Human development in the Anthropocene

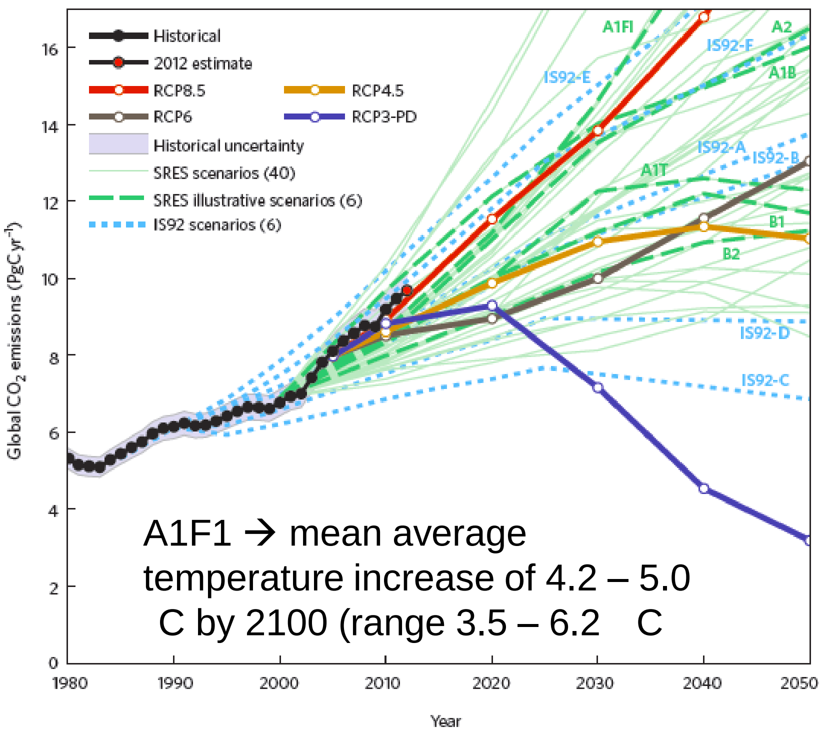
Global Change and Biosphere Interactions
YESI Launch and BES Centenary Conference
University of York
8th April 2013

Prof. Johan Rockström
Stockholm Resilience Centre

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

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

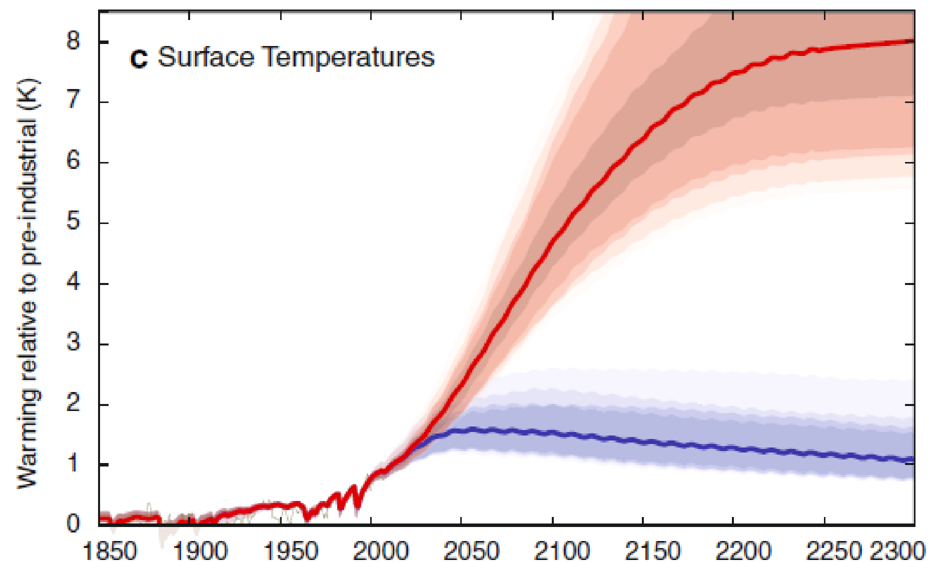
Tipping the Scales towards a stable future basis for humanity



The challenge to keep global warming below 2 °C

Glen P. Peters, Robbie M. Andrew, Tom Boden, Josep G. Canadell, Philippe Ciais, Corinne Le Quéré, Gregg Marland, Michael R. Raupach and Charlie Wilson

NATURE CLIMATE CHANGE | VOL 3 | JANUARY 2013 | www.nature.com/natureclimatechange

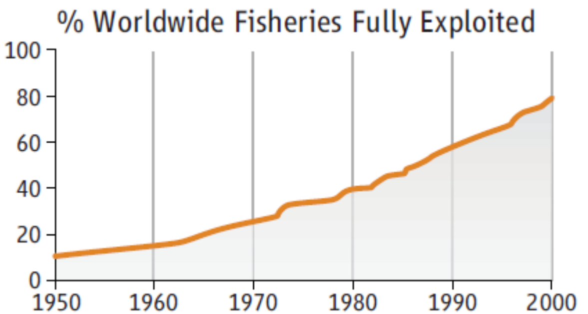


The RCP greenhouse gas concentrations and their extensions from 1765 to 2300

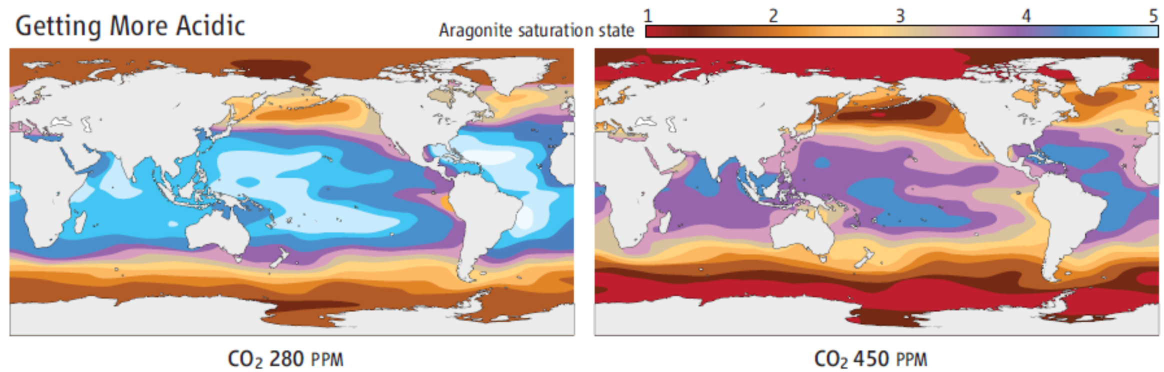
Malte Meinshausen · S. J. Smith · K. Calvin · J. S. Daniel · M. L. T. Kainuma · J-F. Lamarque · K. Matsumoto · S. A. Montzka · S. C. B. Raper · K. Riahi · A. Thomson · G. J. M. Velders · D.P. P. van Vuuren

A Global Perspective on the Anthropocene

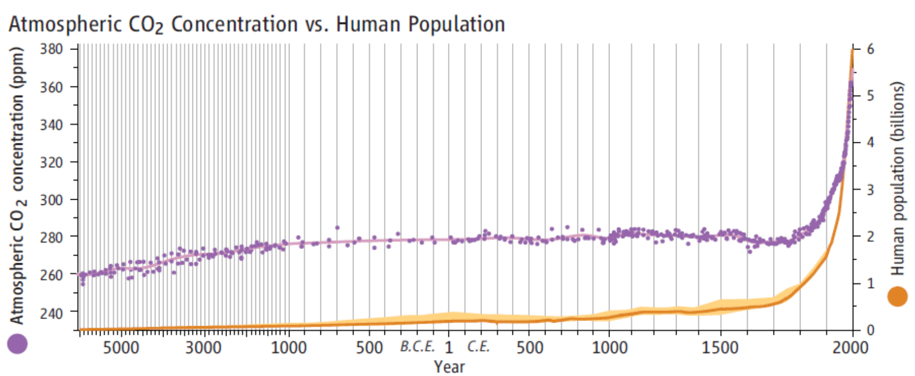
www.sciencemag.org SCIENCE VOL 334 7 OCTOBER 2011



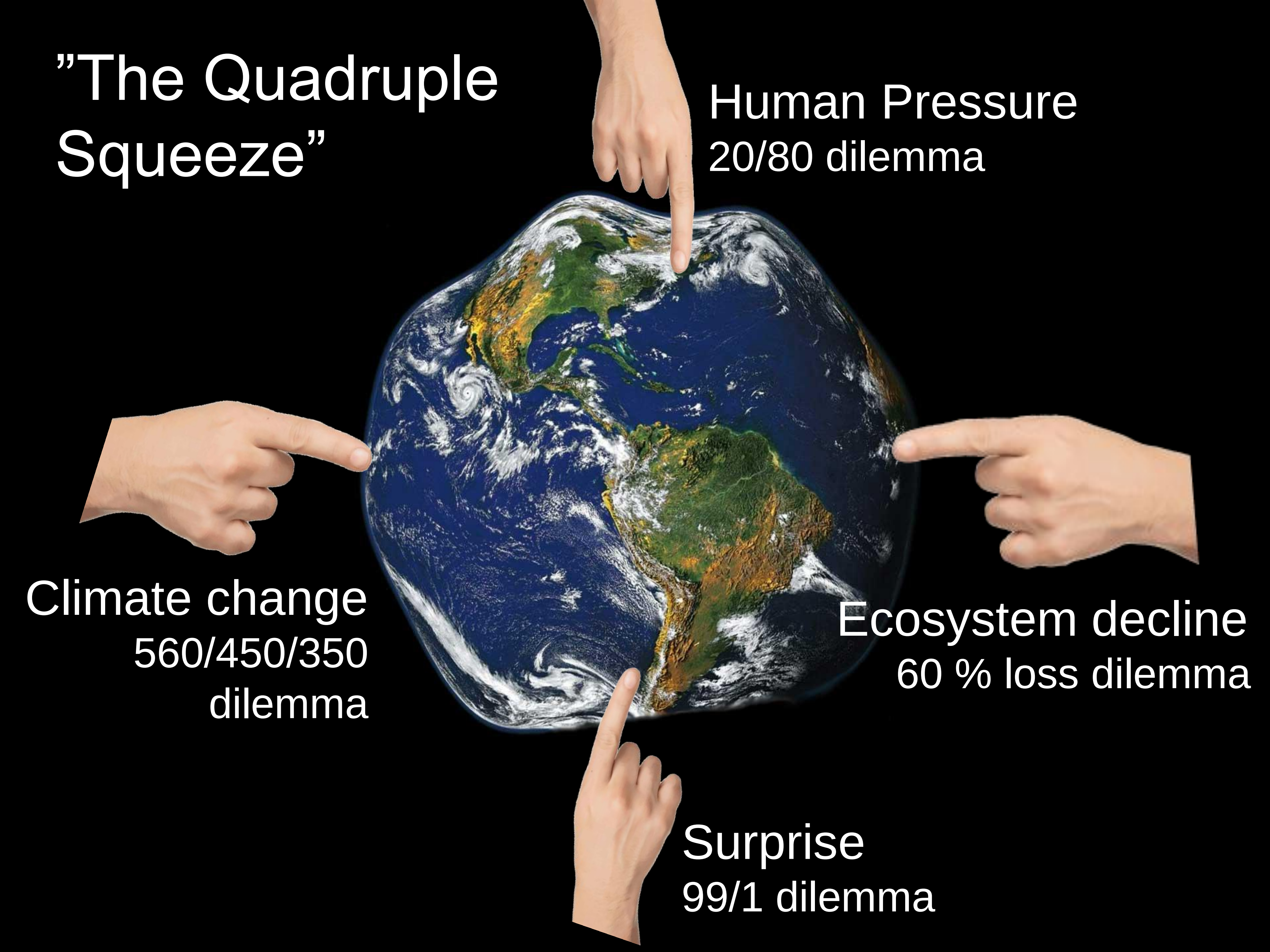
SOURCE: WILL STEFFEN *ET AL.*, *PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A* **369** (2011)

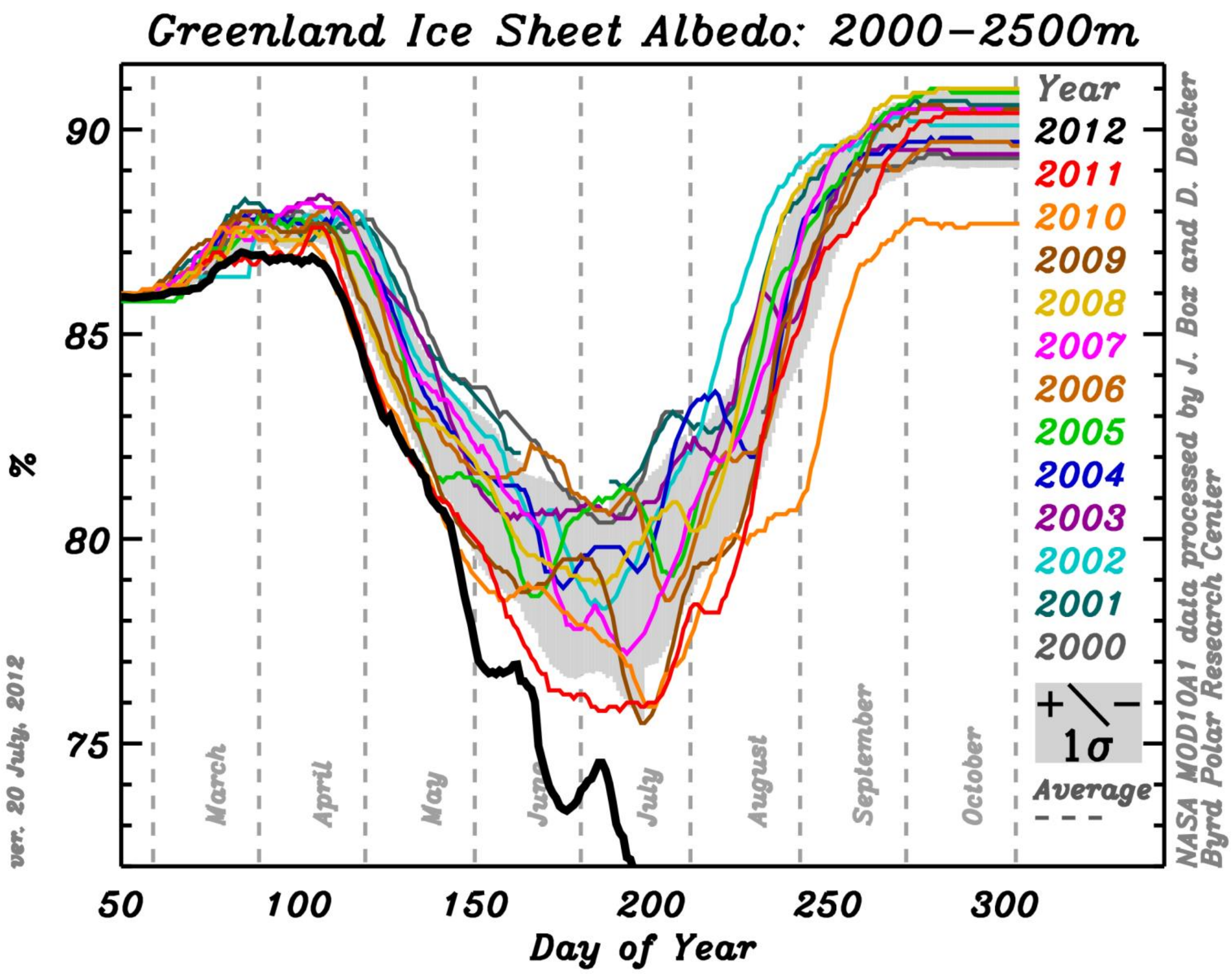


SOURCE: O. HOEGH-GULDBERG *ET AL.*, *SCIENCE* **318**, 5857 (14 DECEMBER 2007)



SOURCE: JED O. KAPLAN *ET AL.*, *THE HOLOCENE* **21**, 5 (AUGUST 2011)


"The Quadruple Squeeze"
Human Pressure
20/80 dilemma
Climate change
560/450/350 dilemma
Ecosystem decline
60 % loss dilemma
Surprise
99/1 dilemma


Greenland Ice Sheet Albedo: 2000–2500m
%
90
85
80
75
50
100
150
200
250
300
Day of Year
March
April
May
June
July
August
September
October
Year
2012
2011
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Average
ver. 20 July, 2012
NASA MOD10A1 data processed by J. Box and D. Decker
Byrd Polar Research Center

Humanity has reached a planetary saturation point

The Human ability to do has vastly outstripped our ability to understand

A resilient biosphere the basis for humen development

Fierce urgency of now

A great transformation to global sustainability necessary, possible, and desirable

photos: www.dawide.com

Future Earth
research for global sustainability

UNEP

UNESCO
United Nations
Educational, Scientific and
Cultural Organization

BELMONT FORUM

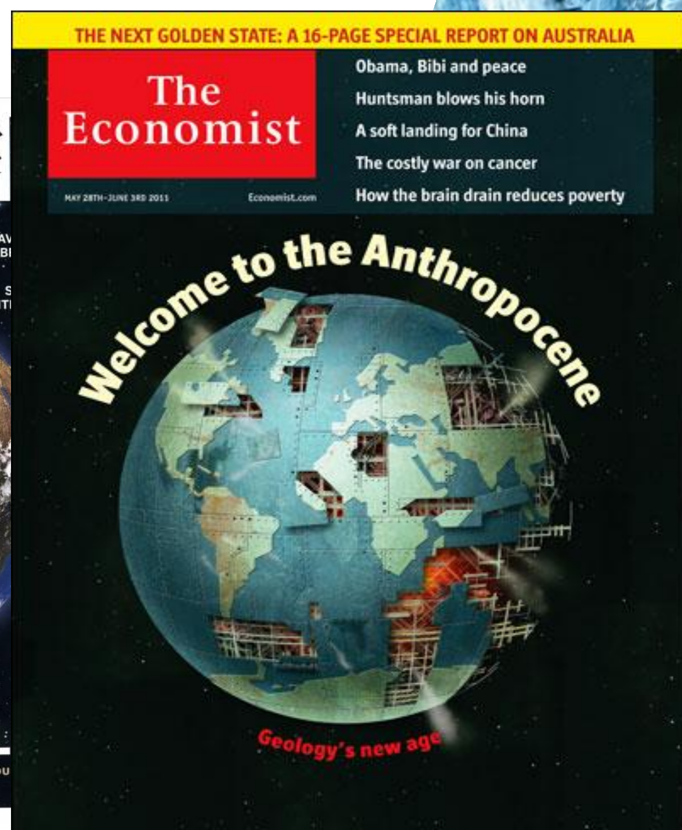
ICSU
International Council for Science

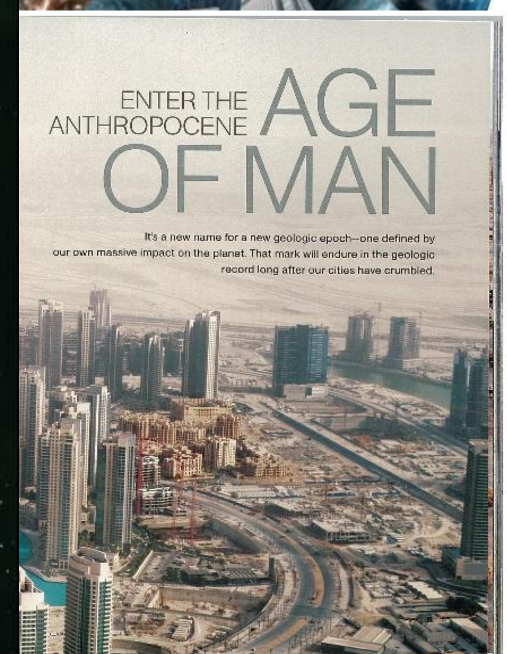
ISSC
international social science council

UNITED NATIONS UNIVERSITY

IGFA
International Group of Funding Agencies for Global Change Research

*"When **reality is changing faster than theory** suggests it should, a certain amount of nervousness is a reasonable response"*
The Economist





Declaration from the High-level dialogue on Global Sustainability

17 June 2012, Rio de Janeiro

The Future we Choose:

Tipping the Scales towards Global Sustainability

The scientific evidence is unequivocal. Risks are rising as humanity's current development paradigm rapidly undermines the resilience of the planet and its peoples. The burden of environmental disintegration and resource depletion pile up and will weigh down on future generations. We have become our own geological epoch, the Anthropocene, where human pressures on the planet are at risk of triggering abrupt and irreversible changes with catastrophic outcomes for human societies.

