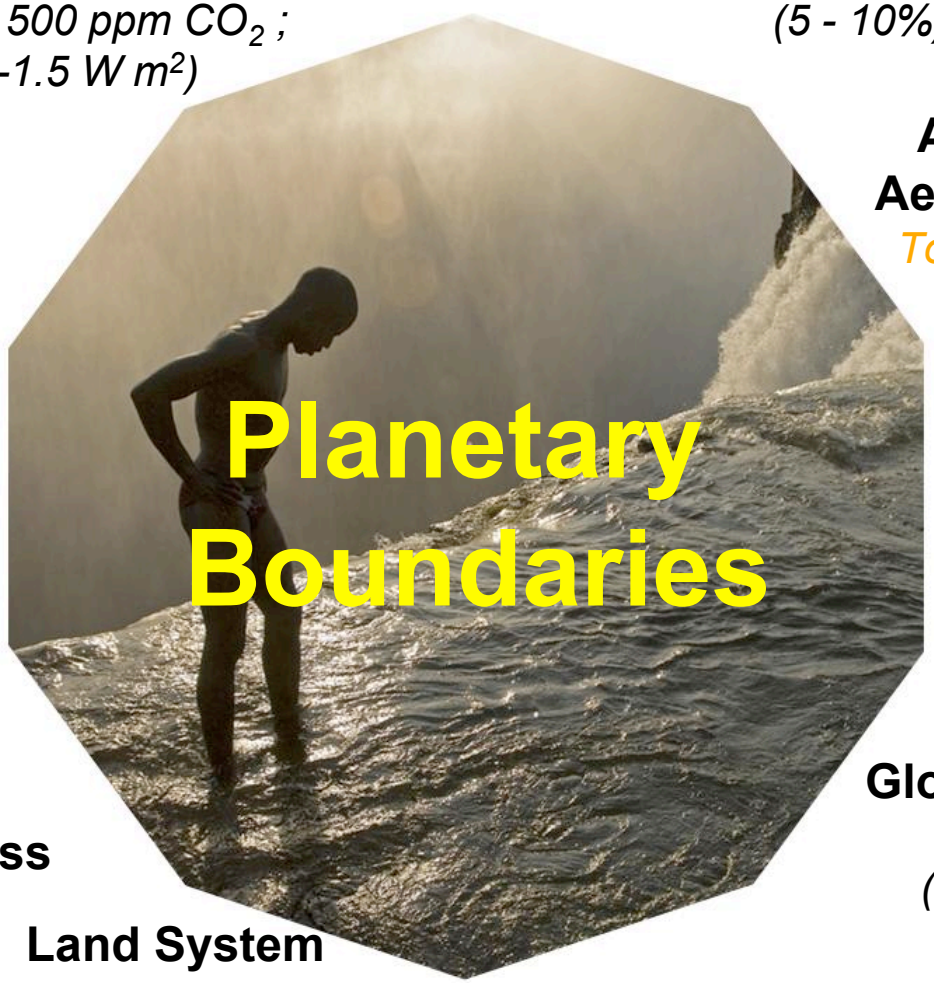
Regime shifts in the Earth system; then humanity's period of grace – the last 10,000 years



Climate Change
< 350 ppm CO_2 < 1W m^2
(350 – 500 ppm CO_2 ;
1-1.5 W m^2)

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

Biogeochemical loading: Global N & P Cycles
Limit industrial fixation of N_2 to 35 Tg N yr^{-1}(25 % of natural fixation)
(25%-35%)
P < 10× natural weathering inflow to Oceans
(10× – 100×)



Atmospheric Aerosol Loading
To be determined

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

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

Global Freshwater Use
<4000 km^3/yr
(4000 – 6000 km^3/yr)

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, CO_2...)
  - 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:

