Taking a systems view

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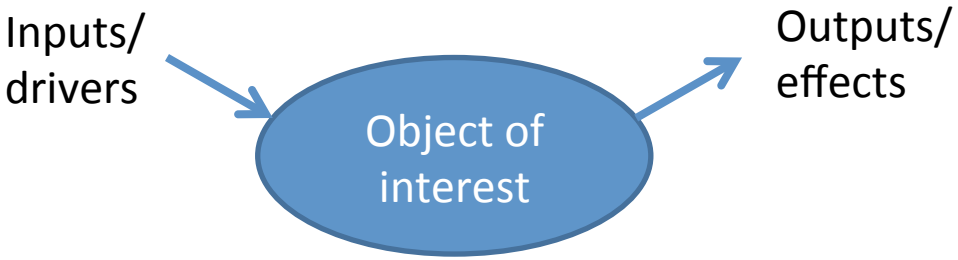
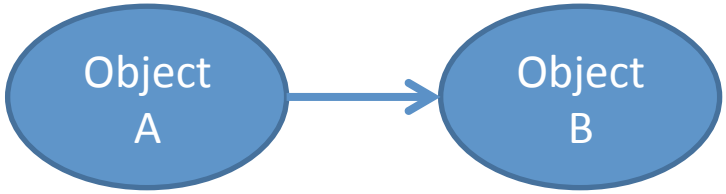
What is a system?

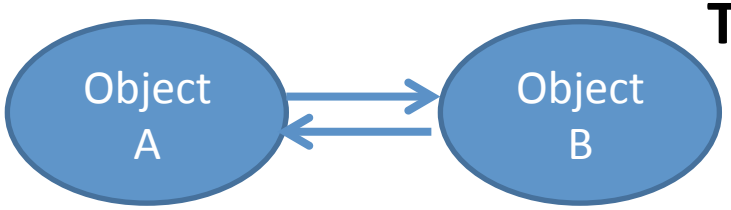
This is not a system



Neither is this



But this is



Two or more interacting bodies

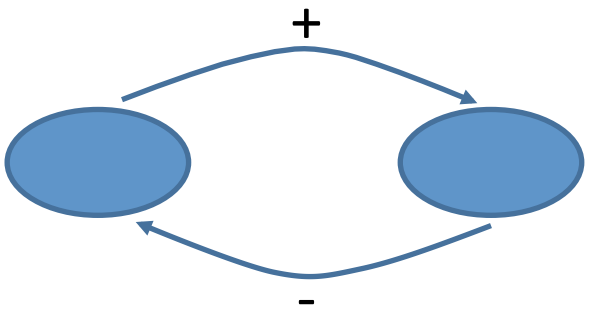
What difference do systems make?

- Causality suddenly becomes a problem
  - The chicken-or-egg problem
- Add just a bit of complexity, and multiple stable states are inevitable
  - About two or more bodies and some lags or non-linearities will do it!
- Under certain parameter combinations you get weird behaviour
  - Indeterminism: bifurcations, bi-stability, chaos
- Systems have 'emergent properties'
  - Impossible to predict how the system behaves just from the properties of its parts

Systems theory 101

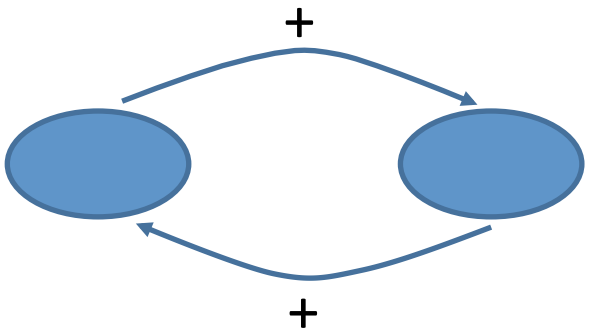
flavours of feedback loop

Negative feedback



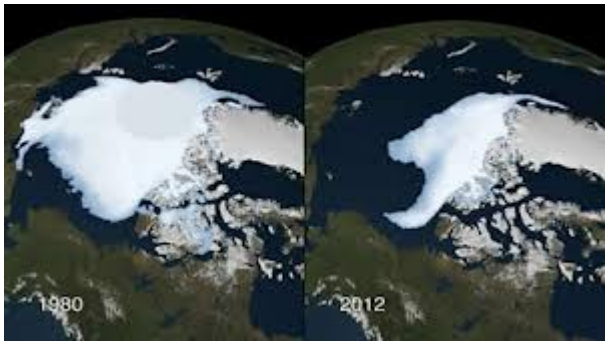
Stabilising
A good thing,
…unless you are stuck in a bad place!

