Planetary boundaries: Implications for forest transitions and sustainable land use

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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[4,6].

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

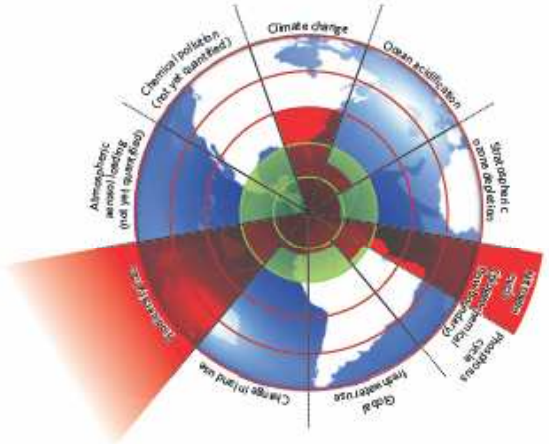

Figure 1| Beyond the boundary. The inner green shading represents the proposed safe operating space for nine planetary systems. The red wedges represent an estimate of the current position for each variable. The boundaries in three systems (rate of biodiversity loss, climate change and human interference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

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Visions of Earth
National Geographic, February 2008

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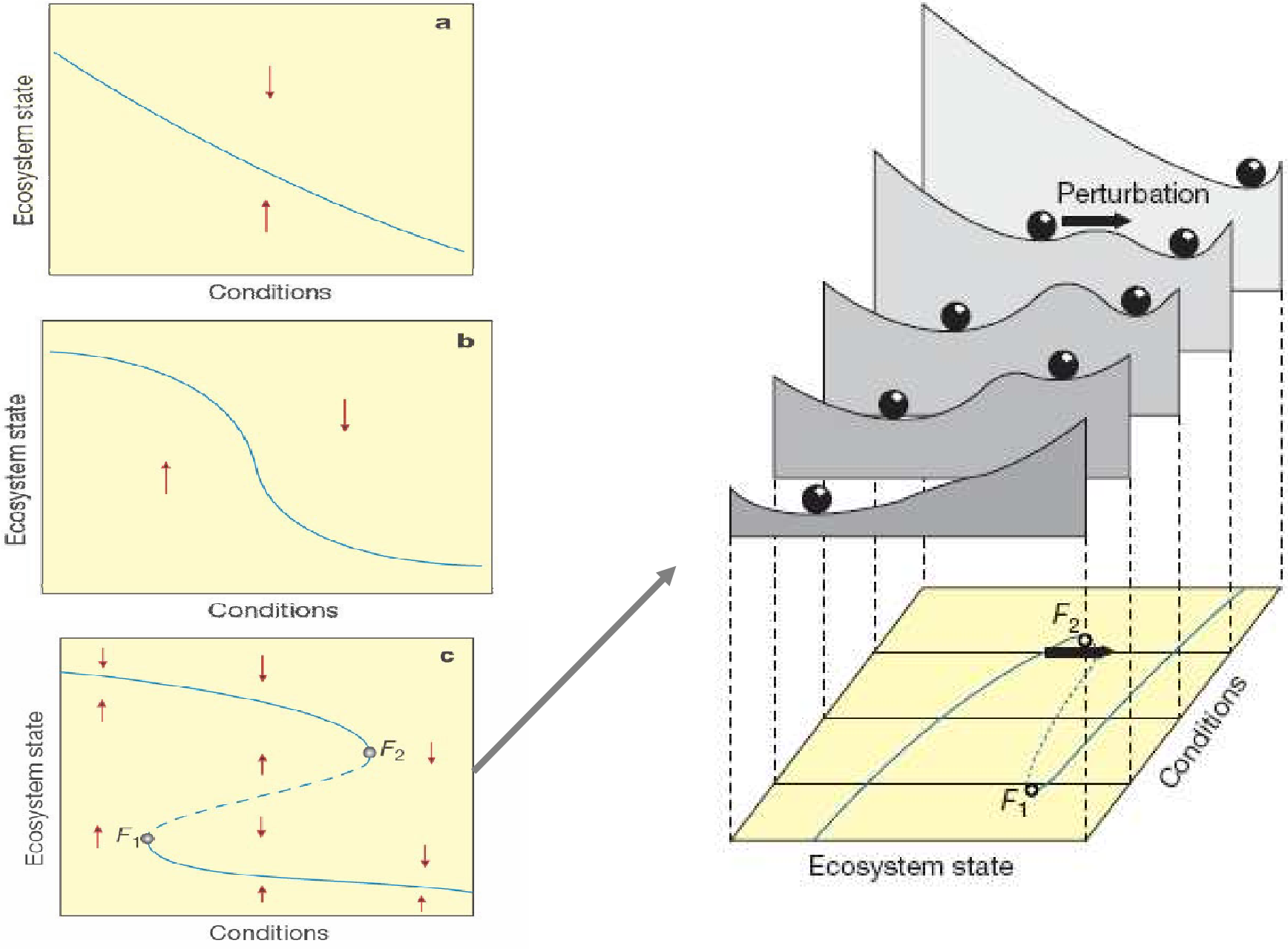
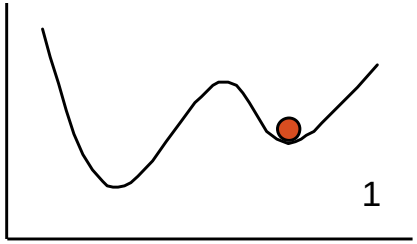
Critical transitions or regime shifts



Valuable Ecosystem Services (Desirable)

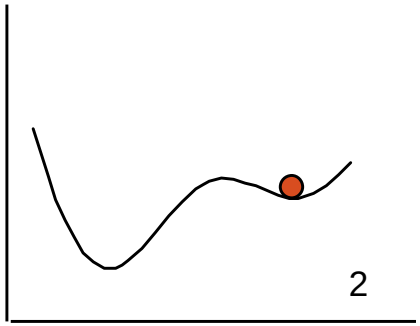
Loss of ecosystem services (Undesirable)