> 50% new cropland expansion in natural forests

- 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

Bad governance: a leading cause of land degradation and tropical deforestation

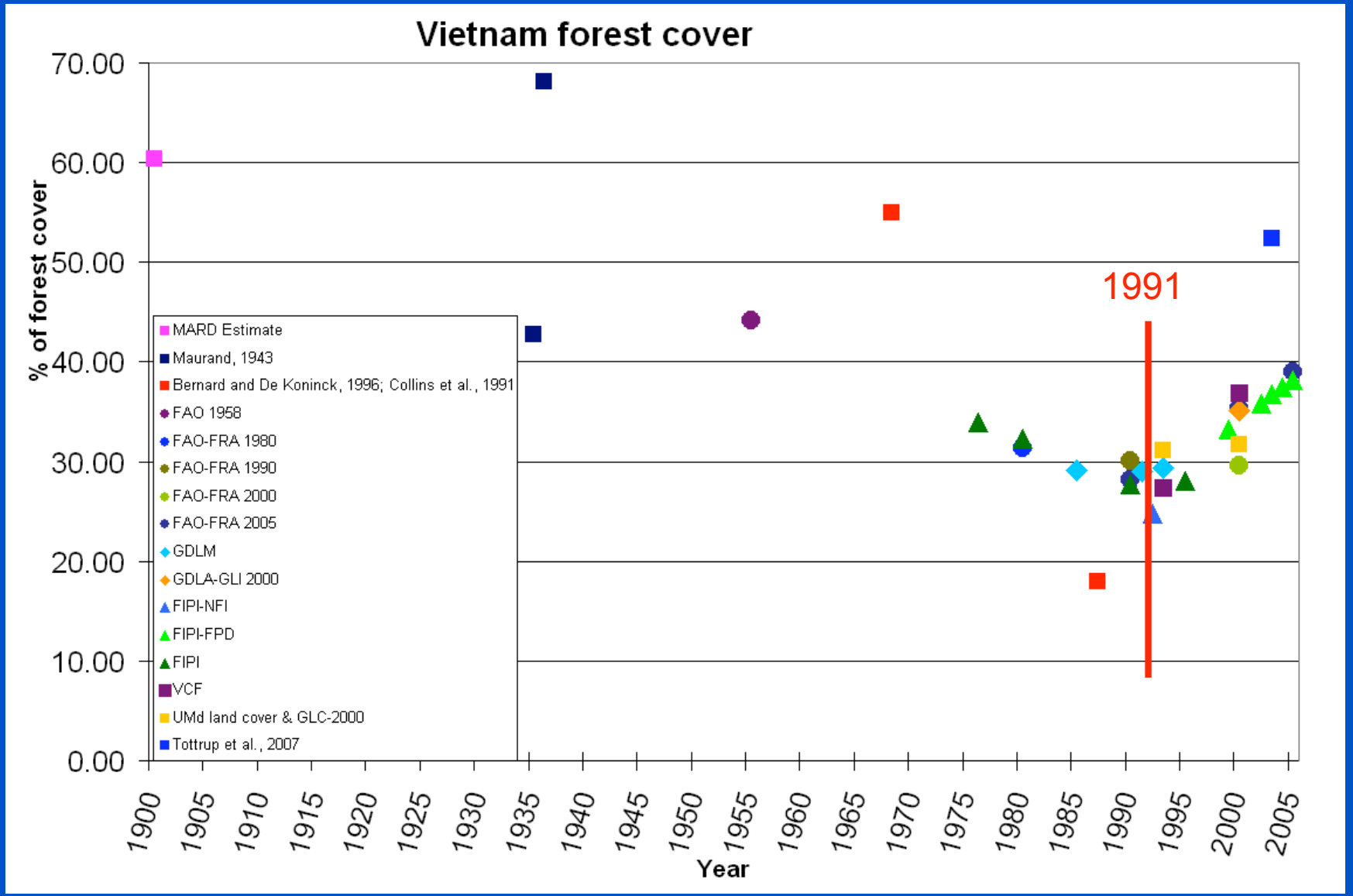
- Misguided policies, policy failure
- Poor enforcement of land use regulations and property rights
- Illegal timber trade

