Human Development within Planetary Boundaries

Planetary Boundaries: Challenging Environmental Ortodoxies

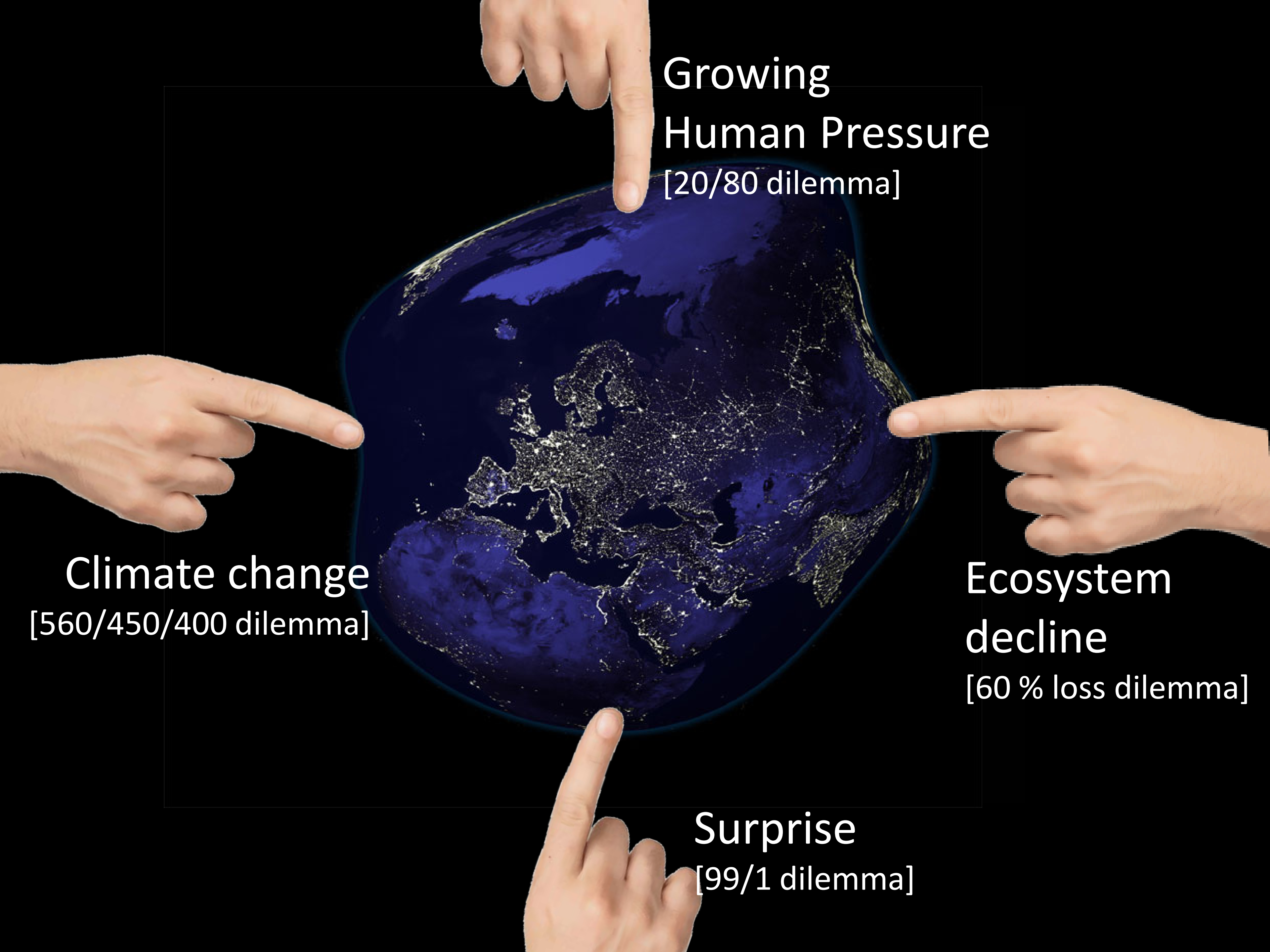
Pugwash Conference

London 6th July 2011

Prof. Johan Rockström

Stockholm Resilience Centre

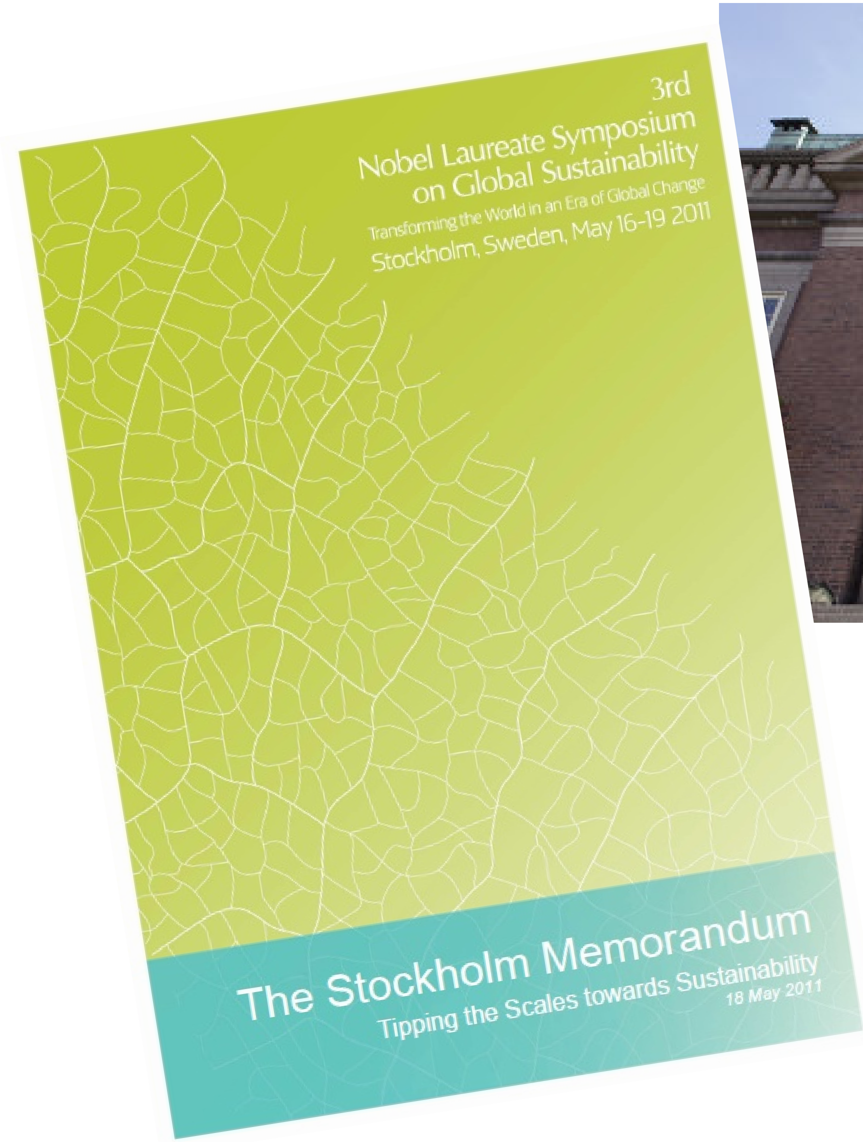
Stockholm Environment Institute


Growing
Human Pressure
[20/80 dilemma]
Climate change
[560/450/400 dilemma]
Ecosystem
decline
[60 % loss dilemma]
Surprise
[99/1 dilemma]

Article

Will Steffen, Paul J. Crutzen and John R. McNeill

The Anthropocene: Are Humans Now Overwhelming the Great Forces of Nature?



- Humanity has reached a planetary saturation point
- A resilient biosphere the basis for humen development
- It is not only about climate change
- A great transformation to global sustainability necessary, possible, and desirable

ENVIRONMENT AND DEVELOPMENT

Earth System Science for Global Sustainability: Grand Challenges

Progress in understanding and addressing both global environmental change and sustainable development requires better integration of social science research.

W. V. Reid,[1]* D. Chen,[2] L. Goldfarb,[2] H. Hackmann,[3] Y. T. Lee,[2] K. Mokhele,[4] E. Ostrom,[5] K. Raivio,[2] J. Rockström,[6] H. J. Schellnhuber,[7] A. Whyte[8]

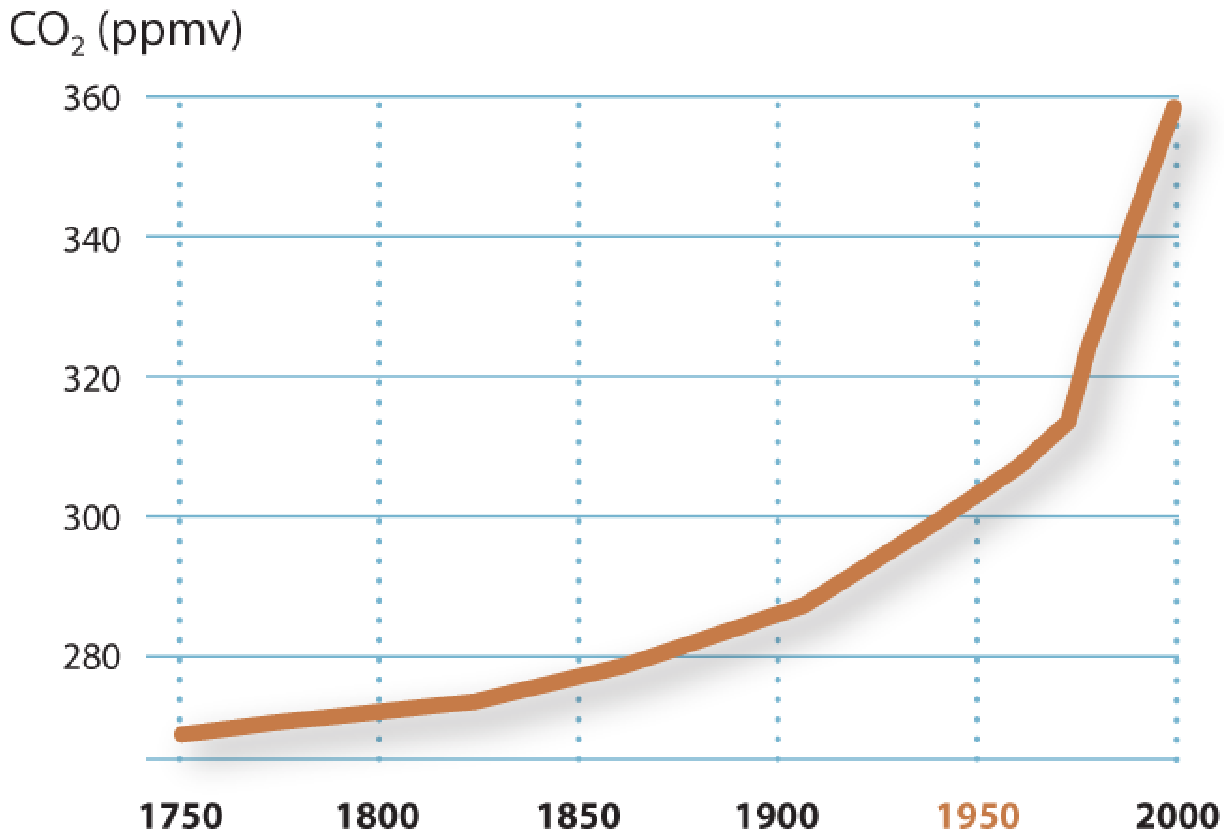
12 NOVEMBER 2010 VOL 330 SCIENCE www.sciencemag.org
Published by AAAS

Rio+20 and Planetary Boundaries

UN Secretary General Ban Ki-Moon

High Level Panel on Global Sustainability

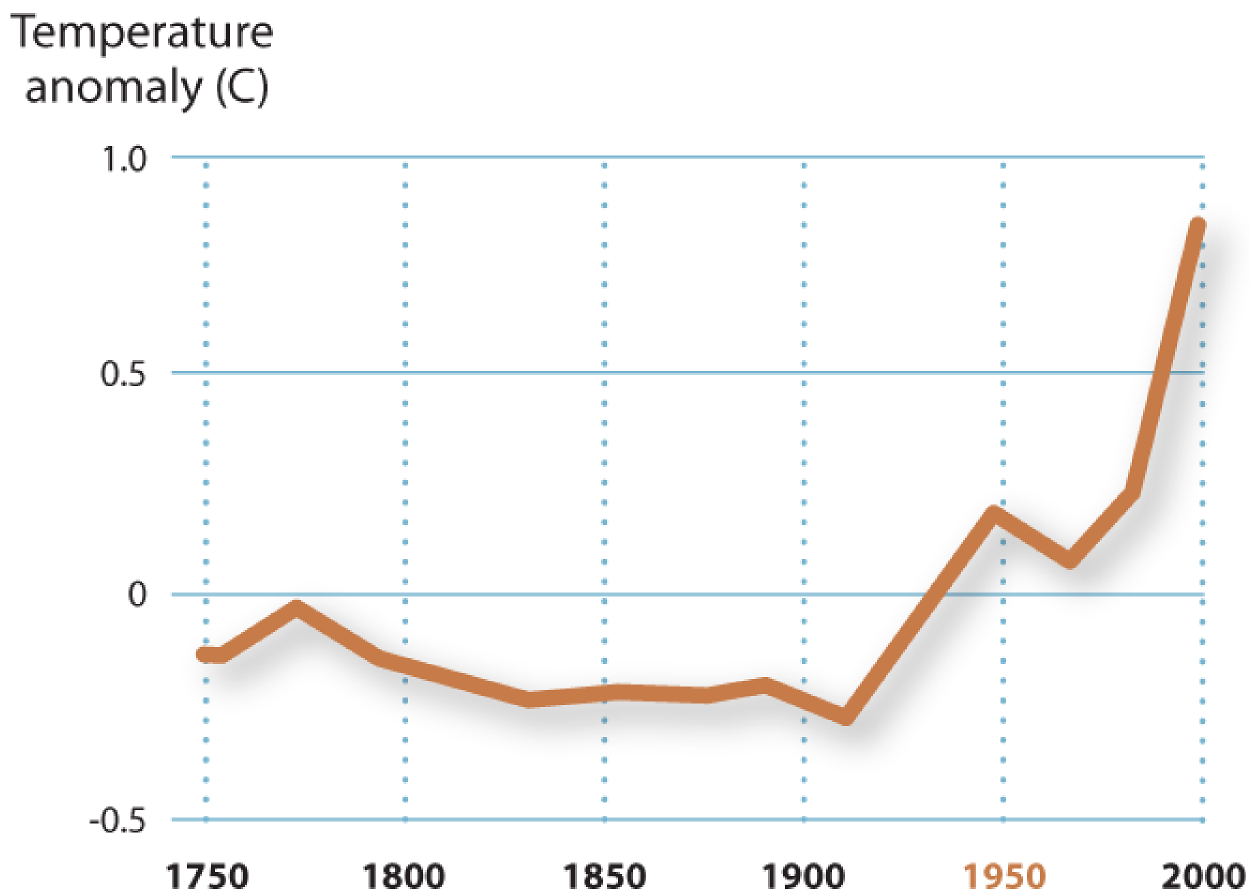
Atmospheric CO_2 concentration



Etheridge et al. Geophys Res 101: 4115-4128

IGBP synthesis: Global Change and the Earth System, Steffen et al 2004

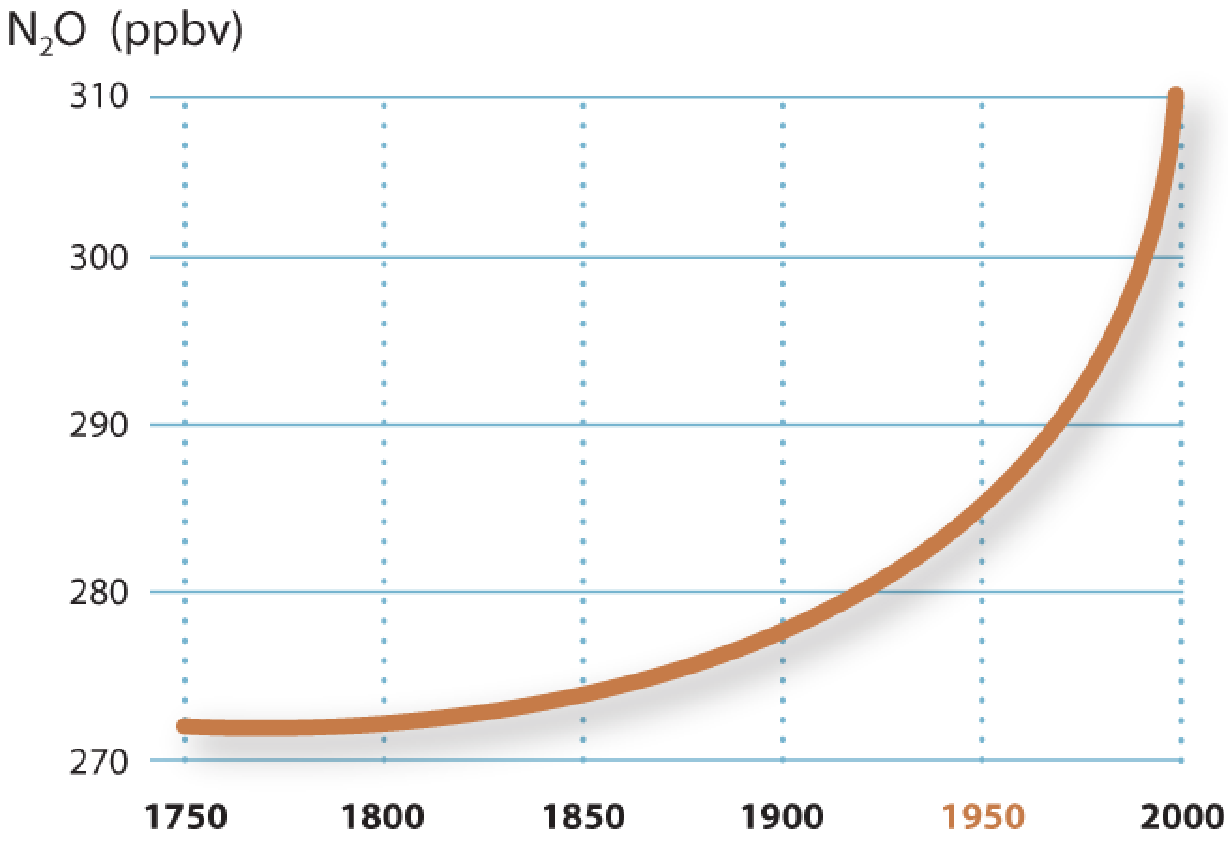
Northern hemisphere average surface temperature



