

An underwater photograph showing a large school of small, silvery fish swimming in clear blue water above a dark, rocky reef. Sunlight rays penetrate the water from the top, creating a bright, shimmering effect.

Scienze per l'Ambiente Marino e Costiero

a.a. 2025-2026

**GESTIONE E CONSERVAZIONE ECOSISTEMI MARINI -
IMPATTI ANTROPICI E CONSERVAZIONE DELLA FAUNA
MARINA**

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Marine ecosystem dynamics

Ecosystem state(s)

Attractor—The dynamic regime to which a system converges under constant environmental condition.

Alternative stable states—The different attractors to which a system may converge for a give set of conditions. Also known as alternative dynamic regimes or alternative attractors.

Critical threshold—The point at which the qualitative behaviour of a system changes. It is usually associated with the shift between two alternative dynamic regimes, or towards a different attractor. Also known as tipping point or bifurcation.



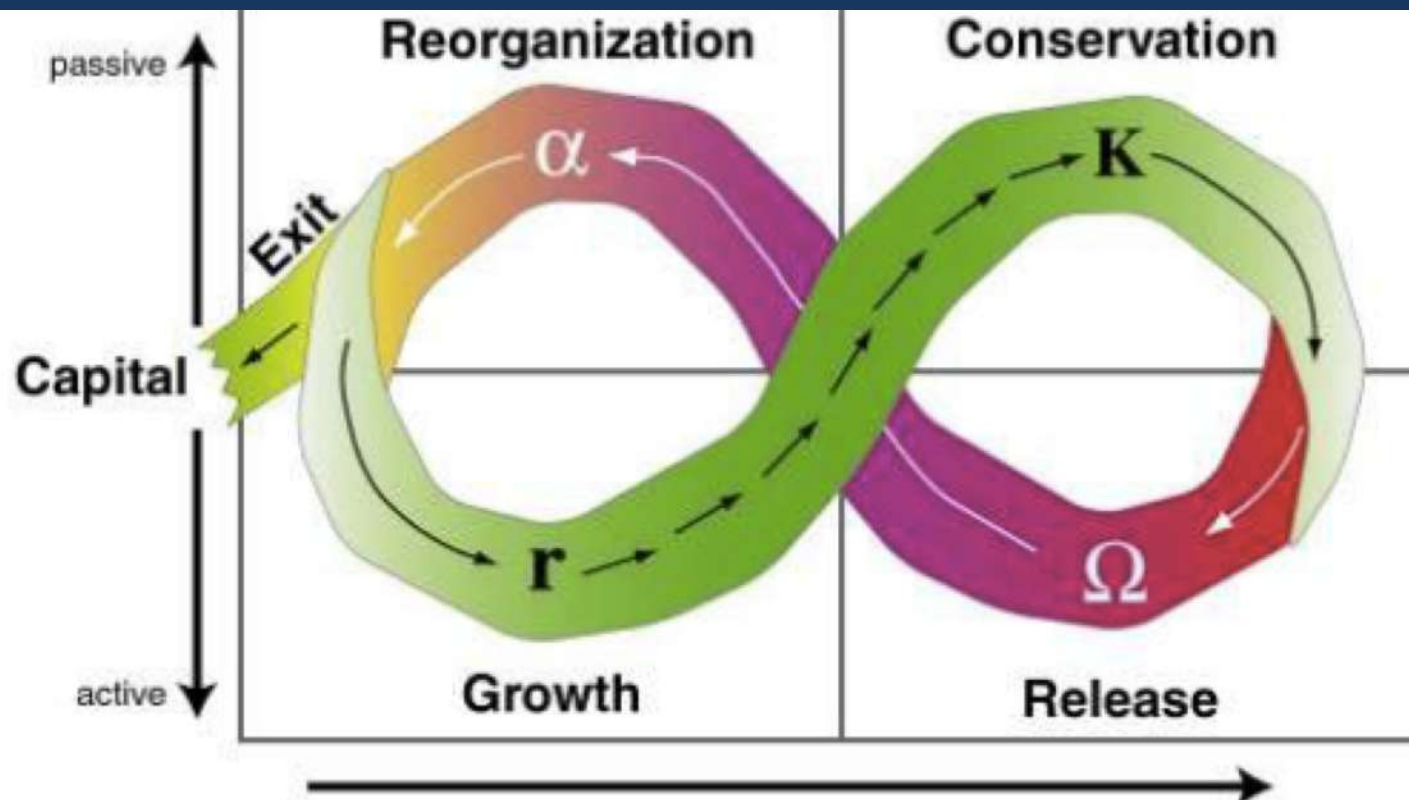
Resilience: resistance and recovery

RESISTANCE: One of the components of resilience—a measure of difficulty in moving a system within a basin of attraction (Walker et al. 2004); the ability of an ecosystem to resist displacement from its reference state as a consequence of disturbance

RECOVERY: The capacity of a system return to previous conditions after being perturbed

RESILIENCE: The capacity of a system to absorb disturbance and reorganize while undergoing change so as to maintain essentially the same functions, structure, identity and feedbacks