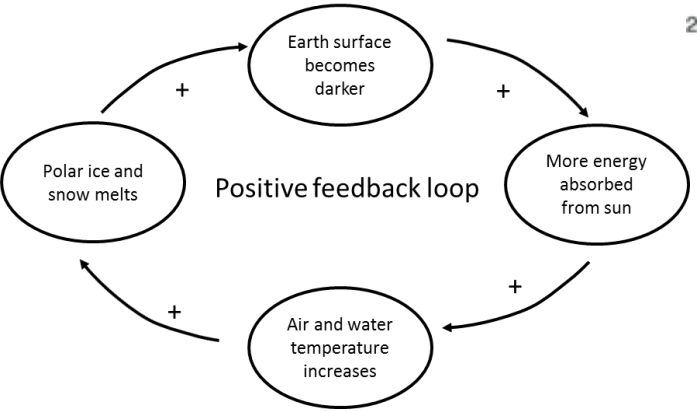
Positive feedback

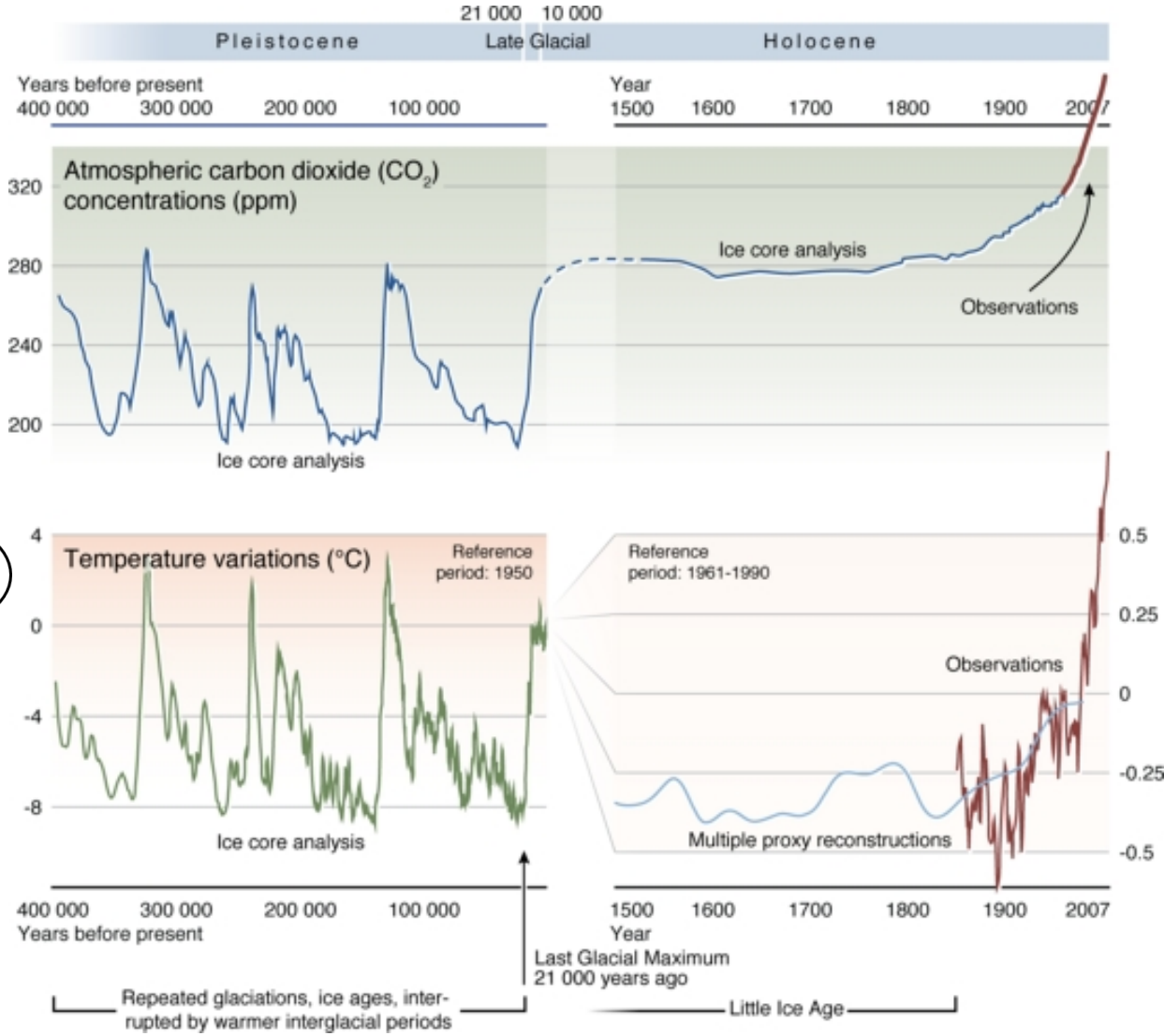


Destabilising – vicious or virtuous cycles
Not automatically 'runaway'
A bad thing,
…unless you want to change the status quo!