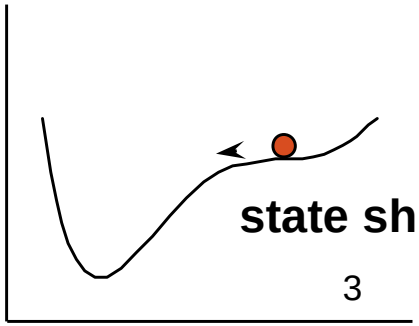
coral dominance

clear water

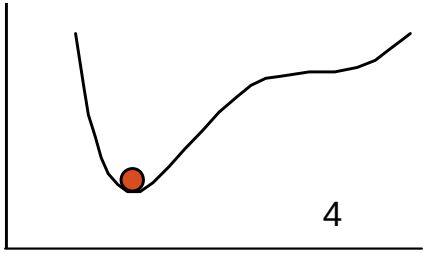
grassland



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



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

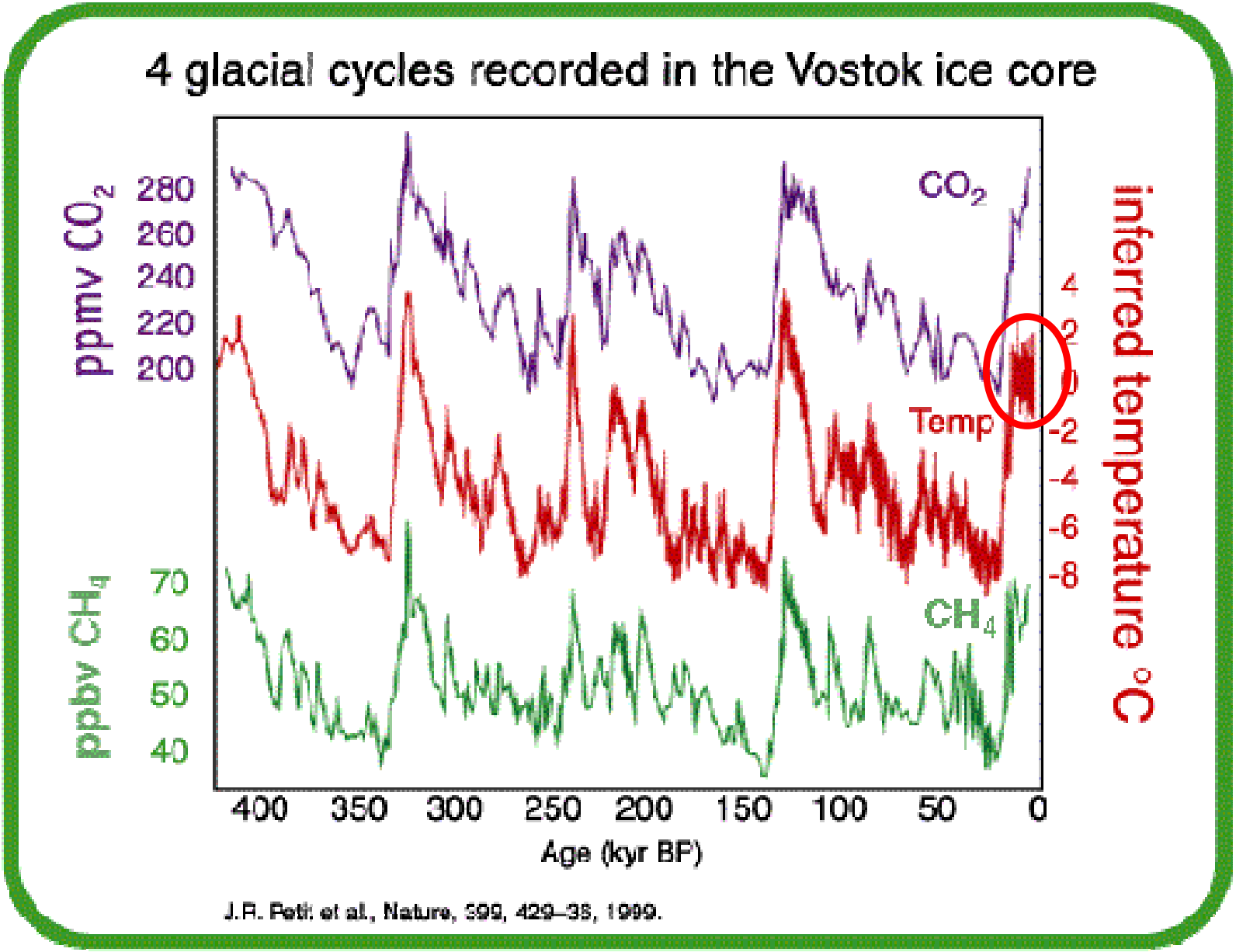


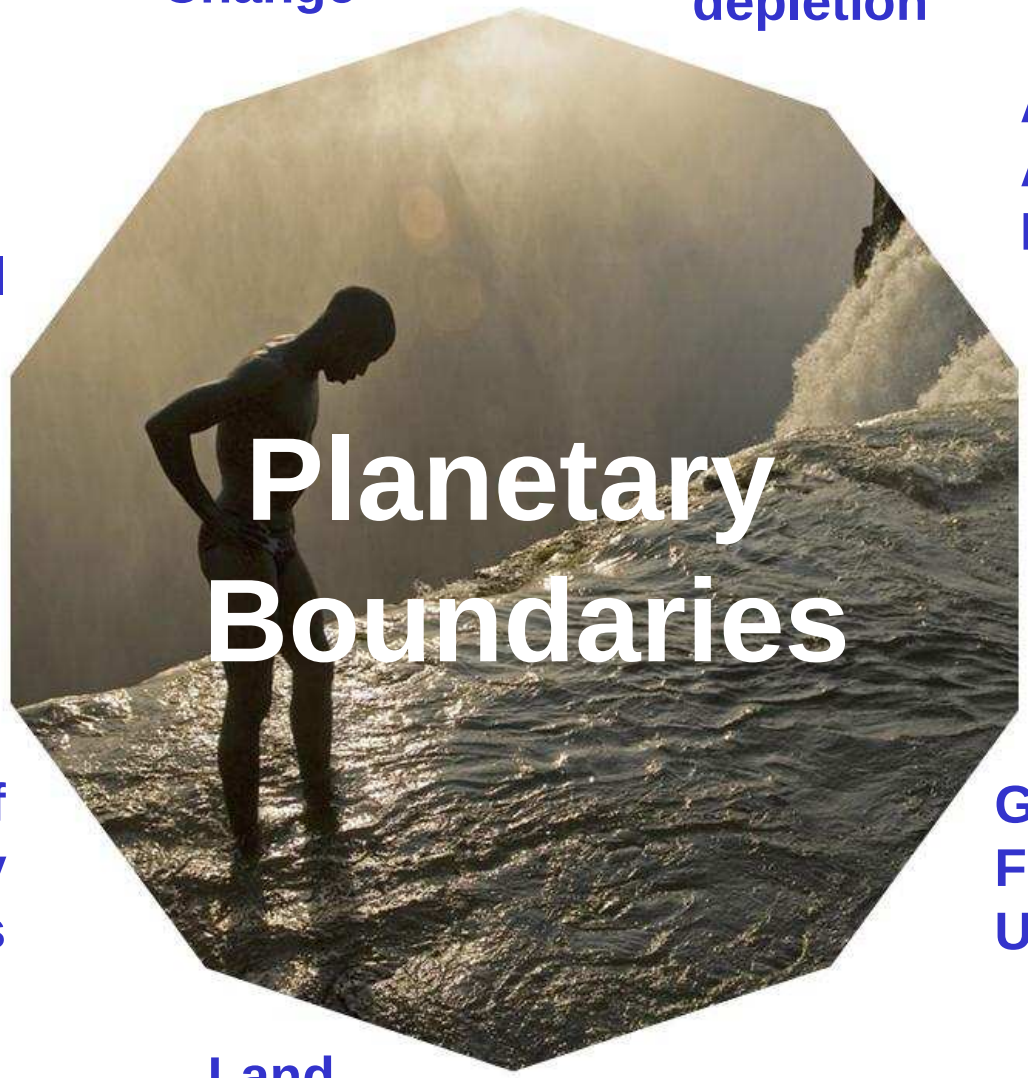
algal dominance

turbid water

shrub-bushland

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





Climate Change

Ozone depletion

Atmospheric Aerosol Loading

Biogeochemical loading: Global N & P Cycles

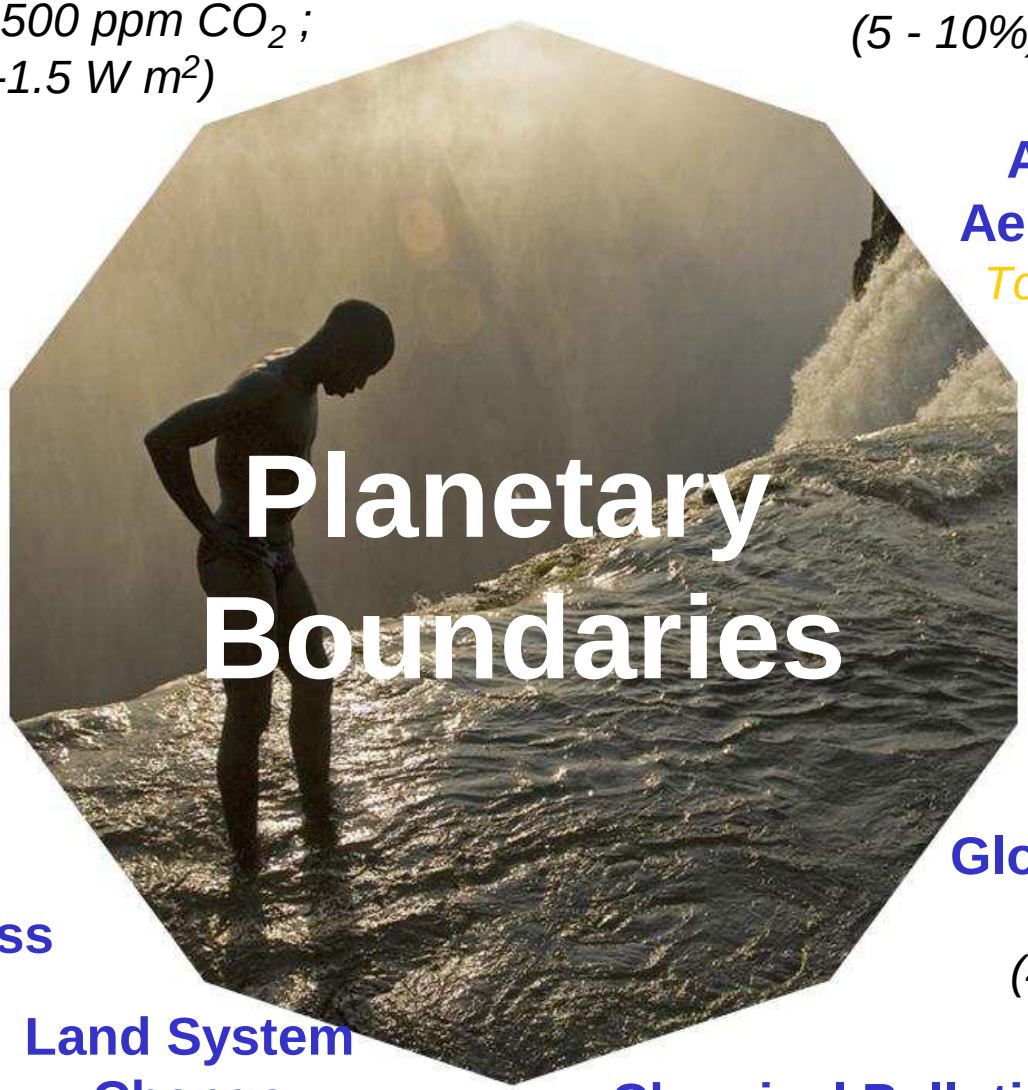
Ocean acidification

Rate of Biodiversity Loss