Cycle of Holling



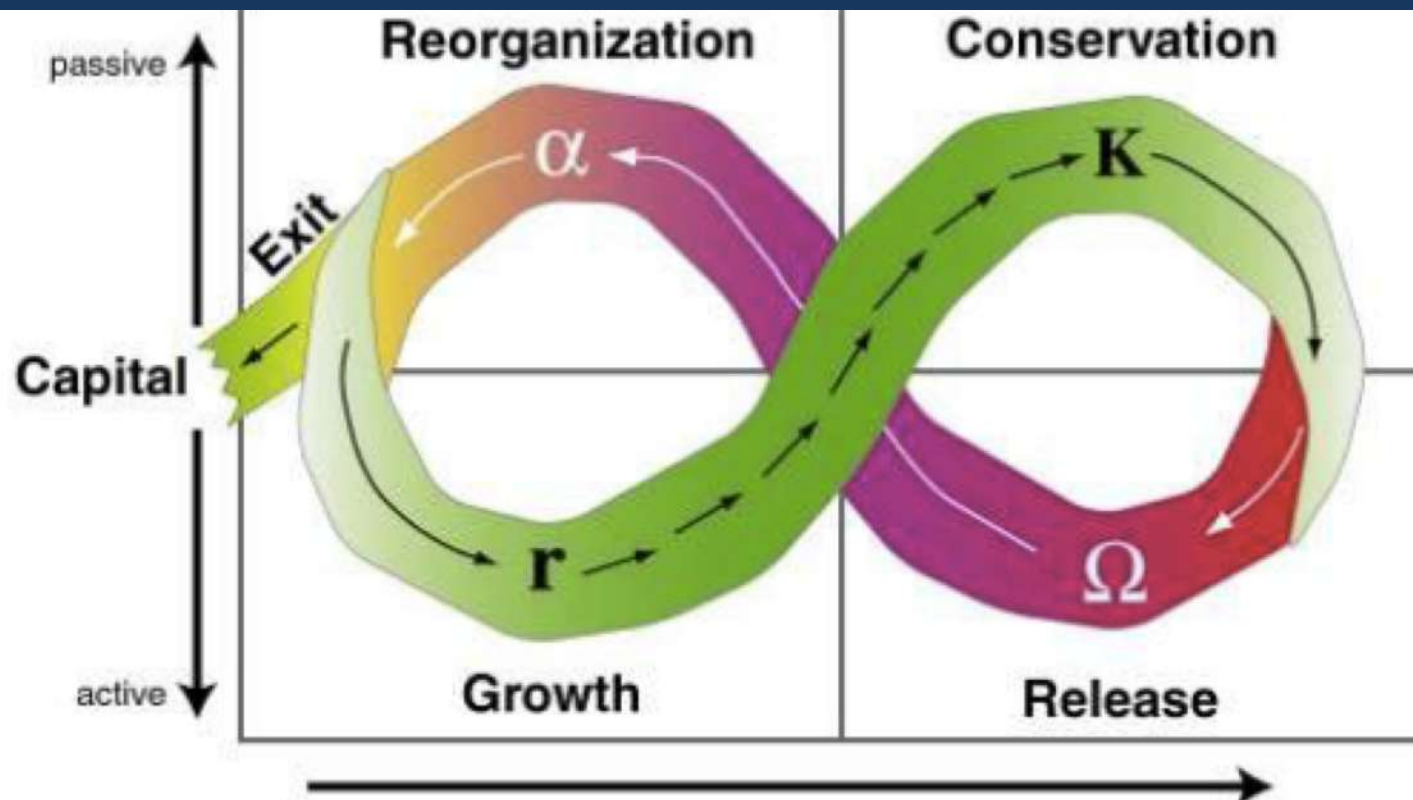
Gunderson e Holling, 2002

connectivity

Adaptative cycle within the stability domain (basin of attraction) of a given system

1. Growth phase
2. Conservation phase
3. Release phase
4. Reorganization phase

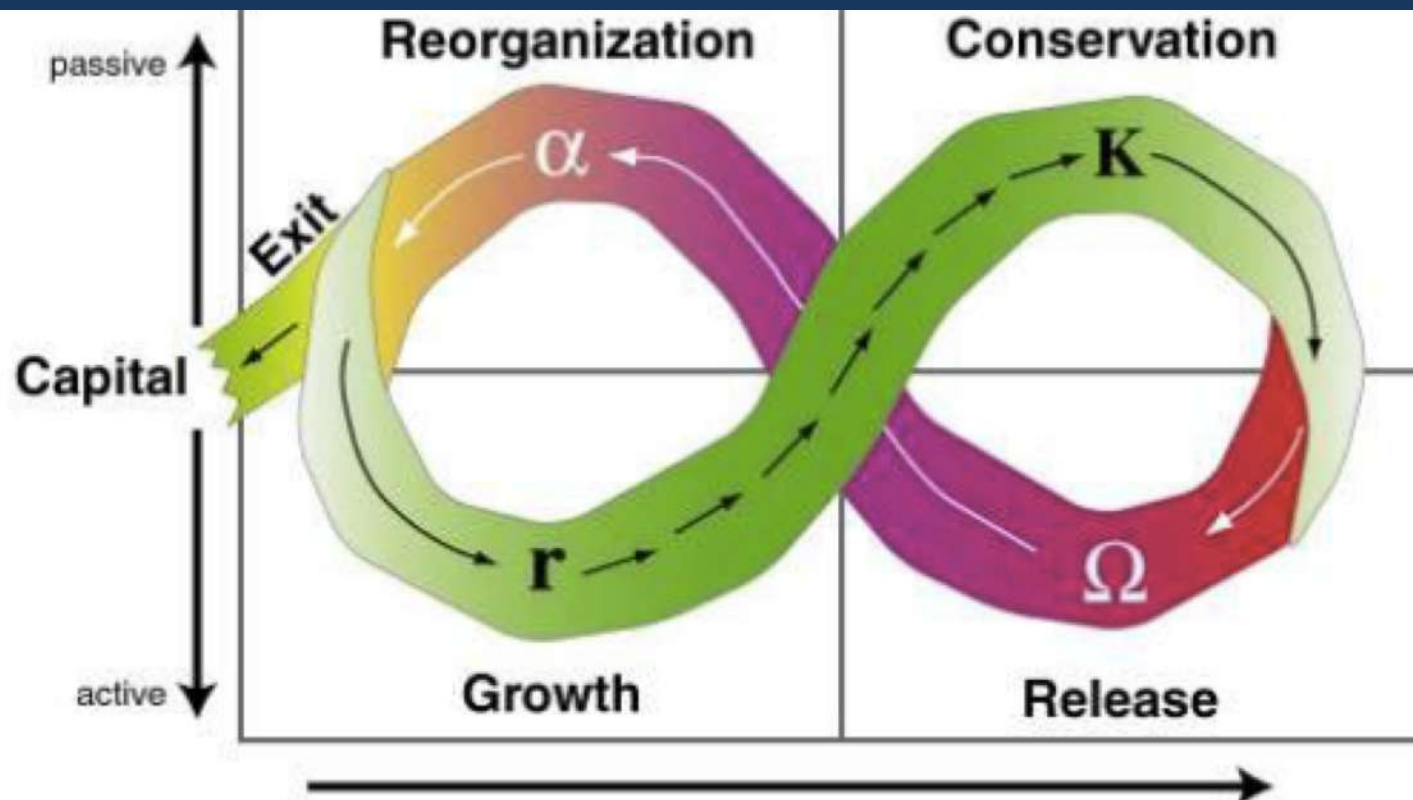
Growth



connectivity

Rapid growth with r species, resources are available and not capitalized. Connection among species are limited. This is the phase in which the system is forming and structuring.