A transition to a safe and prosperous future is possible. But time is running short, and the path to success will require the full use of humanity's capacity for innovation and creativity within new economic development pathways that are fully integrated with the precepts of global sustainability. Worldwide cooperation is necessary with the engagement of science and civil society and guided by the principles of responsibility and equity. Real political leadership is required now to tackle these systemic issues.

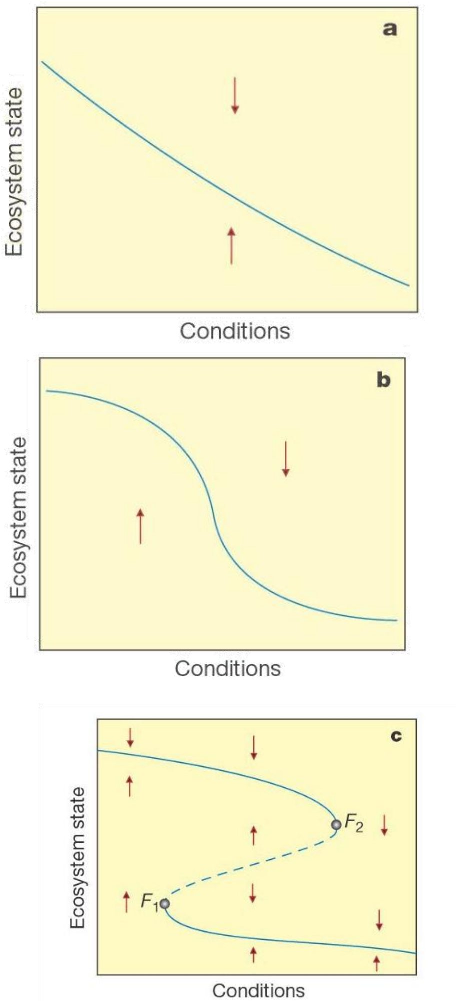
Stockholm Resilience Centre
Research for Governance of Social-Ecological Systems

Stockholm University

Regime shifts, Human prosperity and Global sustainability

Critical transitions or regime shifts

Regime shifts are substantial, persistent, reorganizations in ecosystem structure and processes

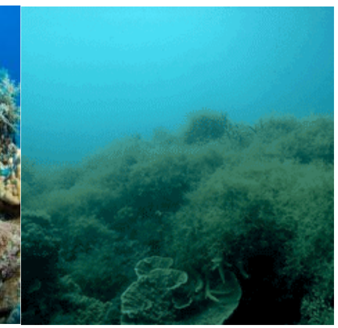


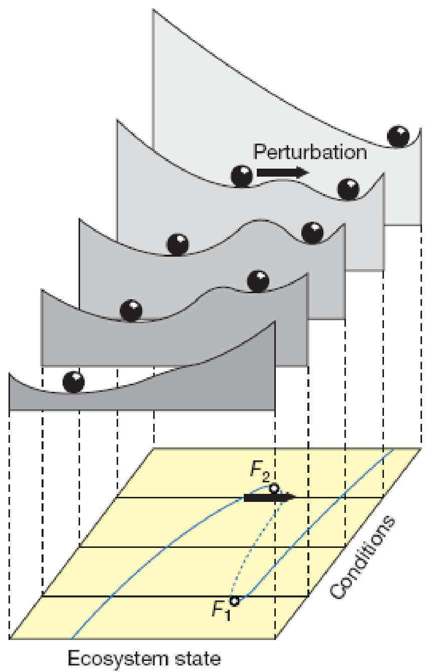
Parkland Savanna

Bush steppe

Diverse Coral dominated

Algae Dominated Reef





Three features of resilience

1. PERSISTENCE in the face of change, buffer capacity, withstand shocks

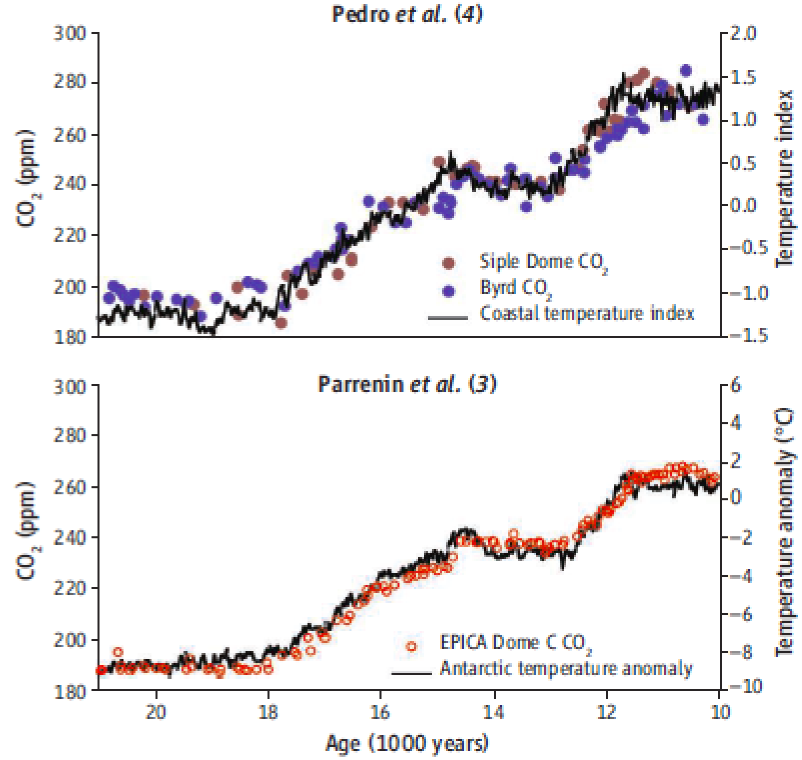
2. ADAPTABILITY the capacity of people in a social-ecological system to manage resilience e.g. through collective action

3. TRANSFORMABILITY the capacity of people in a social-ecological system to create a new system when ecological, political, social or economic conditions make the existing system untenable

Synchronous Change of Atmospheric CO_2 and Antarctic Temperature During the Last Deglacial Warming

F. Parrenin,[1]* V. Masson-Delmotte,[2] P. Köhler,[3] D. Raynaud,[1] D. Paillard,[2] J. Schwander,[4]
C. Barbante,[5,6] A. Landais,[2] A. Wegner,[3]† J. Jouzel[2]

1 MARCH 2013 VOL 339 SCIENCE www.sciencemag.org



Lead and lag. Carbon dioxide concentrations and averages of temperature proxy records for last deglaciation, as compiled by Parrenin *et al*. (*3*) and Pedro *et al*. (*4*). Pedro *et al*. used existing CO_2 and temperature proxy data from coastal Antarctic cores and the temperature anomaly is presented in standard deviation units (the number of standard deviations from the mean of the record) to illustrate the average timing of temperature change. Parrenin *et al*.'s record is the average temperature anomaly for all the records they combine (in °C), relative to modern conditions. Using largely independent methods and data, both studies indicate a very tight coupling between regional Antarctic temperatures and CO_2.

ATMOSPHERE

Leads and Lags at the End of the Last Ice Age

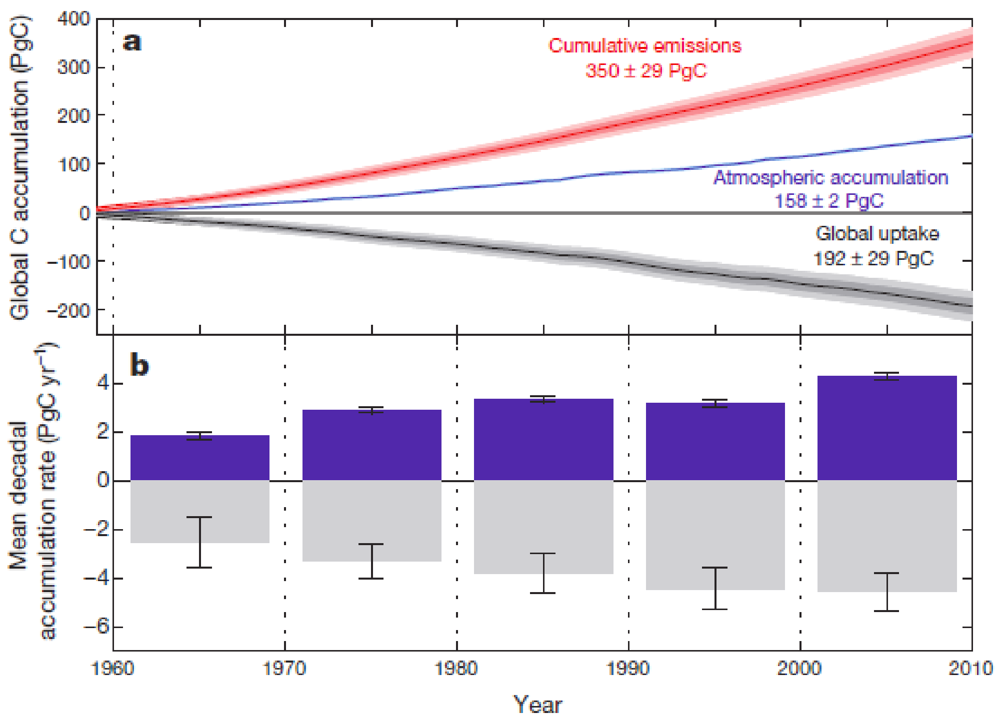
Edward J. Brook

LETTER

doi:10.1038/nature11299

Increase in observed net carbon dioxide uptake by land and oceans during the past 50 years

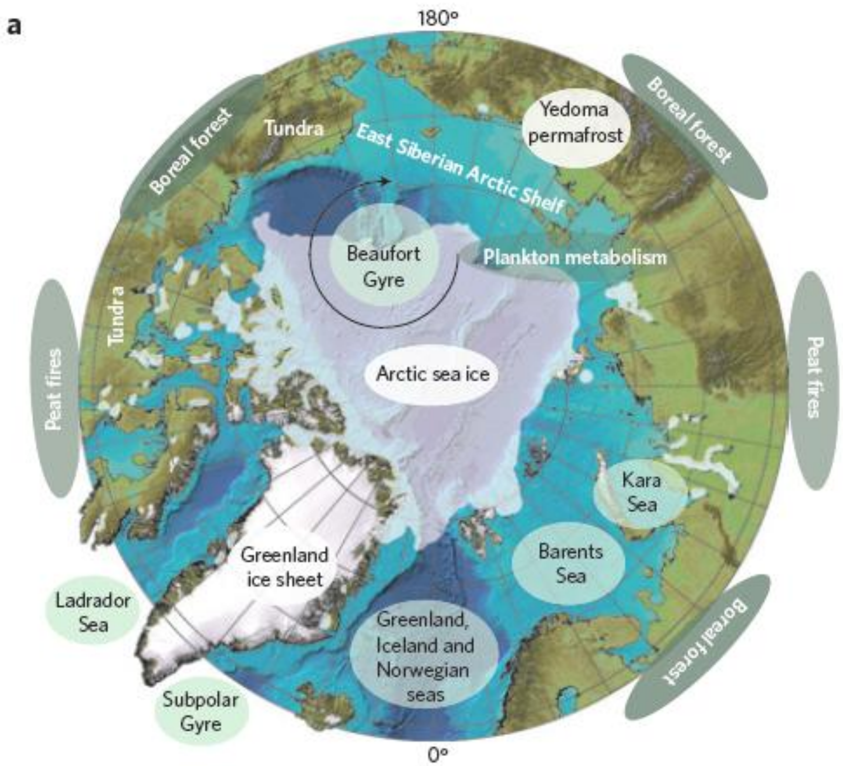
A. P. Ballantyne[1]†, C. B. Alden[2], J. B. Miller[3,4], P. P. Tans[4] & J. W. C. White[1,2]



COMMENTARY:

Abrupt climate change in the Arctic

Carlos M. Duarte, Timothy M. Lenton, Peter Wadhams and Paul Wassmann



Is Greenland more resilient than previously thought?

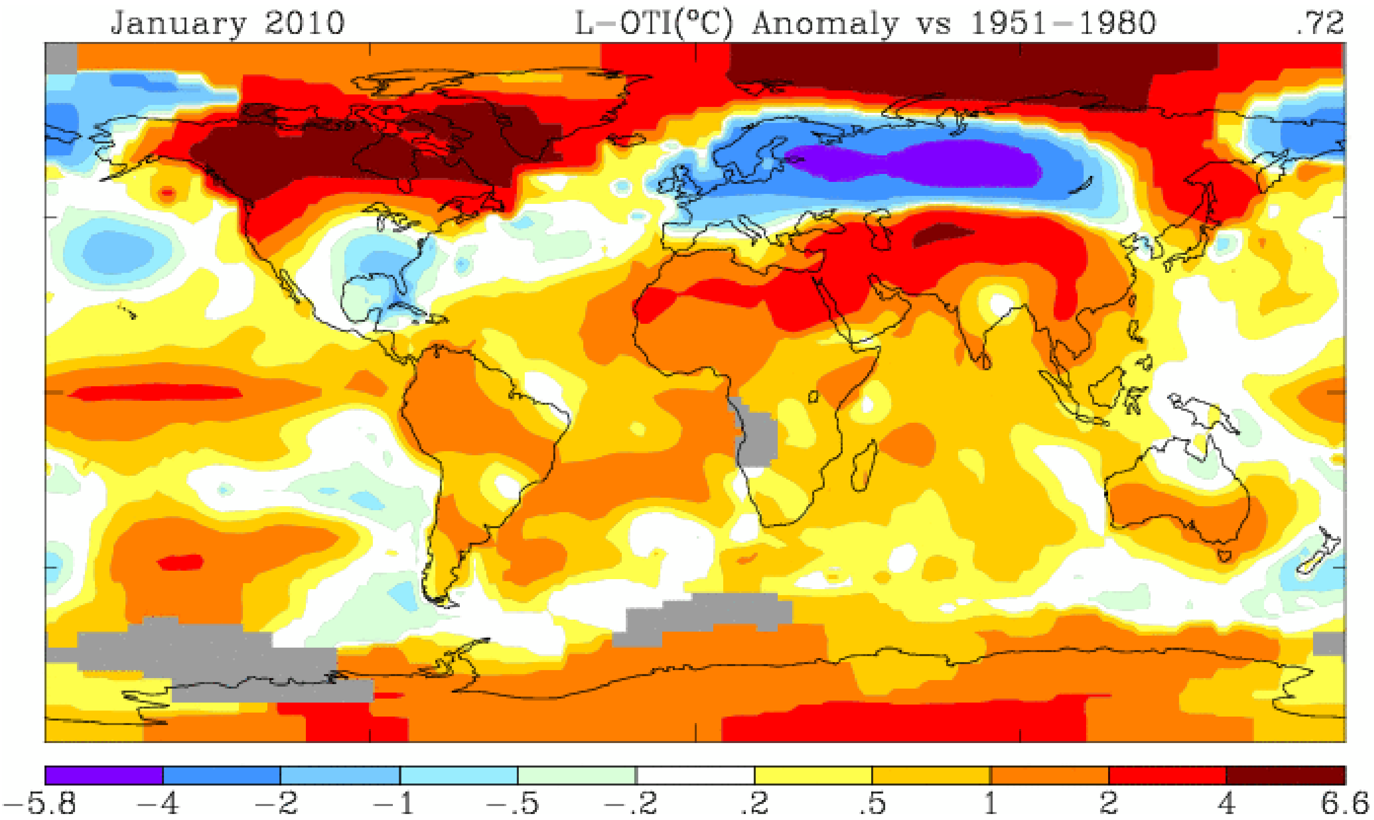
ARTICLE

doi:10.1038/nature11789

Eemian interglacial reconstructed from a Greenland folded ice core

NEEM community members*

Indicates Greenland contributed ~2 m to sea level rise compared to observed 4-8 m at Eemian peak (+8 C)



IOP Publishing
Environmental Research Letters
Environ. Res. Lett. 7 (2012) 014007 (8pp)
doi:10.1088/1748-9326/7/1/014007

Arctic warming, increasing snow cover and widespread boreal winter cooling

Judah L Cohen[1], Jason C Furtado[1], Mathew A Barlow[2], Vladimir A Alexeev[3] and Jessica E Cherry[3]

www.regimeshifts.org

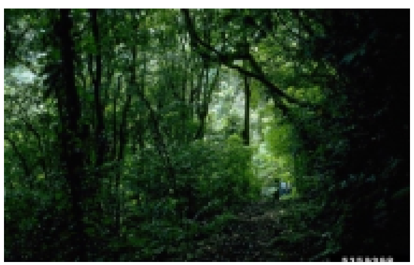
Regime Shifts DataBase

Large persistent changes in ecosystem services

The Regime Shifts DataBase provides examples of different types of regime shifts that have been documented in social-ecological systems. The database focuses specifically on regime shifts that have large impacts on ecosystem services, and therefore on human well-being.

Latest Regime Shifts

Forest to Savannas

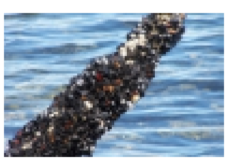


Forest to savannas is a regime shift typical from tropical areas. Several feedback play an important role including albedo effects, evapotranspiration and clouds forming, fragmentation and fire-prone areas expansion, change in ocean circulation and self organizing vegetation patterns. However, not always these feedbacks are strong enough to produce alternative regimes; and in some areas shifts are expected to occur under stochastic events like ENSO droughts or unlikely events like Earth orbit ch...

Read more...