Global Freshwater Use

Land System Change

Chemical Pollution



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

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*

In 2000:

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

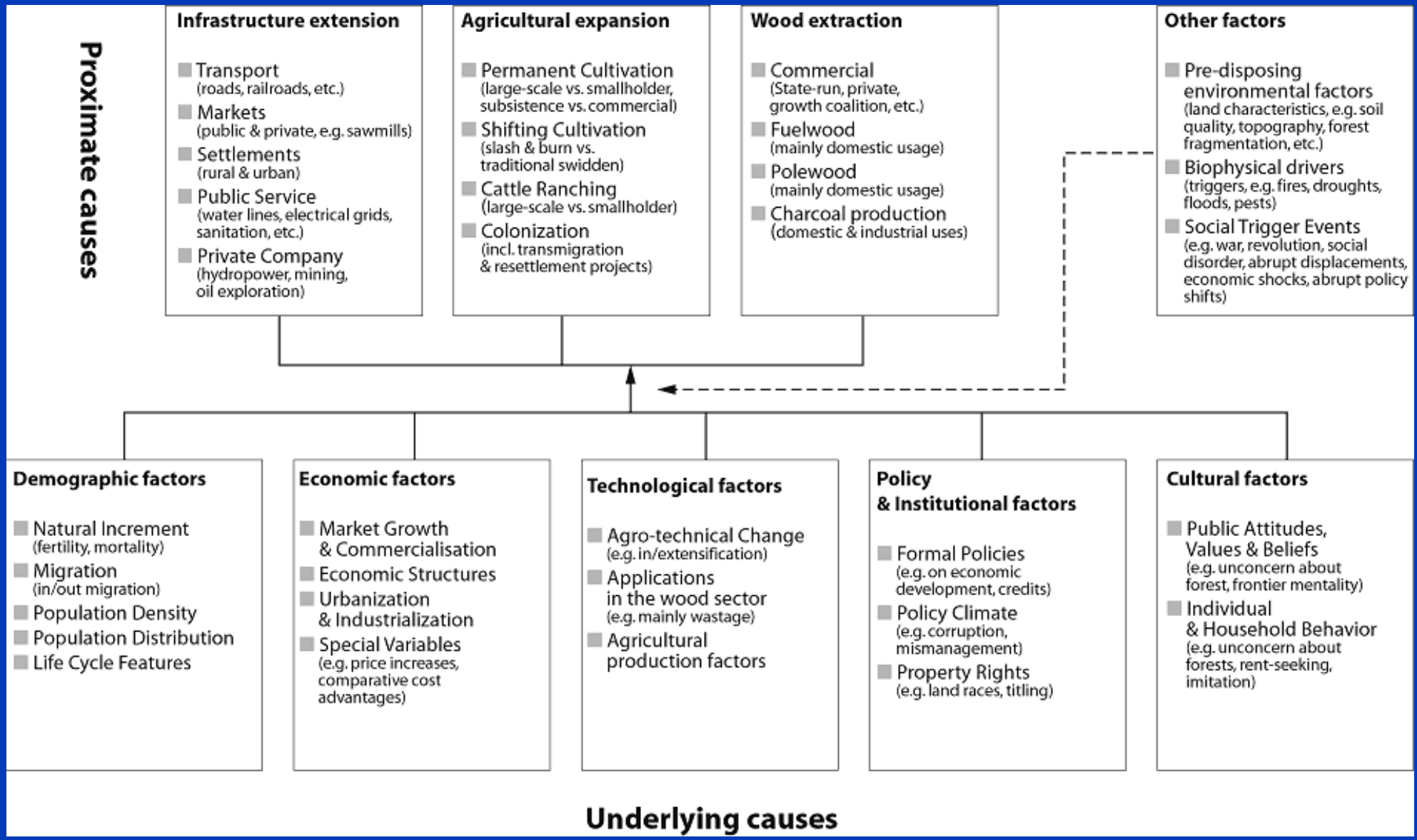
> 50% new cropland expansion in natural forests

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

Causes of tropical deforestation



Geist & Lambin, *Bioscience* (2002)

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
- Forest protection/reforestation offset by displacement to other countries (leakage)