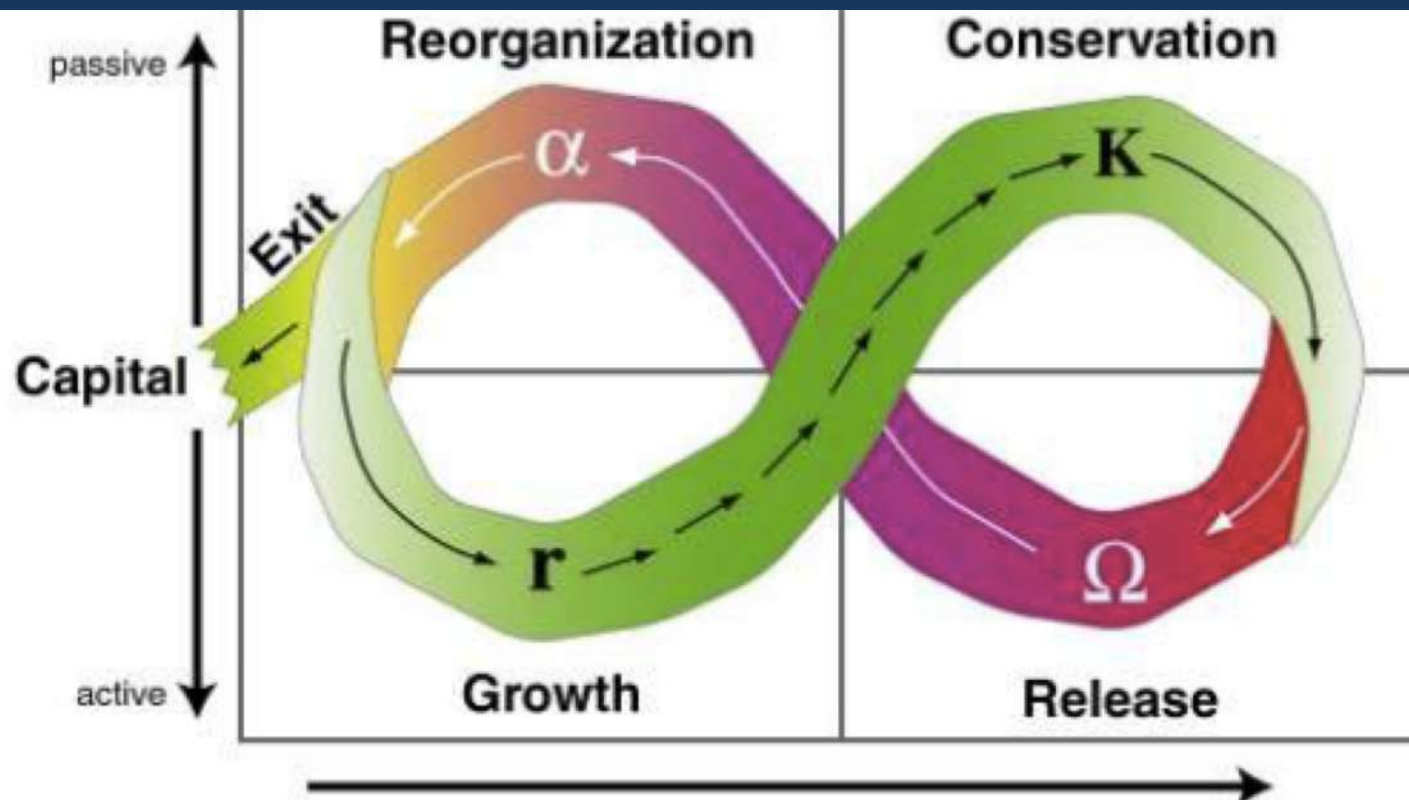
Conservation



connectivity

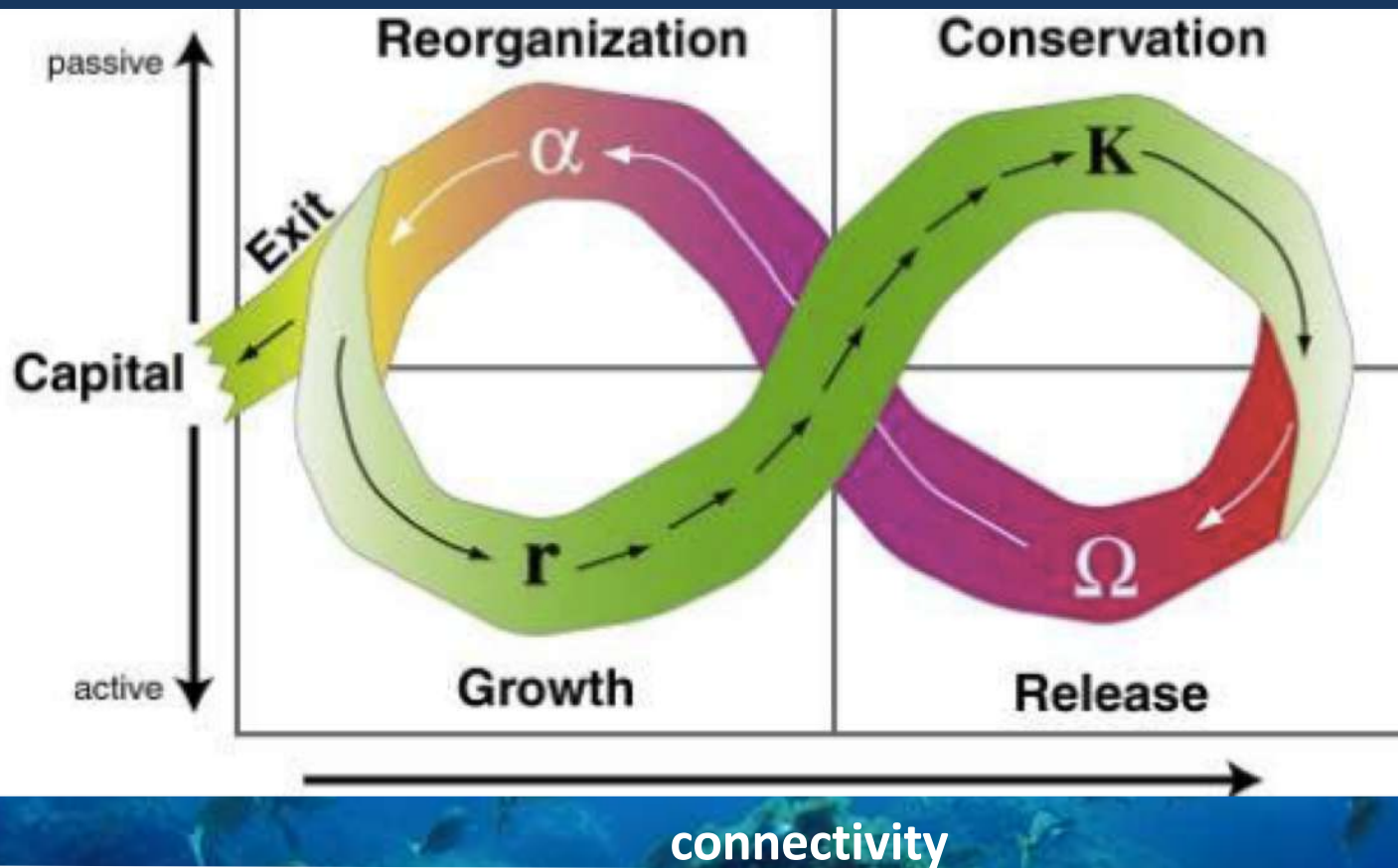
Period of conservative status, with k species. Resources are capitalized, and connections among species are strong and