Mann et al Geophys Res Lett 26(6): 759-762

IGBP synthesis: Global Change and the Earth System, Steffen et al 2004

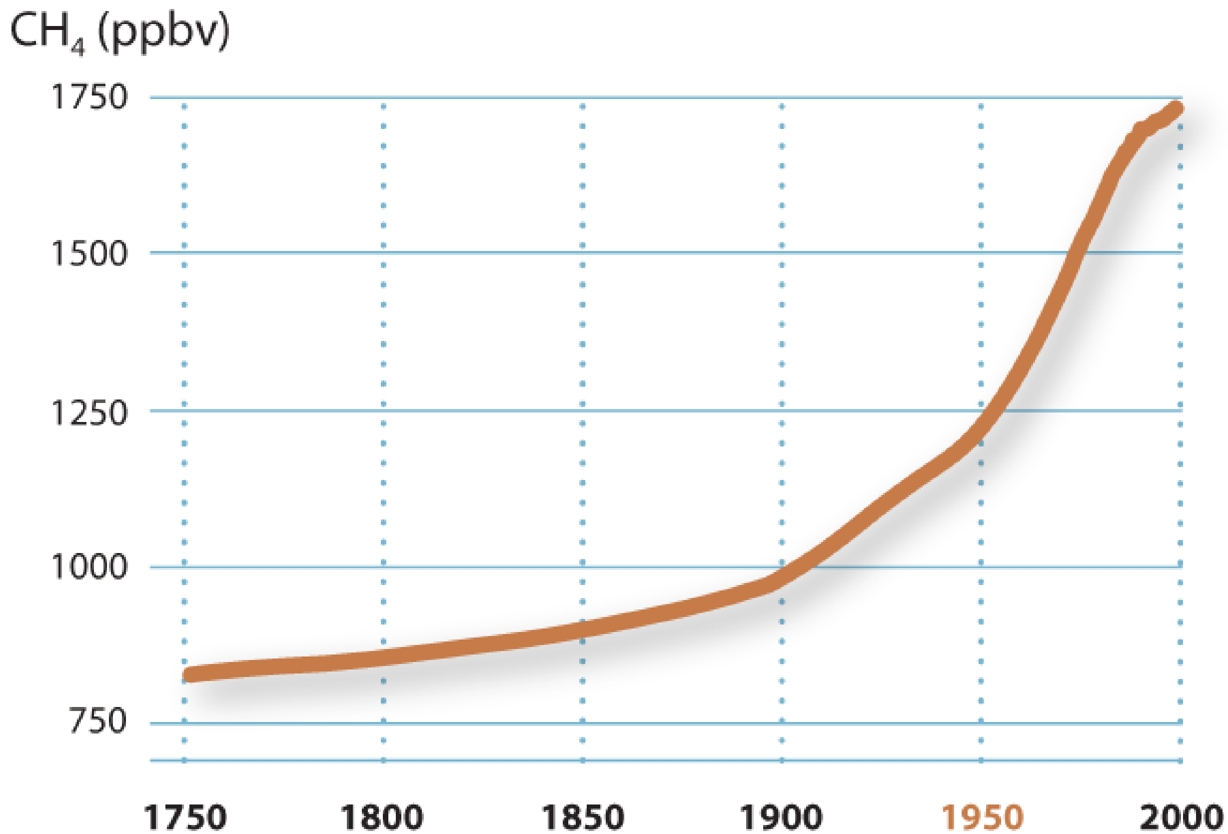
Atmospheric N_2O concentration



Machida et al Geophys Res Lett 22:2921-2925

IGBP synthesis: Global Change and the Earth System, Steffen et al 2004

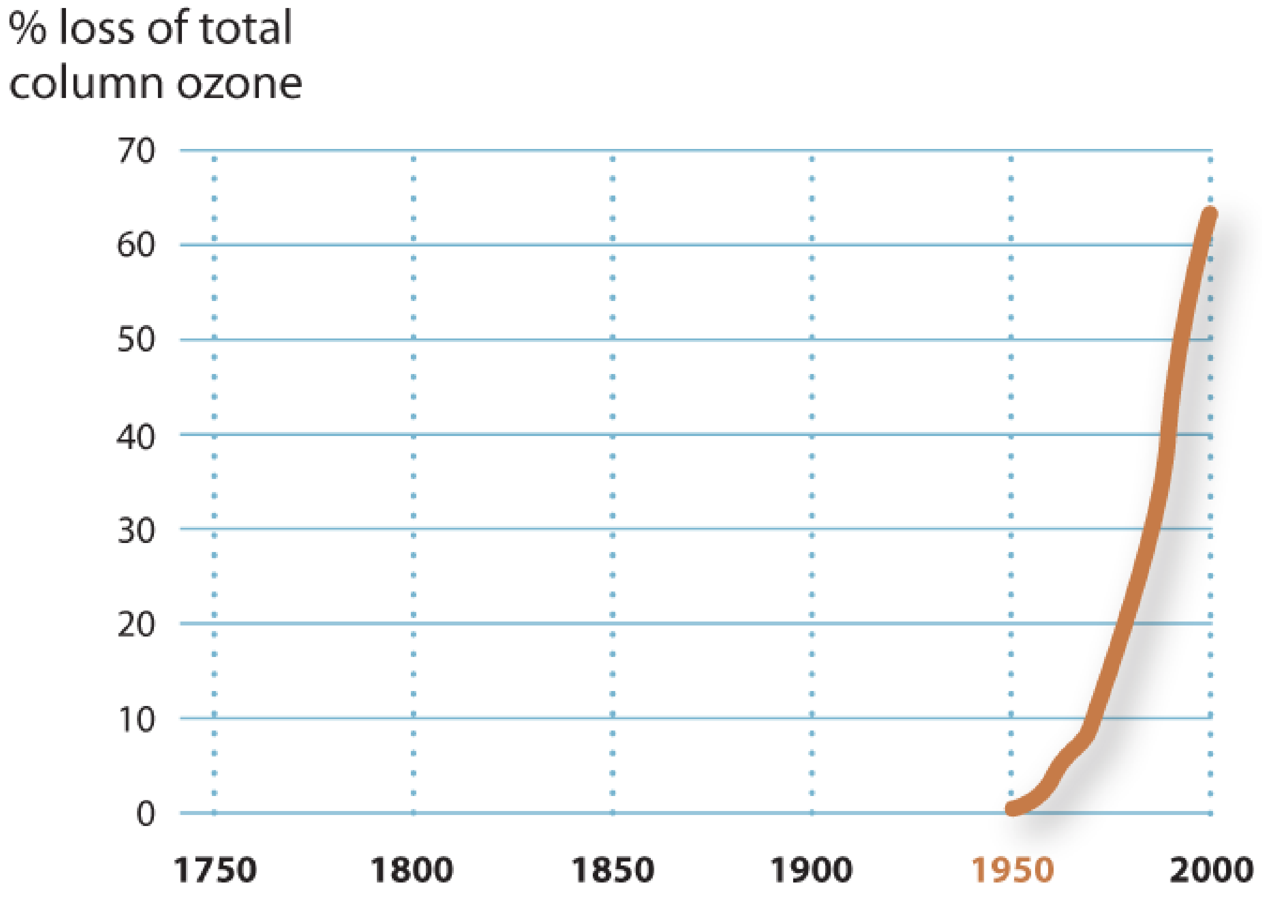
Atmospheric CH_4 concentration



Blunier et al J Geophy Res 20: 2219-2222

IGBP synthesis: Global Change and the Earth System, Steffen et al 2004

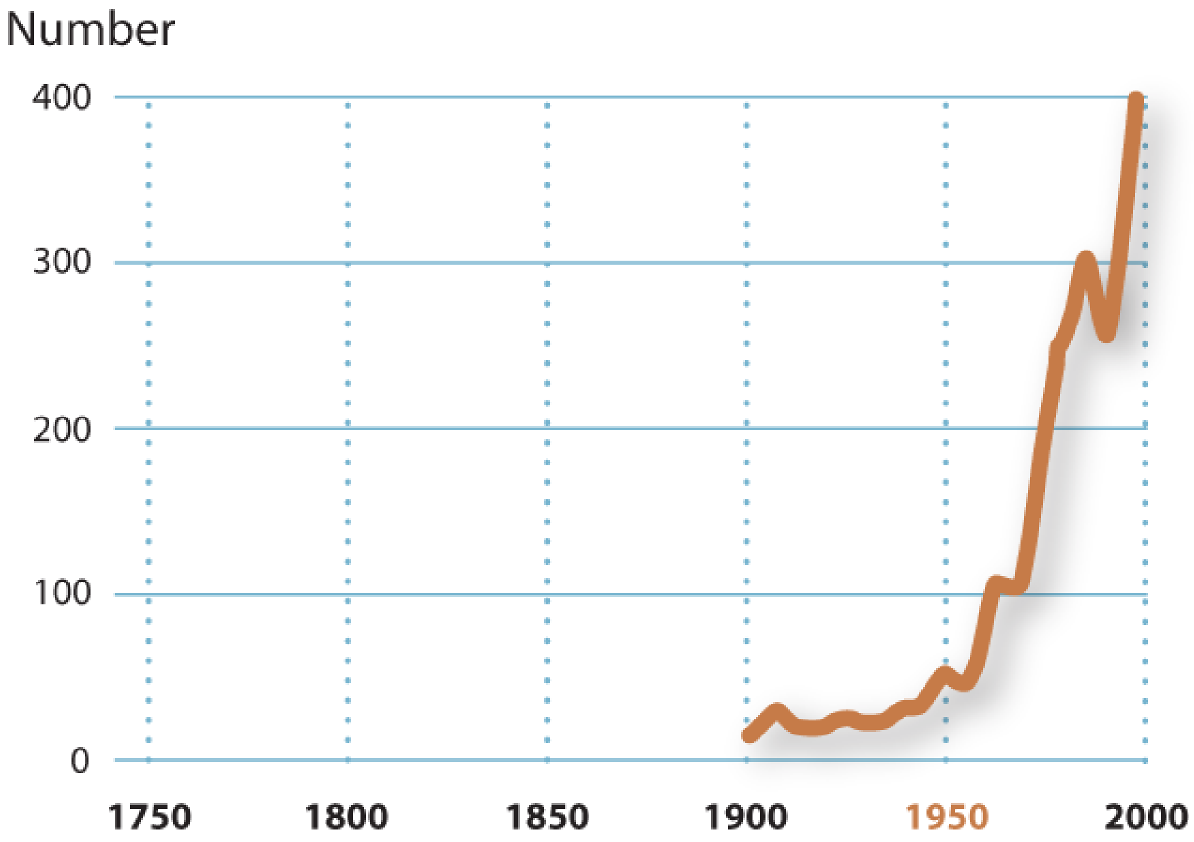
Ozone depletion



JD Shanklin British Antarctic Survey

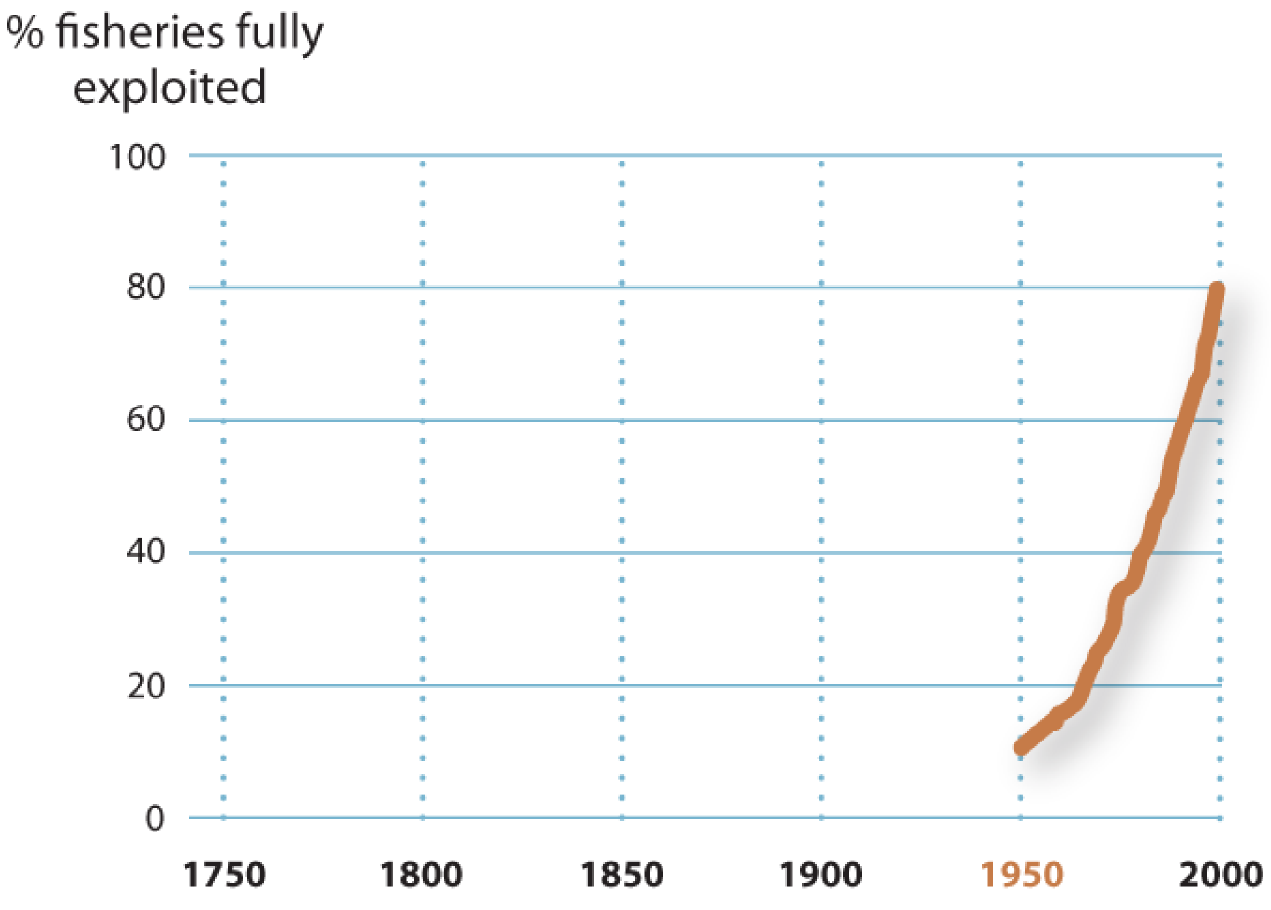
IGBP synthesis: Global Change and the Earth System, Steffen et al 2004