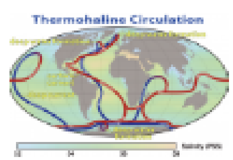
1 2 3 4 5

Browse Database



Bivalves Collapse

Bush Encroachment



Collapse of the thermohaline circulation

Coral Bleaching

Quick Search

Regime Shift

- Select a regime shift

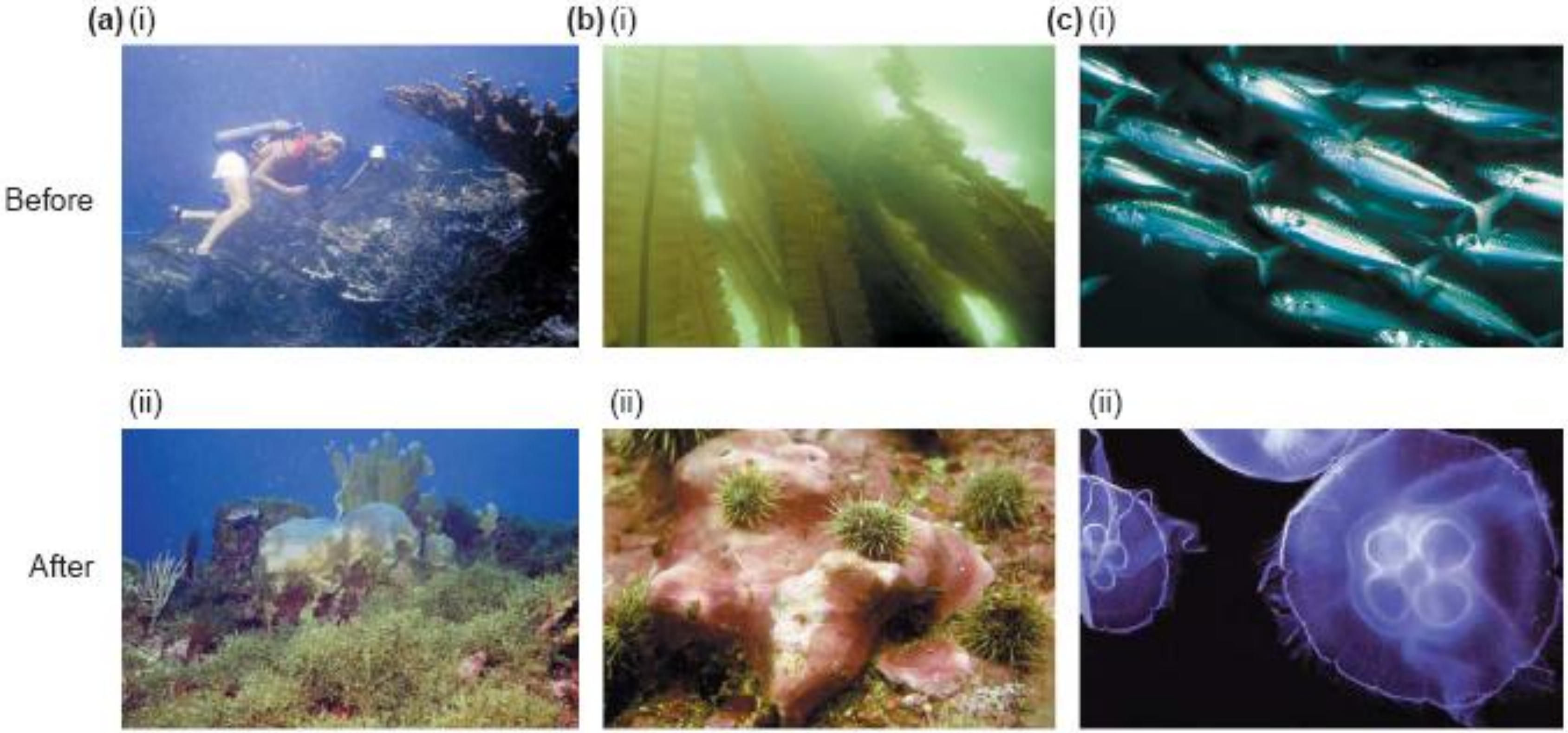
Case Study

- Select a case study -

Advanced Search

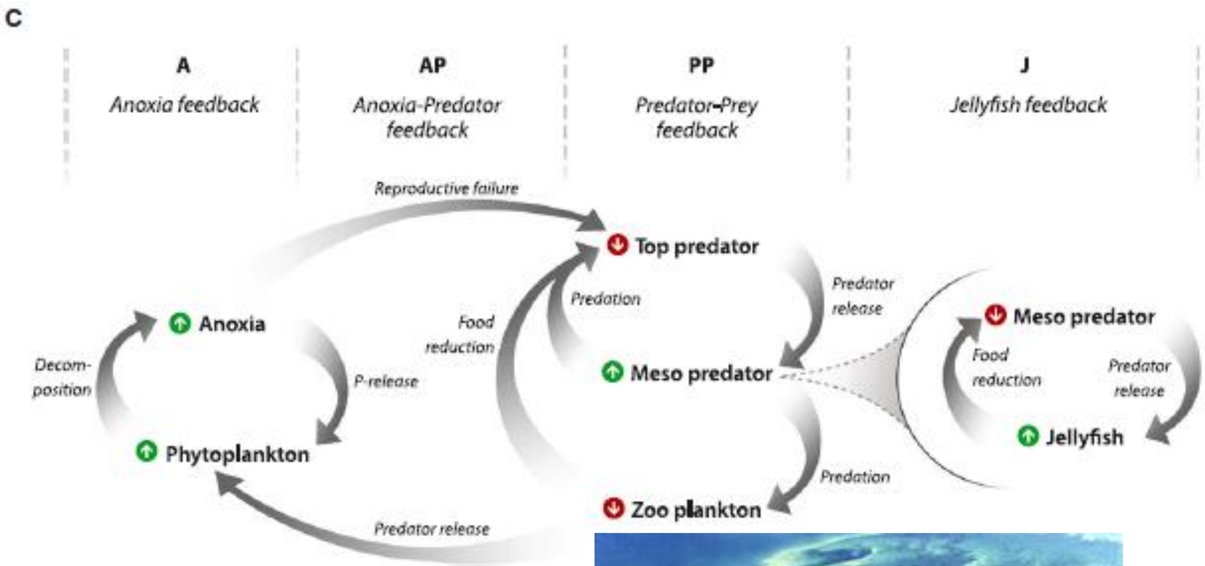
Click for detailed search

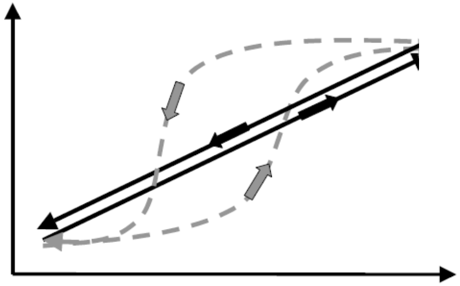
Marine regime shifts



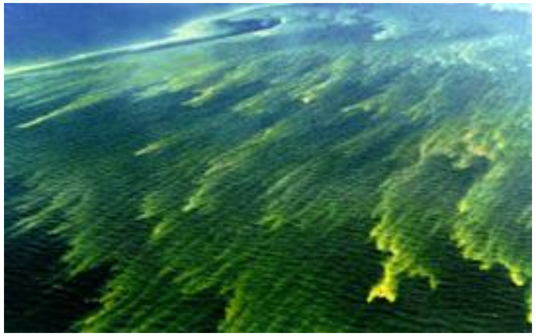
Hughes et al. 2005. TREE

Interactions between global environmental change, eutrophication, and loss of biodiversity





Källa: Ulf Larsson, Stockholms universitet



Trophic Downgrading of Planet Earth

James A. Estes,[1*] John Terborgh,[2] Justin S. Brashares,[3] Mary E. Power,[4] Joel Berger,[5] William J. Bond,[6] Stephen R. Carpenter,[7] Timothy E. Essington,[8] Robert D. Holt,[9] Jeremy B. C. Jackson,[10] Robert J. Marquis,[11] Lauri Oksanen,[12] Tarja Oksanen,[13] Robert T. Paine,[14] Ellen K. Pikitch,[15] William J. Ripple,[16] Stuart A. Sandin,[10] Marten Scheffer,[17] Thomas W. Schoener,[18] Jonathan B. Shurin,[19] Anthony R. E. Sinclair,[20] Michael E. Soulé,[21] Risto Virtanen,[22] David A. Wardle[23]

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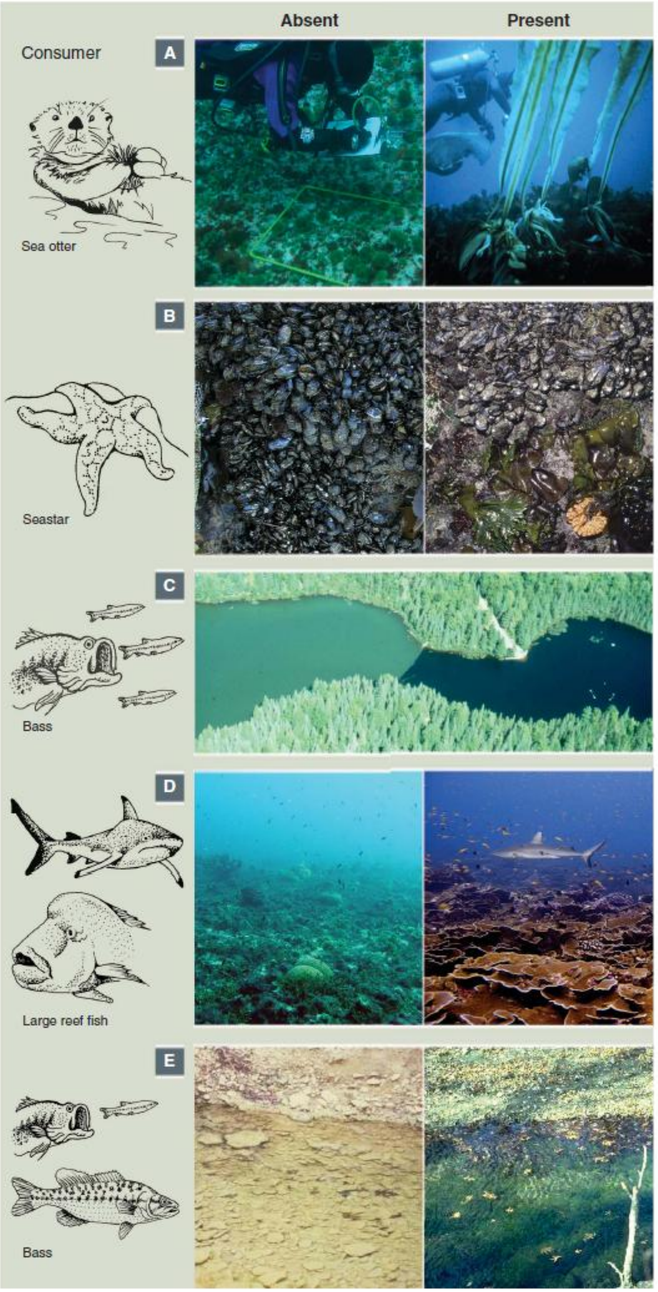
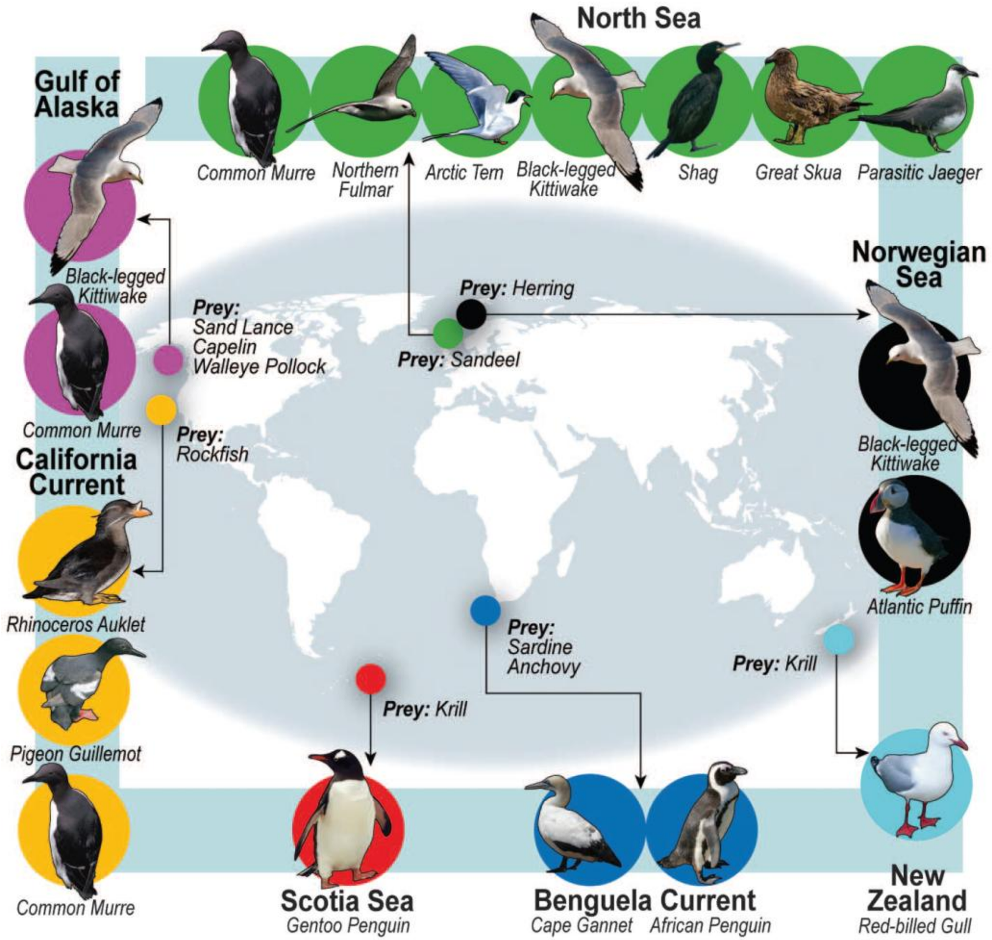


"Save a third for the birds"



Map of the distribution of seabird and prey species.

- Successful seabird breeding depends on access to one third of the world's fish
- Global consistency between access to fish and seabird breeding success.
- A threshold exist below which the numerical breeding response declines strongly as food abundance decreases

Source: Philippe M. Cury, Henrik Österblom, and others. 2011. *Science.*

Risk of Tipping Point in the Amazon Rainforest

Interactions between climate and land use change

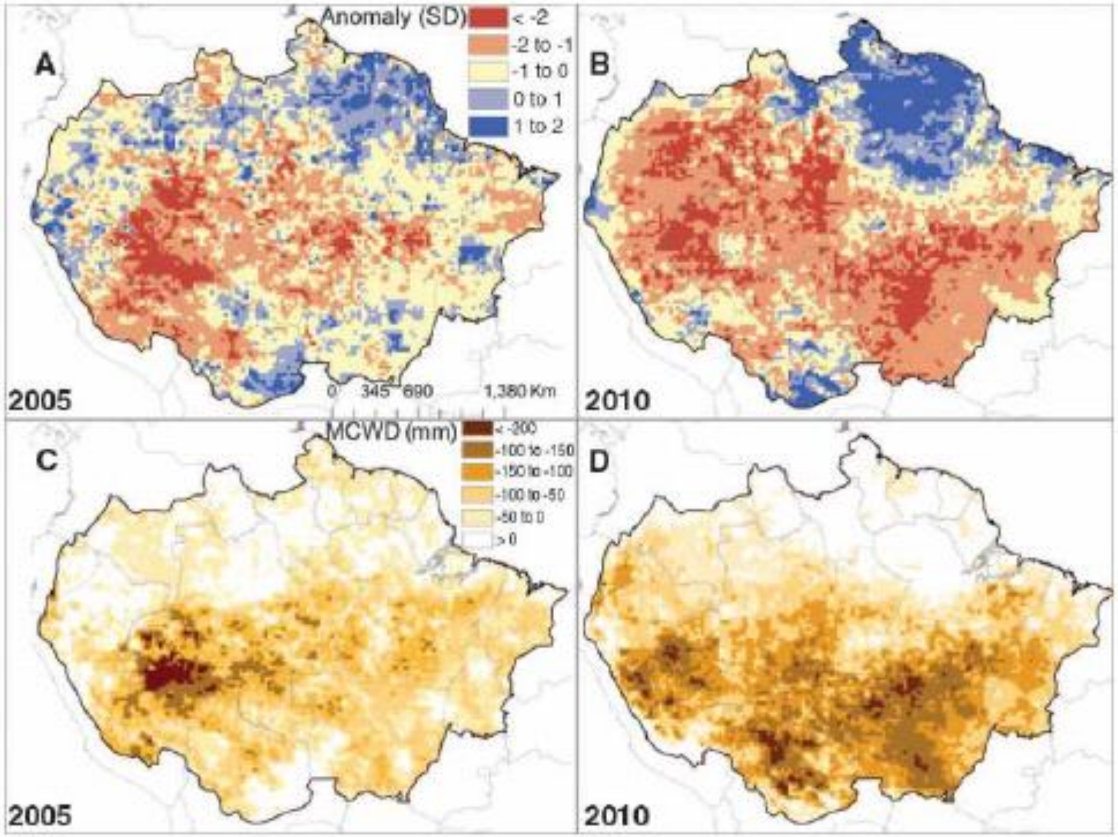


Fig. 1. (**A** and **B**) Satellite-derived standardized anomalies for dry-season rainfall for the two most extensive droughts of the 21st century in Amazonia. (**C** and **D**) The difference in the 12-month (October to September) MCWD from the decadal mean (excluding 2005 and 2010), a measure of drought intensity that correlates with tree mortality. (A) and (C) show the 2005 drought; (B) and (D) show the 2010 drought.