structured. Specialization and conservation of functions.

Release

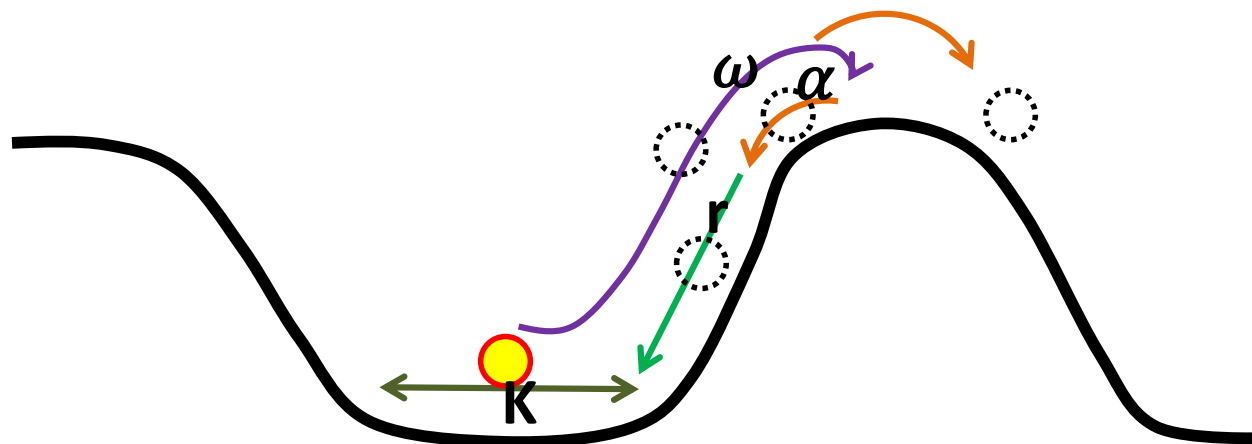


Following a perturbation the system is destabilized, resources are released and available. Connections start to break eventually