The polar ice – albedo feedback

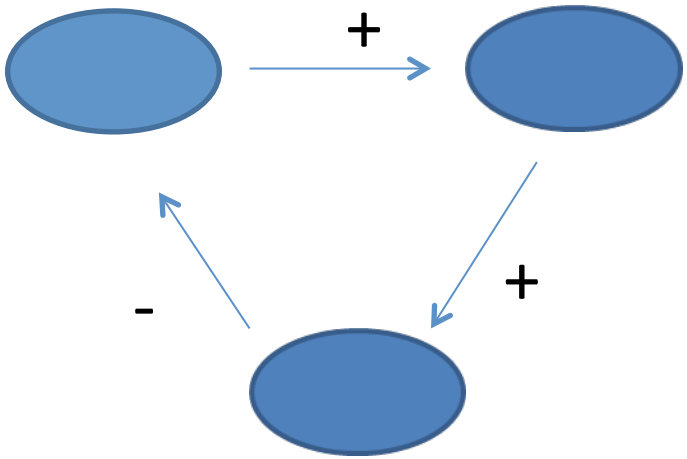




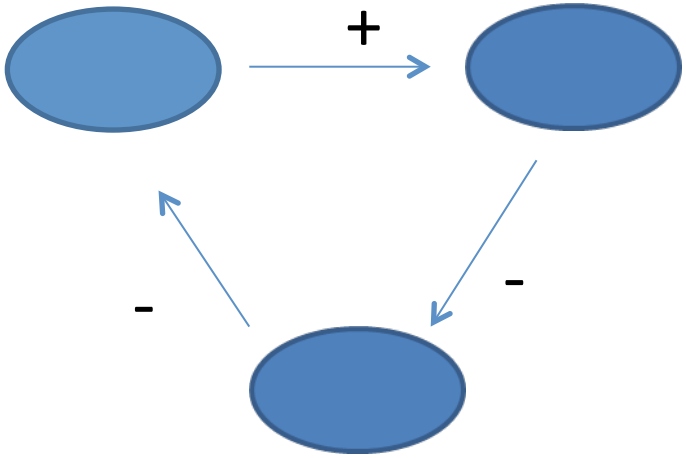


Rule of signs

To find the overall sign of a multi-step feedback loop, multiply the signs



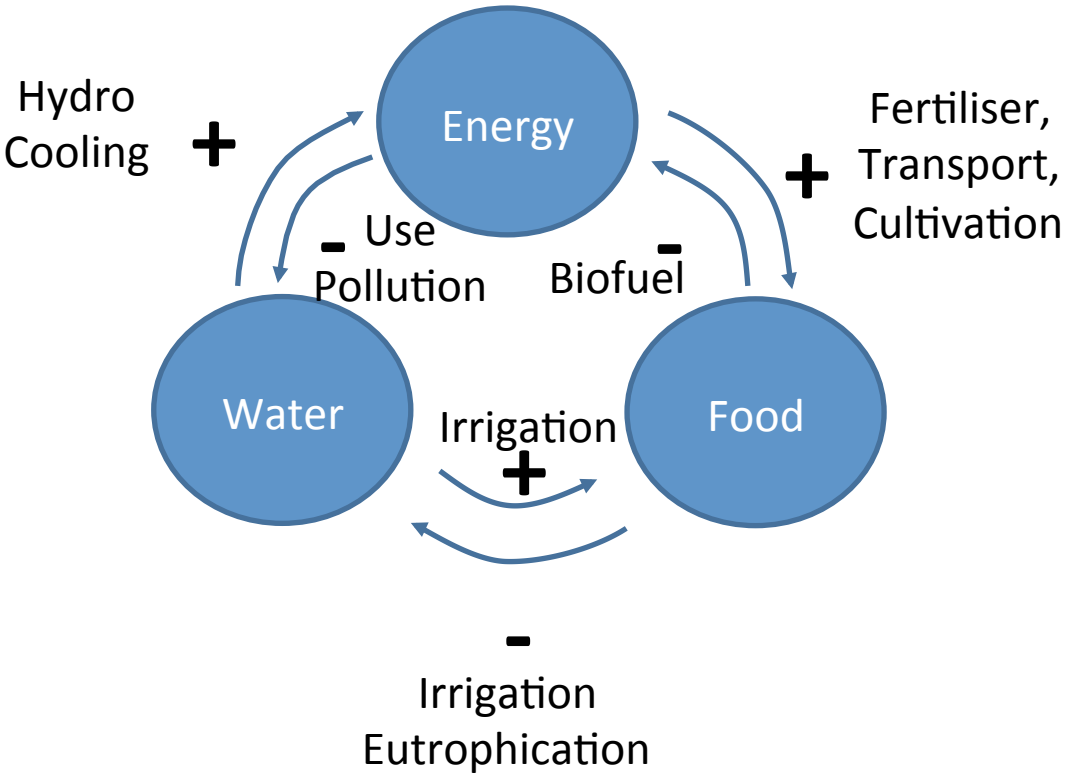
+ x + x - = -



+ x - x - = +

Complex loops

the outcome depends on the balance of the various loops
often that means that there are several possible outcomes