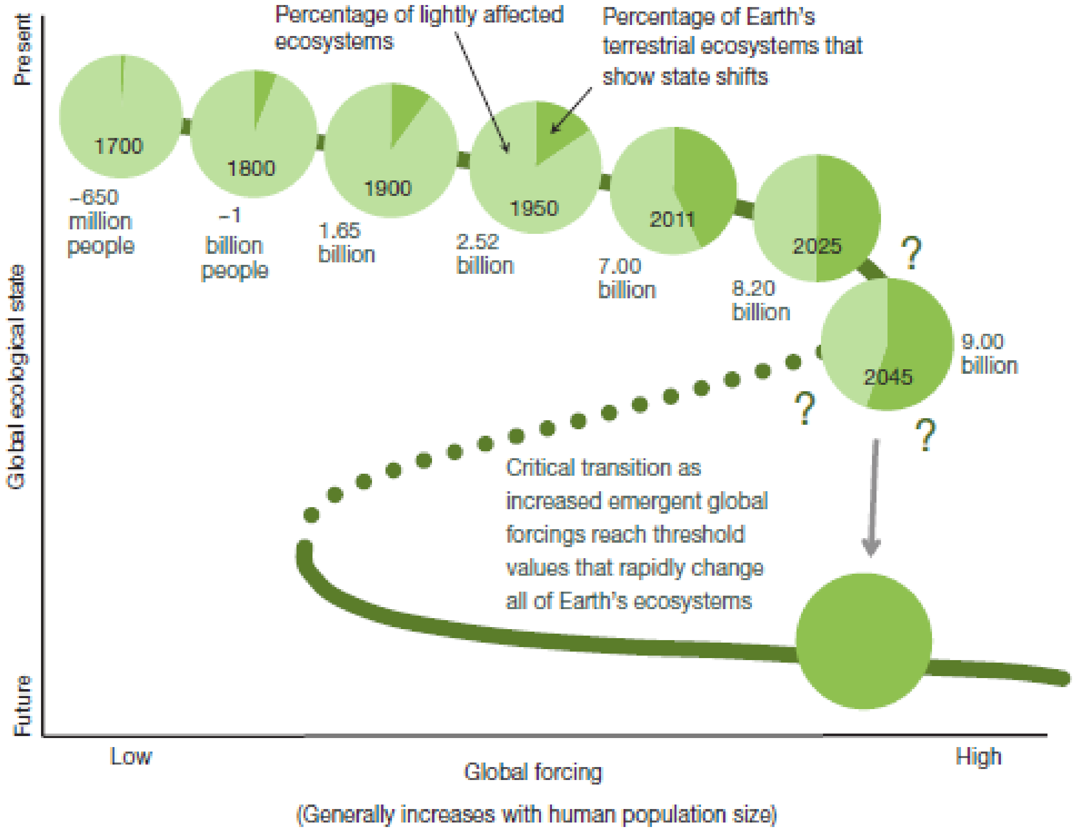
Lewis et al. 2011 Science

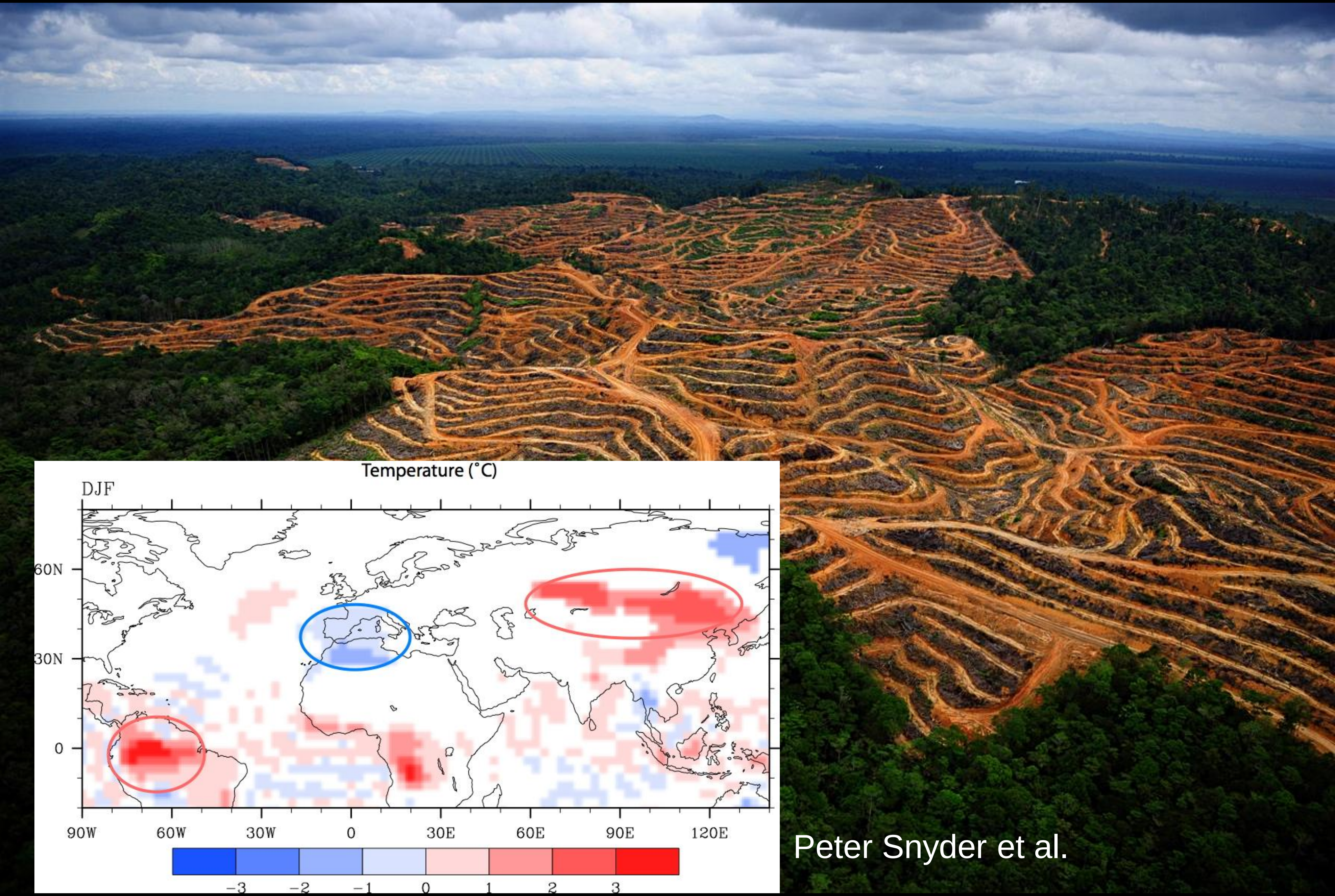
REVIEW

doi:10.1038/nature11018

Approaching a state shift in Earth's biosphere

Anthony D. Barnosky[1,2,3], Elizabeth A. Hadly[4], Jordi Bascompte[5], Eric L. Berlow[6], James H. Brown[7], Mikael Fortelius[8], Wayne M. Getz[9], John Harte[9,10], Alan Hastings[11], Pablo A. Marquet[12,13,14,15], Neo D. Martinez[16], Arne Mooers[17], Peter Roopnarine[18], Geerat Vermeij[19], John W. Williams[20], Rosemary Gillespie[9], Justin Kitzes[9], Charles Marshall[1,2], Nicholas Matzke[1], David P. Mindell[21], Eloy Revilla[22] & Adam B. Smith[23]





Peter Snyder et al.

Rainfall dependent on moisture feedback from functioning forest landscapes

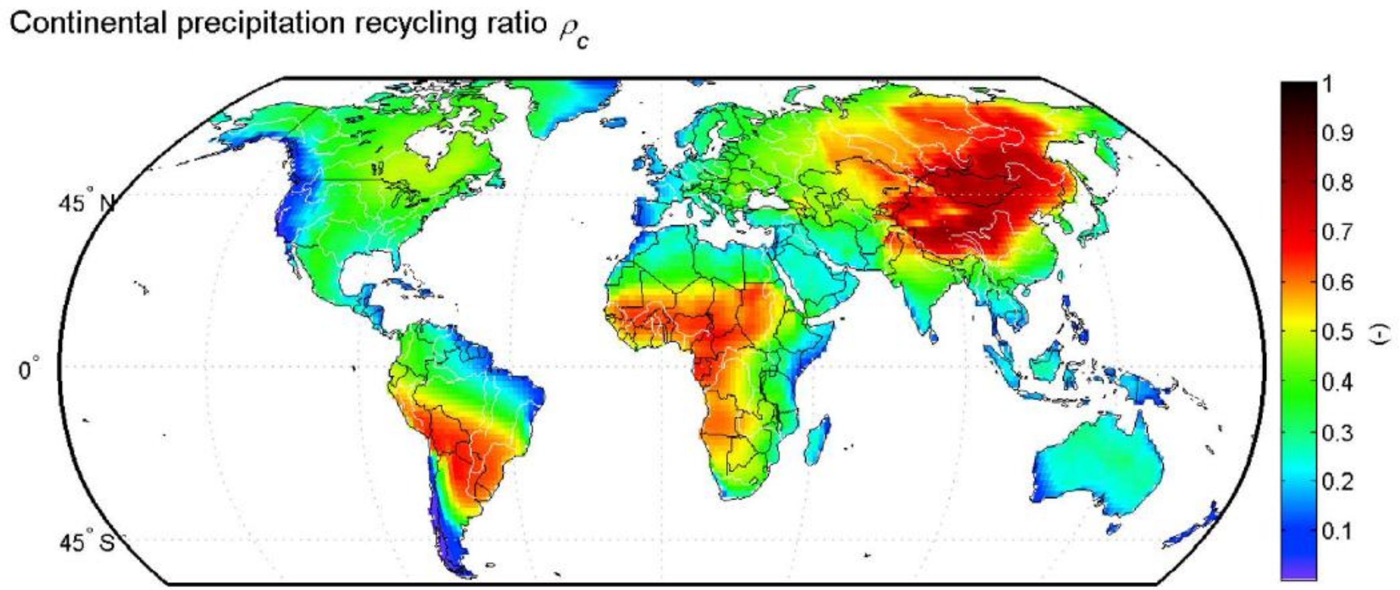
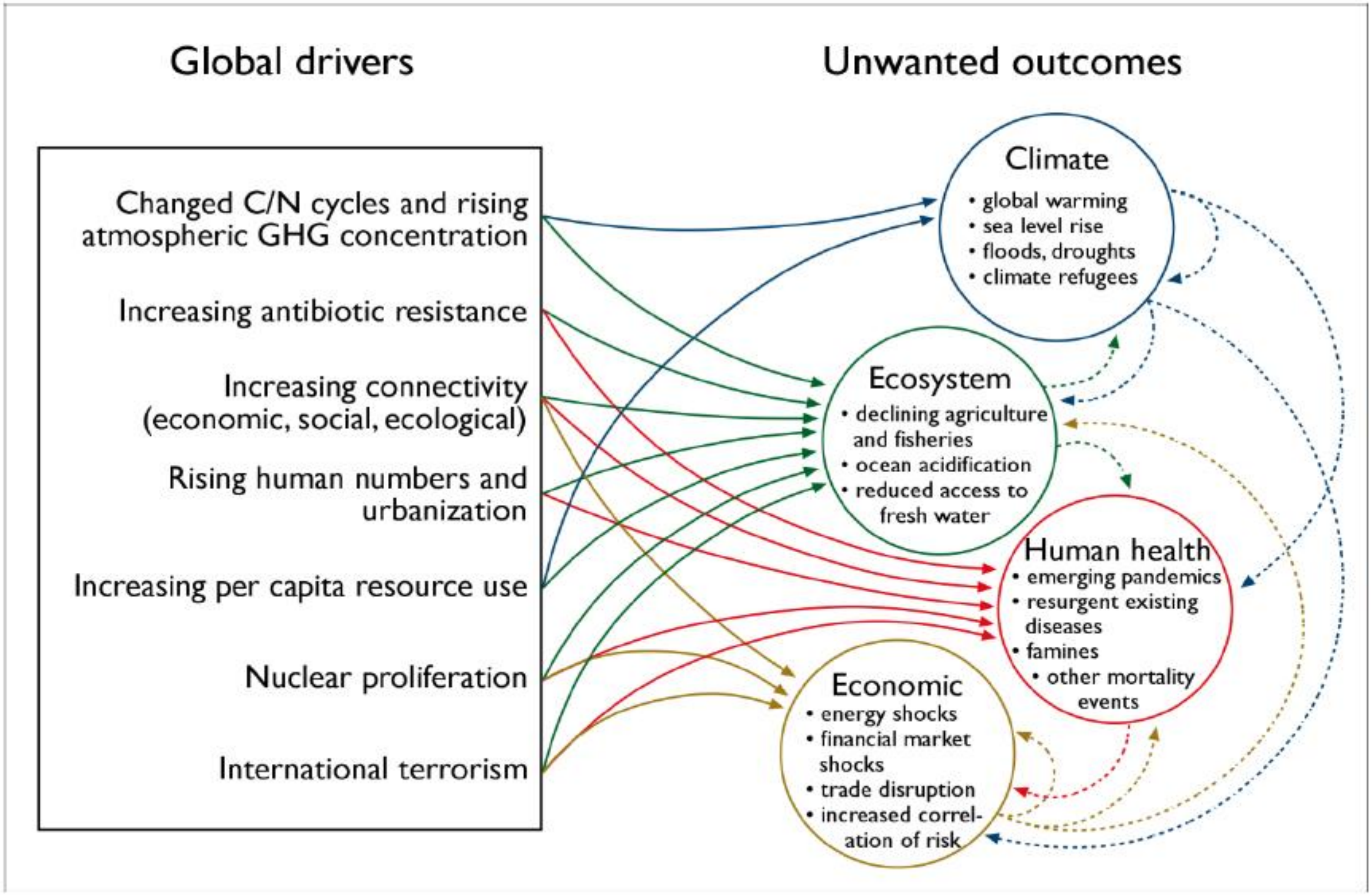


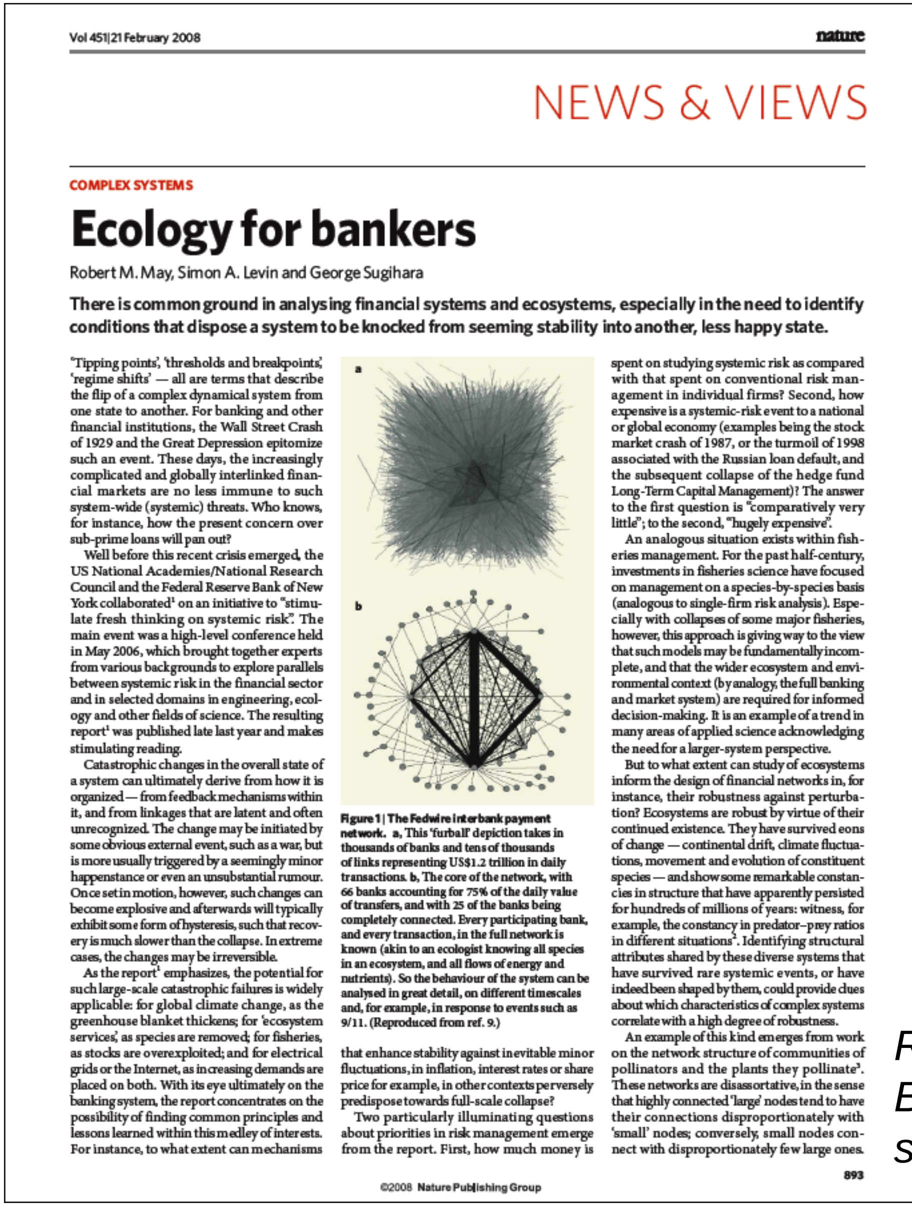
Figure 3. Average continental precipitation recycling ratio ρ_c (1999–2008).

Invonvenient Feedbacks in a hyper-connected World



Folke et al. 2011. Ambio, Walker et al. 2009. Science

Regime shifts in Social Systems – can we learn from the biosphere?



Vol 451|21 February 2008 nature

NEWS & VIEWS

COMPLEX SYSTEMS

Ecology for bankers

Robert M. May, Simon A. Levin and George Sugihara

There is common ground in analysing financial systems and ecosystems, especially in the need to identify conditions that dispose a system to be knocked from seeming stability into another, less happy state.

'Tipping points', 'thresholds and breakpoints', 'regime shifts' — all are terms that describe the flip of a complex dynamical system from one state to another. For banking and other financial institutions, the Wall Street Crash of 1929 and the Great Depression epitomize such an event. These days, the increasingly complicated and globally interlinked financial markets are no less immune to such system-wide (systemic) threats. Who knows, for instance, how the present concern over sub-prime loans will pan out?

Well before this recent crisis emerged, the US National Academies/National Research Council and the Federal Reserve Bank of New York collaborated[1] on an initiative to "stimulate fresh thinking on systemic risk". The main event was a high-level conference held in May 2006, which brought together experts from various backgrounds to explore parallels between systemic risk in the financial sector and in selected domains in engineering, ecology and other fields of science. The resulting report[1] was published late last year and makes stimulating reading.

Catastrophic changes in the overall state of a system can ultimately derive from how it is organized — from feedback mechanisms within it, and from linkages that are latent and often unrecognized. The change may be initiated by some obvious external event, such as a war, but is more usually triggered by a seemingly minor happenstance or even an unsubstantial rumour. Once set in motion, however, such changes can become explosive and afterwards will typically exhibit some form of hysteresis, such that recovery is much slower than the collapse. In extreme cases, the changes may be irreversible.

As the report[1] emphasizes, the potential for such large-scale catastrophic failures is widely applicable: for global climate change, as the greenhouse blanket thickens; for 'ecosystem services', as species are removed; for fisheries, as stocks are overexploited; and for electrical grids or the Internet, as increasing demands are placed on both. With its eye ultimately on the banking system, the report concentrates on the possibility of finding common principles and lessons learned within this medley of interests. For instance, to what extent can mechanisms that enhance stability against inevitable minor fluctuations, in inflation, interest rates or share price for example, in other contexts perversely predispose towards full-scale collapse?

Two particularly illuminating questions about priorities in risk management emerge from the report. First, how much money is spent on studying systemic risk as compared with that spent on conventional risk management in individual firms? Second, how expensive is a systemic-risk event to a national or global economy (examples being the stock market crash of 1987, or the turmoil of 1998 associated with the Russian loan default, and the subsequent collapse of the hedge fund Long-Term Capital Management)? The answer to the first question is "comparatively very little"; to the second, "hugely expensive".

An analogous situation exists within fisheries management. For the past half-century, investments in fisheries science have focused on management on a species-by-species basis (analogous to single-firm risk analysis). Especially with collapses of some major fisheries, however, this approach is giving way to the view that such models may be fundamentally incomplete, and that the wider ecosystem and environmental context (by analogy, the full banking and market system) are required for informed decision-making. It is an example of a trend in many areas of applied science acknowledging the need for a larger-system perspective.

But to what extent can study of ecosystems inform the design of financial networks in, for instance, their robustness against perturbation? Ecosystems are robust by virtue of their continued existence. They have survived eons of change — continental drift, climate fluctuations, movement and evolution of constituent species — and show some remarkable constancies in structure that have apparently persisted for hundreds of millions of years: witness, for example, the constancy in predator–prey ratios in different situations[2]. Identifying structural attributes shared by these diverse systems that have survived rare systemic events, or have indeed been shaped by them, could provide clues about which characteristics of complex systems correlate with a high degree of robustness.

An example of this kind emerges from work on the network structure of communities of pollinators and the plants they pollinate[3]. These networks are disassortative, in the sense that highly connected 'large' nodes tend to have their connections disproportionately with 'small' nodes; conversely, small nodes connect with disproportionately few large ones.

Figure 1 | The Fedwire interbank payment network. a, This 'furball' depiction takes in thousands of banks and tens of thousands of links representing US$1.2 trillion in daily transactions. b, The core of the network, with 66 banks accounting for 75% of the daily value of transfers, and with 25 of the banks being completely connected. Every participating bank, and every transaction, in the full network is known (akin to an ecologist knowing all species in an ecosystem, and all flows of energy and nutrients). So the behaviour of the system can be analysed in great detail, on different timescales and, for example, in response to events such as 9/11. (Reproduced from ref. 9.)