Natural climactic disasters



IGBP synthesis: Global Change and the Earth System, Steffen et al 2004

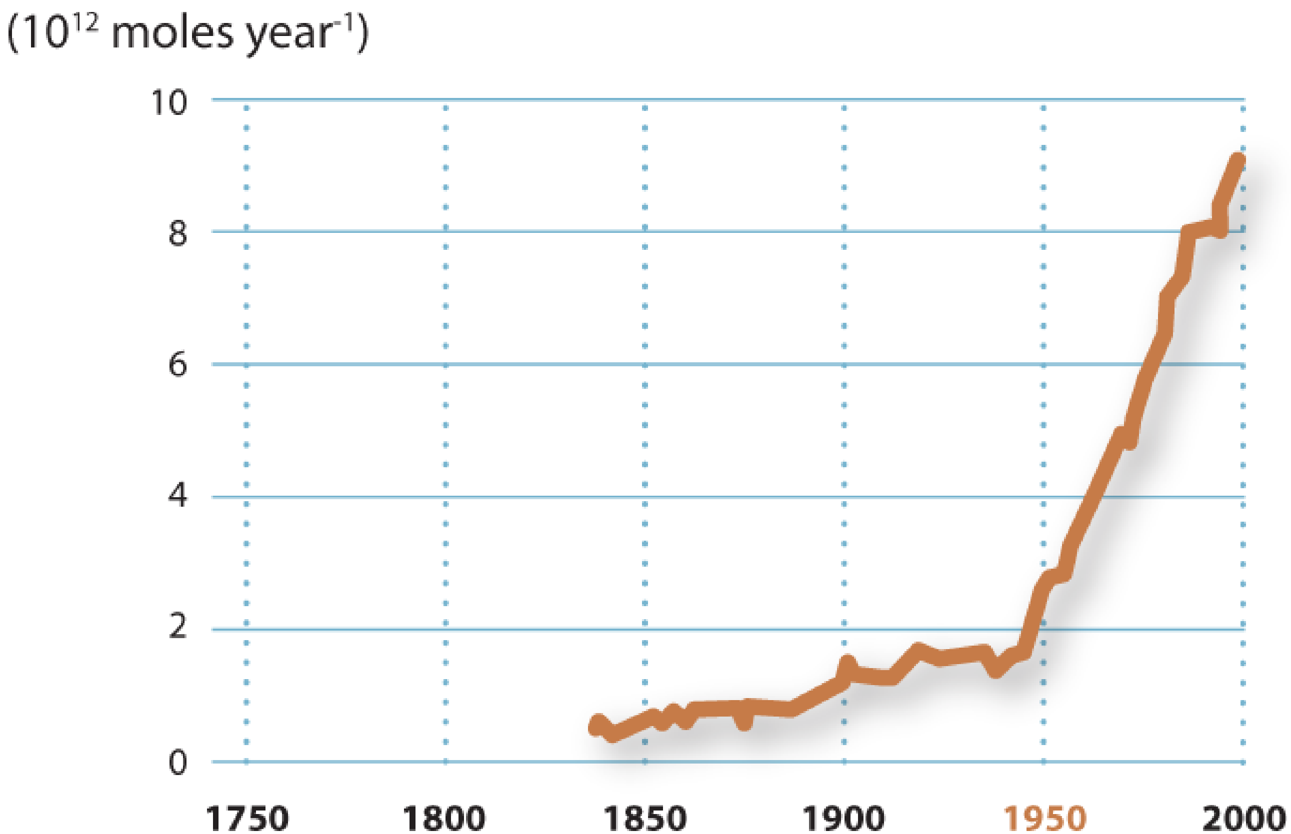
Ocean ecosystems



FAOSTAT 2002 Statistical database

IGBP synthesis: Global Change and the Earth System, Steffen et al 2004

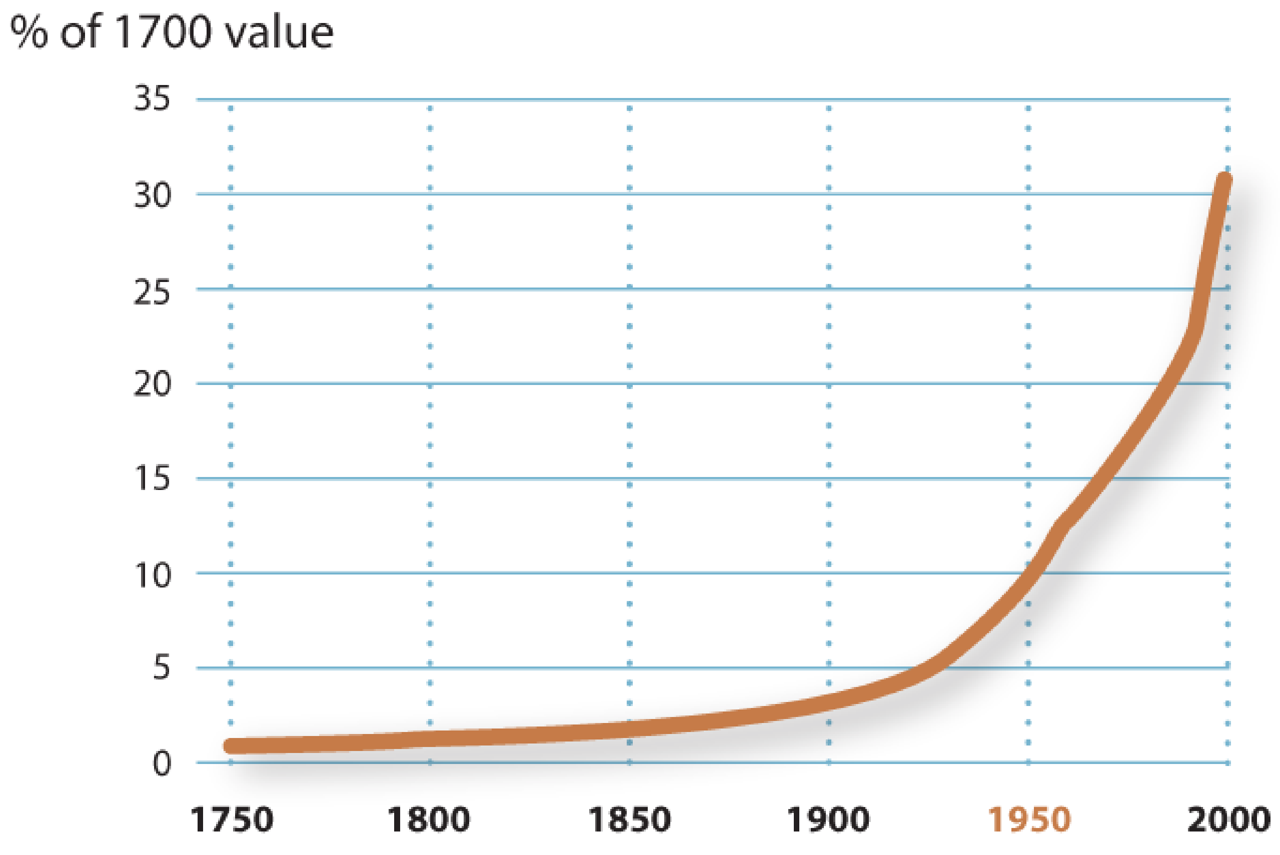
Coastal zone nitrogen flux



Mackenzie et al 2002.

IGBP synthesis: Global Change and the Earth System, Steffen et al 2004

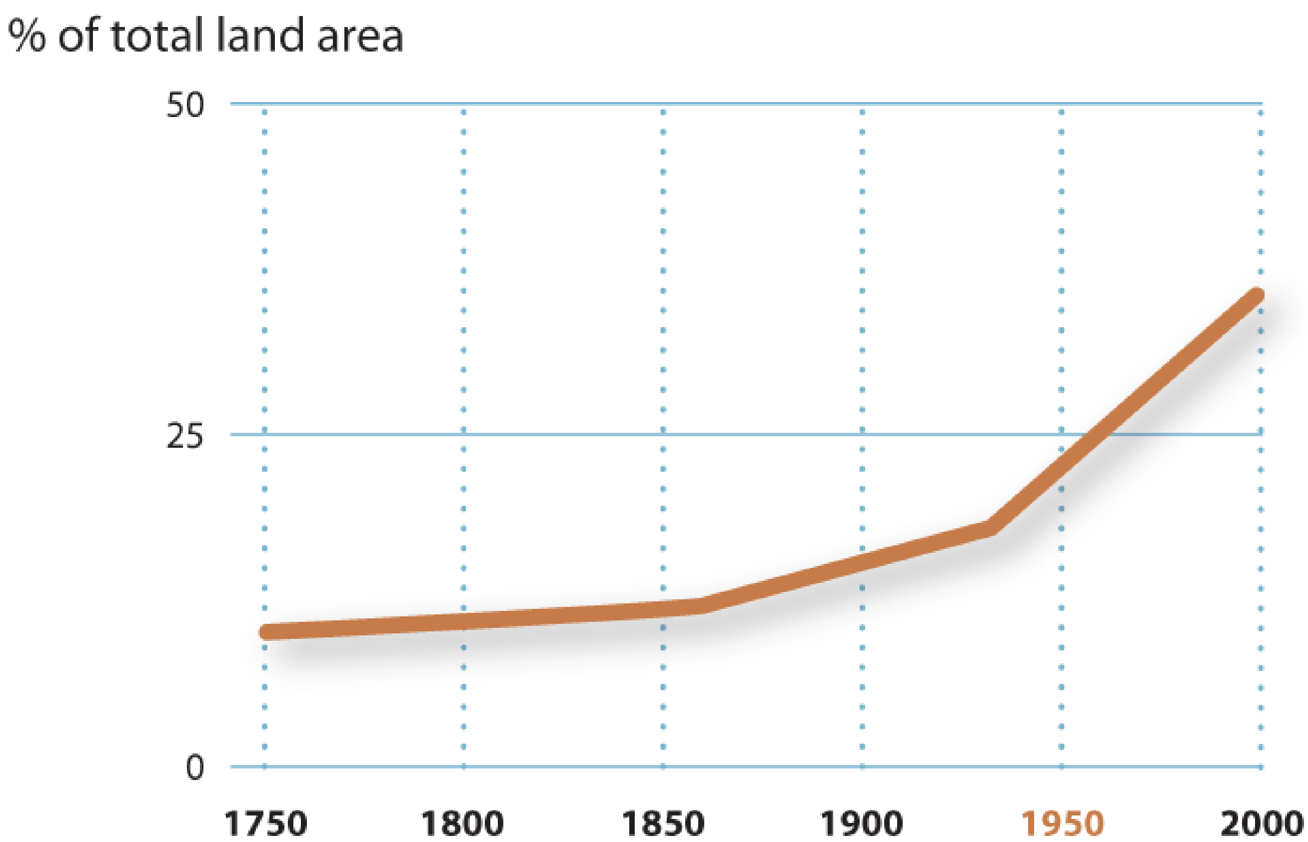
Tropical rainforest and woodland loss



Richards, the Earth as transformed by human action, Cambridge University Press

IGBP synthesis: Global Change and the Earth System, Steffen et al 2004

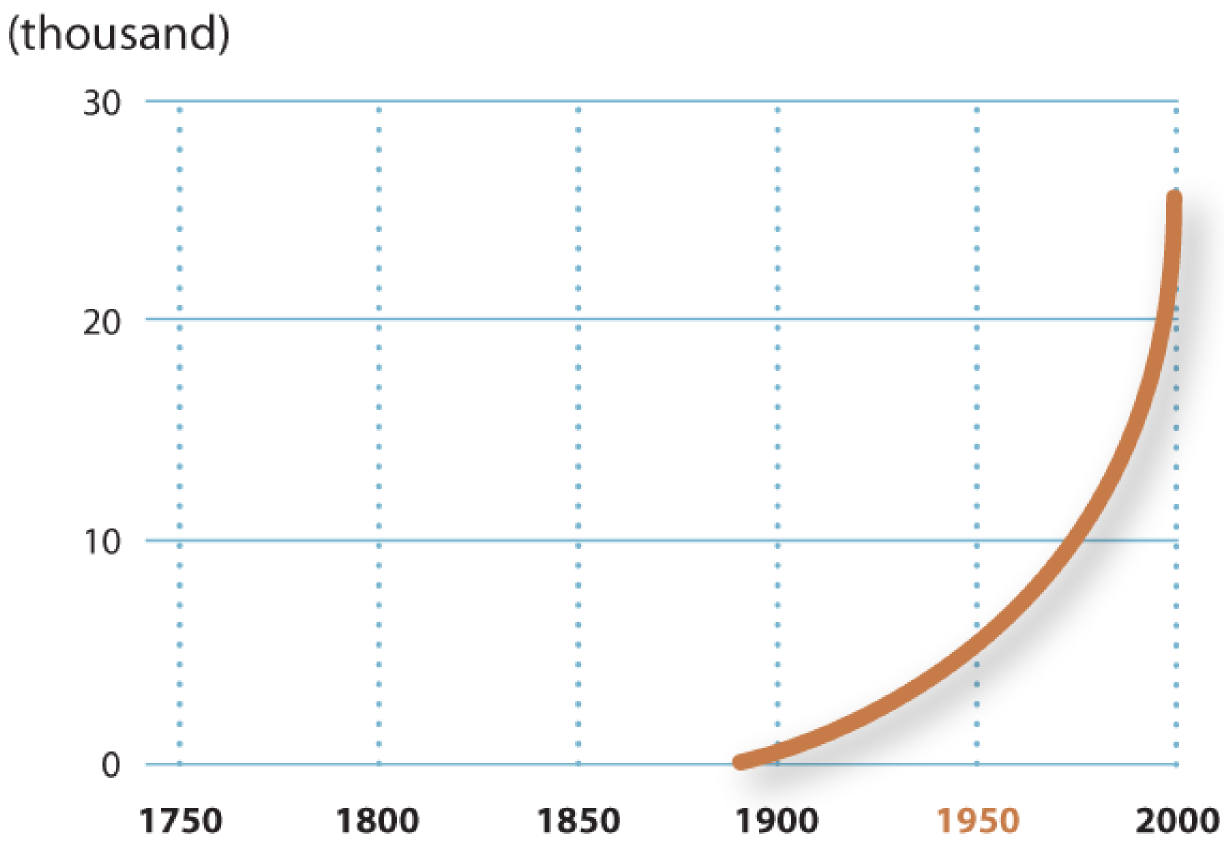
Domesticated land



Klein Goldewijk and Batties

IGBP synthesis: Global Change and the Earth System, Steffen et al 2004

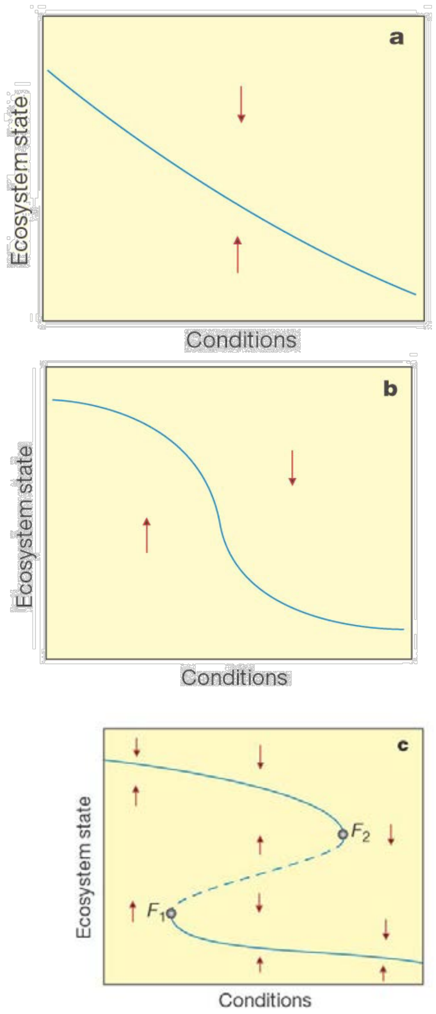
Species extinctions

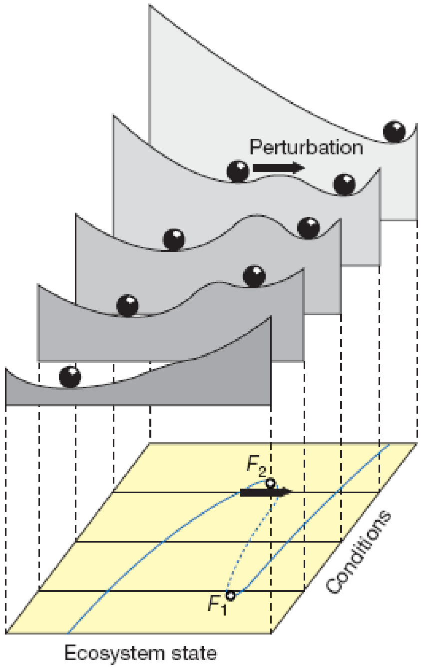


Wilson, the Diversity of Life.