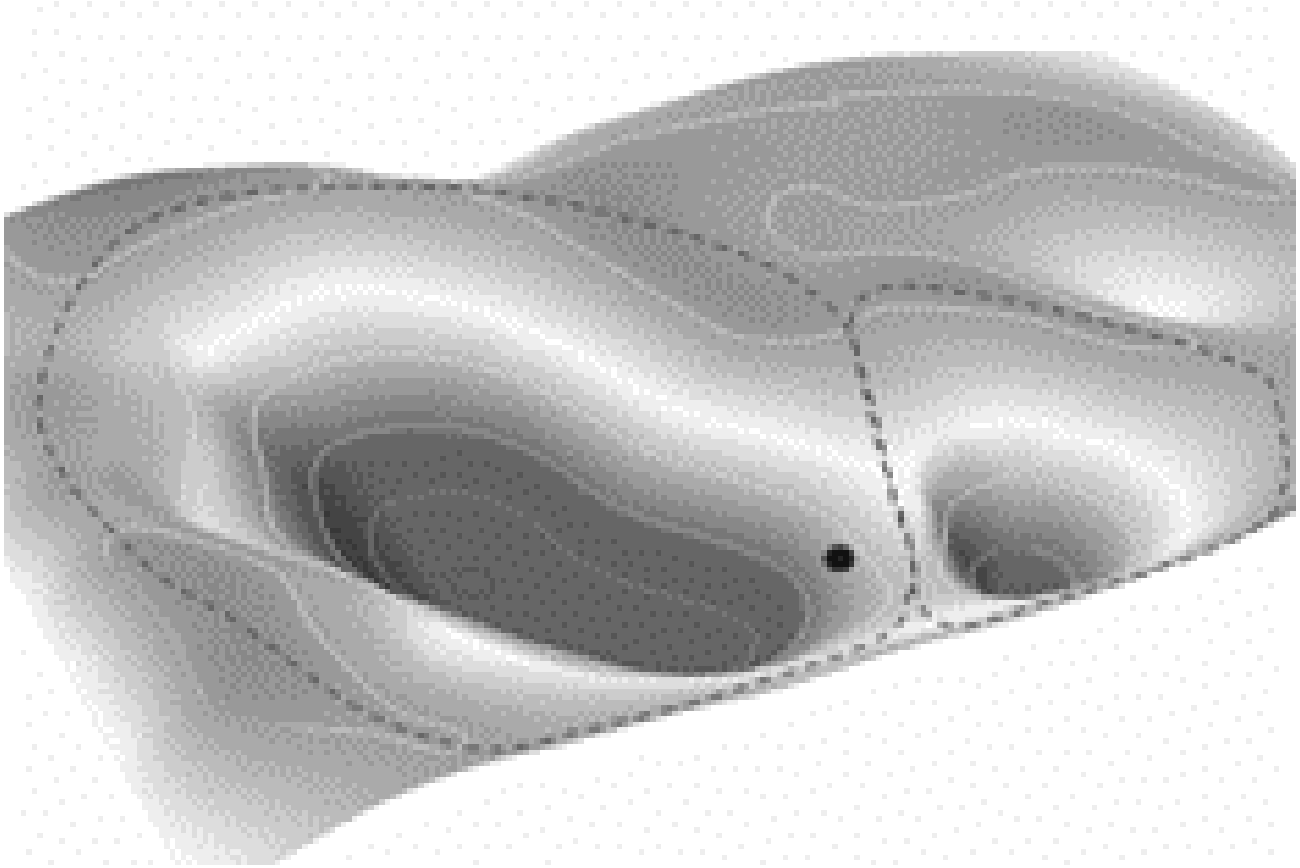


What is a 'tipping point' ?

A **tipping point** is a level of change in system properties beyond which a system reorganises, often abruptly, and persists in this condition even if the drivers of the change are mitigated. [*IPCC 5AR*]

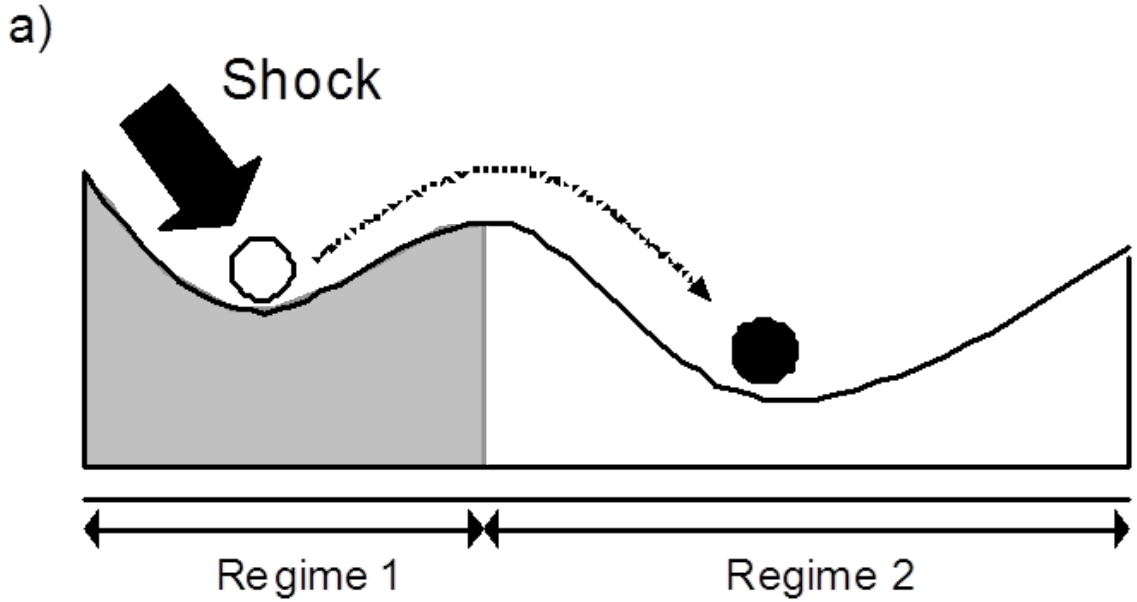
*Tipping points often involves a switch from **net negative** feedback (stabilising) to **net positive** feedback (amplifying).*
Note that weak positive feedback does not lead to 'runaway' change, just amplified change.