893

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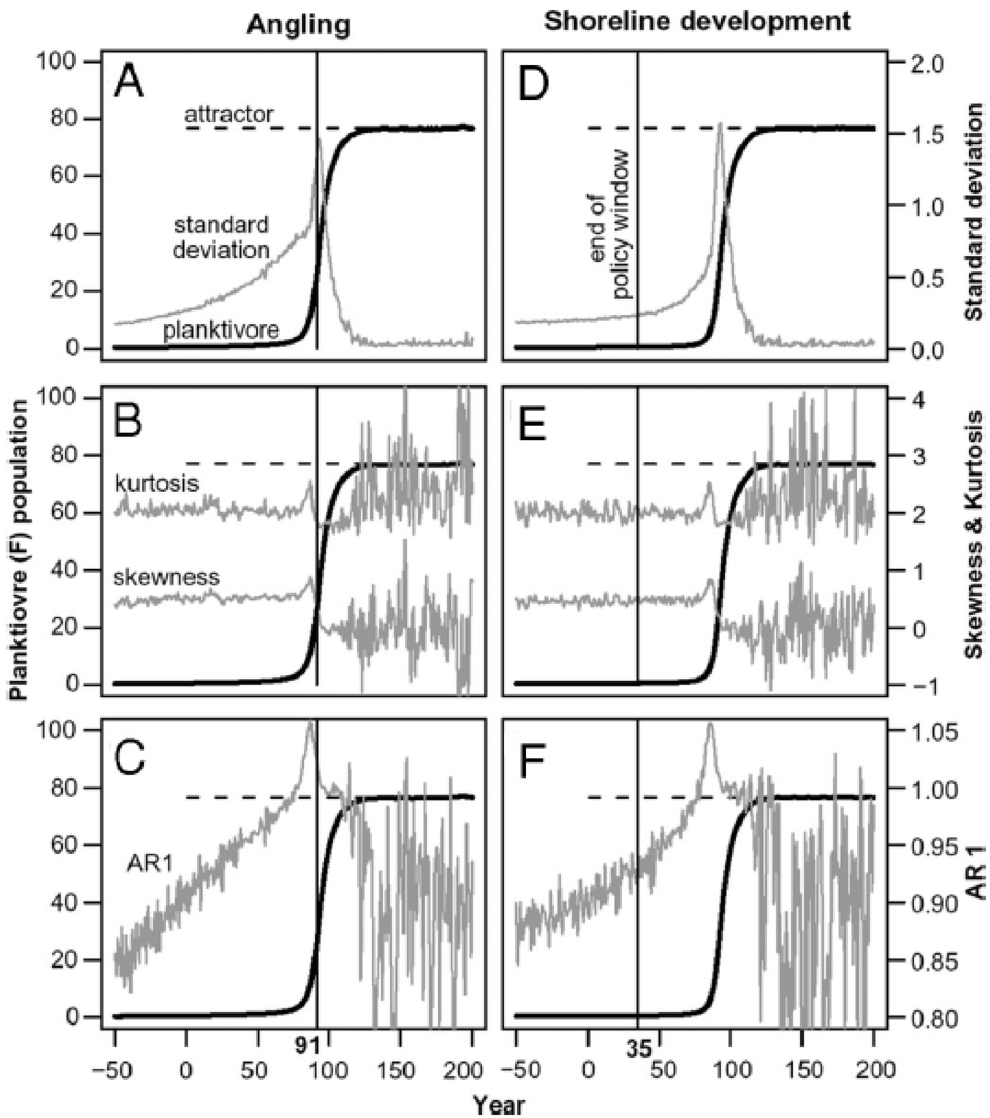
Robert May, Nature 1977. Thresholds and Breakpoints in ecosytems with a multiplicity of stable states...

Turning back from the brink: Detecting an impending regime shift in time to avert it

Reinette Biggs[a,1], Stephen R. Carpenter[a,2], and William A. Brock[b]



Averting Regime Shifts:

Defining Critical Indicator Levels

Rather than

Detecting changes in Regime shift indicators

Unexpected Social-ecological Wammies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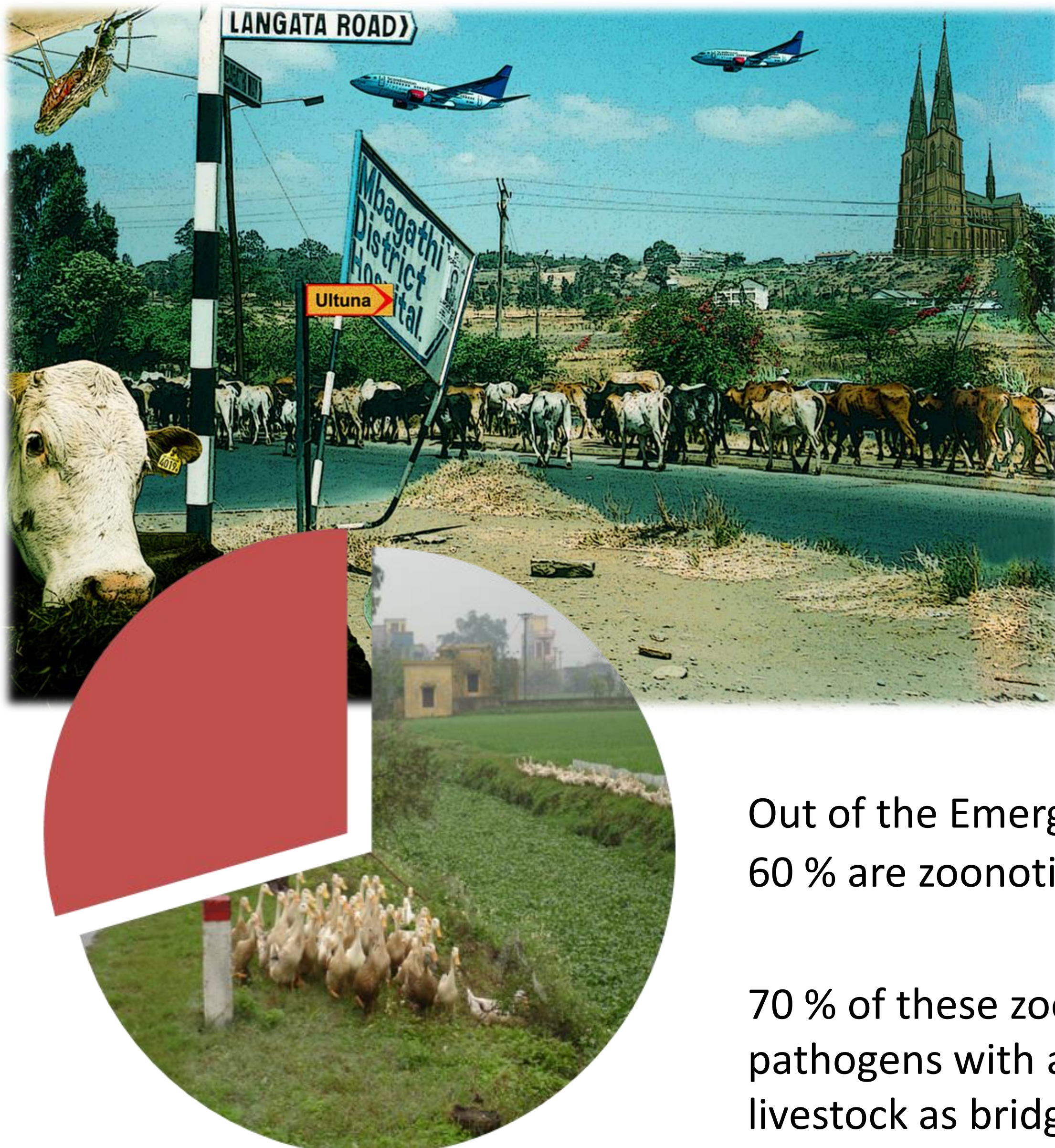
Energy & Sustainability :: Climatewire :: March 4, 2013 :: 4 Comments :: Email :: Print

Climate Change and Rising Food Prices Heightened Arab Spring

The effects of climate change on the food supply exacerbated the underlying tensions that have led to ongoing Middle East instability

Global Environmental Change and Zoonoses



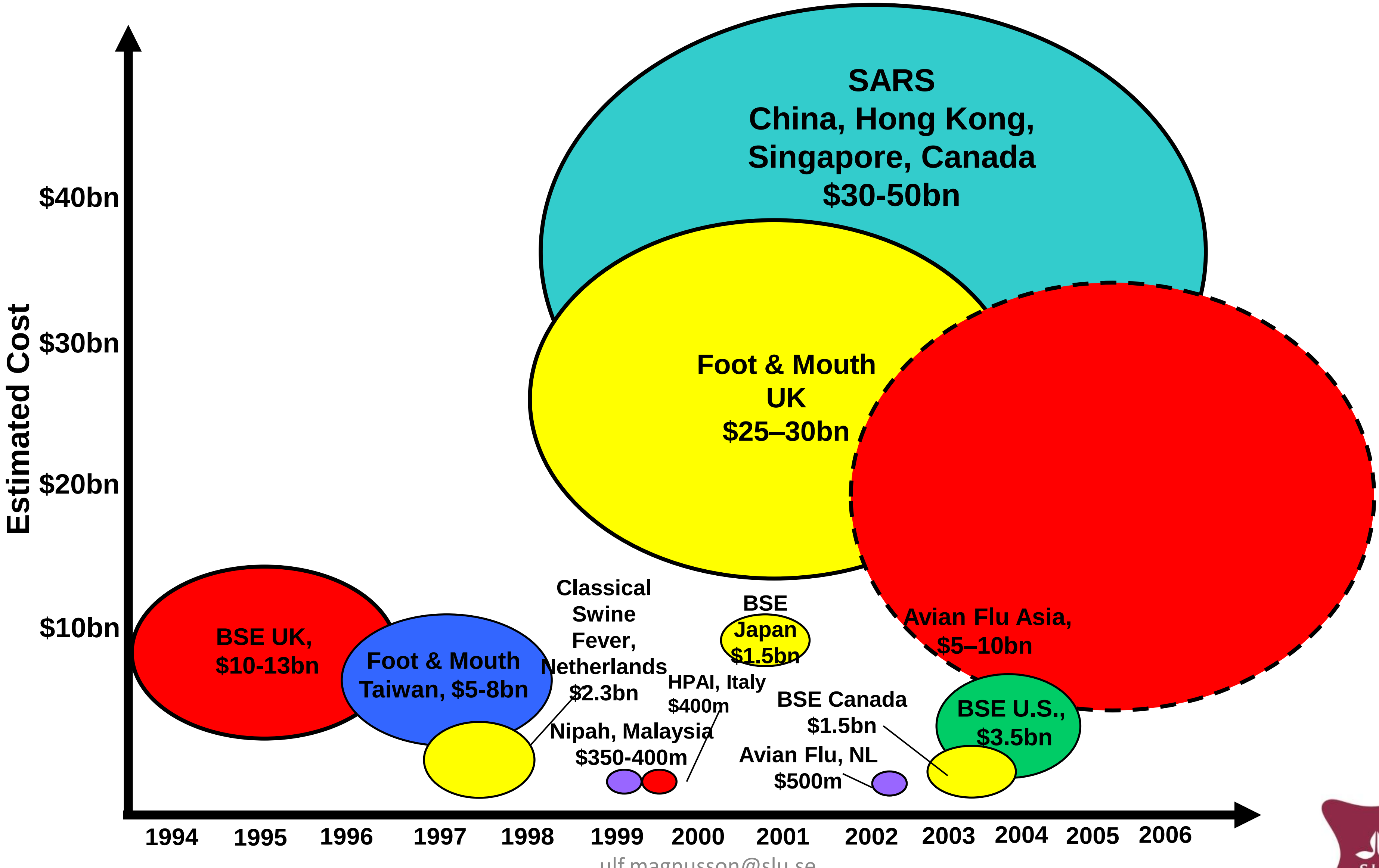
Out of the Emerging Infectious Disease (EID) events, 60 % are zoonotic.

70 % of these zoonotic EID events are caused by pathogens with a wildlife origin, and often with livestock as bridge to humans, for example SARS and the emergence of Nipah virus

Courtesy: Ulf Magnusson, SLU

Courtesy: Ulf Magnusson, SLU

Economic impact of EIDs



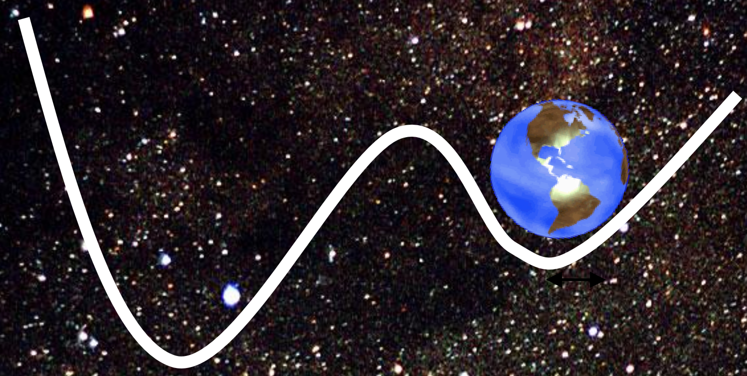
ulf.magnusson@slu.se

The Great Acceleration:
facing the risk that we have only reached
Humanity's Double Apperitif

Putting in the Social High Gear

Earth system starting its Engine of positive feedbacks

Earth Resilience in the Anthropocene



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]

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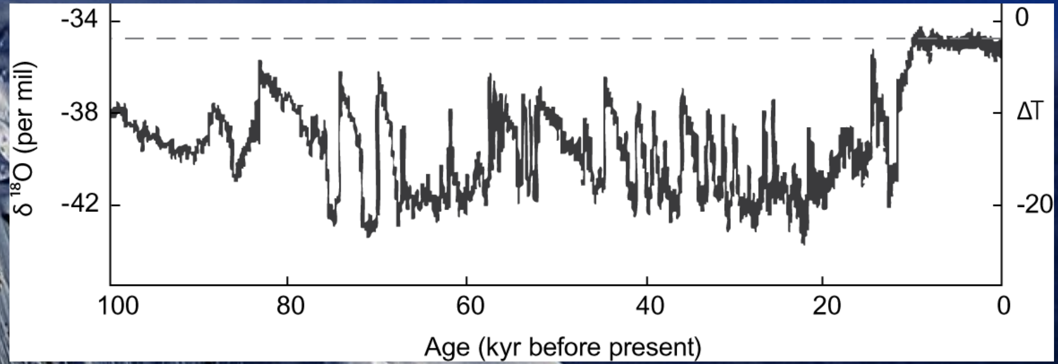
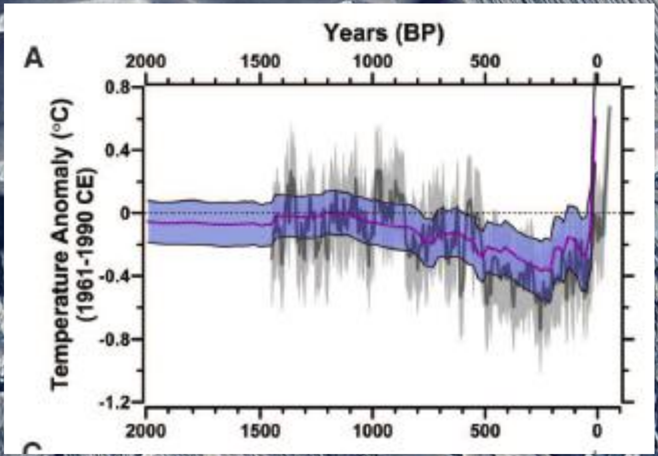
[2]Center for Limnology, University of Wisconsin, 680 North Park Street, Madison, WI 53706, USA





A Reconstruction of Regional and Global Temperature for the Past 11,300 Years

Shaun A. Marcott,[1] Jeremy D. Shakun,[2] Peter U. Clark,[1] Alan C. Mix[1]

Transgressing safe boundaries


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

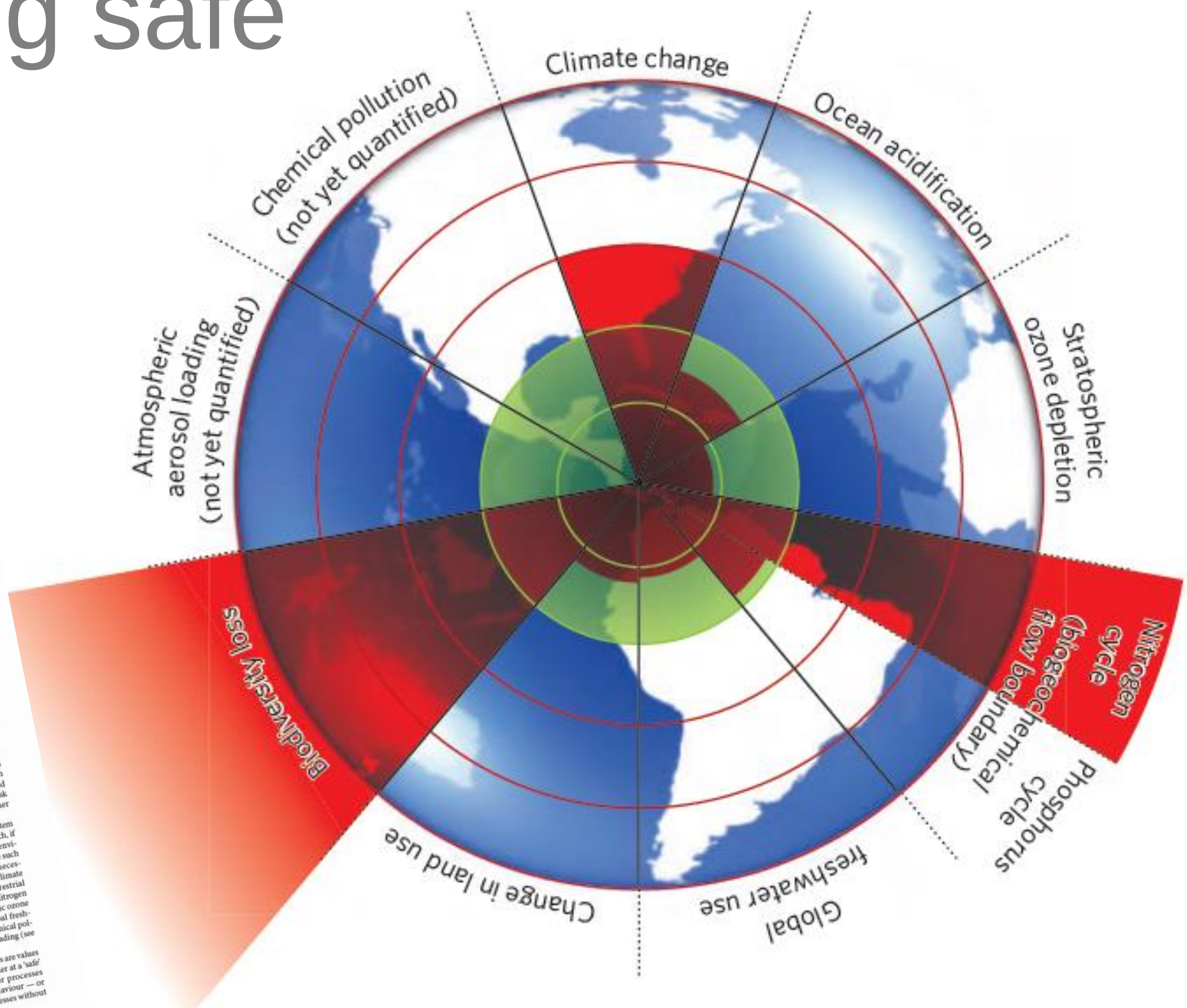
To meet the challenge of maintaining the Holocene state, we propose a framework based on 'planetary boundaries'. These boundaries define the safe operating space for humanity with respect to the Earth system and are associated with the planet's biophysical subsystems or processes. Although Earth's complex 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

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.