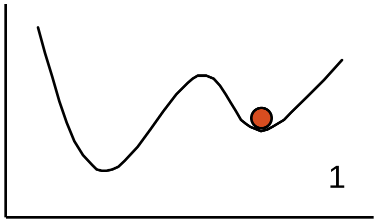
IGBP synthesis: Global Change and the Earth System, Steffen et al 2004

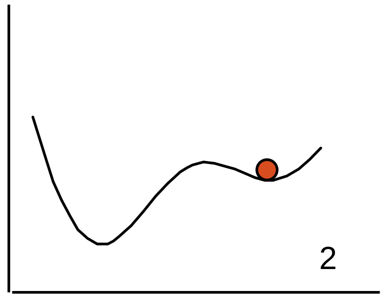
Critical transitions or regime shifts

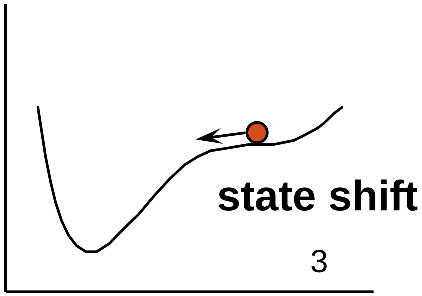


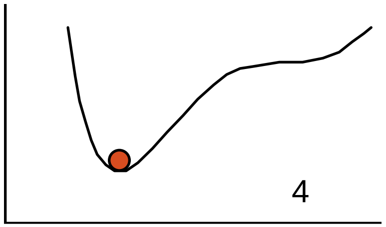


Valuable Ecosystem Services (Desirable) → **Loss of ecosystem services (Undesirable)**









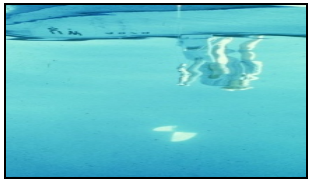
coral dominance

- overfishing, coastal eutrophication

- disease, hurricane

algal dominance

clear water



- phosphorous accumulation in soil and mud

- flooding, warming, overexploitation of predators

turbid water

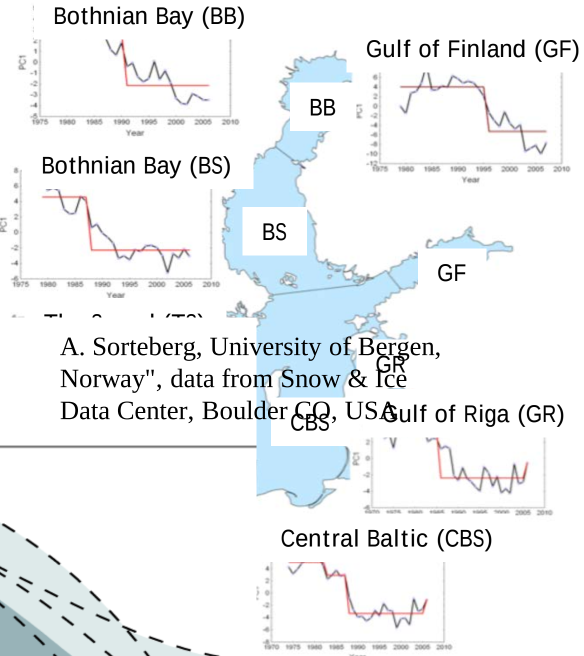
grassland

- fire prevention

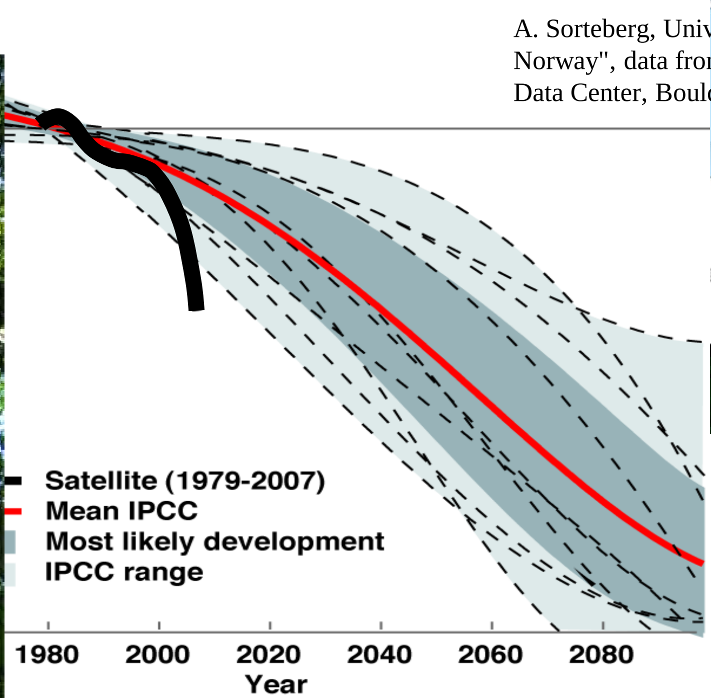
- good rains, continuous heavy grazing

shrub-bushland

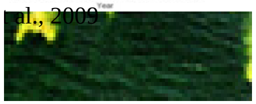
Regime shifts in all systems



A. Sorteberg, University of Bergen, Norway", data from Snow & Ice Data Center, Boulder CO, USA

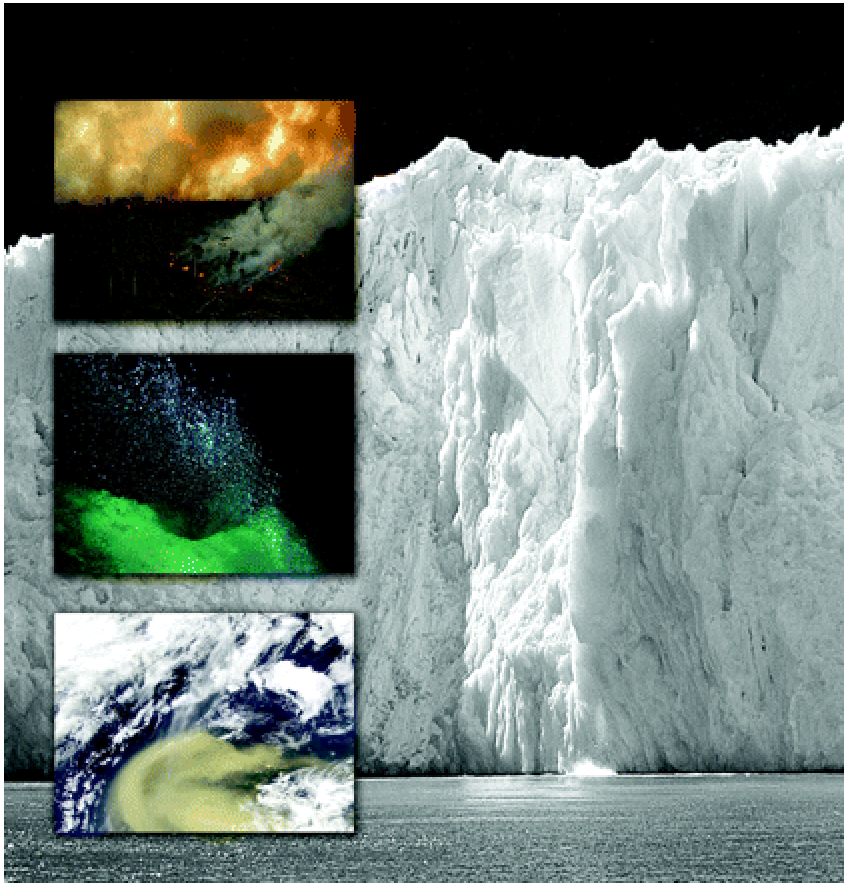


al., 2009



Tipping elements in the Earth system –

PNAS Special Feature released December 2009



PNAS Special Feature: Tipping elements in the Earth System, Jan 2010, vol 106 (49)

Article Will Steffen, Paul J. Crutzen and John R. McNeill

The Anthropocene: Are Humans Now Overwhelming the Great Forces of Nature?

Ambio Vol. 36, No. 8, December 2007

+

648 Review TRENDS in Ecology and Evolution Vol.18 No.12 December 2003

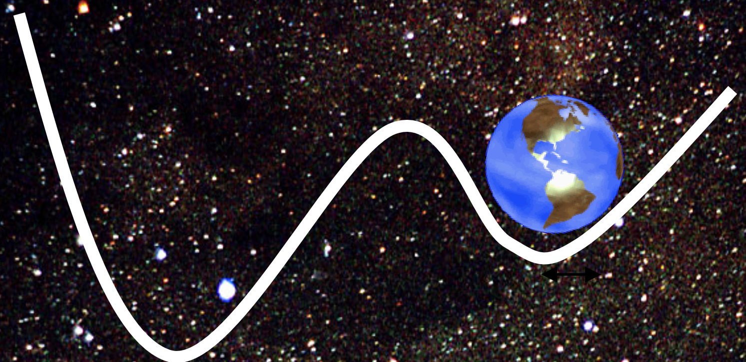
ELSEVIER

Catastrophic regime shifts in ecosystems: linking theory to observation

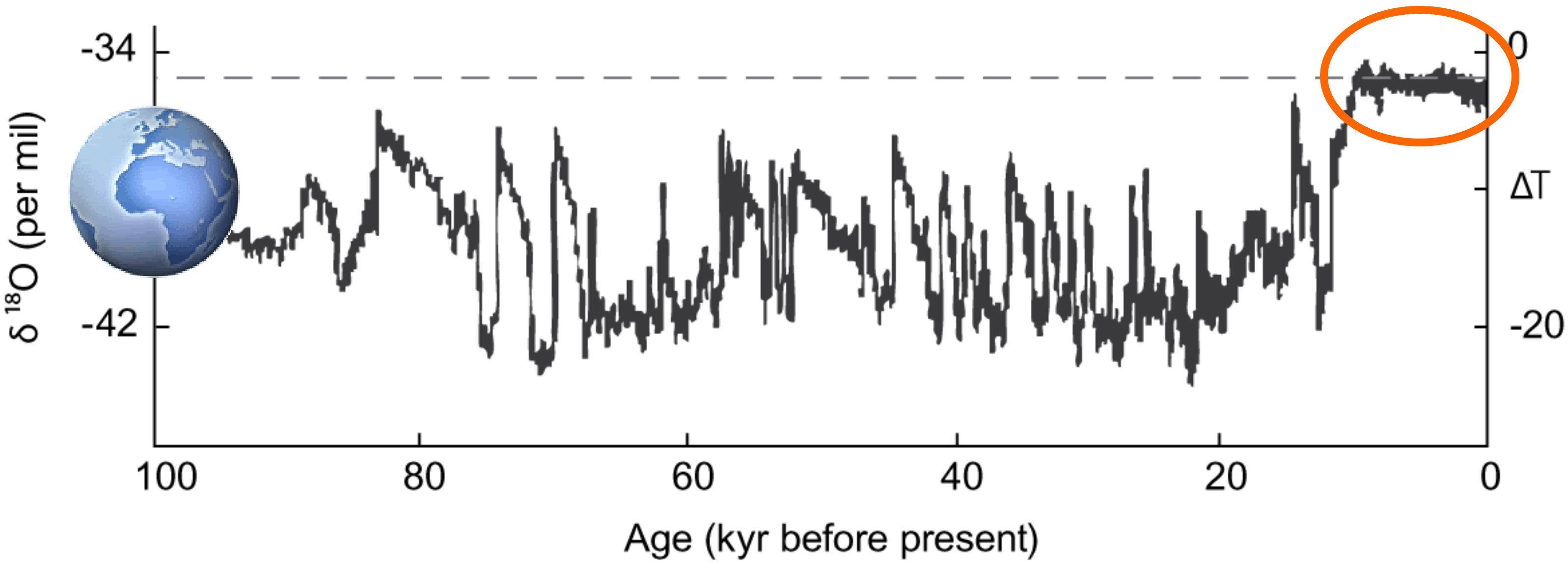
Marten Scheffer[1] and Stephen R. Carpenter[2]

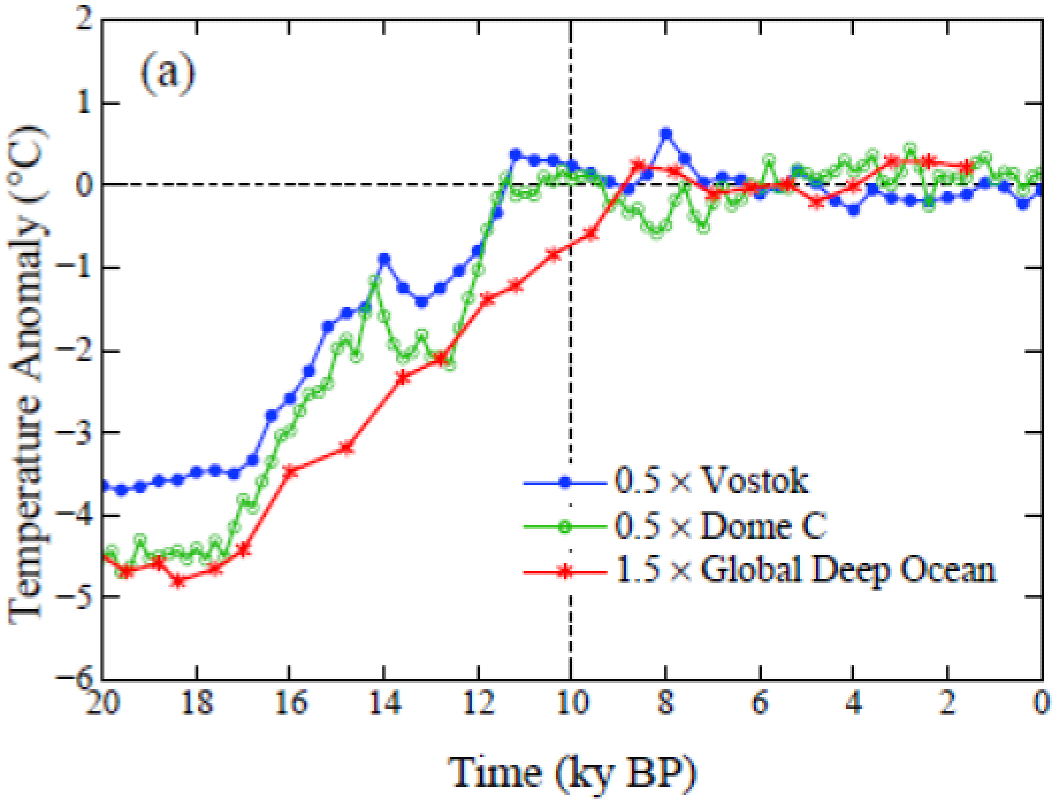
[1]Department of Aquatic Ecology and Water Quality Management, Wageningen University, PO Box 8080, 6700 DD Wageningen, The Netherlands
[2]Center for Limnology, University of Wisconsin, 680 North Park Street, Madison, WI 53706, USA

The Resilience of the Earth System



Humanity's 10,000 years of grace





(Hansen and Sato, 2011)

Planetary Boundaries: Exploring the safe operating space for humanity in the Anthropocene (*Nature*, 461 : 472 – 475, Sept 24 - 2009)

nature

Vol 461|24 September 2009

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

ROAD TO COPENHAGEN

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[6]. Without pressure from humans, the Holocene is expected to continue for at least several thousands of years[7].

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[8,9].