The ‘cup-and-ball’ analogy

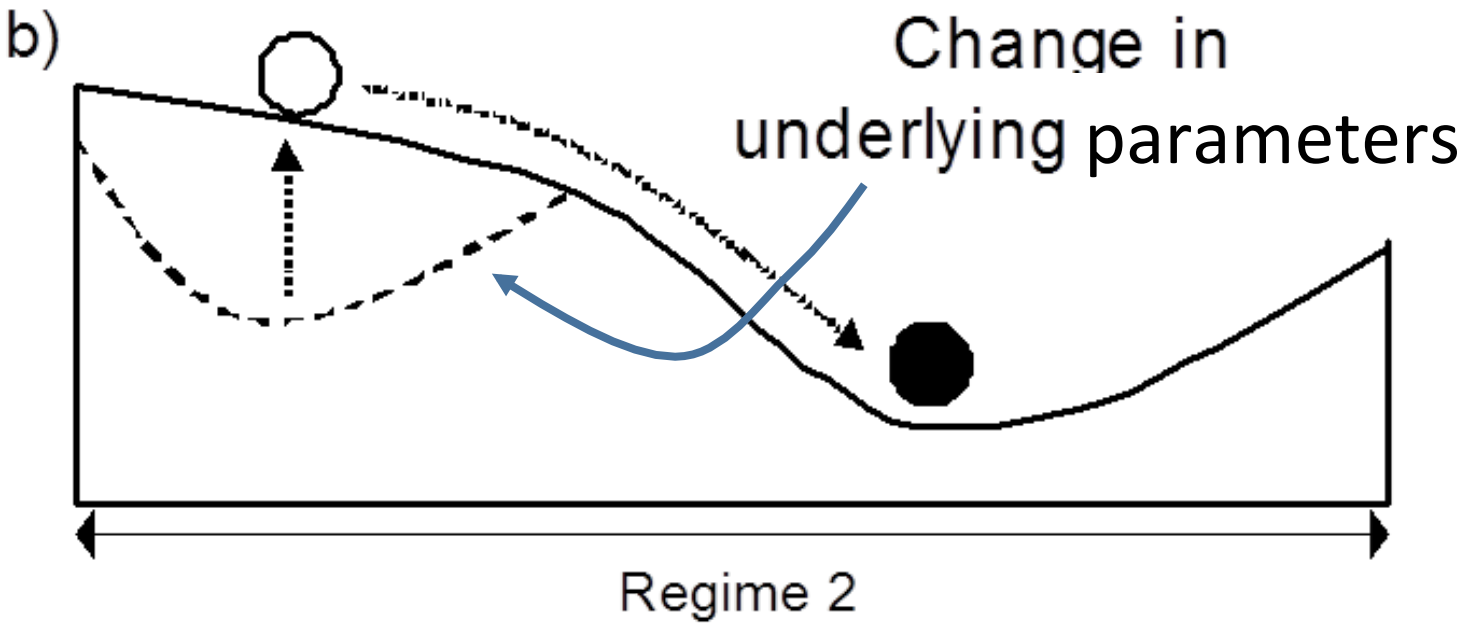


Biggs R et al (2011) In: Sourcebook of Theoretical Ecology, Univ of California Press

You can change regime by being bumped out of the old one



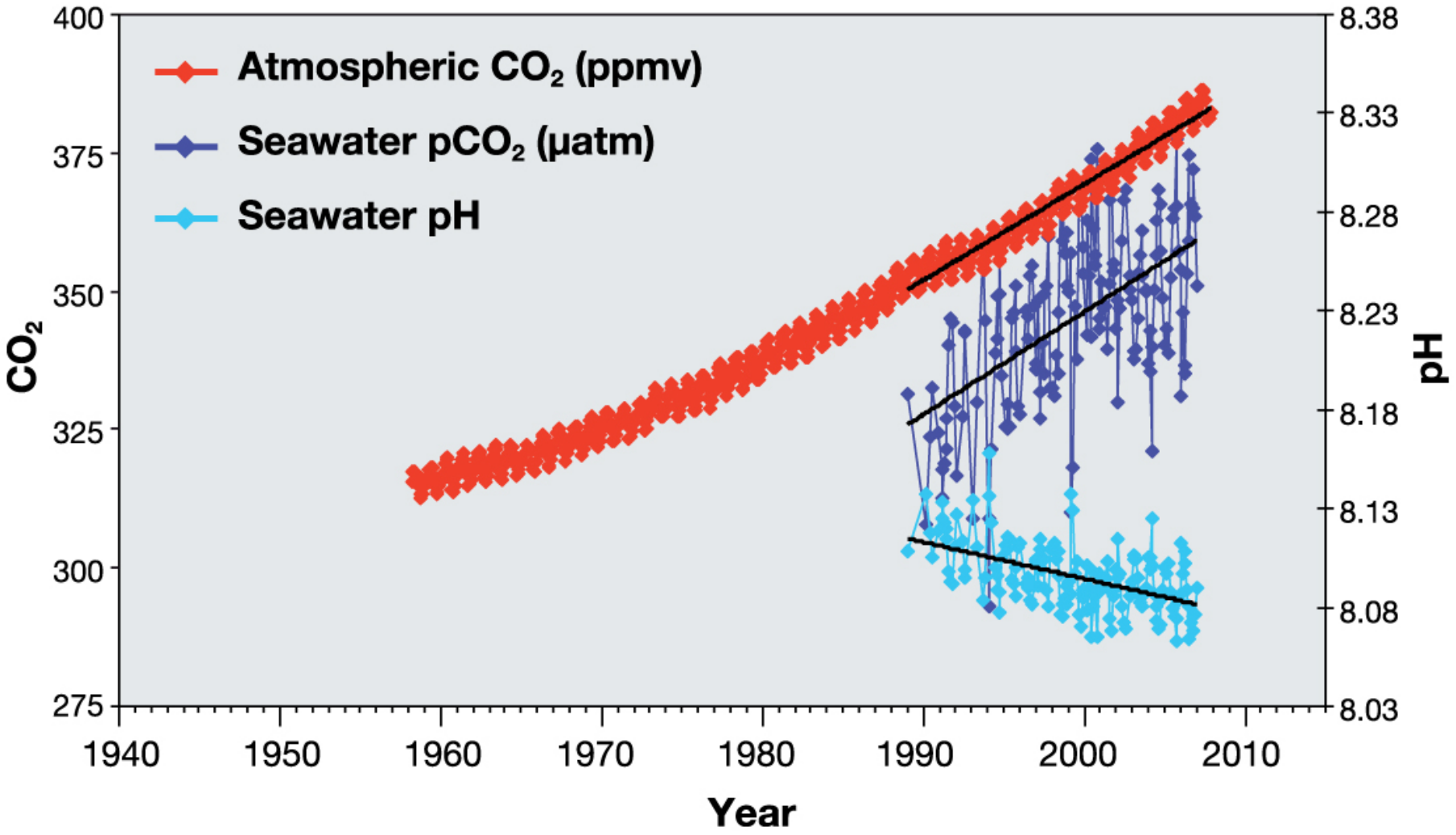
…but more often the stability domain just moves out from underneath you