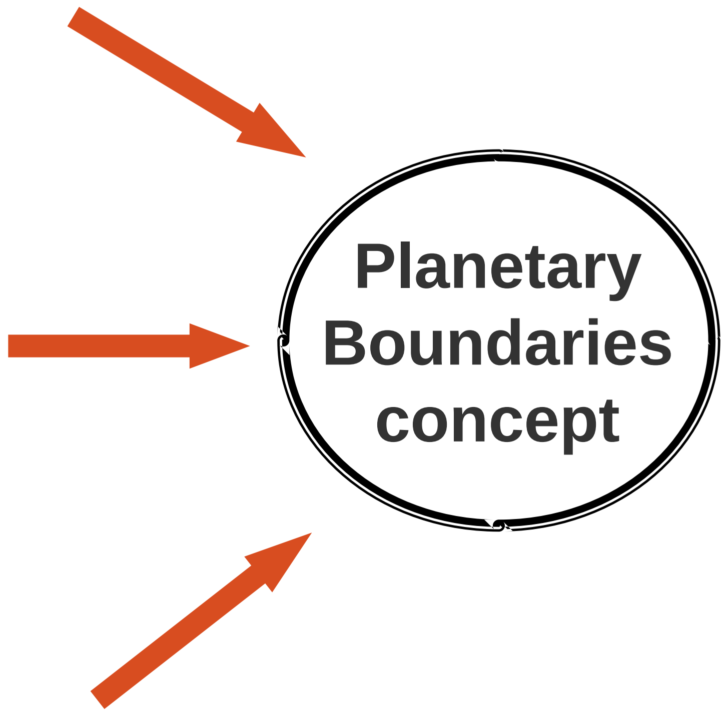
Rockström et al. 2009 Nature, 461 (24): 472-475

PB concept rests on three branches of Scientific inquiry

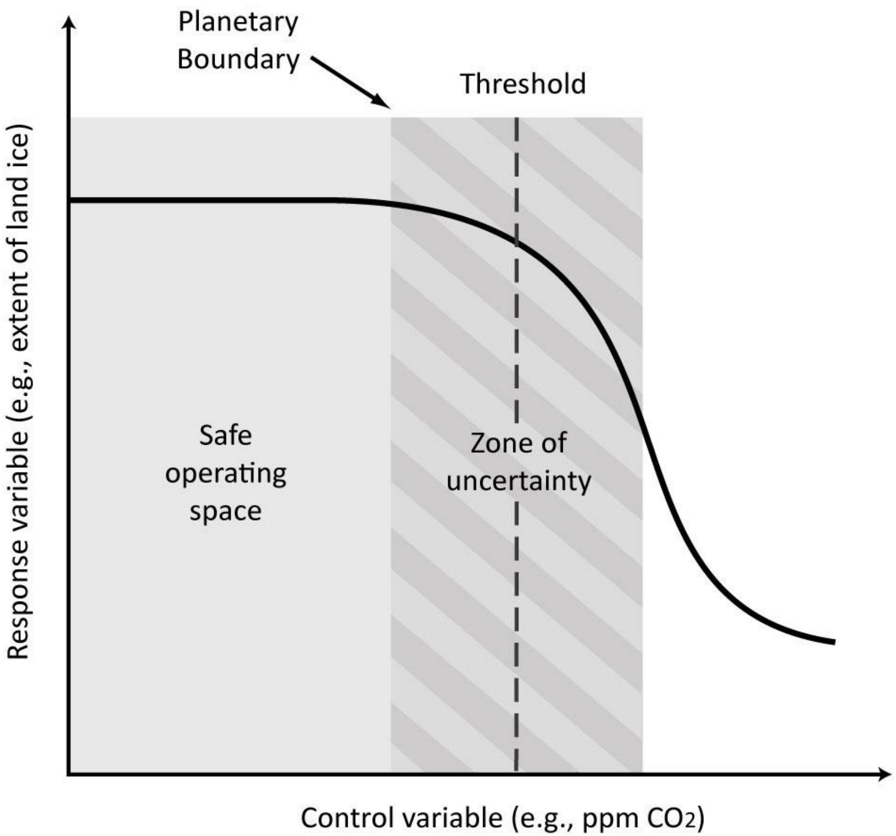
1. **Earth System and sustainability science**
   (Understanding Earth System processes; ICSU, IGBP, ESSP, IPCC, MEA, evolution of sustainability science…)

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...)

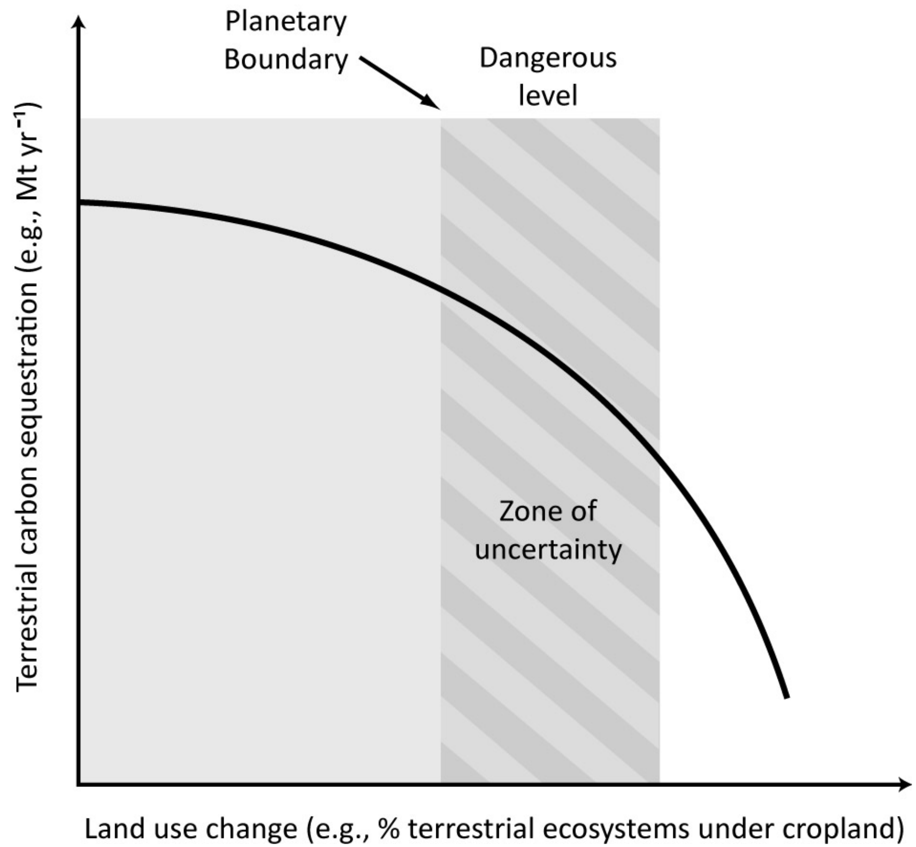
3. **Shocks and Abrupt change in Social-Ecological systems from local to global scales**
   (Resilience, tipping elements, guardrails...)



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

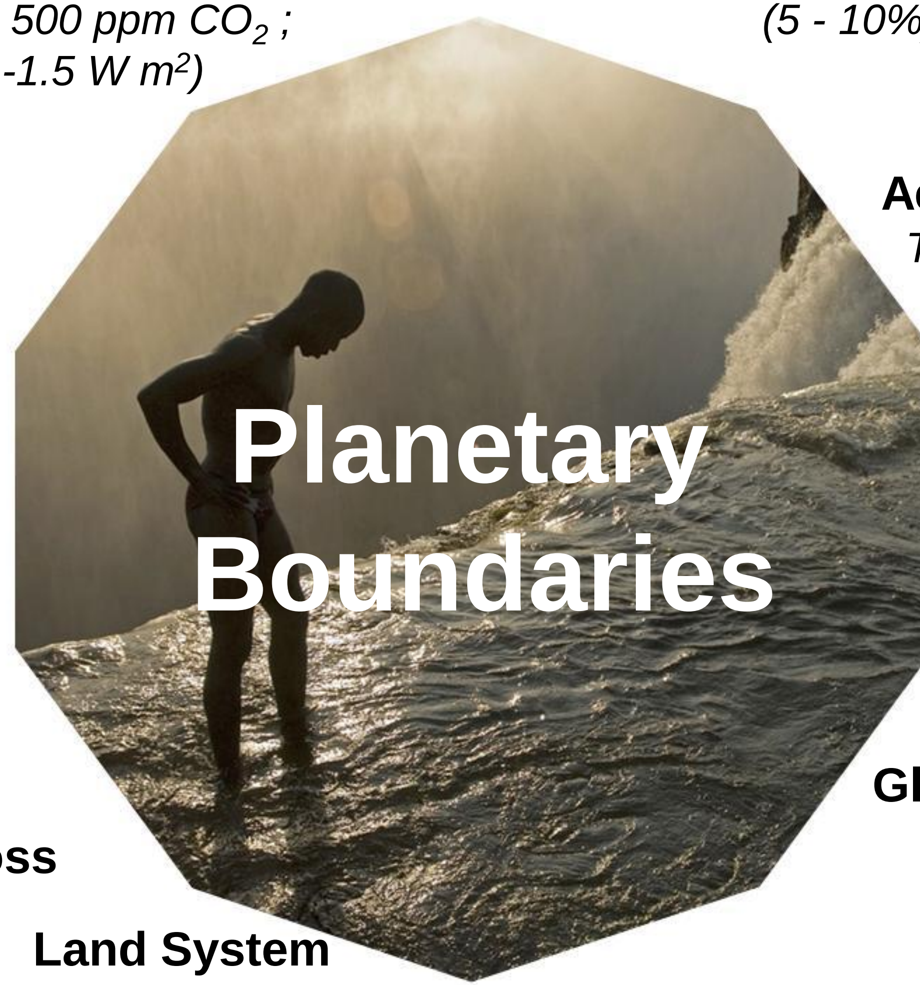
< 5 % of Pre-Industrial 290 DU
(5 - 10%)

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

Planetary ”Must Haves” by 2020 In partnership with WBCSD

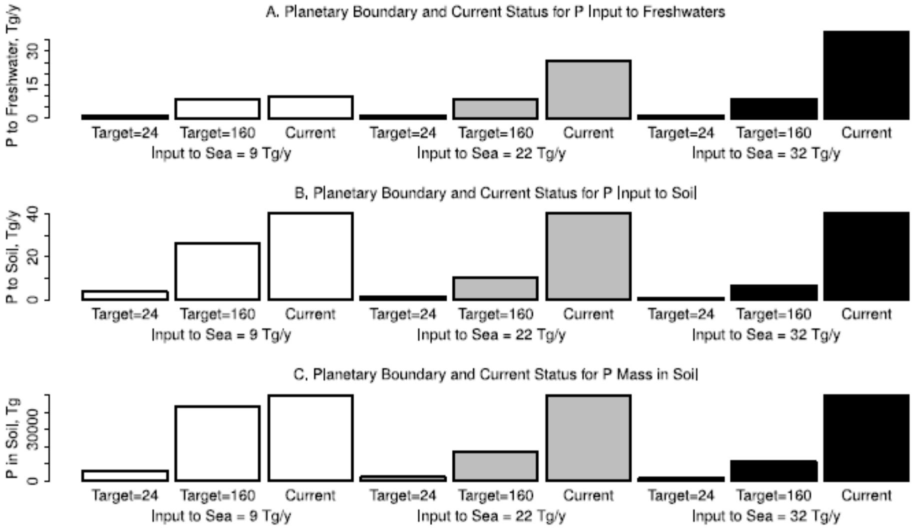
Planetary Boundary	2020 ”Must Have”	Key Links	Key Business Tools
Climate Boundary	Bend Global Emission curve of CO2 by 2020 5-6 %/yr decline thereafter 80-100 % global reduction by 2050	Land, Water, Nutrients, Ocean Acidification	Footprint analysis LCA Target setting
Land Boundary	Sustaining remaining Rainforests on Earth Keep > 70 % forest stand	Water, Climate, Nutrients, Biodiversity	Sustainable Agric and Forest strategy
Water Boundary	Ensure > 30 % river flow	Climate, Land, Biodiversity, N&P	Water productivity indicator Sustainable intensification of production systems Product labelling
Nitrogen & Phosphorus Boundary	>50 % reduction of P leakages in soils > 50 % reduction in N leakage in soils	Land, Water, Climate, Biodiversity	Monitor N and P flows in entire value chain Sustainable Agriculture
Biodiversity Boundary	Absolute global halt of habitat loss Safeguard Critical Biomes (Forests, Marine systems, Polar ecosystems)	Land, Water; Climate	Restoring ”hot-spots” Protect critical biomes Economic value of ecosystem services (TEEB)

IOP Publishing | Environmental Research Letters

Environron. Res. Lett. **6** (2011) 014009 (12pp) | doi:10.1088/1748-9326/6/1/014009

Reconsideration of the planetary boundary for phosphorus

Stephen R Carpenter[1] and Elena M Bennett[2]