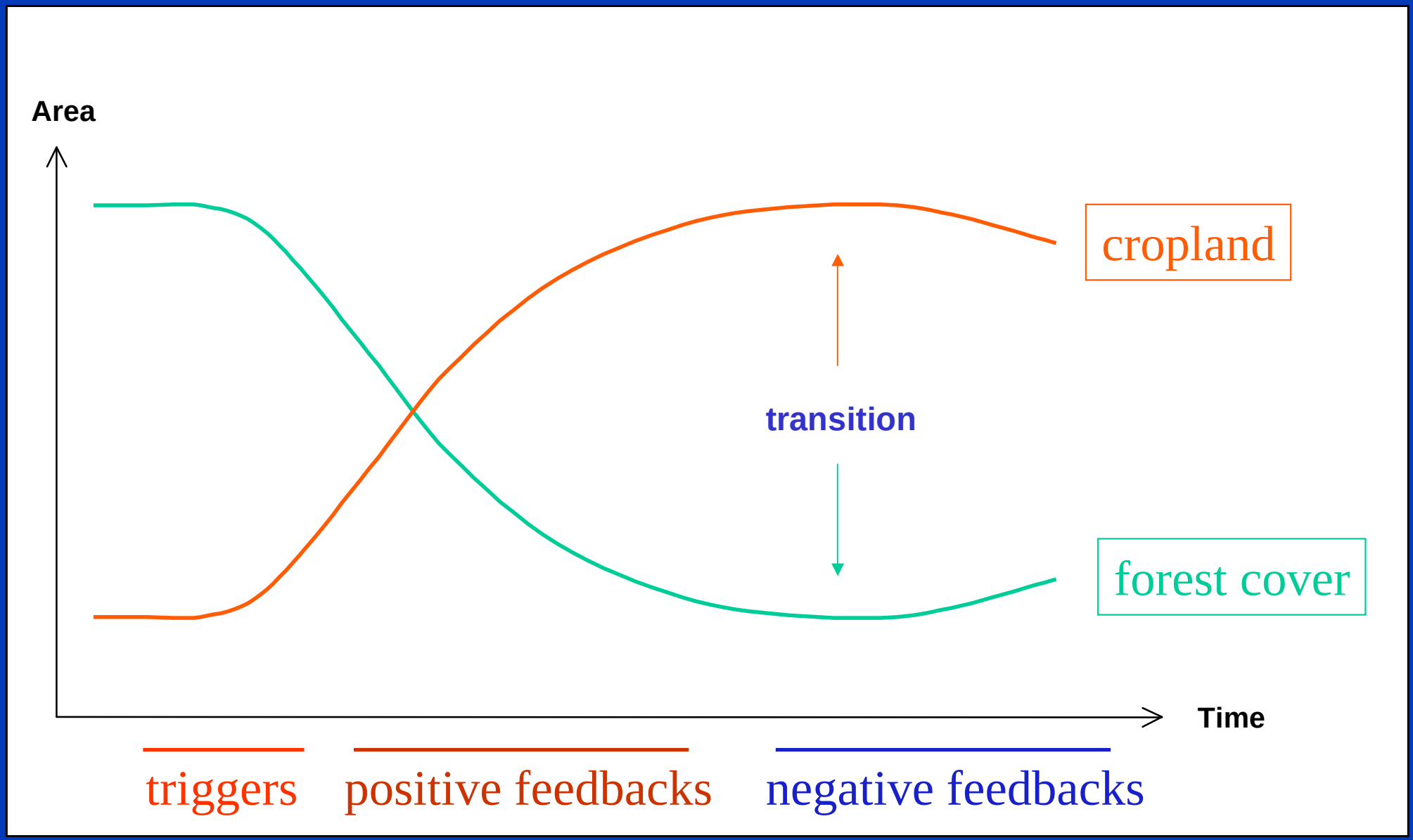
Geist & Lambin, *Bioscience* (2002)

Mix of good policies, economic reforms and cultural changes can restore forests and spare land

« Forest transition », « forest resurgence »:

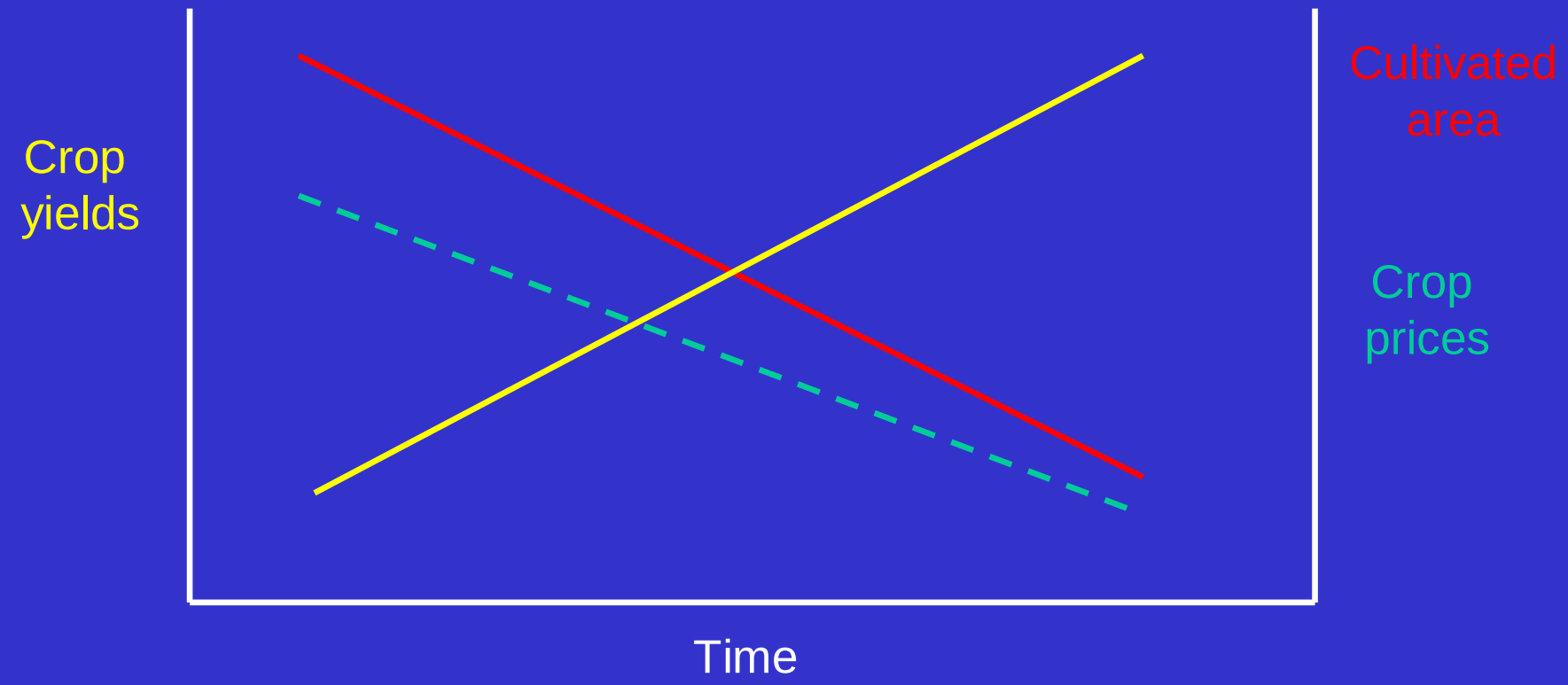
China, India, Vietnam, Bhutan, Costa Rica, El Salvador, Dominican Republic, Panama...