Some possible contemporary tipping points

- Economic instability
  - Consumption and connectivity
- Governance instability
  - Rising expectations, falling capacity to deliver
- Global-scale disruptions
  - Food security, overheated land and overfished ocean
  - The failure of ice sheets, sea-level rise and albedo
  - Ocean acidification
  - The tundra and Amazon carbon stores

Ocean acidification

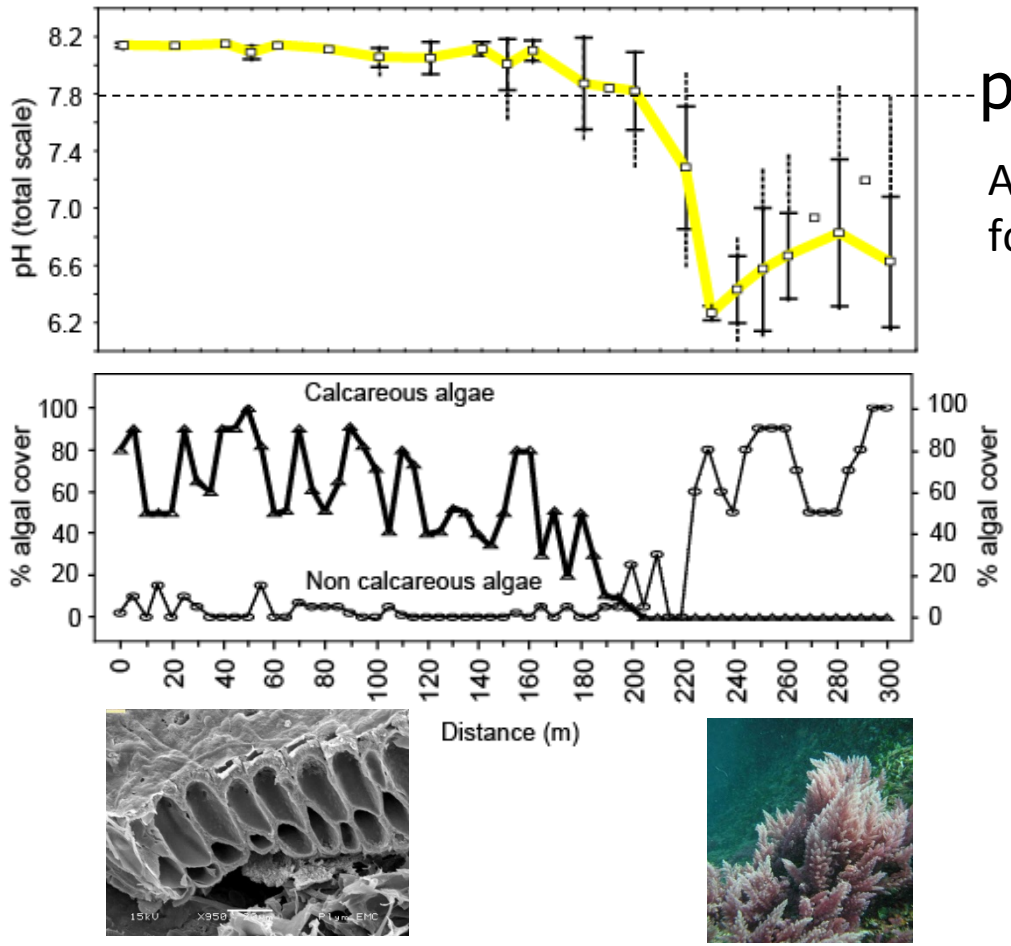


Regime shifts in response to ocean acidification

Insights from natural CO_2 vents

Normal seawater

pH 8.2



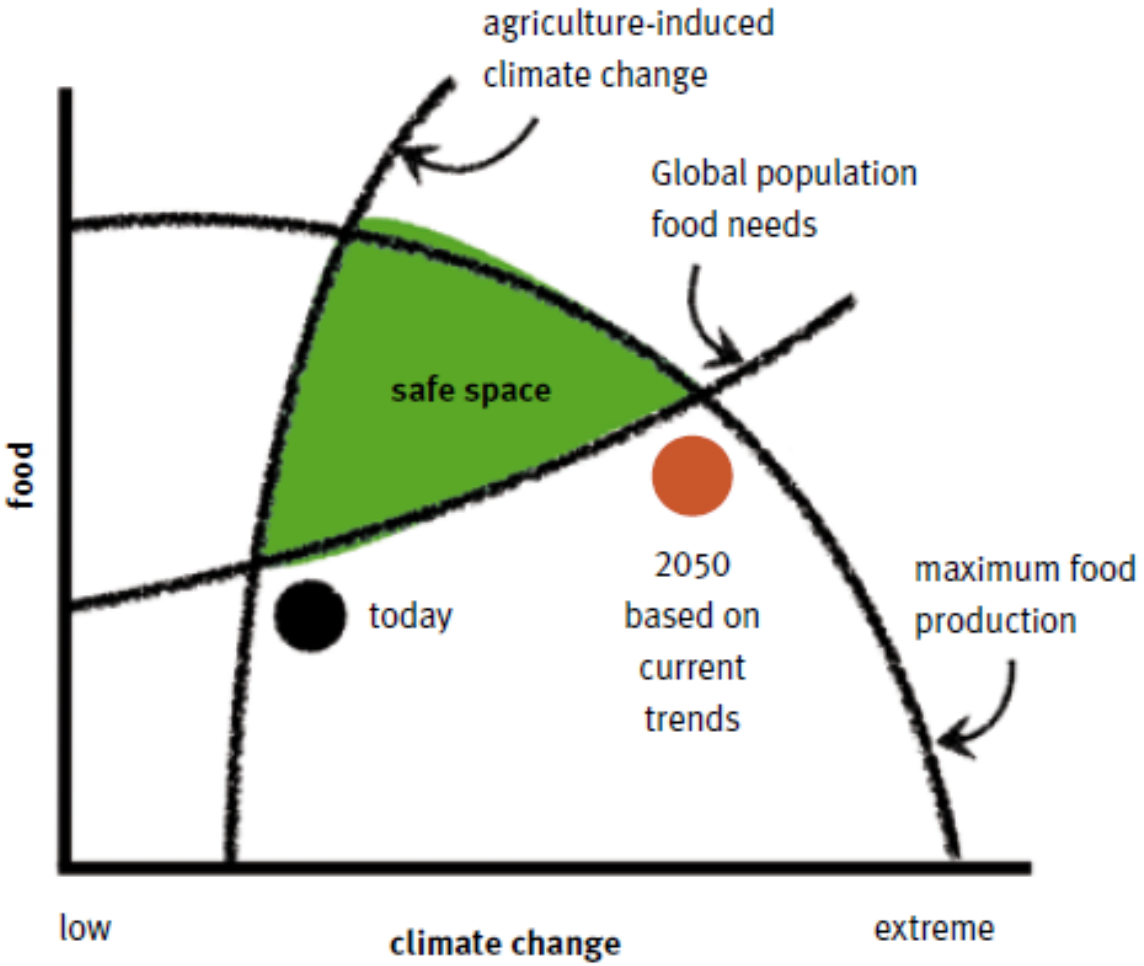
pH 7.8

Aragonite cannot form

Hall-Spenser et al. 2010 Science

Food security

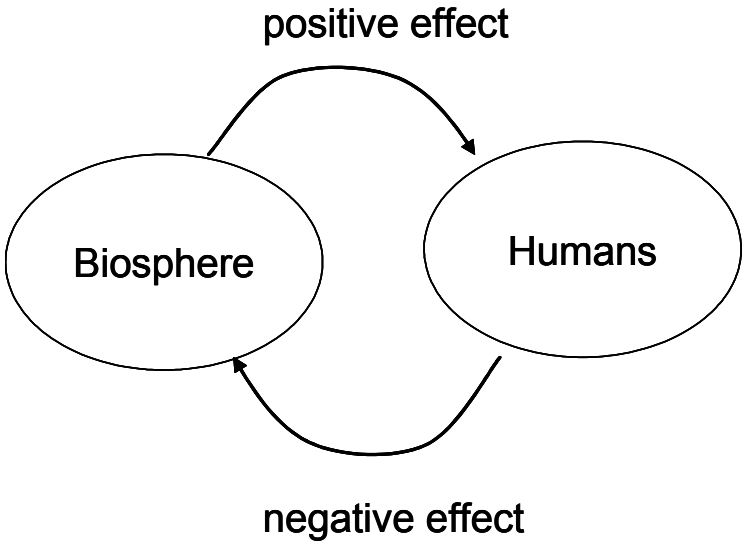
keeping the world in a safe space



Beddington J, Asaduzzaman M, Clark M, Fernández A, Guillou M, Jahn M, Erda L, Mamo T, Van Bo N, Nobre CA, Scholes R, Sharma R, Wakhungu J. 2012. *Achieving food security in the face of climate change: Final report from the Commission on Sustainable Agriculture and Climate Change. CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS)*. Copenhagen, Denmark. Available online at:

The human-biosphere interaction

Brown G and J Roughgarden 1995 An ecological economy: notes on harvest and growth. In Perrings, C et al *Biodiversity loss: Ecological and economic issues*. CUP, Cambridge
Scholes et al 2007 In: *Restoring Natural Capital*. Island Press, Washington DC.



$$\frac{\delta B}{\delta t} = aB - bBH$$

$$\frac{\delta H}{\delta t} = cBH - dH$$

B = state of Biosphere
H = state of Humans
a = replenishment rate of biosphere
b = extraction rate factor
c = conversion efficiency factor
d = decline rate of humans

There are four possible outcomes

1. Terminal overshoot (crash-and-burn)
2. Oscillations
   -damping, amplifying, or persistent
3. Peak and then stabilisation at a lower level
4. Steady approach to stability

Can social-ecological collapse actually happen?

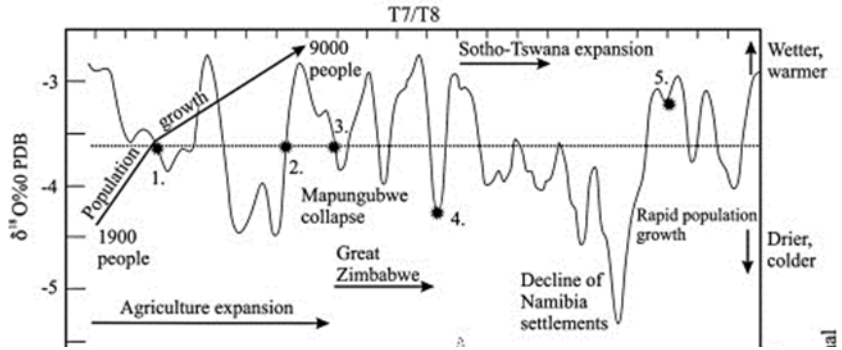
It has happened repeatedly in the past

- **Sumer** – accumulation of salinity
- Six Egyptian dynasties in the **Nile** Valley – climate?
- **Easter Island** - deforestation
- The Norse in **Greenland** - overgrazing?
- The Mayans of **Central America** – soil fertility?
- The Chaco of **North America** – deforestation?