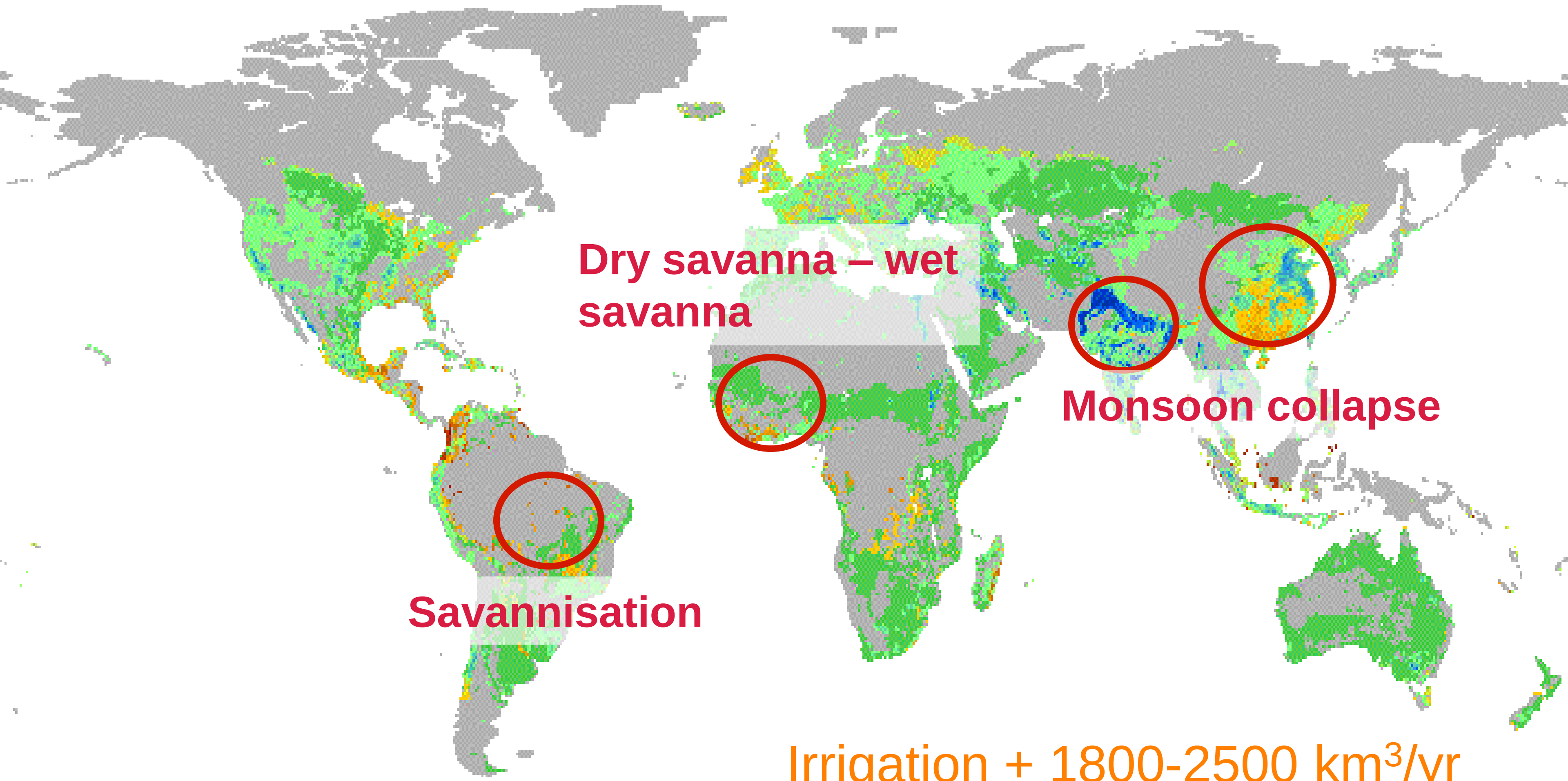


Global Freshwater Use

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 $km^3\ yr^{-1}$

Agricultural Modification of 'Green' (ET) water flows

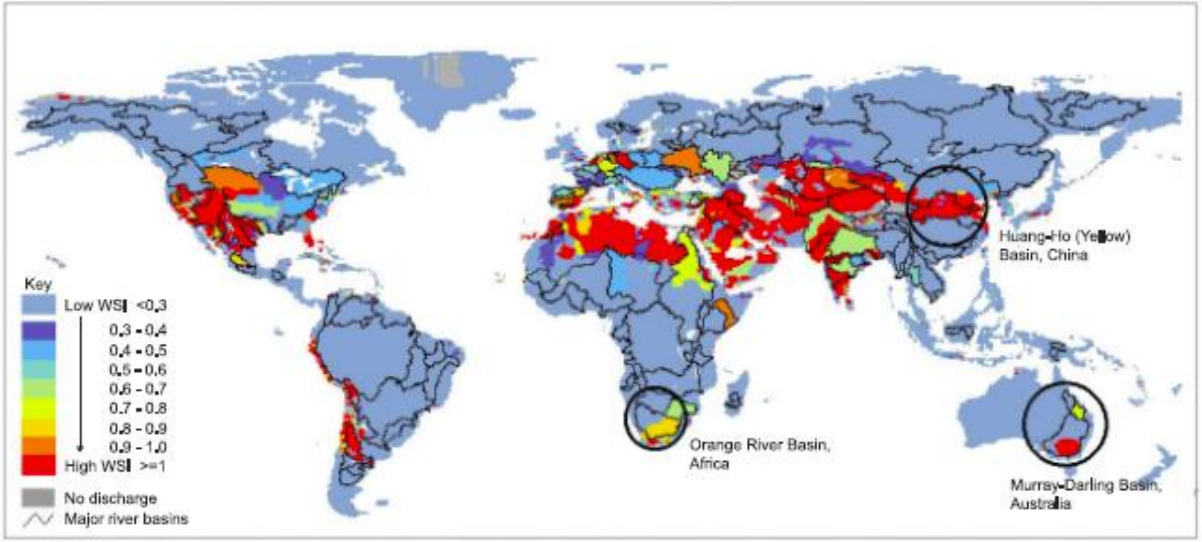


Irrigation + 1800-2500 km^3/yr

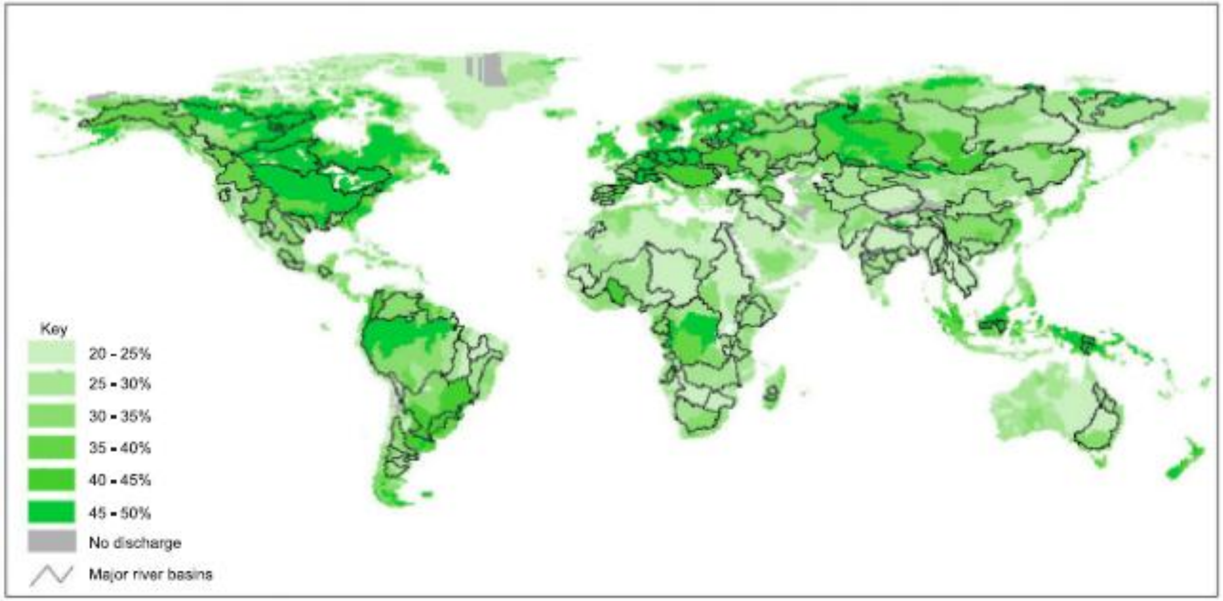
Deforestation - 3000 km^3/yr

Total ET roughly 67000 km^3/yr

Gordon et al. 2005, 2008

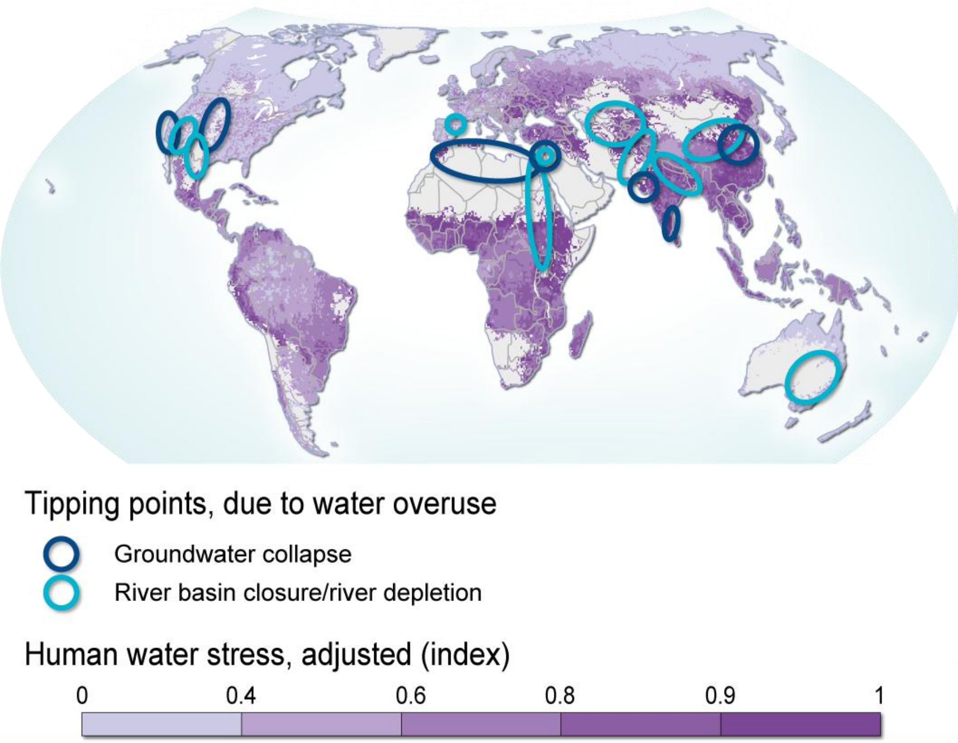


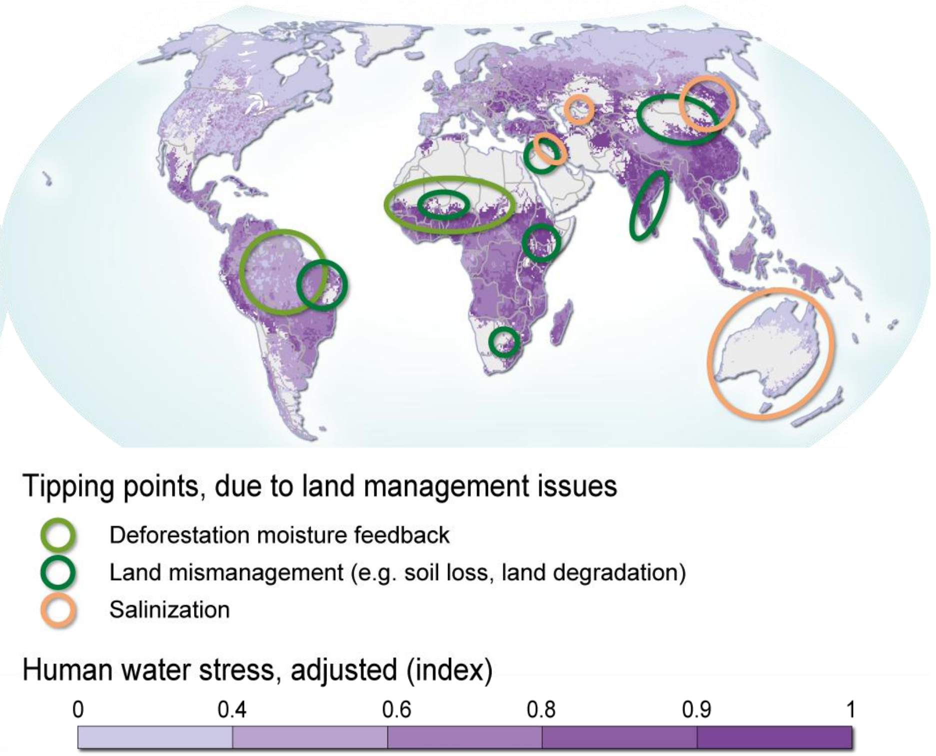
Water Stressed River Basins in the World
(Smakhtin et al., 2007)



Thresholds for Environmental Water Flow
(Smakhtin et al., 2007)

Risk of Water Induced Tipping Points

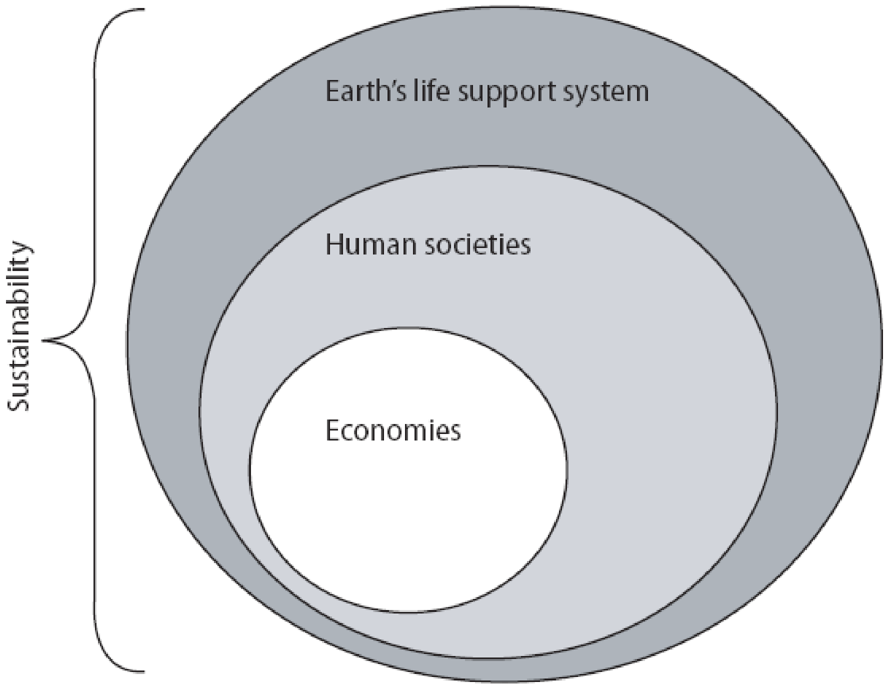




Earth System Process	Control Variable(s)	Thresholds	Planetary Boundary (zone of uncertainty)	Current Value of Control Variable(s)	State of Knowledge
Land system change	Global: area of forested land Biome: area of forested land	Tropical: Amount of land clearing beyond which self-reinforcing feedbacks lead to land-cover change across a much larger area, with atmospheric circulation teleconnections: Temperate: No known thresholds. Boreal: Possible threshold related to albedo changes associated with land clearing	Global: 75% of early Holocene (pre-agric) forest cover Biome: Tropical: 85% of original forest cover Temperate: 50% Boreal: 85%		Threshold for tropical forests best understood for Amazon, but complex with significant uncertainties. Albedo effect for boreal forest well understood but position of any possible threshold is not known
Biodiversity loss	Genetic diversity (library of life): Extinction rate Functional diversity: Mean species abundance (MSA)	"Soft threshold" proposed somewhere around 50% drop in MSA, beyond which rapid and much larger loss of biodiversity. Threshold known at ecosystem level and proposed for global level	Genetic: no more than 10x background extinction rate but aspirational goal of no loss of genetic diversity. Functional: Maintain MSA at 70% or above (uncertainty range of 70-30%)	Genetic: Current extinction rate is 100-1000x background Functional: Global MSA is currently estimated to be ca. 67%	Aspirational genetic boundary based on first principles. Growing body of evidence for threshold of functional biodiversity loss at multiple levels (ecosystem to global)

Planetary Stewardship: Transitions to Global Sustainability

Reshaping global development paradigm



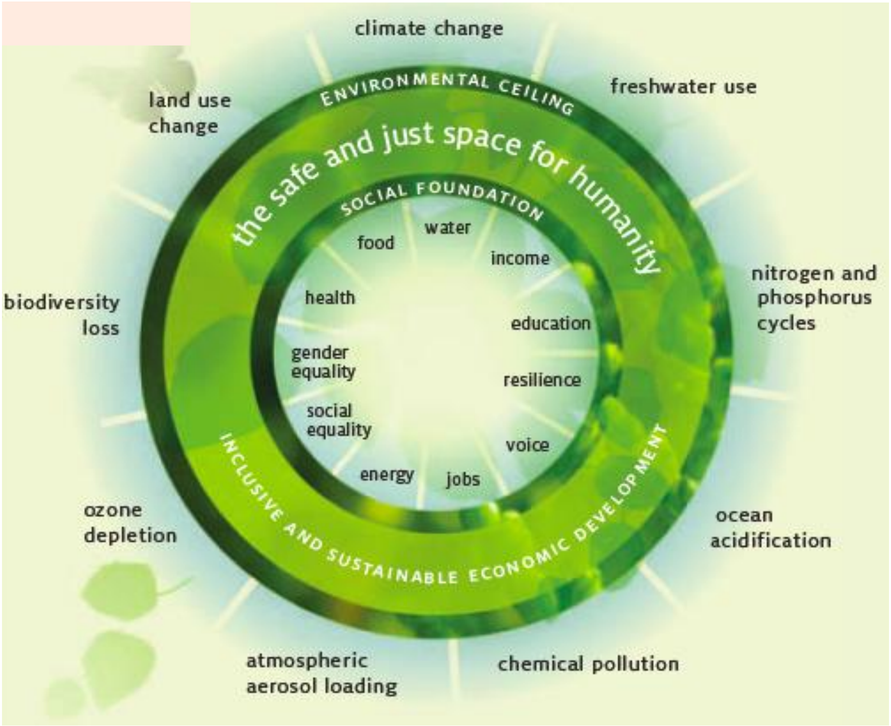
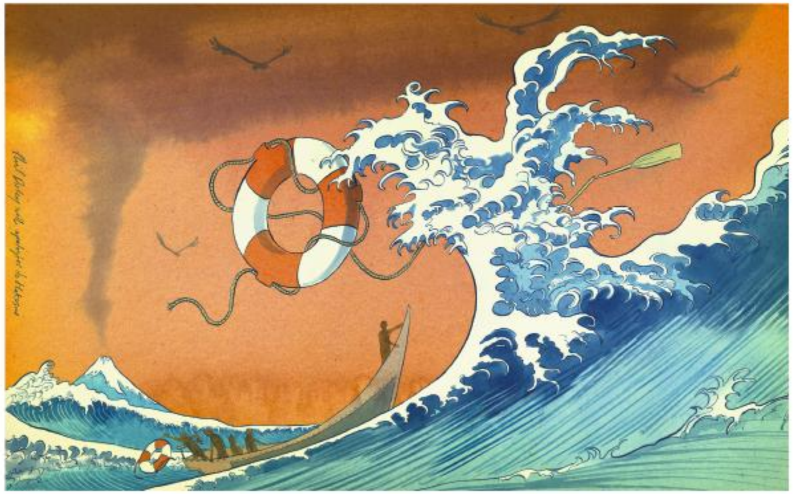