Reorganization



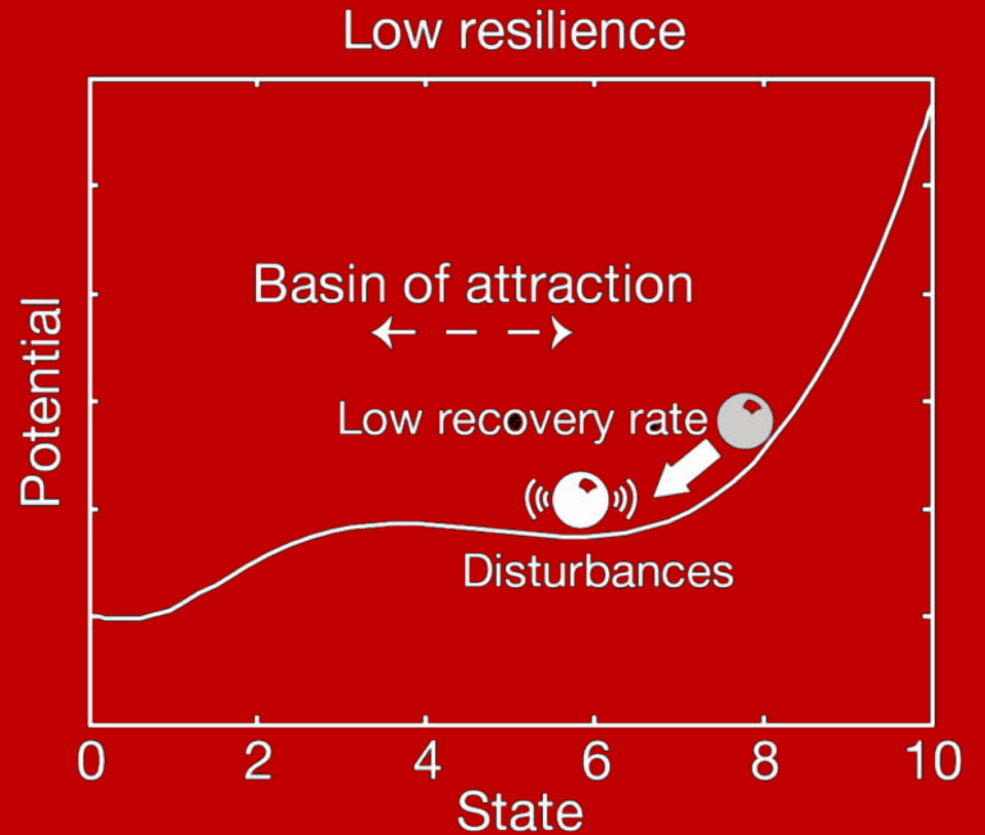
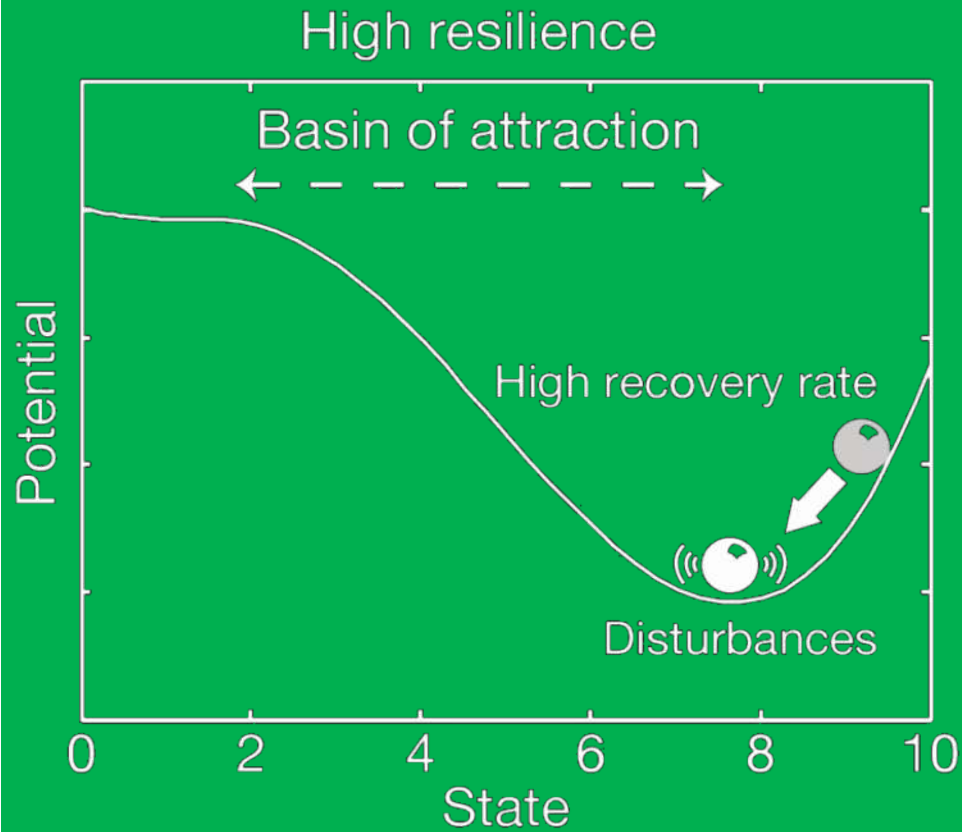
Resources are available for reorganizing the system, to reestablish the original structure and connections passing by a new growth phase...or shifting towards a different regime



Holling cycle and the ball-in-cup paradigm

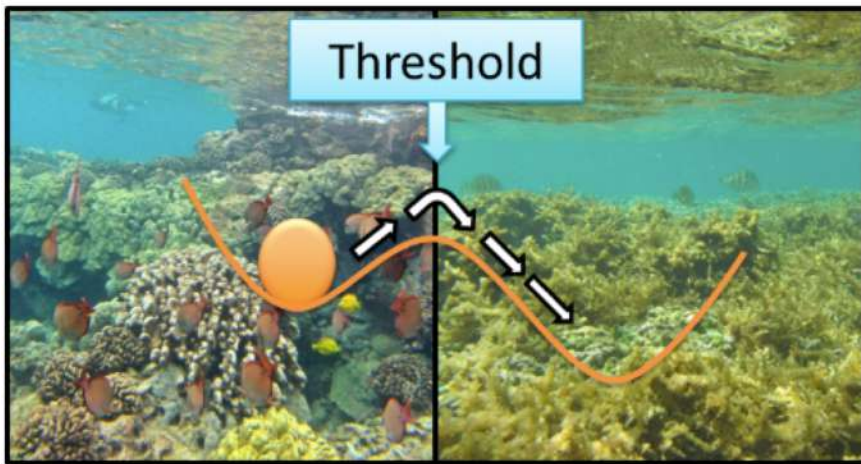
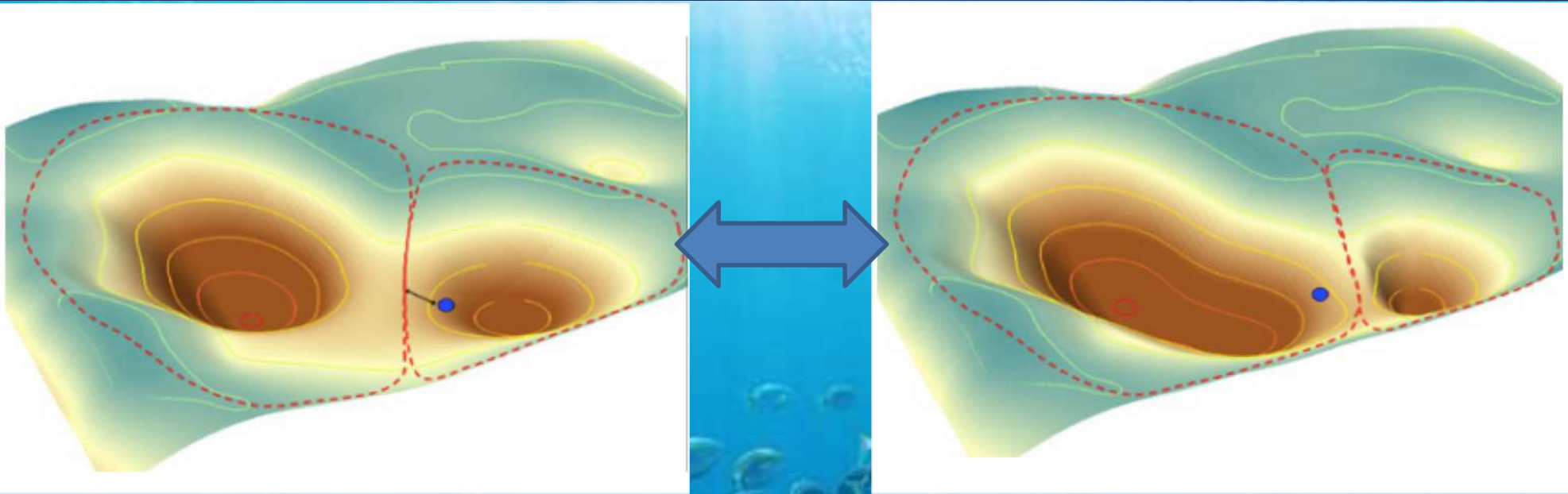
Ecosystem stability