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

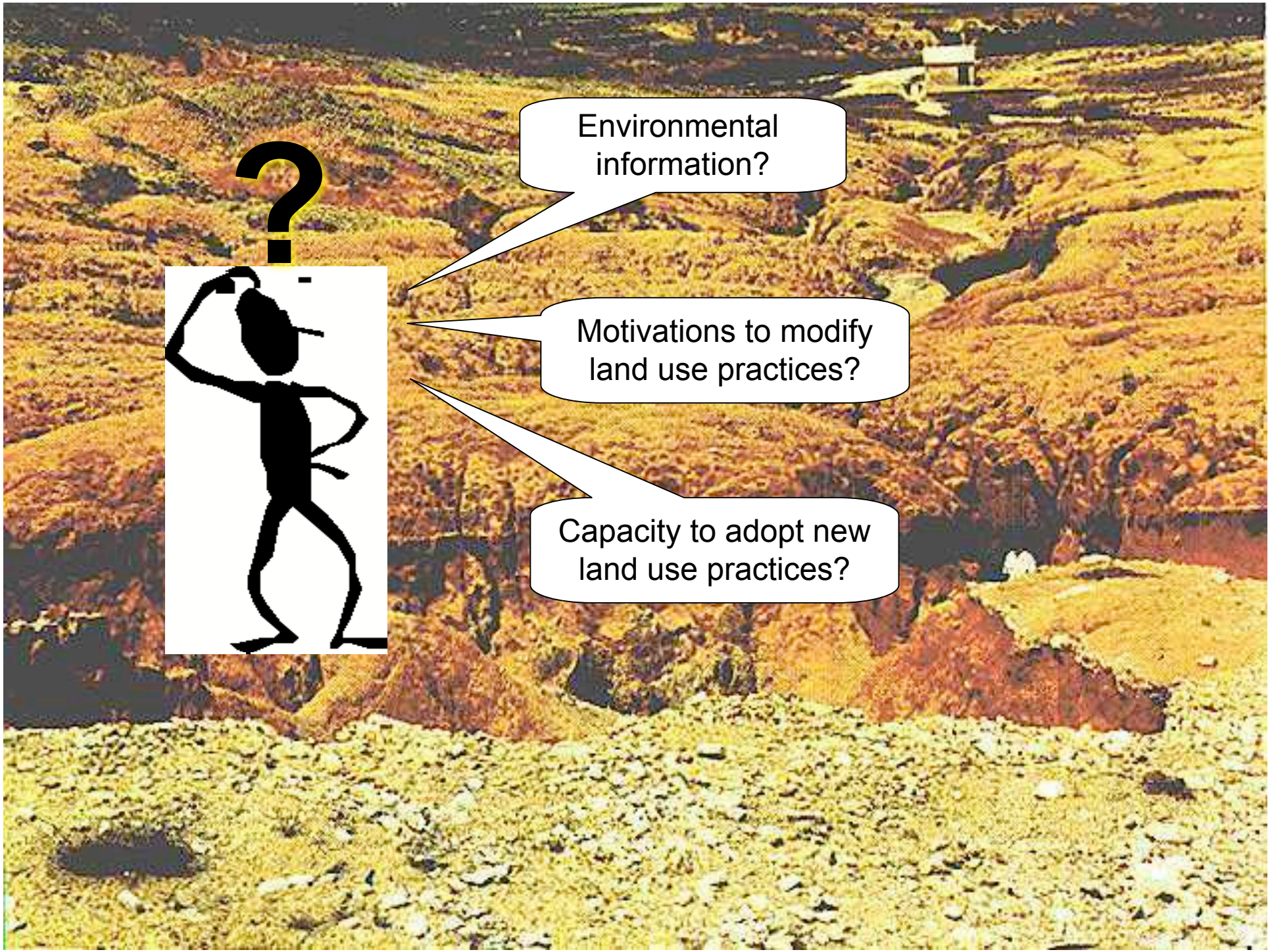
Implementing planetary stewardship

- 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

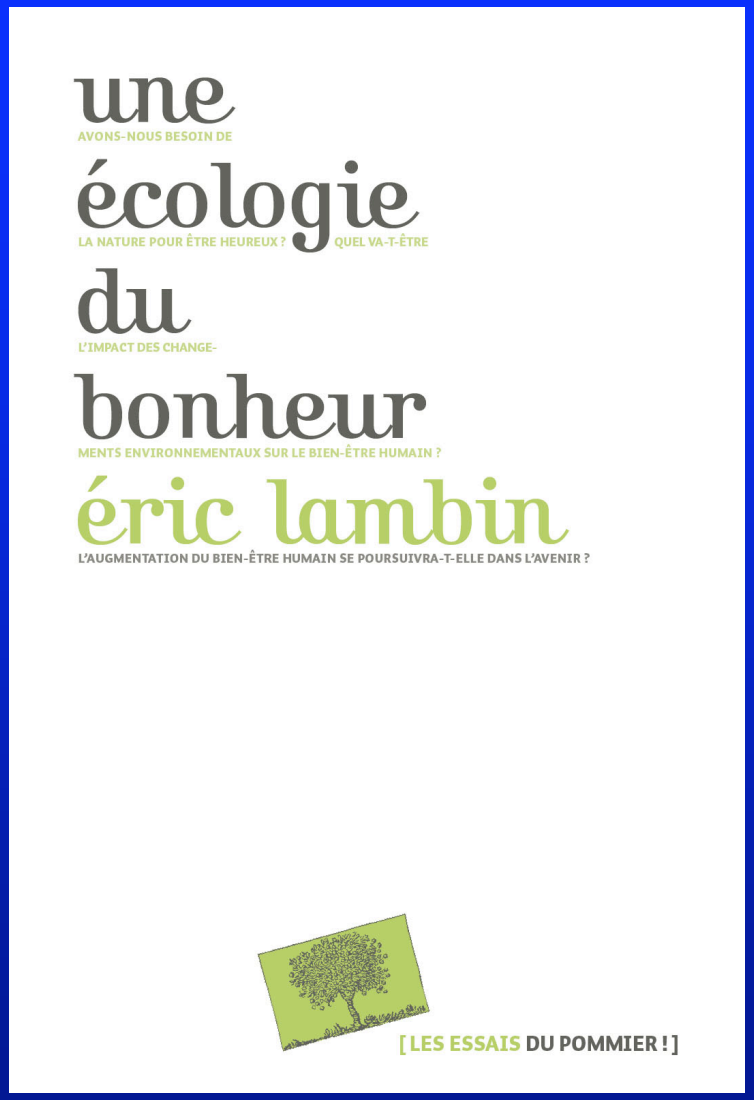
information - motivation - capacity

Social heterogeneity

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

  - social models

  - 7% richests = 50% global CO_2 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