Forest transition



Borlaug hypothesis

Increasing the productivity of agriculture on the best farmland can help control deforestation by reducing the demand for new farmland



Evidence for land sparing

- *Global scale:* 1961-2000: food production increased by 2.3 while cropland area increased by only 12%
- *National scale:* Most countries with greatest yield increase are not those with a contraction of cropland Unless: increased imports of grains or conservation set aside programs
- *Local scale:* Rice cultivation + abandonment of uplands *versus* expansion of soybean or oil palm plantations

Rudel et al., *PNAS* (2009)

Pathways of forest transition

Economic development path: Economic development creates enough non-farm jobs to pull farmers off of the land, thereby inducing the spontaneous regeneration of forests in old fields

Forest scarcity path: A scarcity of forest products and a decline in ecosystem services (e.g., floods) prompts governments and landowners to plant trees

Rudel et al., *GEC* (2005)

State forest policy path: Changes in national forest policies modify management practices on forests. Motivations:

(i) modernize the economy

(ii) integrate marginal social groups

(iii) promote tourism or foreign investments

(iv) assert control over remote territories

Globalization path:

(i) Neo-liberal economic reforms: free trade, specialization

(ii) Labour out-migration, remittances

(iii) Growing tourism, land acquisition by expatriates

(iv) Diffusion of nature conservation ideology

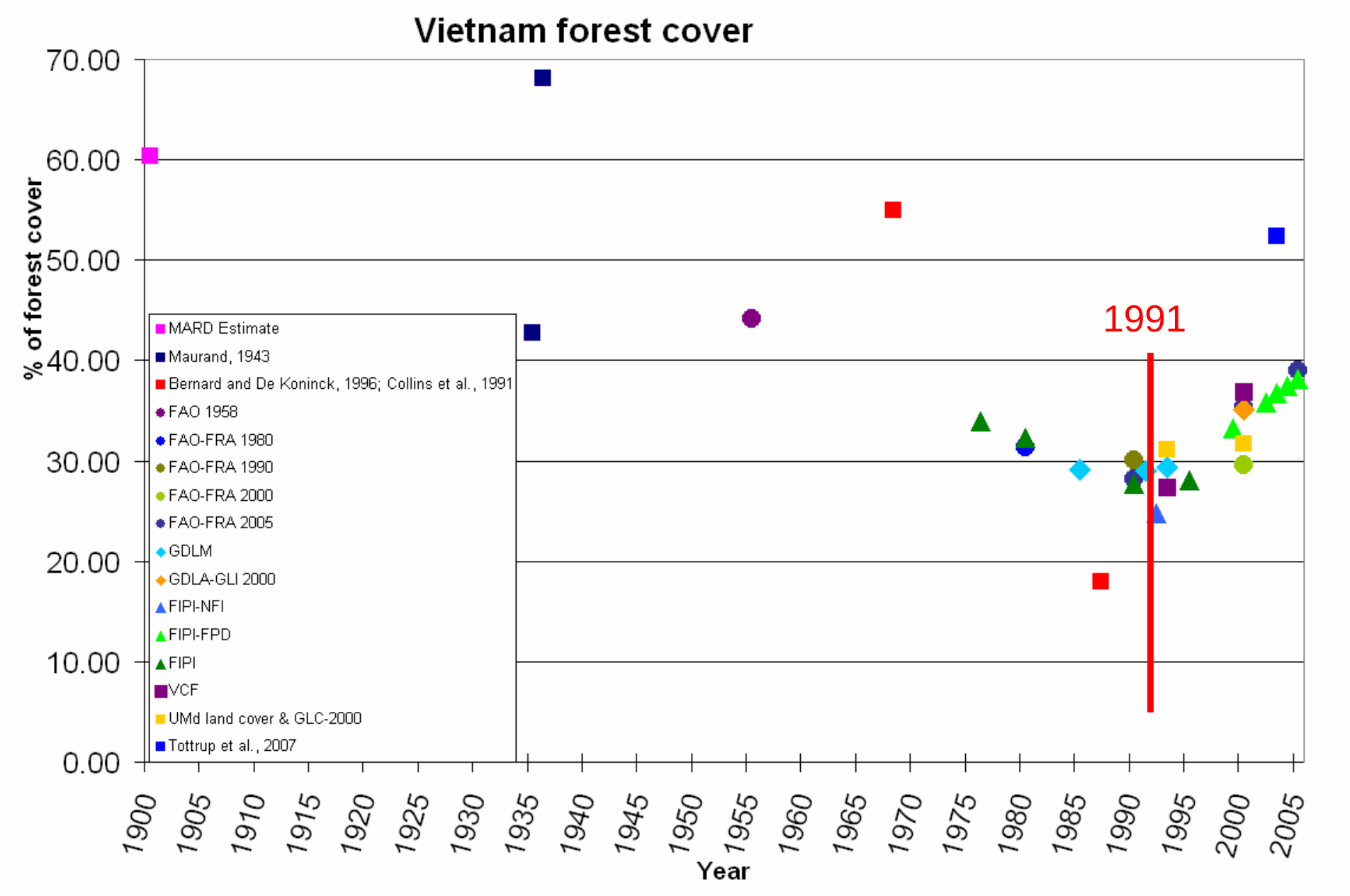
Lambin & Meyfroidt, *Land Use Policy* (2010)

Smallholder, tree-based land use intensification path:

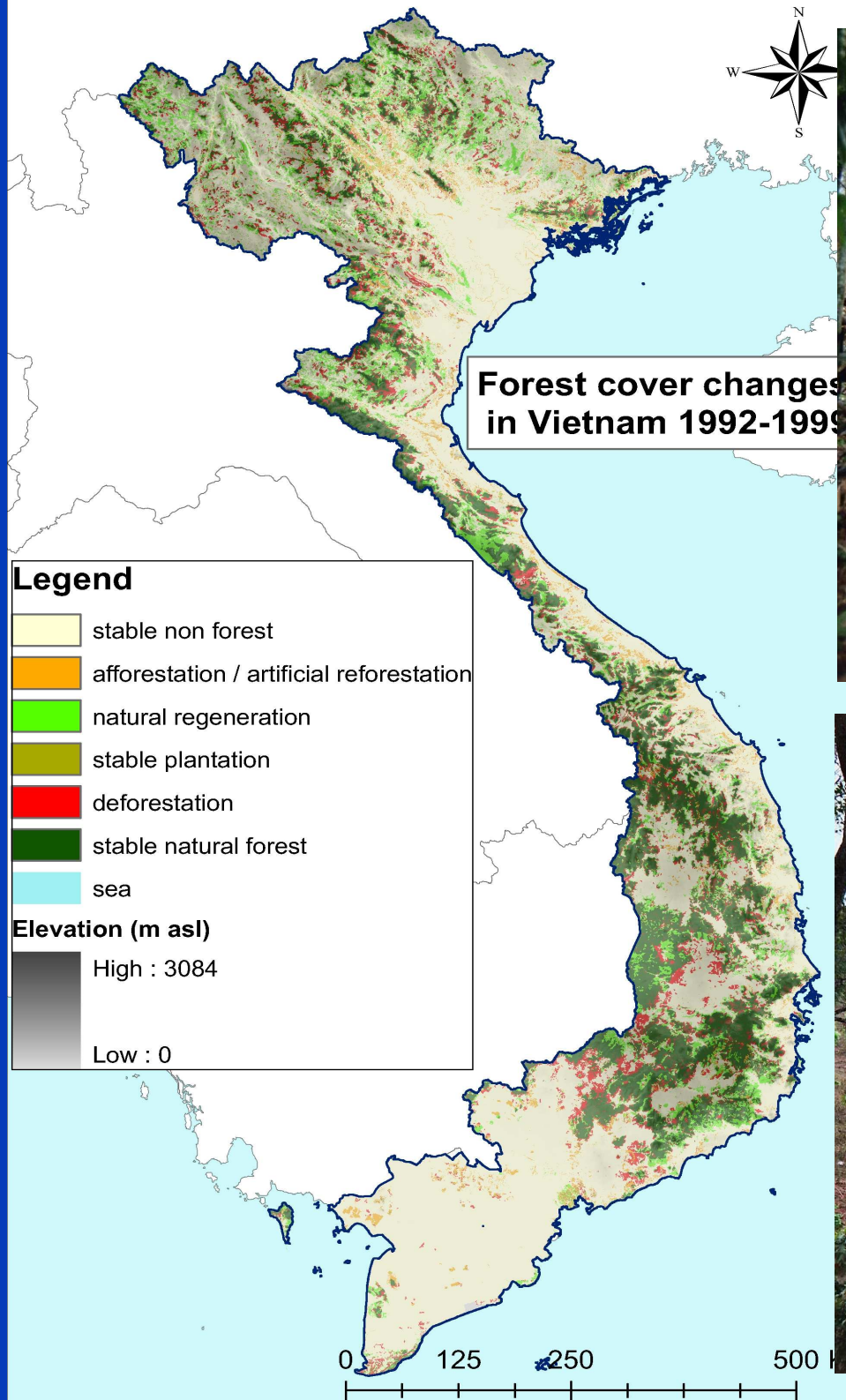
- Marginal regions with smallholder agriculture: landscape mosaics with “anthropogenic” or “domestic” forests
- Agroforestry systems, fruit orchards, secondary successions, wood lots, abandoned pastures, gardens, hedgerows
- Conservation value; provide multiple ecosystem services
- No decline in rural population or agriculture
- Smallholders decrease their vulnerability & guarantee their livelihood through ecological and economic diversification

Lambin & Meyfroidt, *Land Use Policy* (2010)

Reforestation in Vietnam



Meyfroidt & Lambin, *GCBiol* (2008)


Forest cover changes
in Vietnam 1992-199
Legend
stable non forest
afforestation / artificial reforestation
natural regeneration
stable plantation
deforestation
stable natural forest
sea
Elevation (m asl)
High : 3084
Low : 0
0
125
250
500