Modified from Scheffer et al., 2009



Decreasing stability

Phase shifts



Changes in conditions and basins of attraction (enlargement, reduction) as a consequence of resilience erosion, smoothing thresholds

Phase shifts

Box 1. Definitions

Ecological regime shift—Dramatic, abrupt changes in the community structure, encompassing multiple variables, and including key structural species (*definition from this Theme Issue*) (figure 1). Note that the term *regime shift* is synonymous with *phase shift*, the former being used prevalently in open ocean systems, the latter in spatially fixed systems such as reefs. Also termed *state shifts* or *ecosystem reorganizations*. Regime shifts that involve the crossing of a tipping point and pertain to systems with alternative states are also called *critical transitions*.

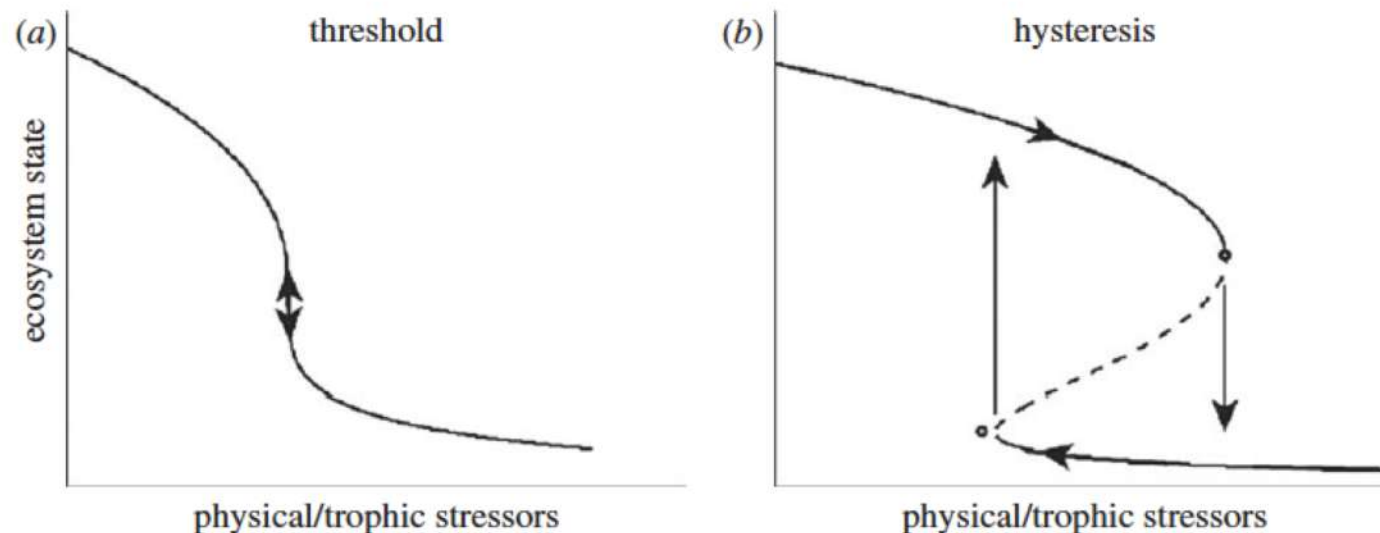
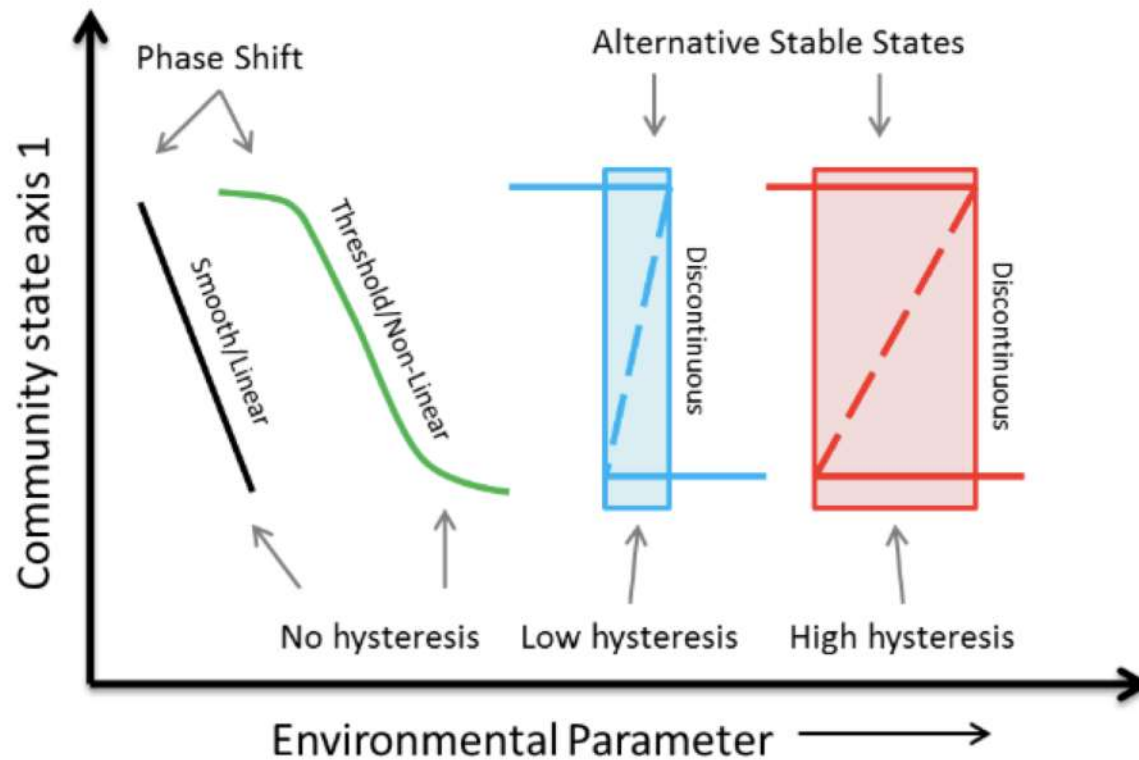