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

Rockström, J., W. Steffen, K. Noone, Å. Persson, F. S. Chapin, III, E. Lambin, T. M. Lenton, M. Scheffer, C. Folke, H. Schellnhuber, B. Nykvist, C. A. De Wit, T. Hughes, S. van der Leeuw, H. Rodhe, S. Sörlin, P. K. Snyder, R. Costanza, U. Svedin, M. Falkenmark, L. Karlberg, R. W. Corell, V. J. Fabry, J. Hansen, B. Walker, D. Liverman, K. Richardson, P. Crutzen, and J. Foley. 2009. Planetary boundaries:exploring the safe operating space for humanity. *Ecology and Society* **14**(2): 32. [online] URL: http://www.ecologyandsociety.org/vol14/iss2/art32/

E&S

Research

Planetary Boundaries: Exploring the Safe Operating Space for Humanity

Johan Rockström[1,2], Will Steffen[1,3], Kevin Noone[1,4], Åsa Persson[1,2], F. Stuart III Chapin[5], Eric Lambin[6], Timothy M. Lenton[7], Marten Scheffer[8], Carl Folke[1,9], Hans Joachim Schellnhuber[10,11], Björn Nykvist[1,2], Cynthia A. de Wit[4], Terry Hughes[12], Sander van der Leeuw[13], Henning Rodhe[14], Sverker Sörlin[1,15], Peter K. Snyder[16], Robert Costanza[1,17], Uno Svedin[1], Malin Falkenmark[1,18], Louise Karlberg[1,2], Robert W. Corell[19], Victoria J. Fabry[20], James Hansen[21], Brian Walker[1,22], Diana Liverman[23,24], Katherine Richardson[25], Paul Crutzen[26], and Jonathan Foley[27]

Ecology and Society 14(2): 32
http://www.ecologyandsociety.org/vol14/iss2/art32/

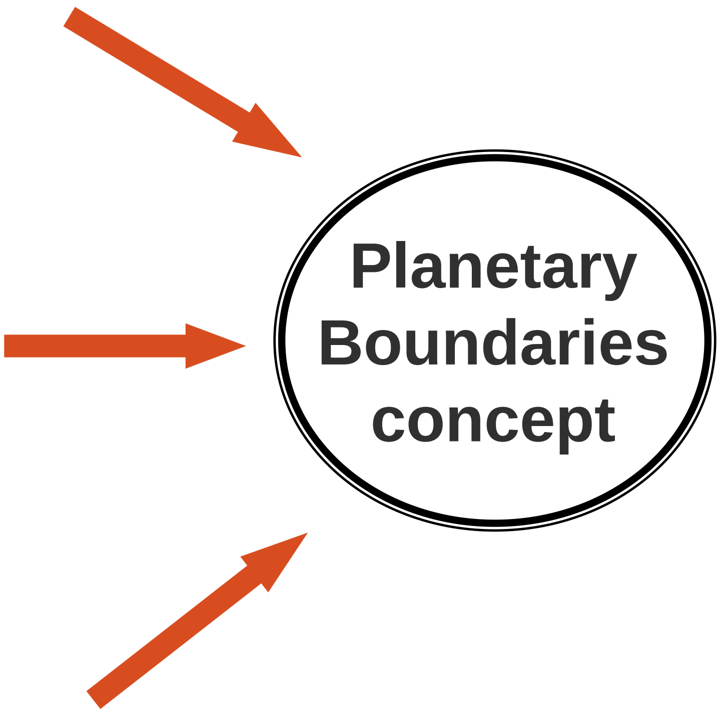
PB concept rests on three branches of Scientific inquiry

1. **Earth System and sustainability science** (Understanding Earth System processes; ICSU, IGBP, ESSP, IPCC, MEA, evolution of sustainability science…)

2. **Scale of human action in relation to the capacity of the planet to sustain it** (Kenneth Boulding Spaceship Earth, Herman Daly, Club of Rome, Ecological Economics reserach agenda, Ecological Footprint...)

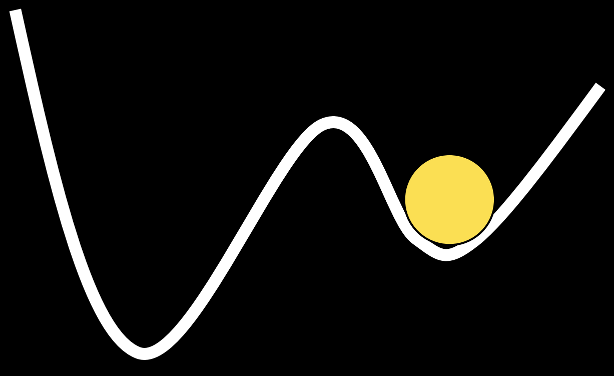
3. **Shocks and Abrupt change in Social-Ecological systems from local to global scales**

   (Resilience, GAIA, tipping elements, guardrails...)

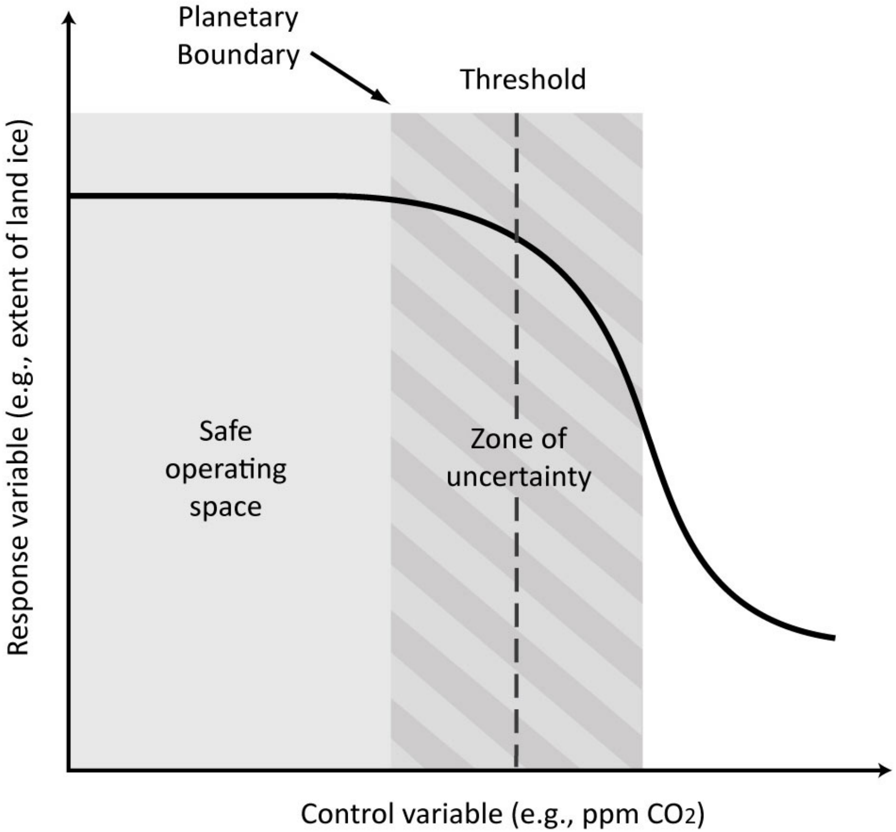


From:
”Limits to growth”
”Carrying capacity”
”Guardrails”
”Tipping Elements”

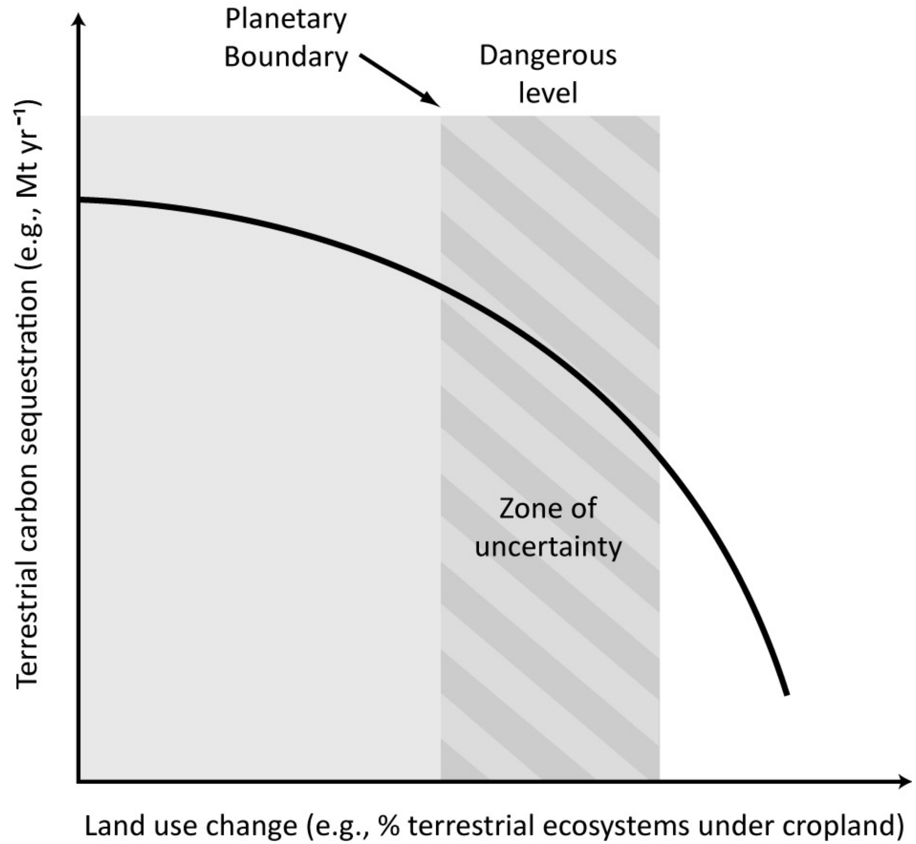
To:
”Planetary Boundaries”



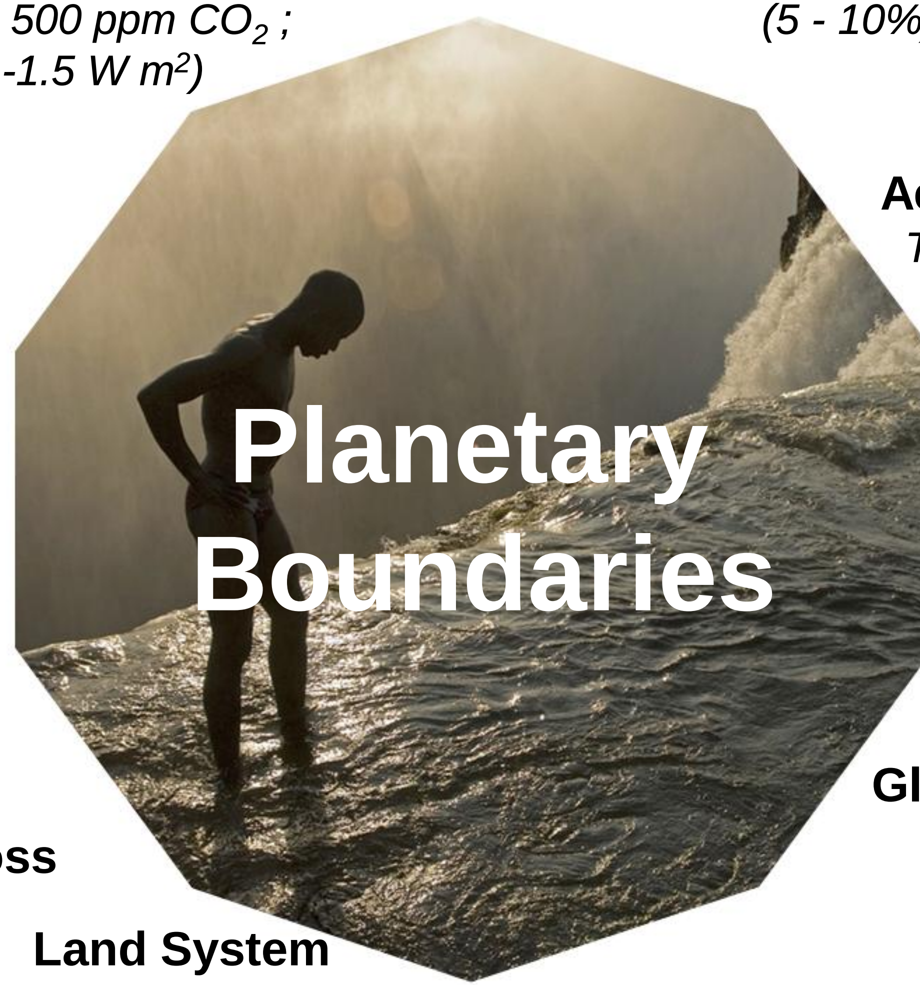
Two different types of planetary boundary processes



1. Critical continental to global threshold



2. No known global threshold effect



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%)

Atmospheric Aerosol Loading
To be determined

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

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

Chemical Pollution
Plastics, Endocrine Desruptors, Nuclear Waste Emitted globally
To be determined

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

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

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×)

Transgressing safe boundaries


nature

Vol 461|24 September 2009

FEATURE

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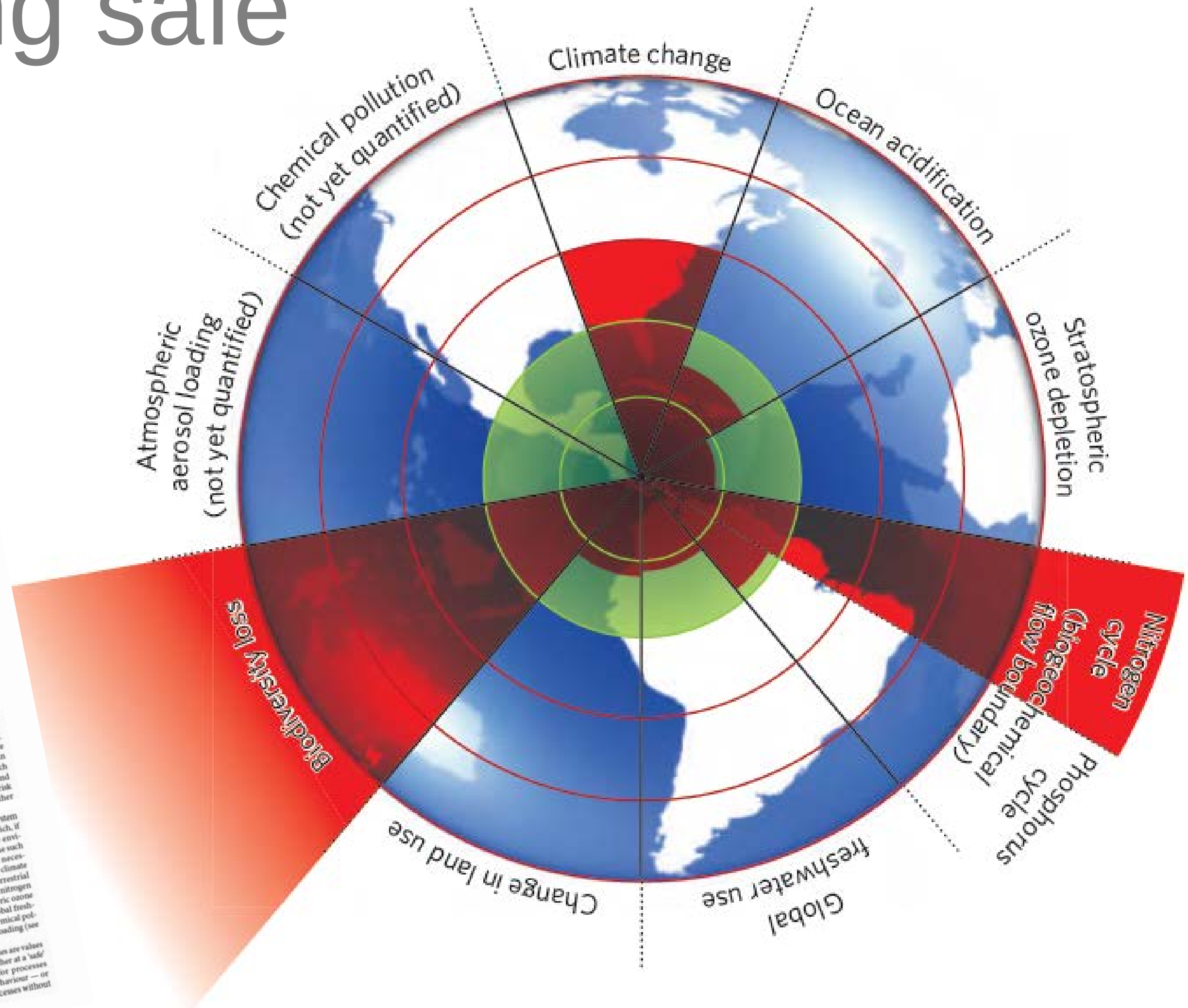