Natural forest regeneration


Plantations

Growing timber imports

- Increase in processed wood imports

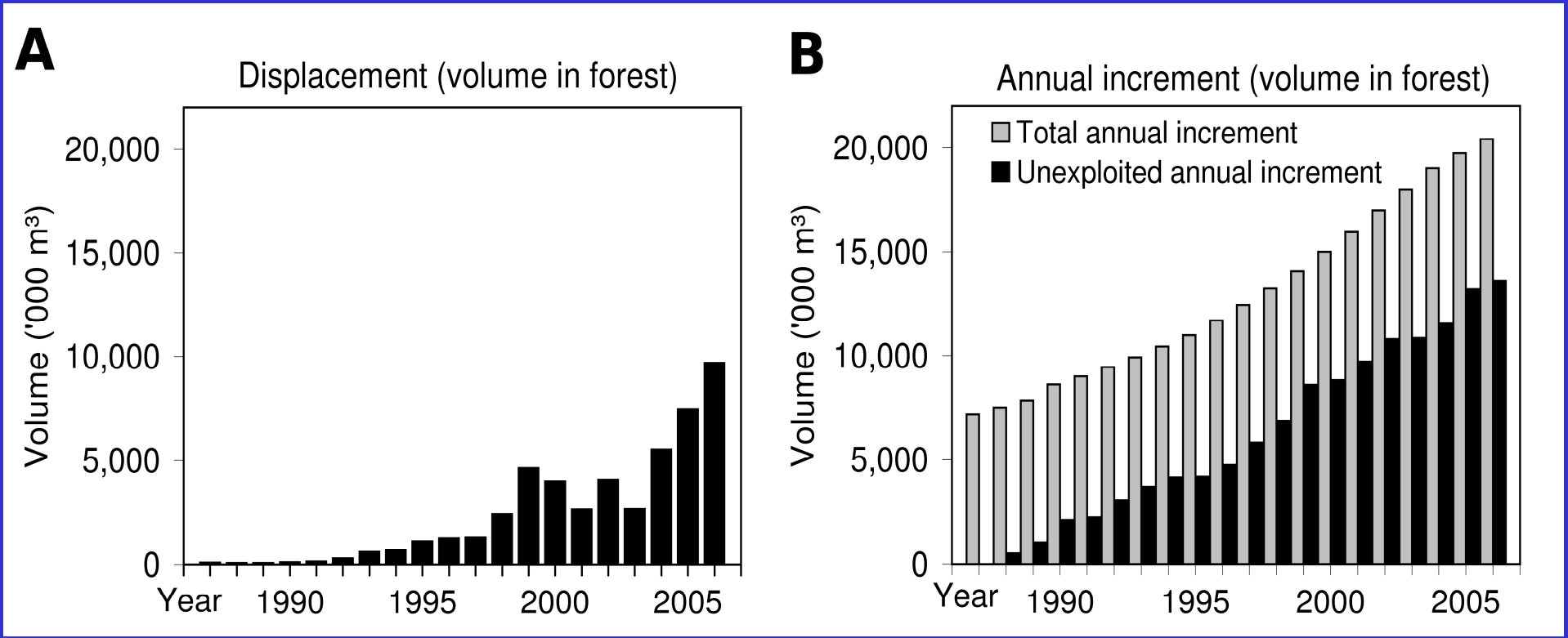
- Increasing imports of illegal timber

From EIA / Telapak

Displacement of deforestation abroad

Displacement = 40 % of 1987-2006 forest regrowth

About 80% of it exported as value-added products

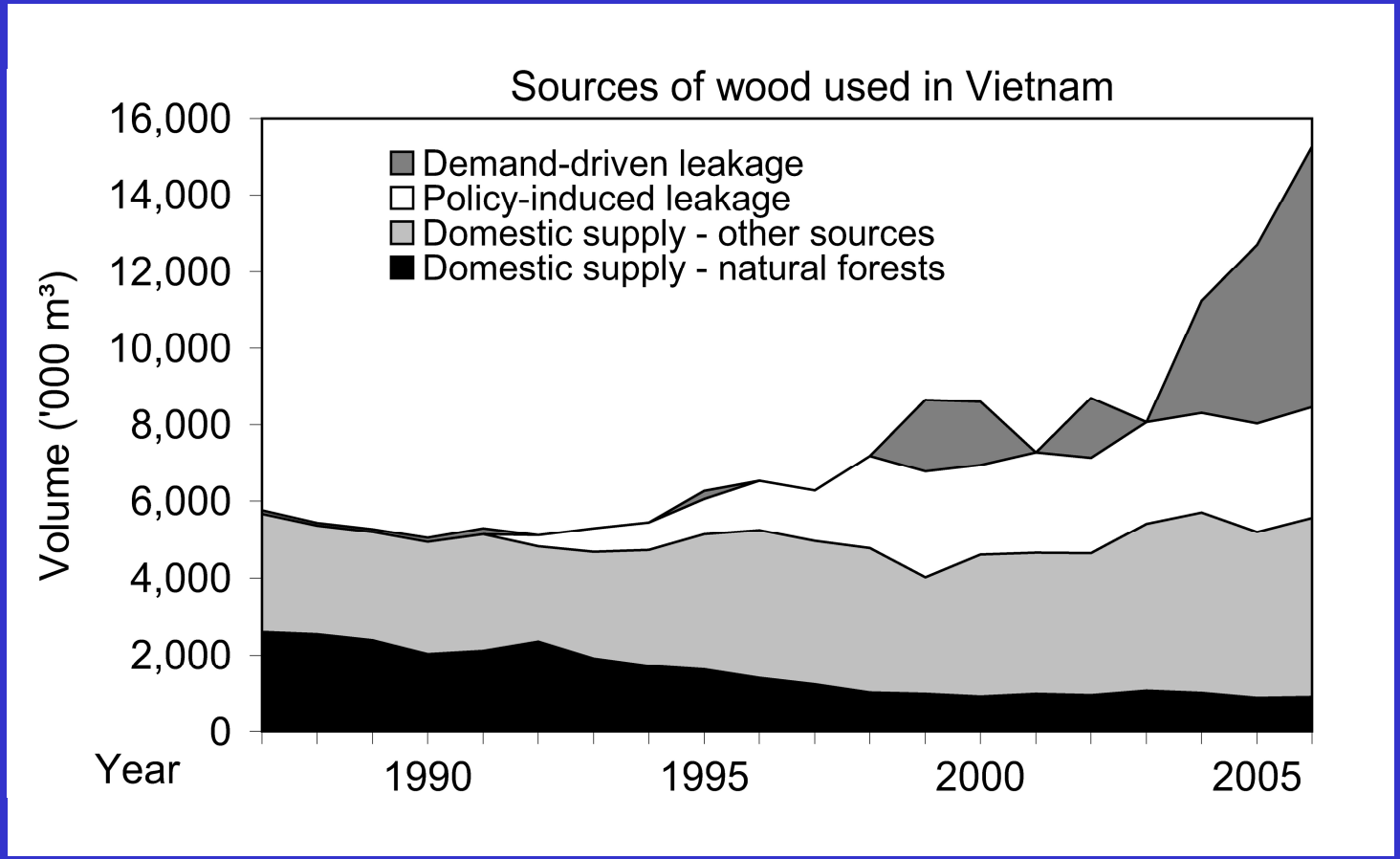


Meyfroidt & Lambin, *PNAS* (2009)

Causes of displacement

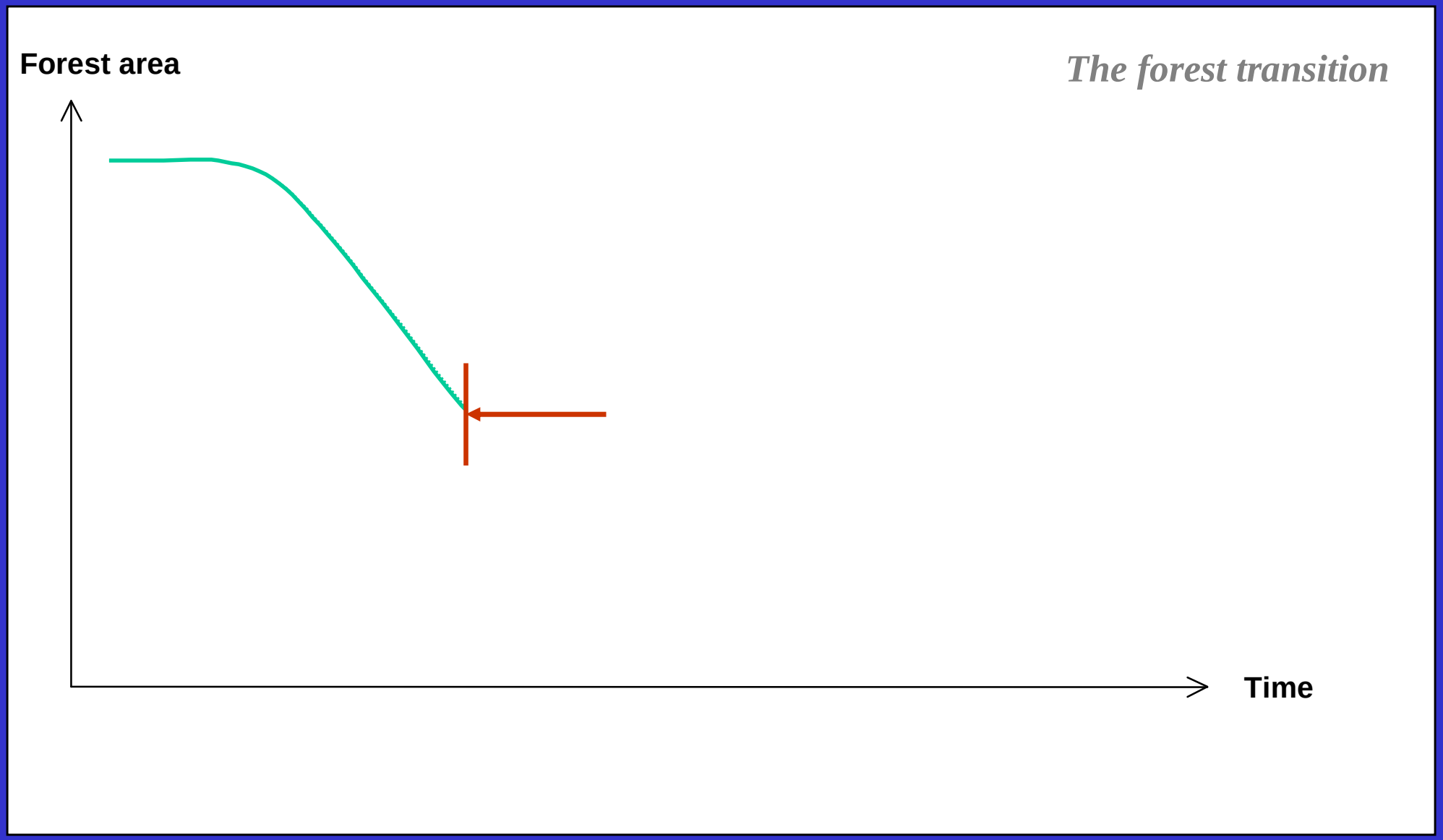
Policy-induced leakage = 60 % of displacement