Figure 1. Examples of regime shift. Two different responses are shown, one without (a), and the other with hysteresis (b), both of which are encompassed by our working definition of regime shifts (adapted from [5]).

Regime and phase shifts – tipping point/bifurcations/critical transitions

Phase shifts



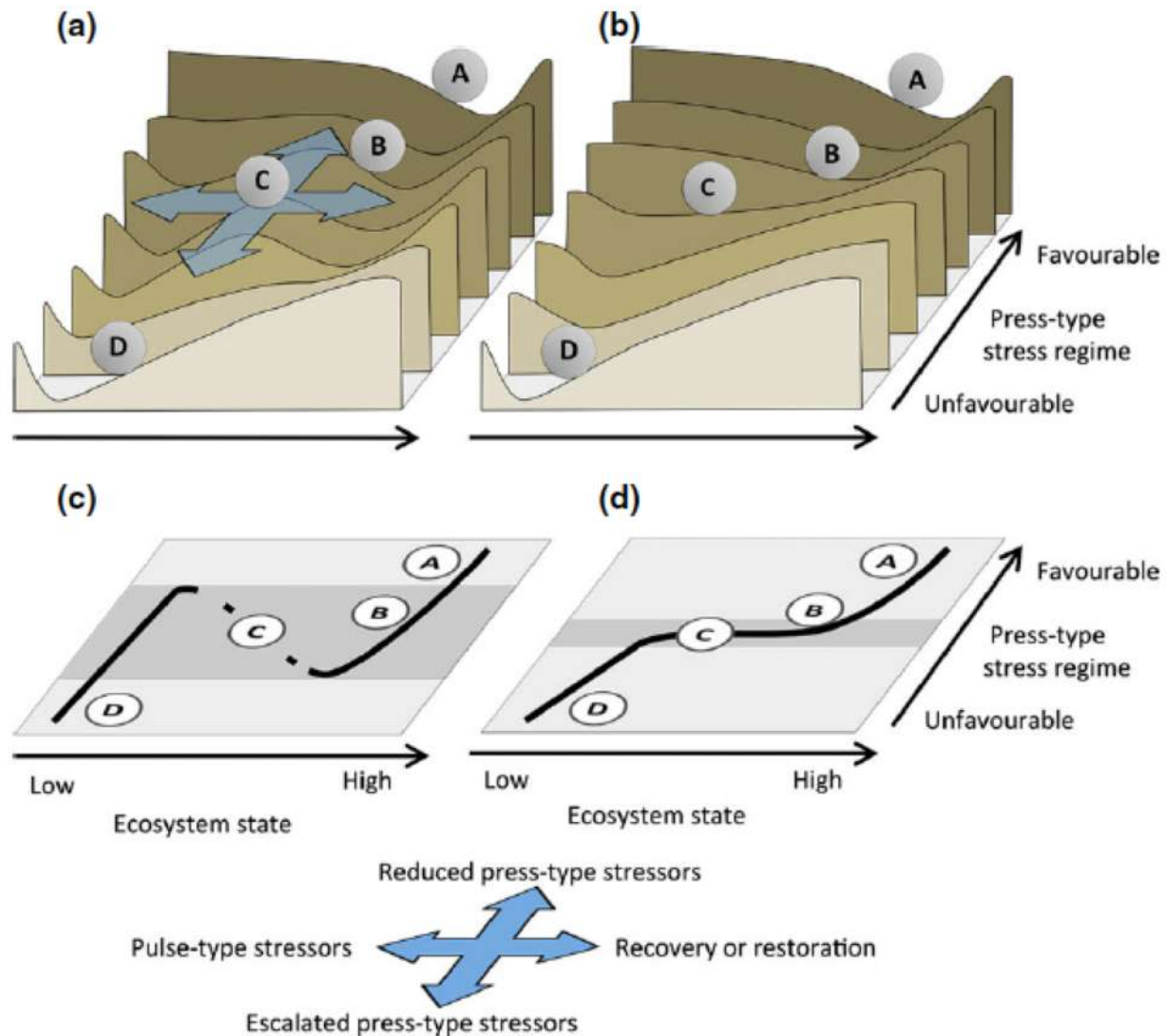
Smooth or Linear- characterized by a linear or nearly linear relationship between the stressor (e.g. fishing effort) and the ecosystem state (e.g. fish abundance) variables