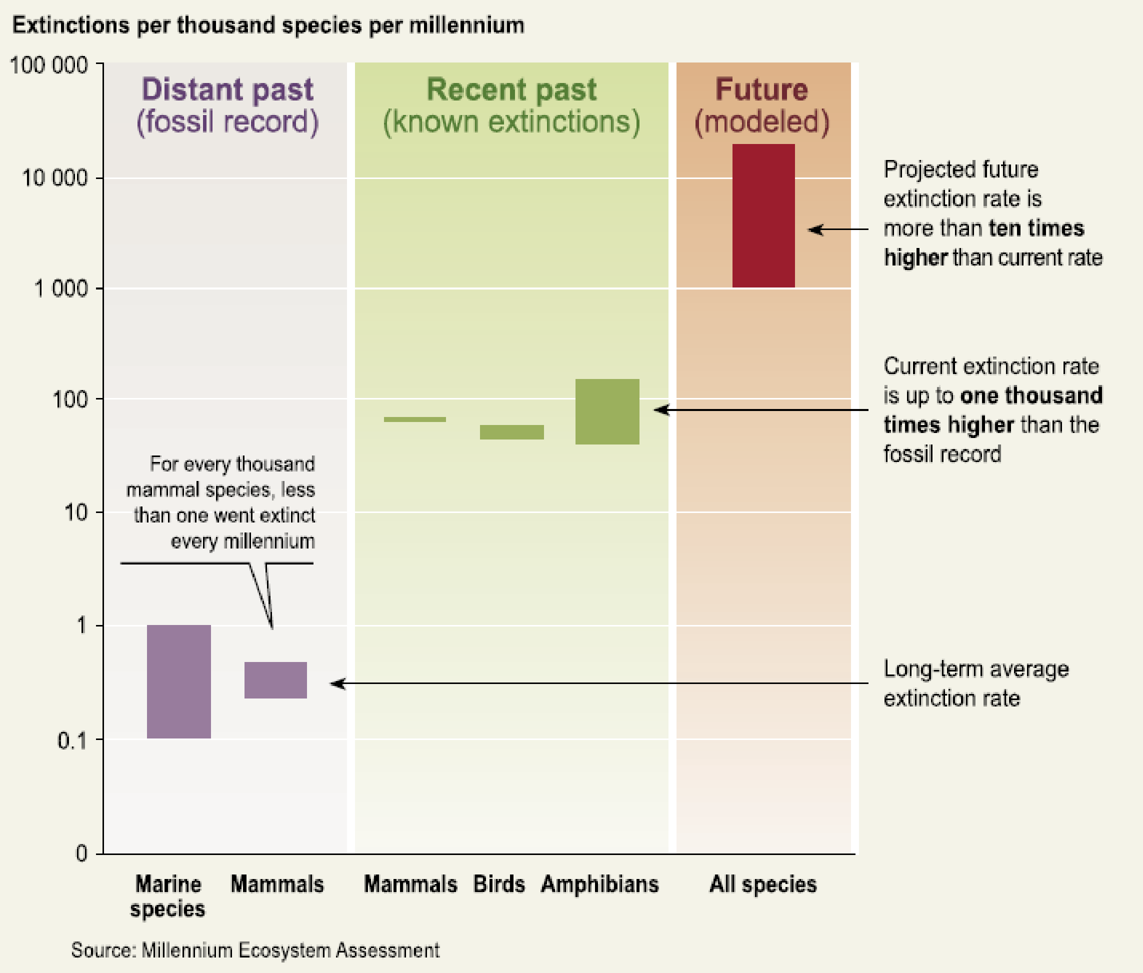
Rockström et al. 2009 Nature, 461 (24): 472-475

Rate of Biodiversity Loss

Avoid large scale irreversible loss of functional diversity and ecological resilience

- The current and projected rate of biodiversity loss constitutes the sixth major extinction event in the history of life on Earth – the first to be driven by human activities on the planet
- 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 that were typical over Earth's history
- Average global extinction rate projected to increase another 10-fold, to 1,000-10,000 E/MSY during the current century

6th Global Mass Extinction of Species on Planet Earth



Biodiversity Loss

Setting the boundary:

- Suggesting a safe planetary boundary (here placed at 10 E/MSY)
- within an order of magnitude of the natural background rate

Land System Change

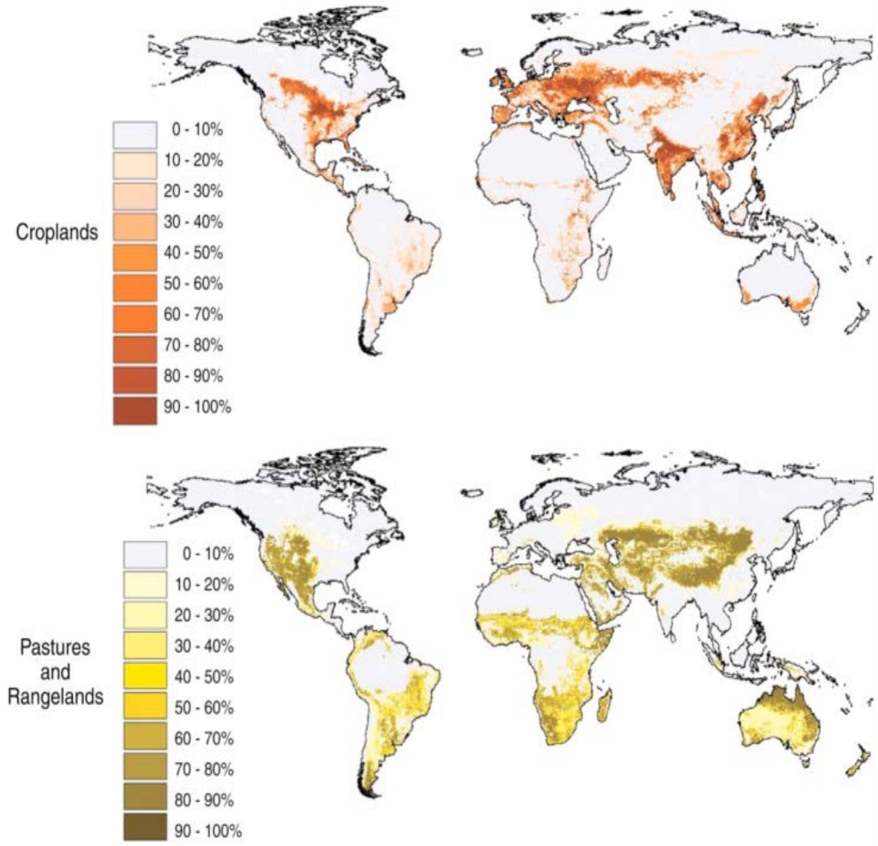
Avoid unsustainable land system change predominantly from intensive agricultural use

- Threat to biodiversity and undermining of regulatory capacity of ecosystems

- Setting the boundary: No more than 15 % of the global ice-free land surface should be converted to cropland (12% today)

Land use change

Agriculture ~35 % of the planets terrestrial land area



Drought-Induced Reduction in Global Terrestrial Net Primary Production from 2000 Through 2009

Maosheng Zhao* and Steven W. Running

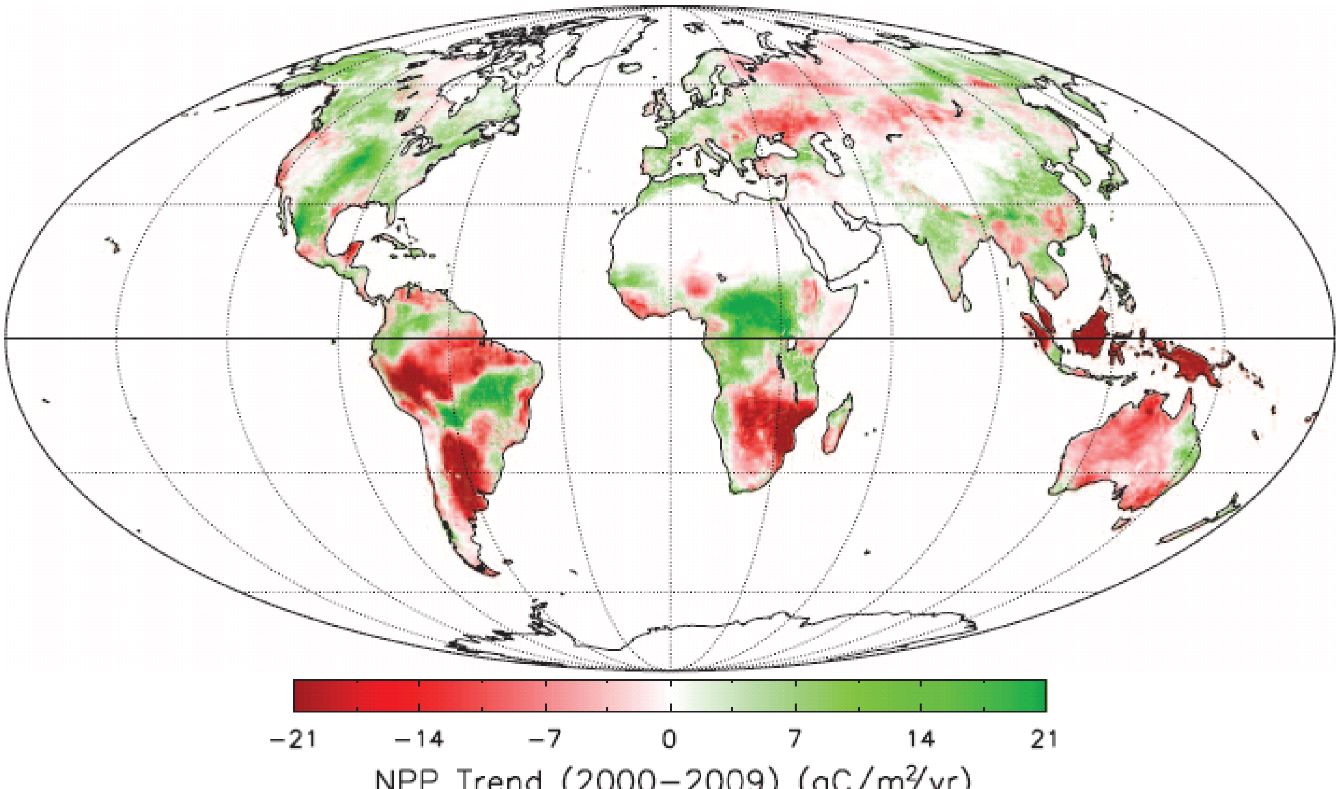


Fig. 2. Spatial pattern of terrestrial NPP linear trends from 2000 through 2009 (SOM text S1) (*8*, *10*).

Global Freshwater Use

Avoid water induced environmental change at regional scale

- Humans now alter global runoff flows, through withdrawals of blue water, and changes in green water flows, affecting water partitioning and moisture feedback
- Physical water scarcity when withdrawals exceed 5000 – 6000 $km^3\ yr^{-1}$
- Final availability of runoff determined by consumptive use of green and blue water flows
- Consumptive use of blue water an aggregate control variable with boundary set at < 4000 $km^3\ yr^{-1}$

THE ROYAL SOCIETY

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Global analysis of river systems: from Earth system controls to Anthropocene syndromes

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WATER RESOURCES RESEARCH, VOL. 45, W00A12, doi:10.1029/2007WR006767, 2009

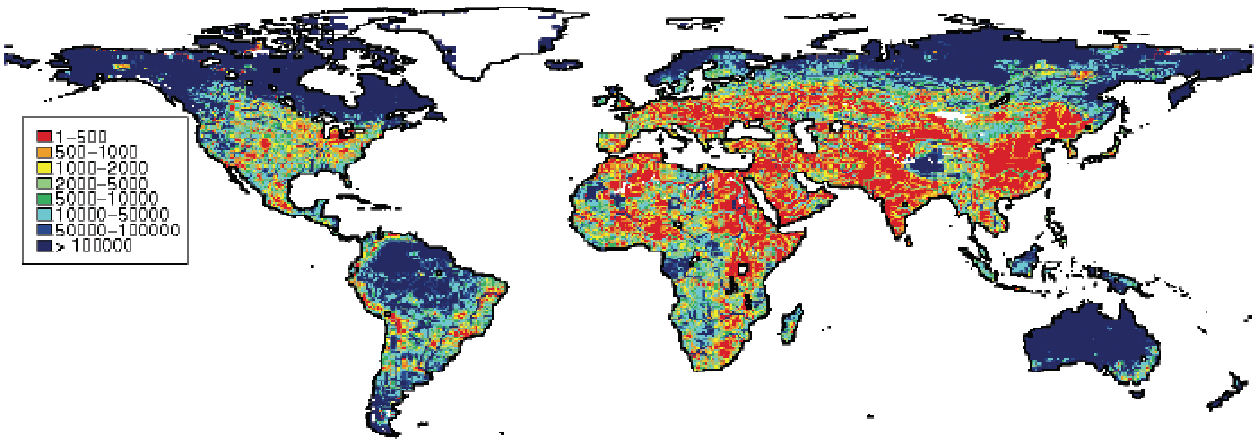
Future water availability for global food production: The potential of green water for increasing resilience to global change

Johan Rockström,[1,2] Malin Falkenmark,[1] Louise Karlberg,[1,2] Holger Hoff,[2,3] Stefanie Rost,[3] and Dieter Gerten[3]

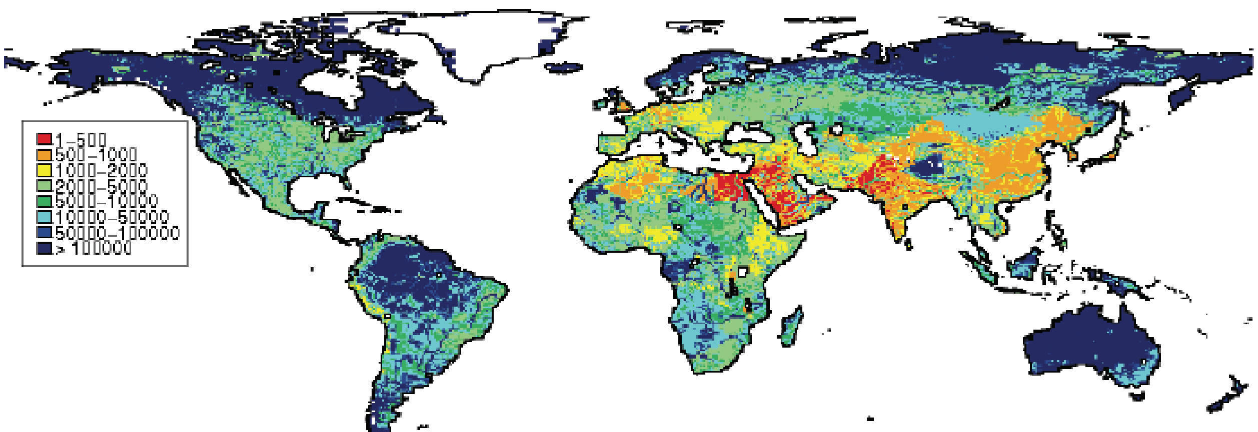
Received 14 December 2007; revised 24 June 2008; accepted 31 July 2008; published 14 February 2009.

Blue Water Resources Stressed

m^3 blue water/person/year



m^3 green water/person/year



Siebert et al., 2009

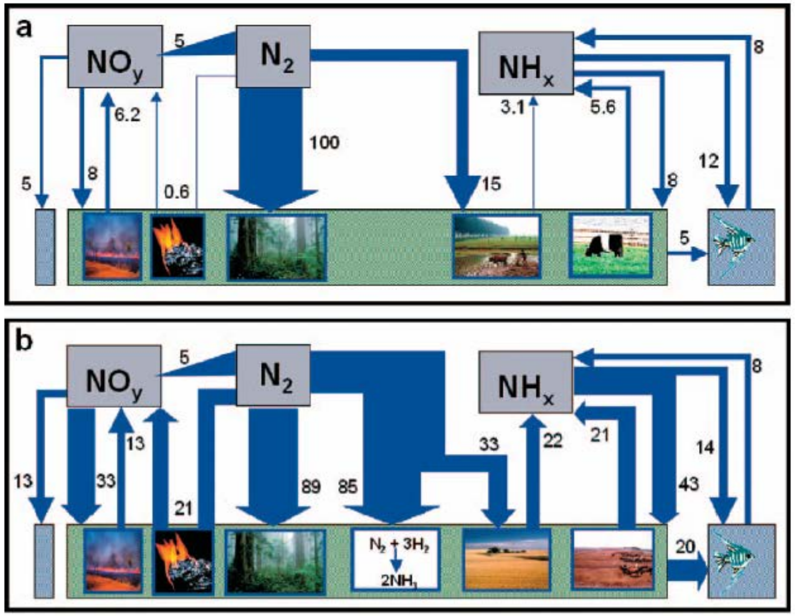
Biogeochemical flows: Human interference with global N cycle

- Local to regional scale interference with N and P flows has pushed aquatic and marine systems across thresholds generating abrupt non-linear change
- Human modification of the nitrogen cycle is now profound (converting more N_2 from the atmosphere into reactive forms than all of the Earth's terrestrial processes combined)
- N and P slow variables eroding resilience of important sub-systems of the Earth system.