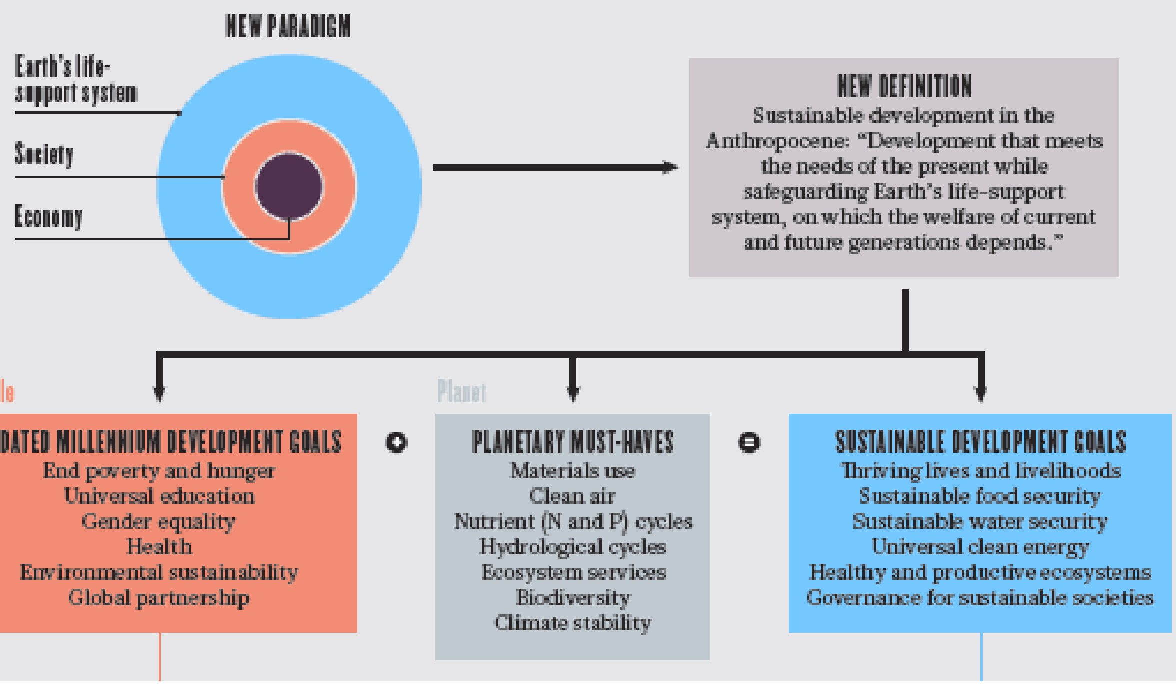
ILLUSTRATION BY PHIL DISLEY

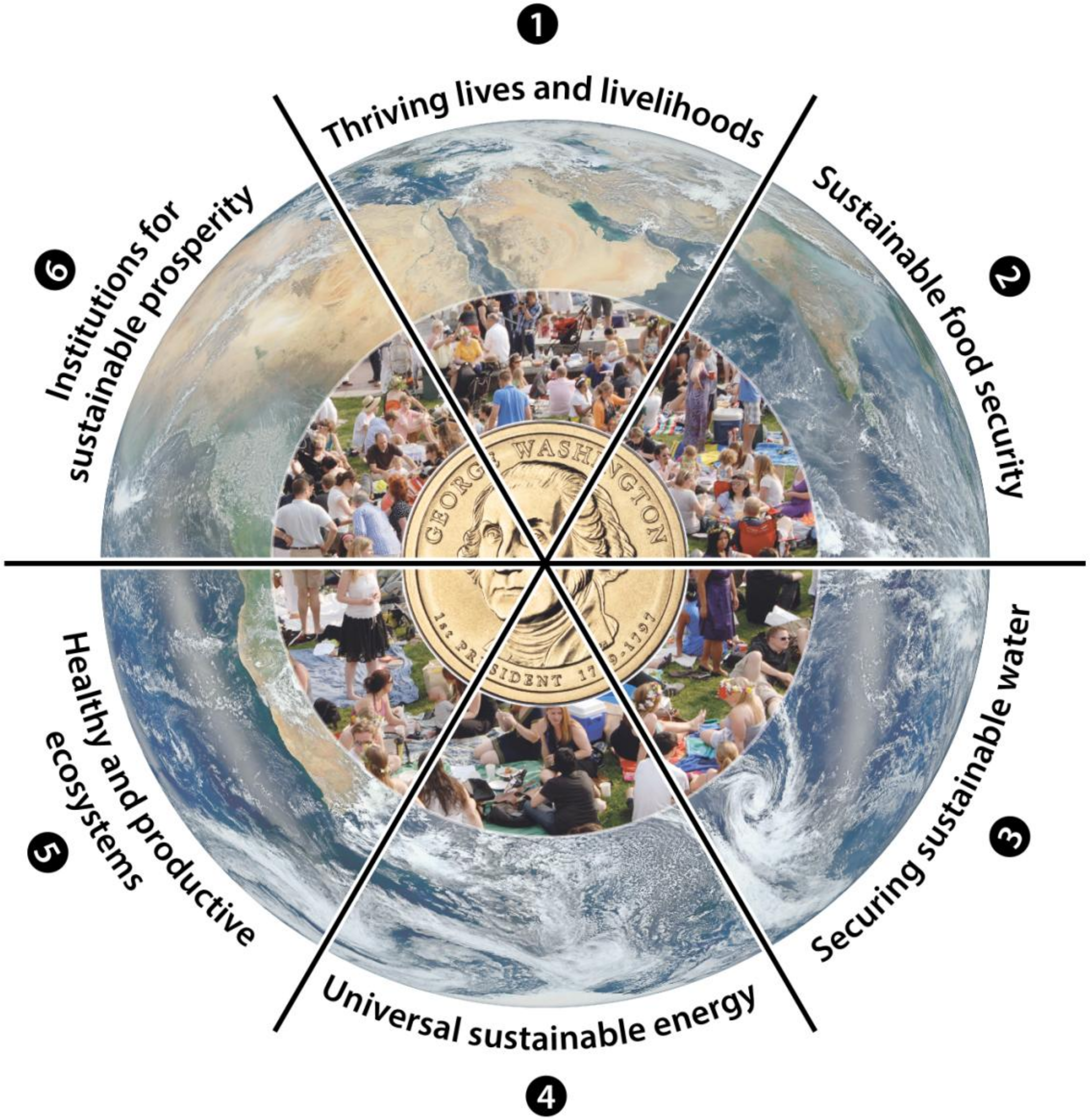


Sustainable development goals for people and planet

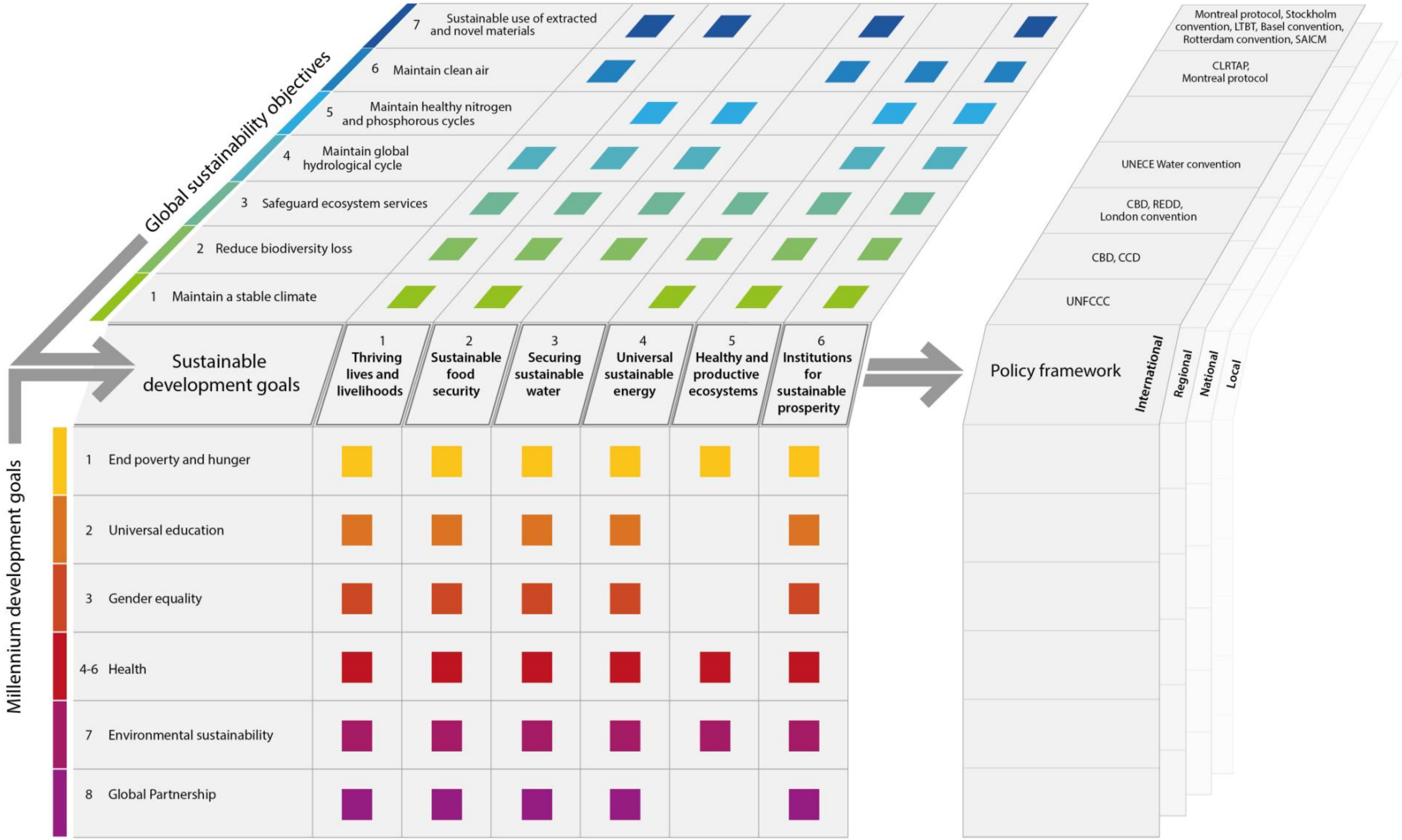
A UNIFIED FRAMEWORK

A set of six sustainable development goals (SDGs) follow from combining the Millennium Development Goals (MDGs) with conditions necessary to assure the stability of Earth's systems.





1
Thriving lives and livelihoods
2
Sustainable food security
3
Securing sustainable water
4
Universal sustainable energy
5
Healthy and productive ecosystems
6
Institutions for sustainable prosperity
GEORGE WASHINGTON

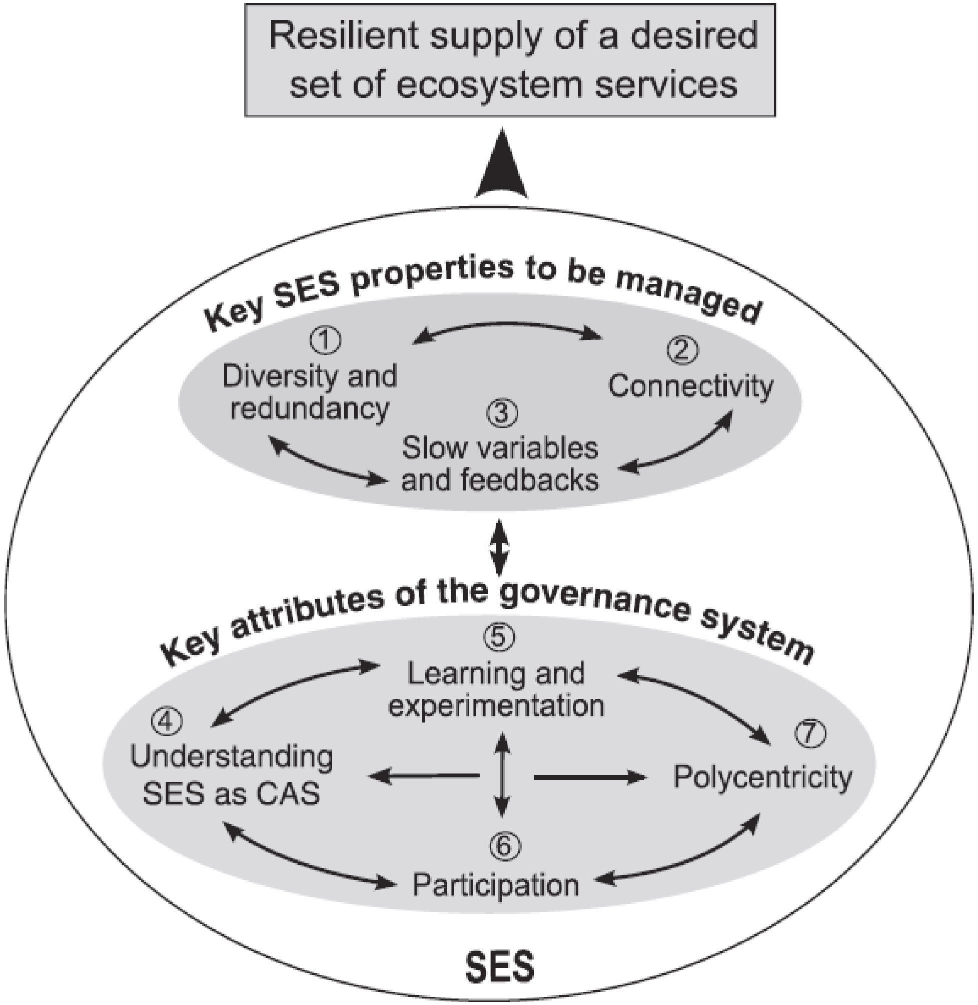


Global sustainability objectives
7 Sustainable use of extracted and novel materials
6 Maintain clean air
5 Maintain healthy nitrogen and phosphorous cycles
4 Maintain global hydrological cycle
3 Safeguard ecosystem services
2 Reduce biodiversity loss
1 Maintain a stable climate
Sustainable development goals
1 Thriving lives and livelihoods
2 Sustainable food security
3 Securing sustainable water
4 Universal sustainable energy
5 Healthy and productive ecosystems
6 Institutions for sustainable prosperity
Millennium development goals
1 End poverty and hunger
2 Universal education
3 Gender equality
4-6 Health
7 Environmental sustainability
8 Global Partnership
Montreal protocol, Stockholm convention, LTBT, Basel convention, Rotterdam convention, SAICM
CLRTAP, Montreal protocol
UNECE Water convention
CBD, REDD, London convention
CBD, CCD
UNFCCC
Policy framework
International
Regional
National
Local

- ***Planetary Boundaries***
- ***Planetary Opportunities***
- ***Planetary Stewardship***

- Part of the biosphere – environment not a sector
- Not about saving the environment – about us
- Not just climate but global change

Sources of Social-Ecological Resilience



Toward Principles for Enhancing the Resilience of Ecosystem Services

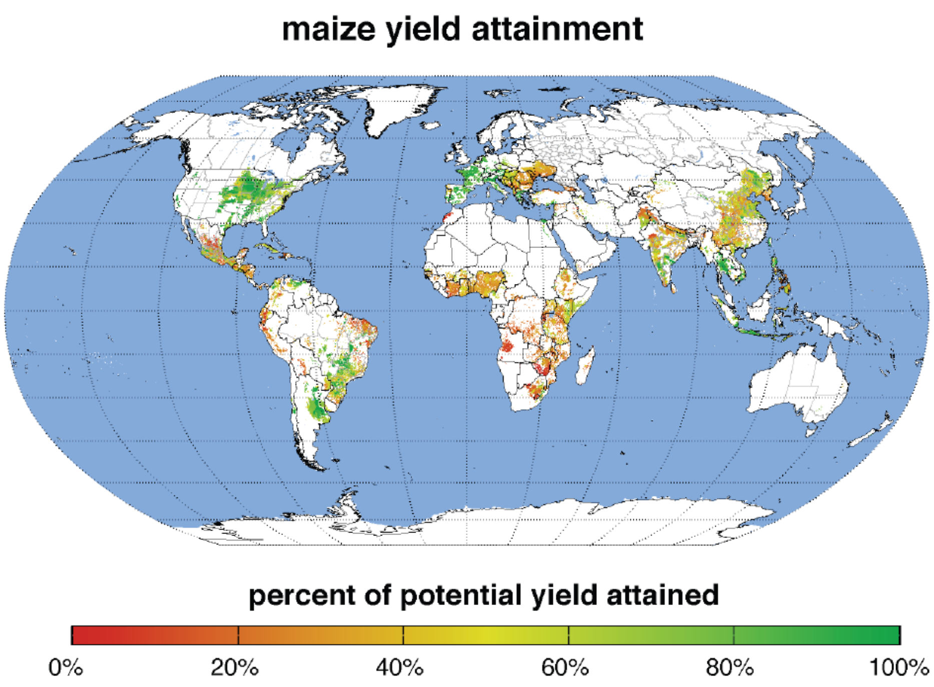
Reinette Biggs,[1,2] Maja Schlüter,[1,3] Duan Biggs,[4,5,6]
Erin L. Bohensky,[7] Shauna BurnSilver,[8]
Georgina Cundill,[10] Vasilis Dakos,[11] Tim M. Daw,[1,12]
Louisa S. Evans,[4] Karen Kotschy,[13] Anne M. Leitch,[4,14]
Chanda Meek,[15] Allyson Quinlan,[16]
Ciara Raudsepp-Hearne,[17] Martin D. Robards,[18]
Michael L. Schoon,[9] Lisen Schultz,[1] and Paul C. West[19]

ANALYSIS

doi:10.1038/nature10452

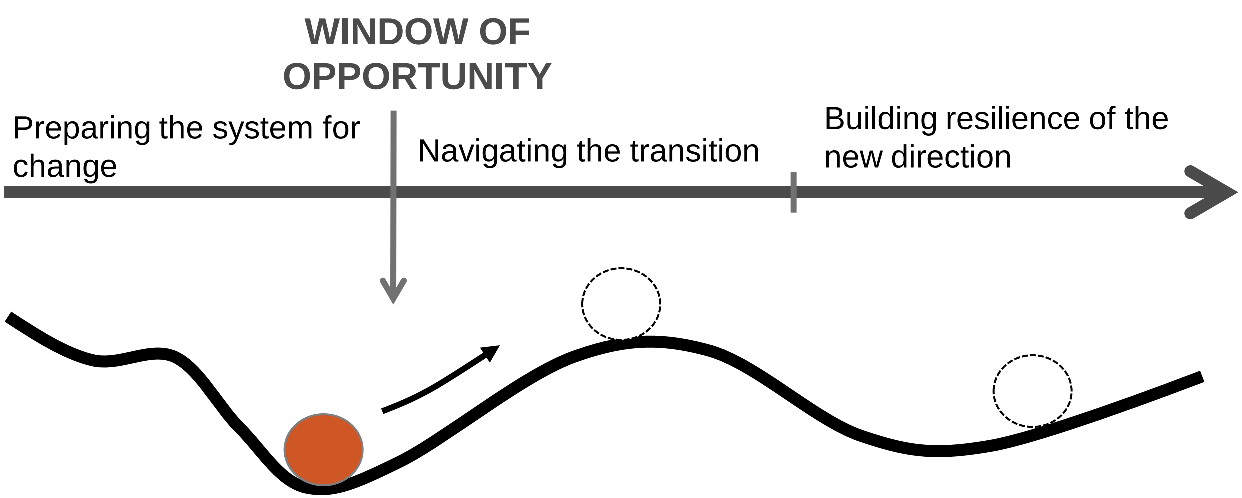
Solutions for a cultivated planet

Jonathan A. Foley[1], Navin Ramankutty[2], Kate A. Brauman[1], Emily S. Cassidy[1], James S. Gerber[1], Matt Joh
Nathaniel D. Mueller[1], Christine O'Connell[1], Deepak K. Ray[1], Paul C. West[1], Christian Balzer[3], Elena M. B
Stephen R. Carpenter[5], Jason Hill[1,6], Chad Monfreda[7], Stephen Polasky[1,8], Johan Rockström[9], John Shee
David Tilman[1,11] & David P. M. Zaks[12]

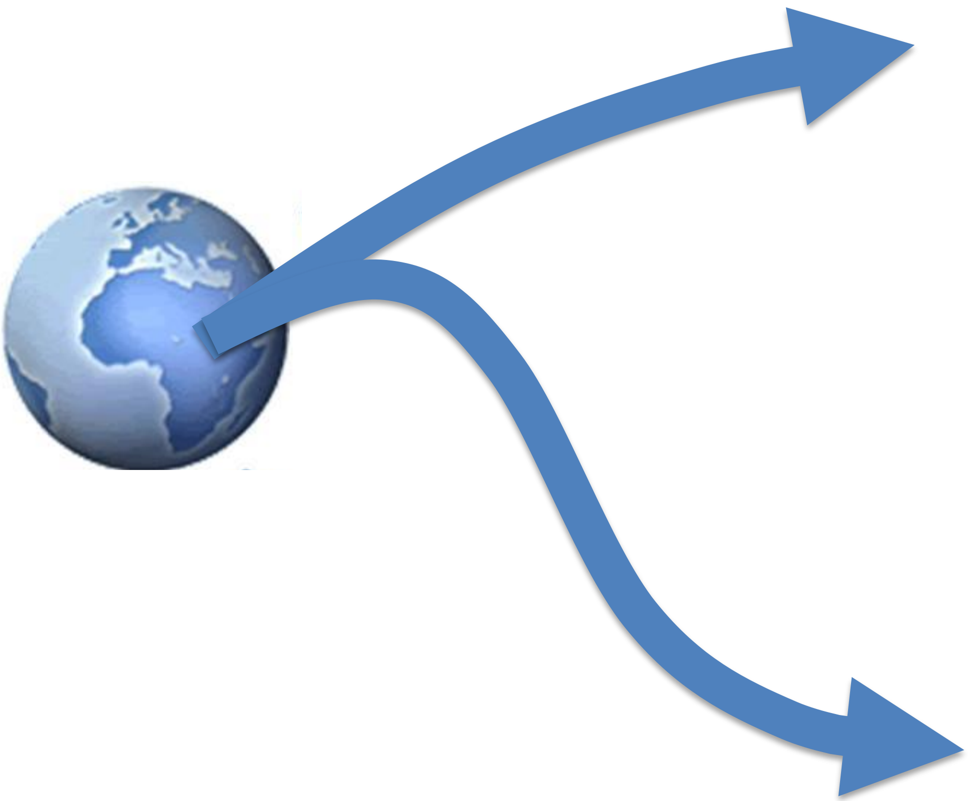


Turning crisis into opportunity

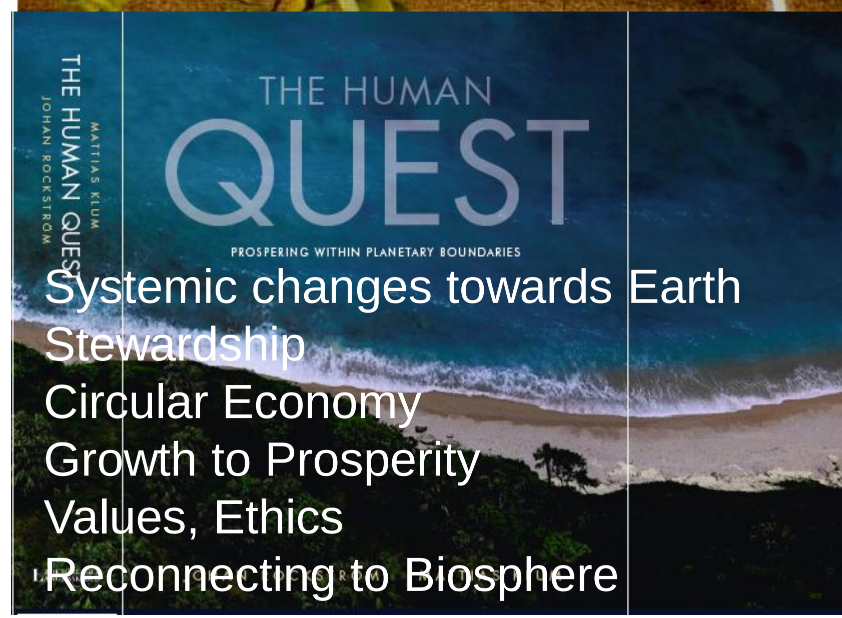
A shift in mindset for transformation



Science in support of a Dual Track for a world transition to global sustainability



Resource Efficiency
Beyond GDP
Productivity/Innovation
Economic value of Ecosystem services
”Working within the 500 MEAs”



Systemic changes towards Earth Stewardship
Circular Economy
Growth to Prosperity
Values, Ethics
Reconnecting to Biosphere

Growth Without Limits

Limits to Growth

Growth within Limits