Tainter, JA 1988 *The collapse of complex societies*. CUP
Wright, R 2004 *A Short History of Progress*
Diamond, G 2005 *Collapse: How Societies Choose to Fail or Succeed*

Mapungubwe

a home-grown case history



1220 Moved from preceding settlement at K2

Flourished as the first complex city-state in southern Africa

1290 Abruptly failed

Reappeared at Great Zimbabwe 1300-1500

1500 Moved to Khami

Huffman, Thomas N. (2008). "Climate change during the Iron Age in the Shashe-Limpopo Basin, southern Africa". Journal of Archaeological Science 35: 2032–2047.

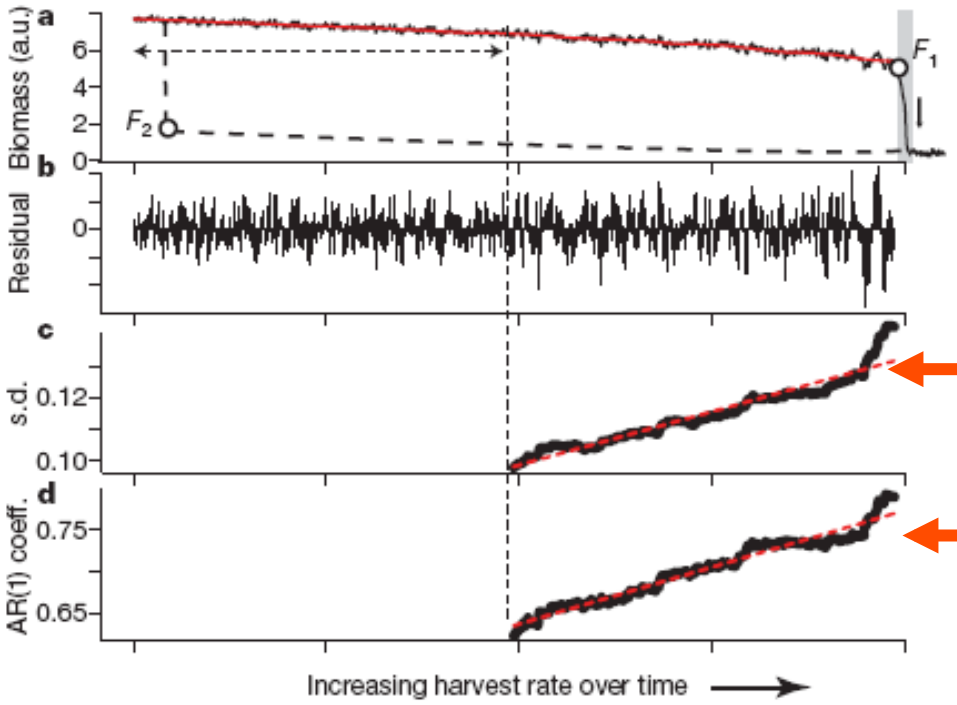
Is overshoot and correction inevitable, or can we do anything about it?

'Avoiding the unmanageable and managing the unavoidable'
Bierbaum & Raven 2007 Science 316:17

- **Staying away from the edge**
  - Technology solutions: renewable energy, climate smart agriculture, sustainable cities
  - Social solutions: a less consumerist, more equal society
- **Principles of a resilient system**
  - Maintain a buffer: the efficiency-resilience tradeoff
  - Encourage diversity: more ways to do things
  - Promote learning: adaptive capacity
- **Post-sustainability**: how to survive (and encourage) transformation

Warnings of impending change

There may be advance warning in the form of increased variance ('jitters') or auto-correlation but this will be hard to detect in time unless you have very good monitoring systems



Variance goes up

'Slowness' (revealed by Autocorrelation) goes up

M Scheffer *et al. Nature* **461**, 53-59 (2009) doi:10.1038/nature08227

Some lessons from systems

- Unintended consequences and unforeseen outcomes are common
- Almost all moderately-complex systems have multiple possible states and thresholds
- Avoiding bad outcomes which are hard to reverse may be a better strategy than trying to find the very best solution
- A narrow focus on efficiency can erode resilience
- Enlarging the scope can avoid getting stuck in local traps

Reading about systems

Aronson, D 1998 An overview of systems thinking. www.thinking.net/Systems_Thinking/OverviewSTarticle.pdf

Biggs, R et al 2012 Toward Principles for Enhancing the Resilience of Ecosystem Services. *Annual Review of Environment and Resources* 37: 421-448

Folke, C., Carpenter, S.R., Walker, B.H., Scheffer, M., Elmqvist, T., Gunderson, L.H. & Holling, C.S. 2004. Regime shifts, resilience and biodiversity in ecosystem management. *Annual Review of Ecology, Evolution and Systematics* 35:557-581.

Meadows, Donella (2008) Thinking in Systems - A primer . Earthscan. ISBN 978-1-84407-726-7

Scheffer, M. 2009. *Critical transitions in nature and society*. Princeton, New Jersey: Princeton University Press.

Walker, B.H. & D. Salt 2006 *Resilience Thinking: Sustaining Ecosystems And People In A Changing World*. Island Press