Biogeochemical flows: Human interference with global P cycle

- The crossing of a critical threshold of P inflow to the oceans could explain global-scale ocean anoxic events (OAE), and past mass extinctions of marine life
- A boundary level should be set that (with current knowledge) allows humanity to safely steer away from the risk of triggering an OAE even over longer time horizons (> 1,000 yrs)

Biogeochemical flows: Setting the boundary



- Nitrogen: return to 25 % of the current human fixation of N_2 from the atmosphere.
- Phosphorus: Anthropogenic P inflow to the ocean is not allowed to exceed a human induced level of ~10 times the natural background rate of ~1 Mt P yr^{-1}.

IOP PUBLISHING ENVIRONMENTAL RESEARCH LETTERS

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Reconsideration of the planetary boundary for phosphorus

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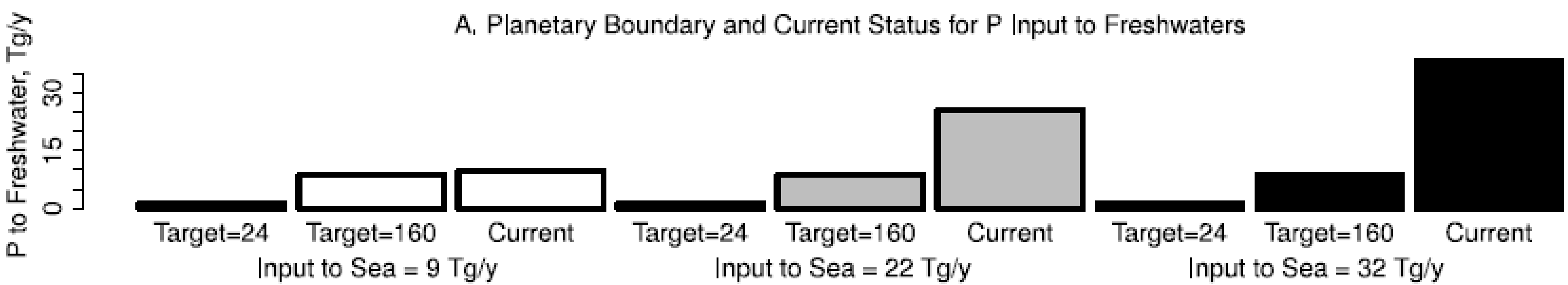
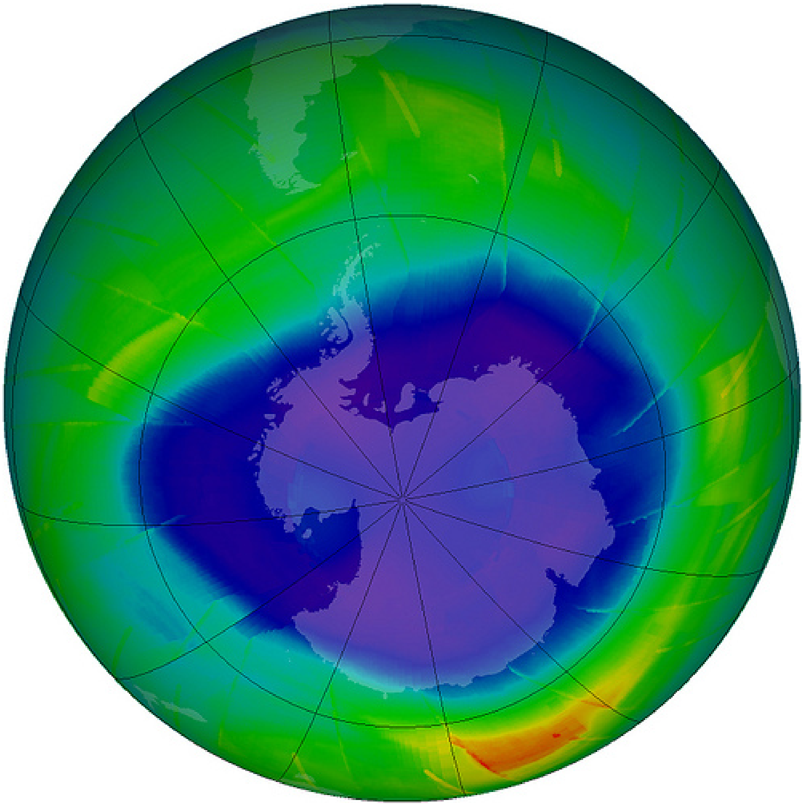


Ozone depletion

Avoiding the risk of large impacts for humans and ecosystem from thinning of extra-polar ozone layer

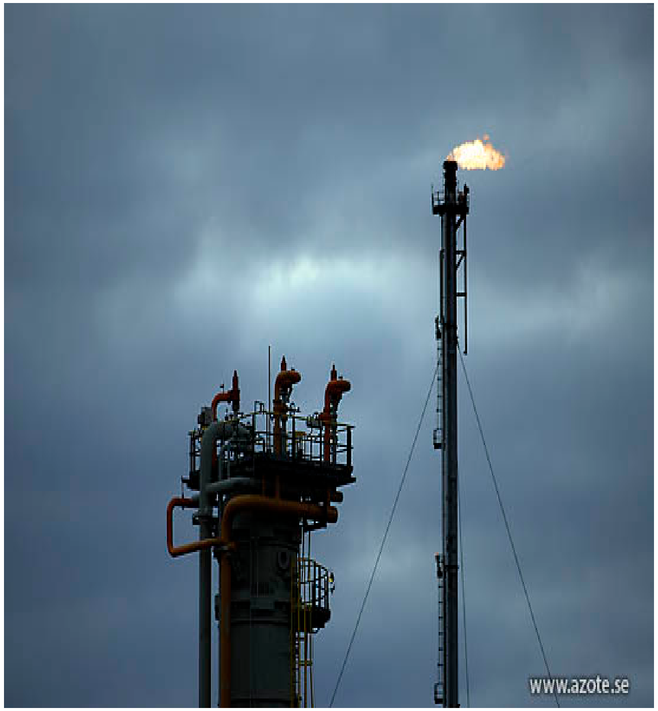
- Antarctic ozone depletion a classic example of an unexpected crossing of a threshold
- Identifying a threshold remains uncertain
- a less than 5% decrease in column ozone levels for any particular latitude



Chemical Pollution

Steer away from irreversible impacts on living organisms

- Global, ubiquitous impact on the physiological development and demography of humans and other organisms with ultimate impacts on ecosystem functioning and structure
- By acting as a slow variable that affects other planetary boundaries (e.g., rate of biodiversity loss)
- 2 complementary approaches: amounts of persistent pollutants with global distribution (e.g., mercury); Effects of chemical pollution on living organisms
- Difficult to find an appropriate aggregate control variable. Close interactions with Aerosol loading; may require sub-boundaries based on sub-impacts/categories of chemicals

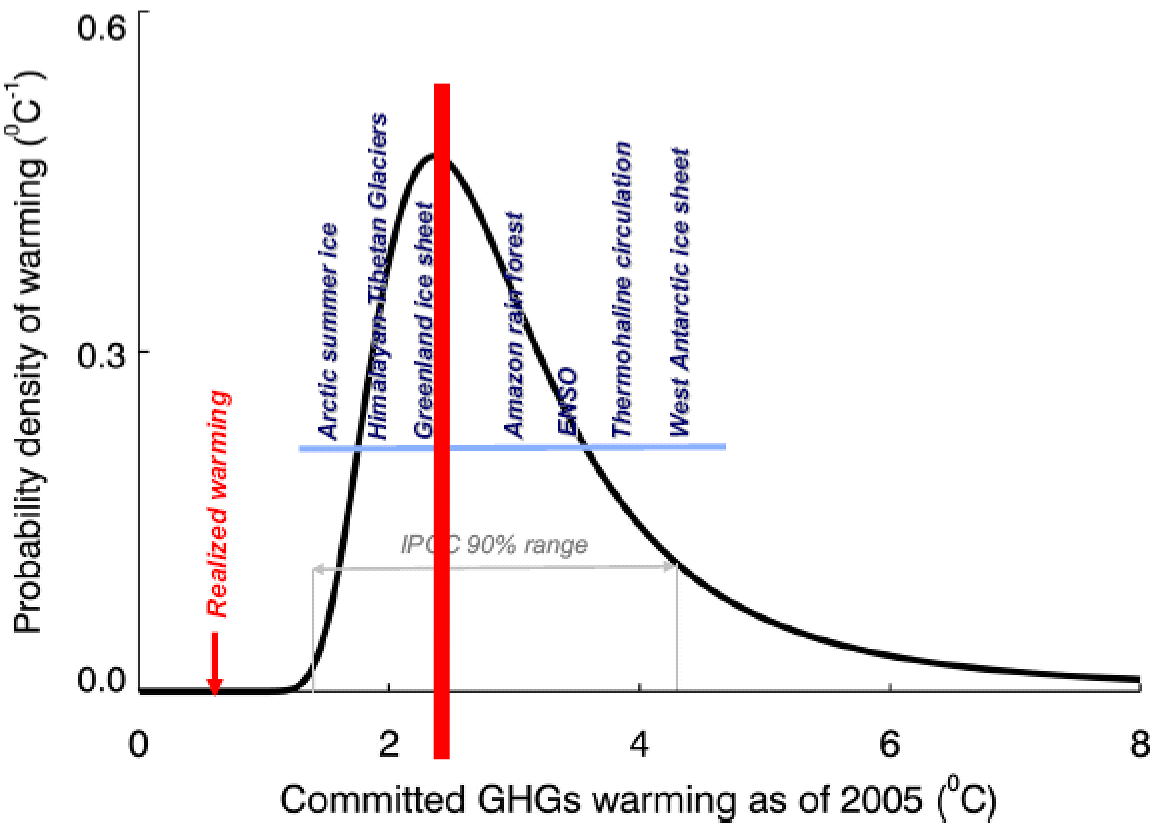


Atmospheric Aerosol Loading

Avoid major influence on climate system and human health at regional to global scales

- Human activities have doubled the global concentration of most aerosols since the pre-industrial era
- Influence on the Earth's radiative balance
- May have substantial implications on hydrological cycle and, e.g., Asian monsoon circulation
- Fine particle ($PM_{2.5}$) air pollution
- Processes and mechanisms behind these correlations remain to be fully explained

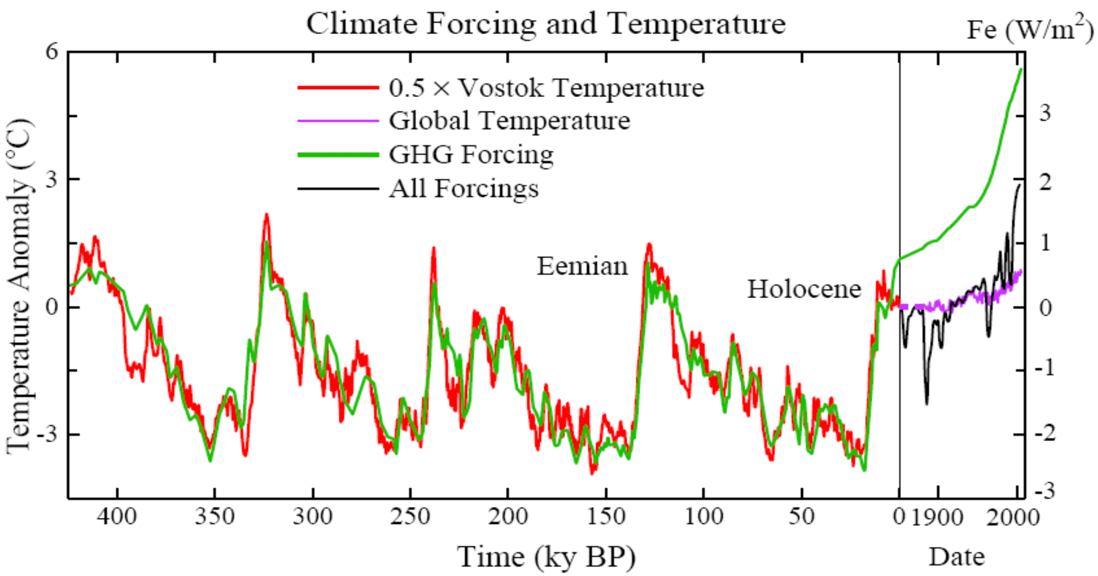
Already Committed Global Warming



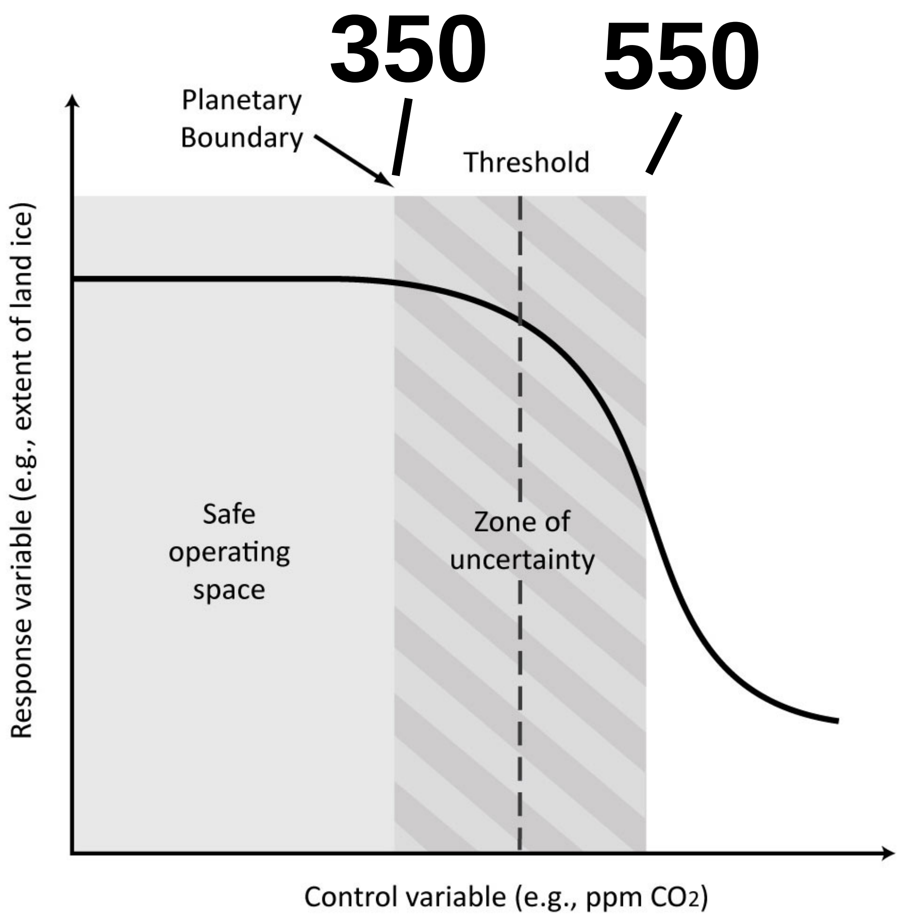
(Ramanathan et al. 2009)

Climate Change

what is required to avoid the crossing of critical thresholds that separate qualitatively different climate system states