Demand-driven displacement = 40 % of displacement

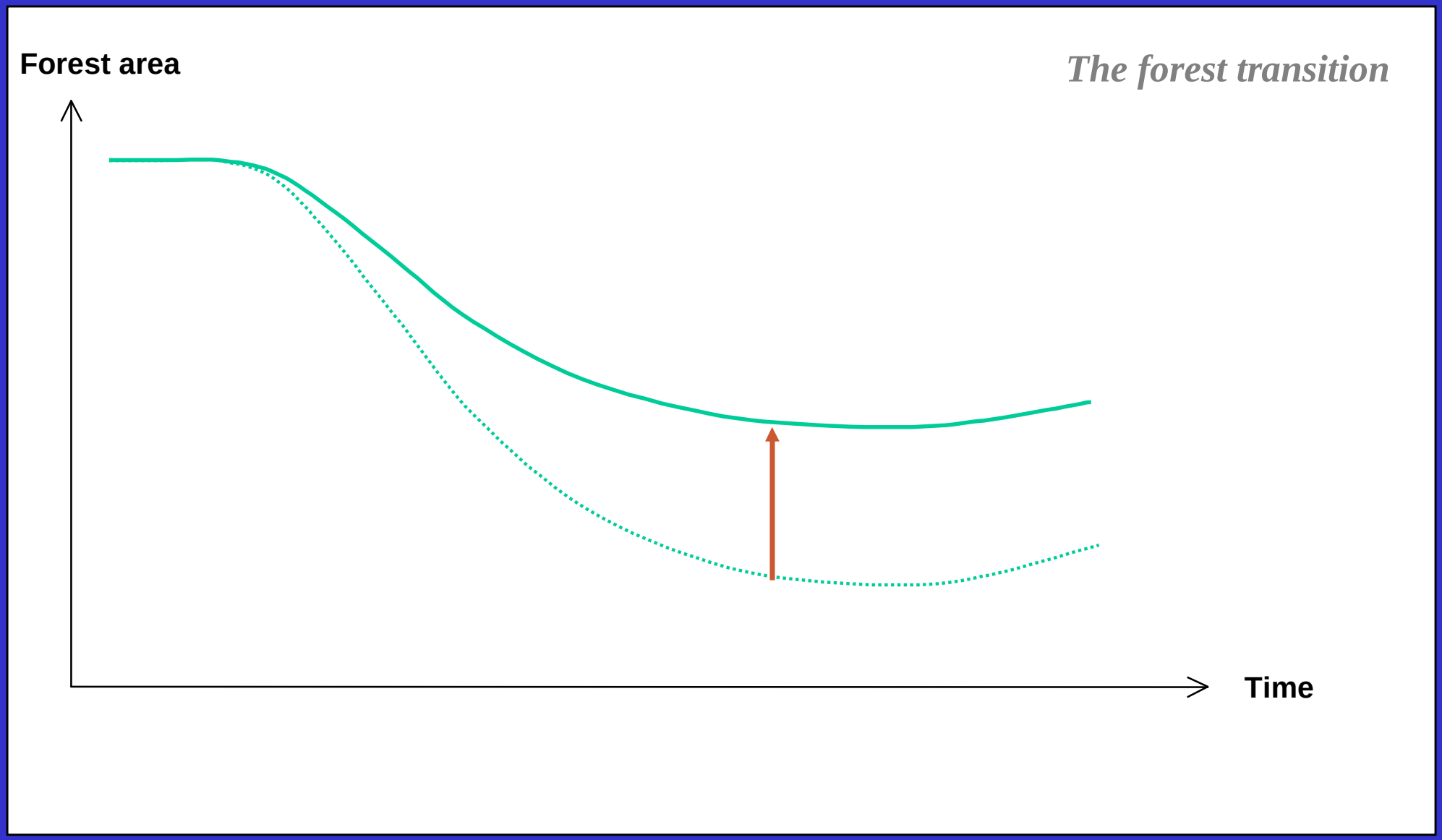


Meyfroidt & Lambin, *PNAS* (2009)

Halting deforestation?



… or accelerating a land-use transition



transition:

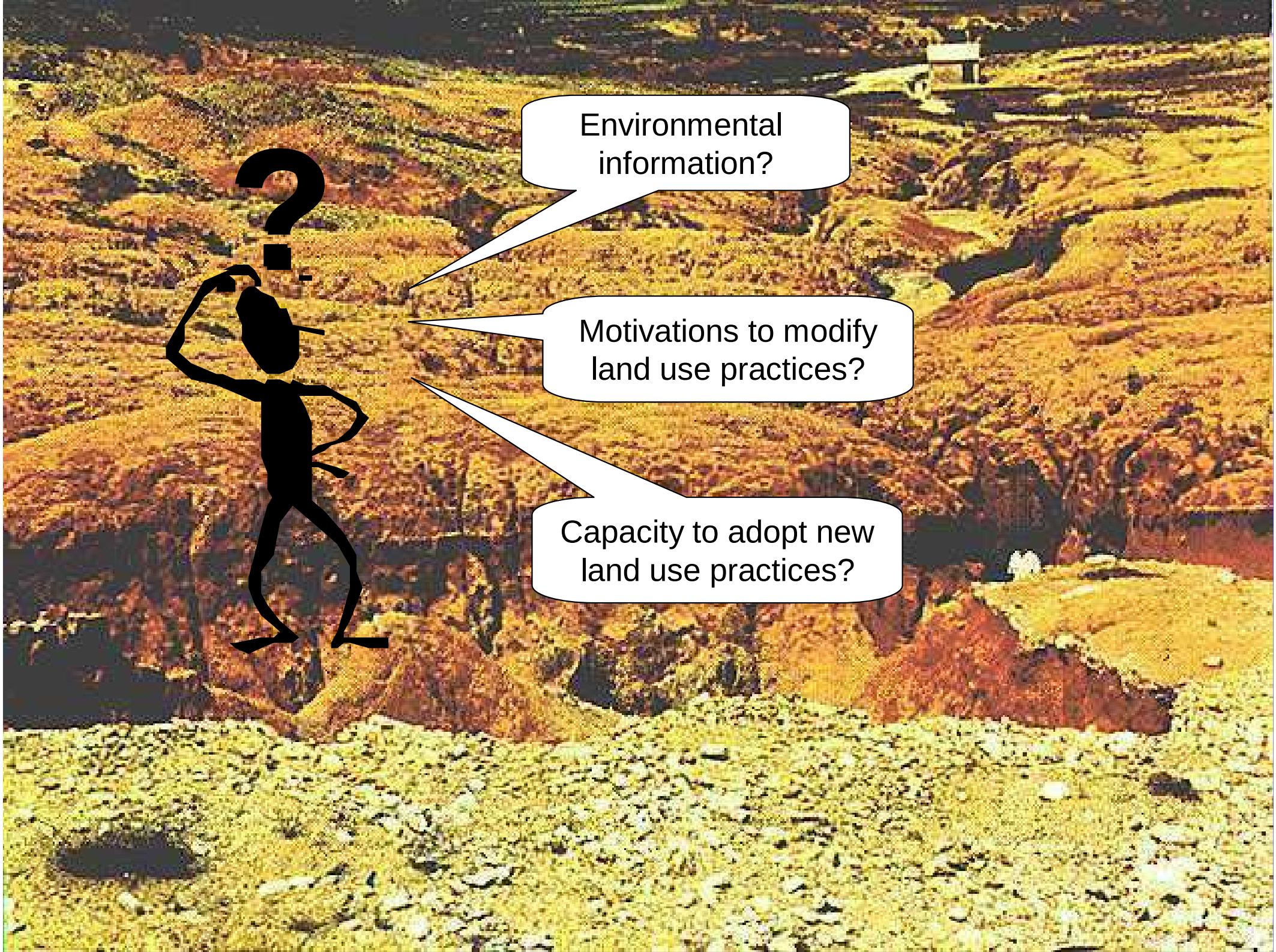
1. Improving **governance**, fighting corruption

2. **Decentralizing** forest management with a concomitant increase in the local capacity to enforce law (*e.g.*, in protected areas)

3. Developing **public participation** in environmental planning (*e.g.*, community forest management)

4. Designing **institutional instruments** such as payments for ecosystem services to increase forest rent (protective & extractive)

5. Providing more off-farm employment


Environmental information?
Motivations to modify land use practices?
Capacity to adopt new land use practices?