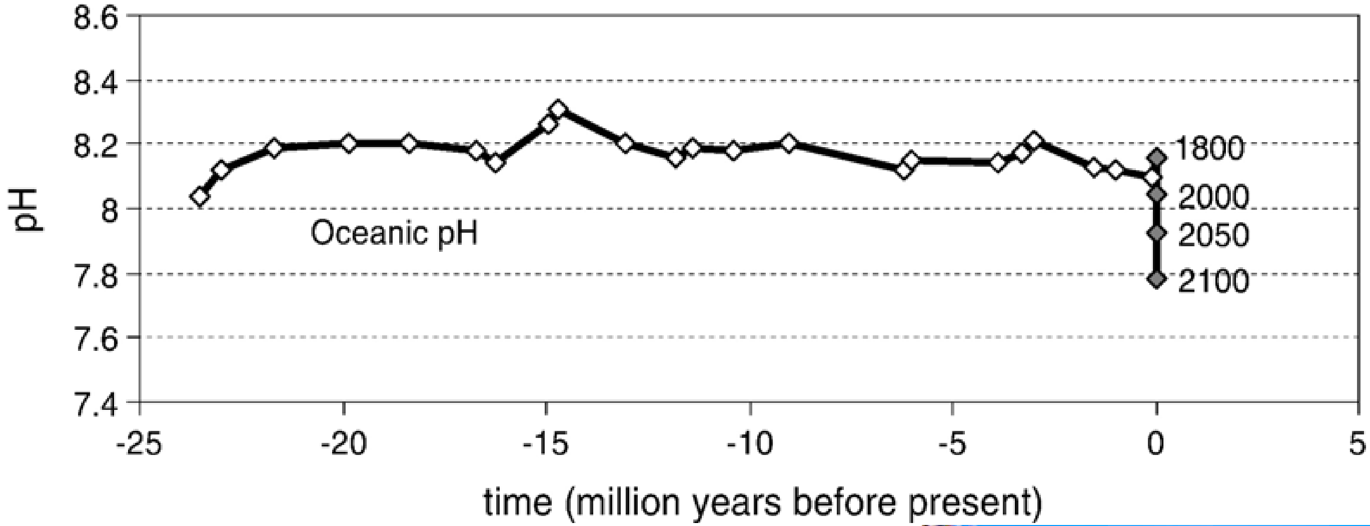


- We suggest boundary values of 350 ppm CO_2 and 1 W m^{-2} above pre-industrial level


350
550
Planetary
Boundary
Threshold
Safe
operating
space
Zone of
uncertainty
Response variable (e.g., extent of land ice)
Control variable (e.g., ppm CO2)

Ocean acidification

Challenge to marine biodiversity and ability of oceans to function as sink of CO_2



Turley et al 2006

- Southern Ocean and Arctic ocean projected to become corrosive to aragonite by 2030-2060

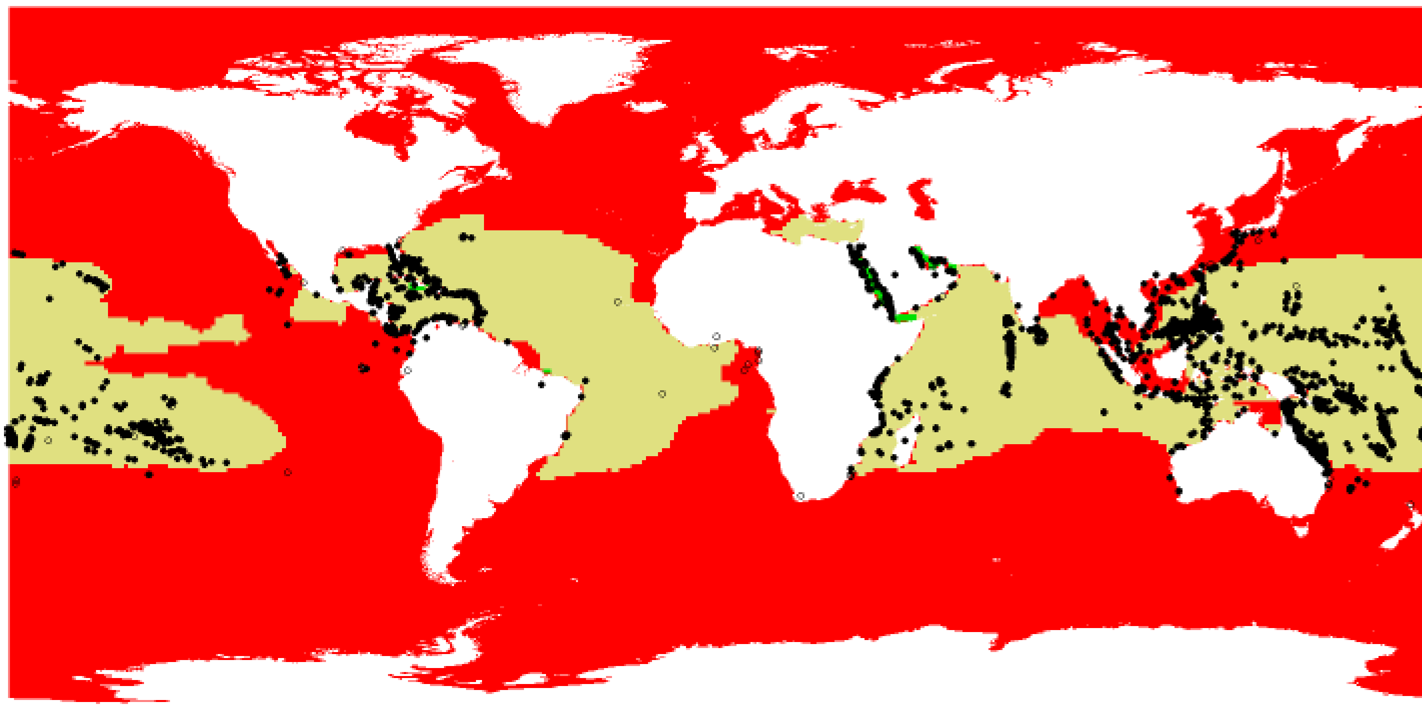
Ocean acidification

Setting the boundary:

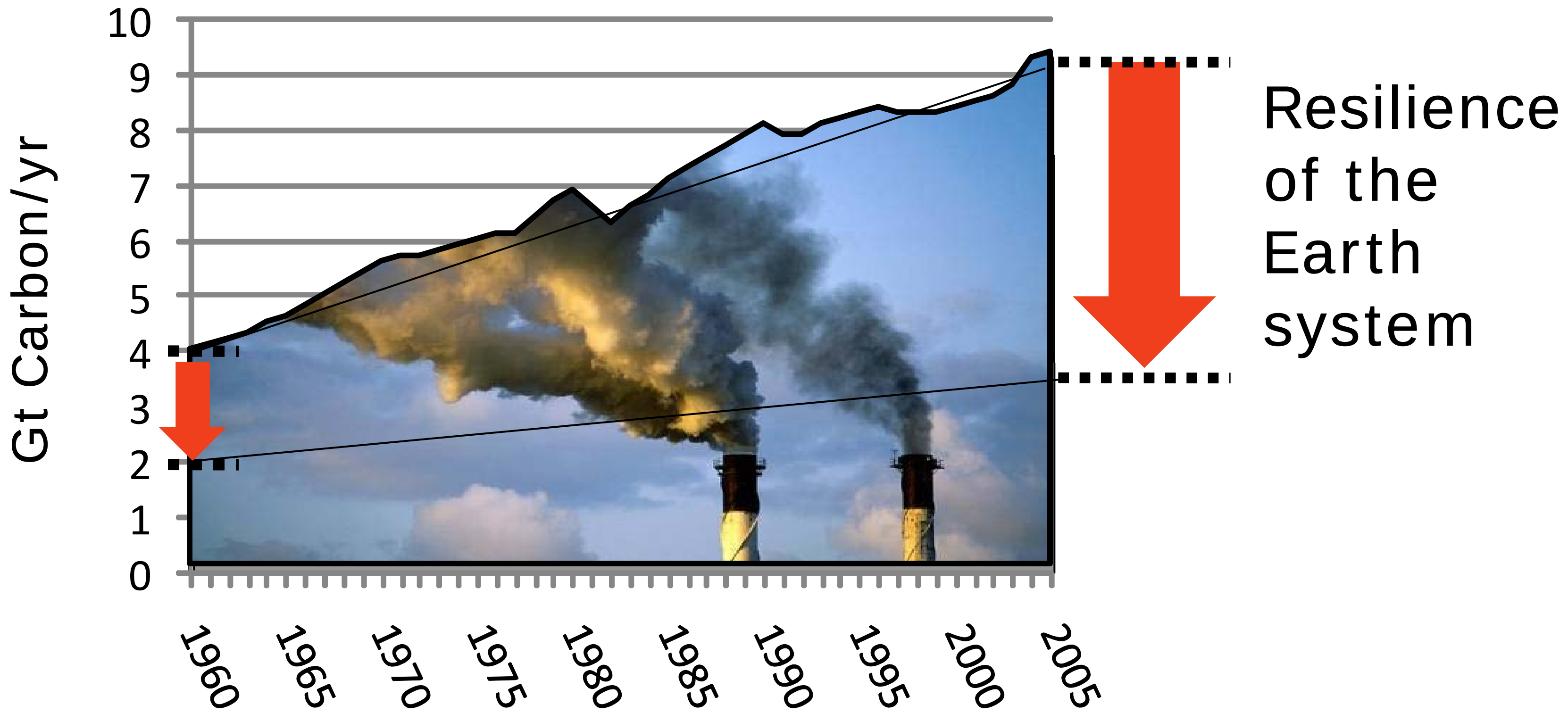
- Globally surface aragonite saturation state is declining (Ω_{arag} = 3.44 to a current value of 2.9)
- $2\times CO_2 \rightarrow \Omega_{arag} = 2.29$
- Proposed boundary > 80 % pre-industrial Ω_{arag} = 2.75

Predicted Future (~2065) Surface Ocean Aragonite Saturation State

References: 5, 7

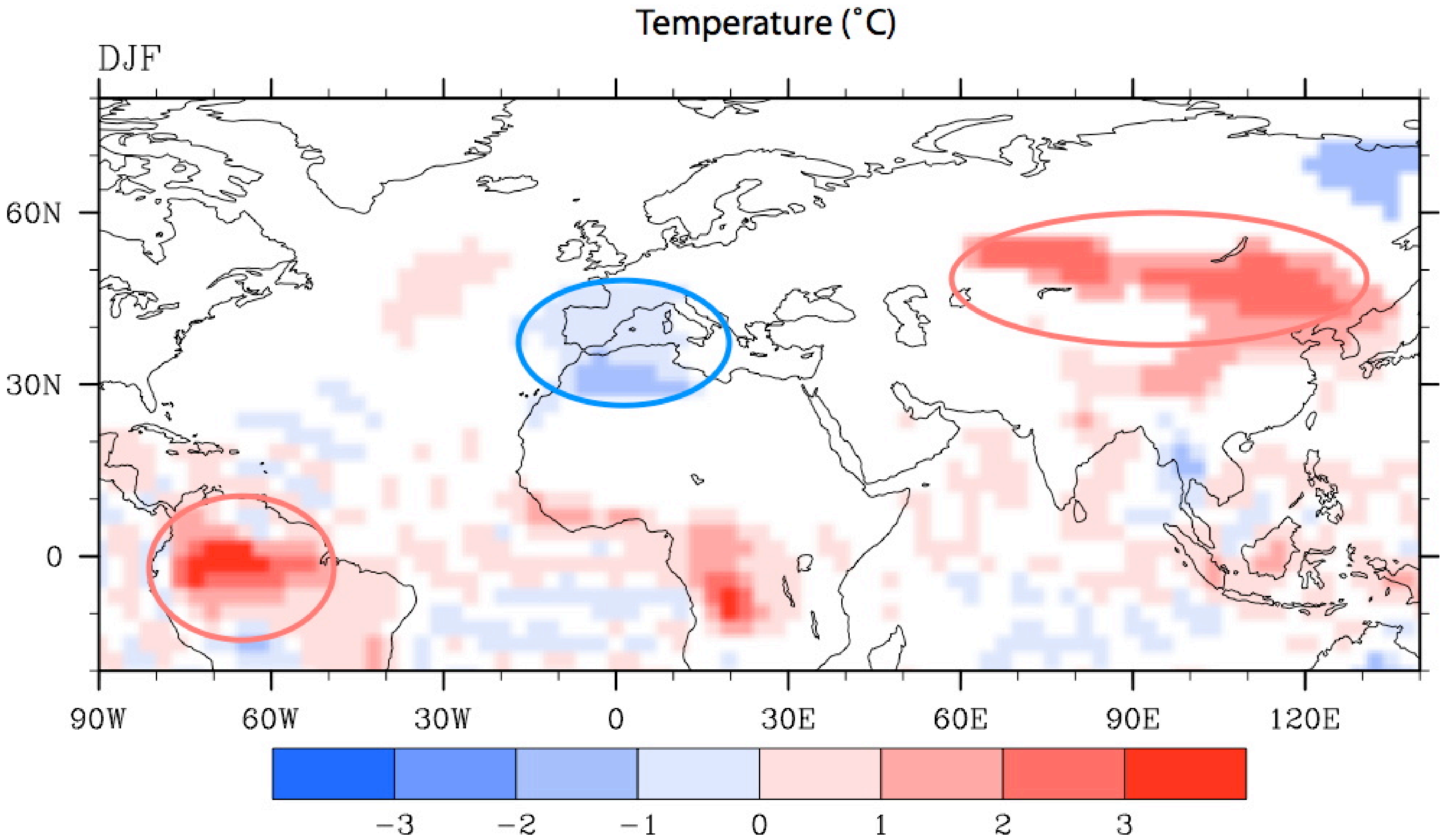


Interactions among Planetary Boundaries



Adapted from Canadell et al., 2007

Planetary Inter-connections



Peter Snyder et al. 2004

A new "global spec" for world food production

1. Stay within 350 ppm, an agricultural system that goes from being a source to a global sink
2. Essentially a green revolution on current cropland (expansion from 12 % to 15 %)
3. Keep global consumptive use of blue water < 4000 km^3/yr, we are at 2,600 km^3/yr today and rushing fast towards 4000 km^3/yr
4. Reduce to 25 % of current N extraction from atmosphere
5. Not increase P inflow to oceans
6. Reduce loss of biodiversity to < 10 E/MSY from current 100-1000 E/MSY

Global emission pathways in compliance with a 2 ºC guardrail

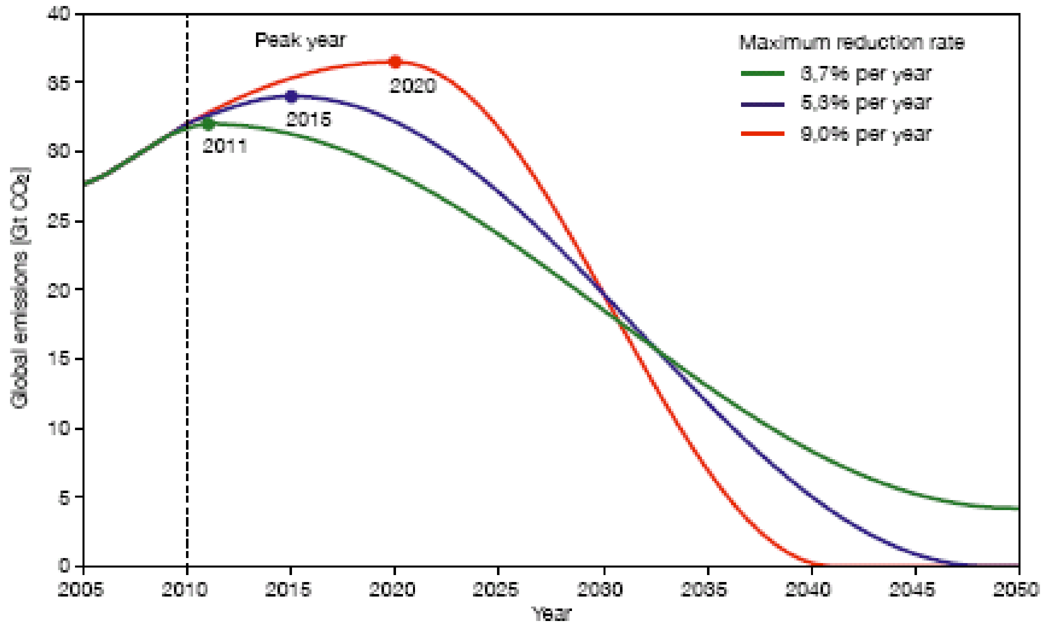


Figure 3.2-1
Examples of global emission pathways for the period 2010–2050 with global CO_2 emissions capped at 750 Gt during this period. At this level, there is a 67 % probability of achieving compliance with the 2 °C guard rail (Chapter 5). The figure shows variants of a global emissions trend with different peak years: 2011 (green), 2015 (blue) and 2020 (red). In order to achieve compliance with these curves, annual reduction rates of 3.7 % (green), 5.3 % (blue) or 9.0 % (red) would be required in the early 2030s (relative to 2008).
Source: WBGU

(WBGU 2009)