Non-linear- characterized by a non-linear relationship between conditions and the ecosystem state variables. The rate of change in ecosystem state speeds up when crossing the threshold between regimes

Hysteretic or Discontinuous- characterized by a non-linear relationship with hysteresis – in which the path from state A to B (degradation) is different from the path from B to A (recovery) and may be very hard to reverse. Or, despite improvement of conditions the system will persist in a degraded state. For a given range of conditions two or more state are possible

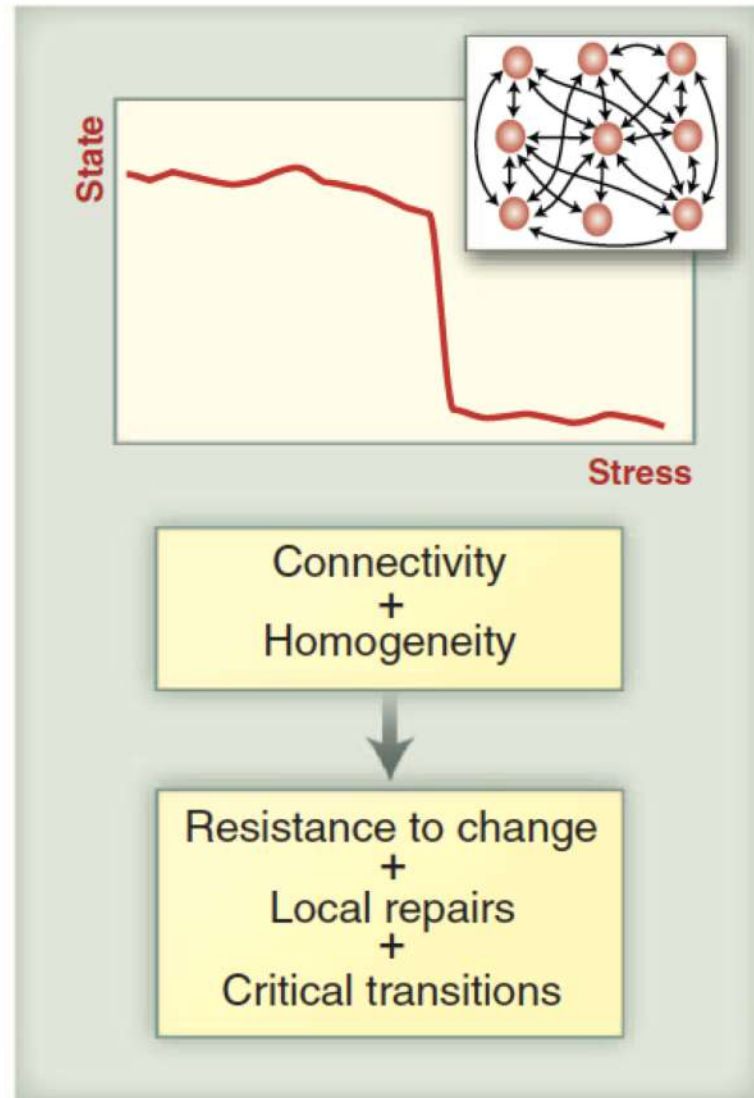
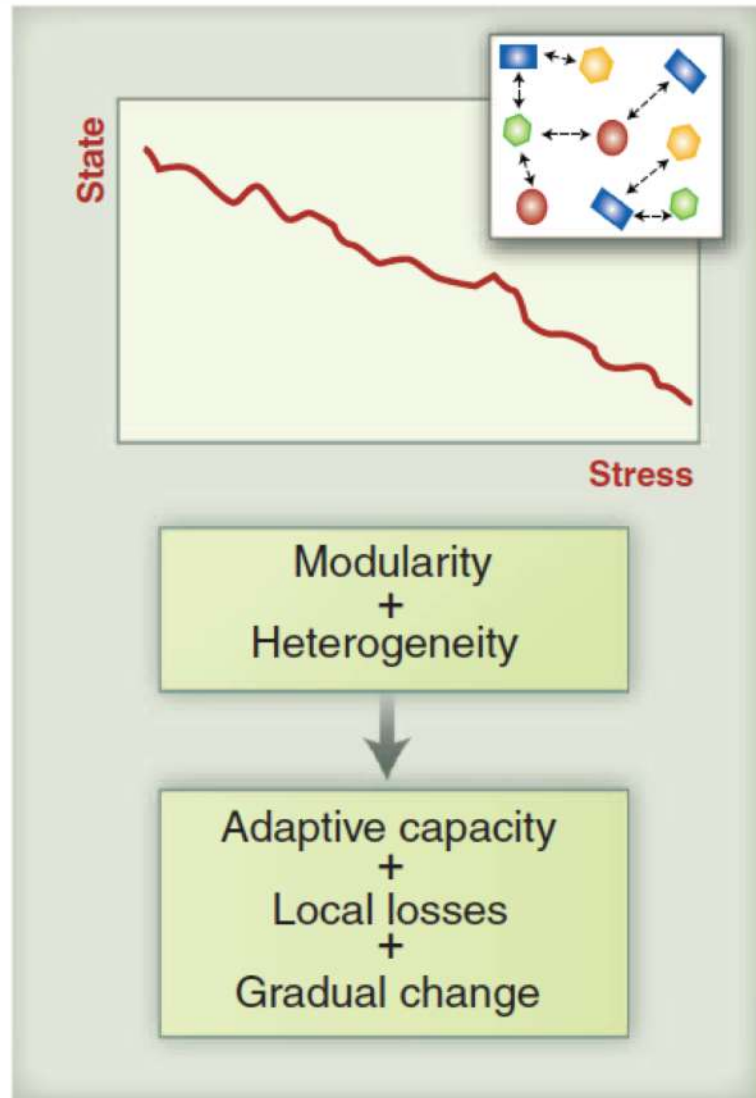
Ecosystem phase shifts: a conceptual model

Two stable states are possible. Normally, the 'good state' is A. Increasing deterioration leads to fragile equilibrium where even a relative minor perturbation could cause a shift



In the case on the right, however, no bifurcation. The system gradually change from A to the worse state

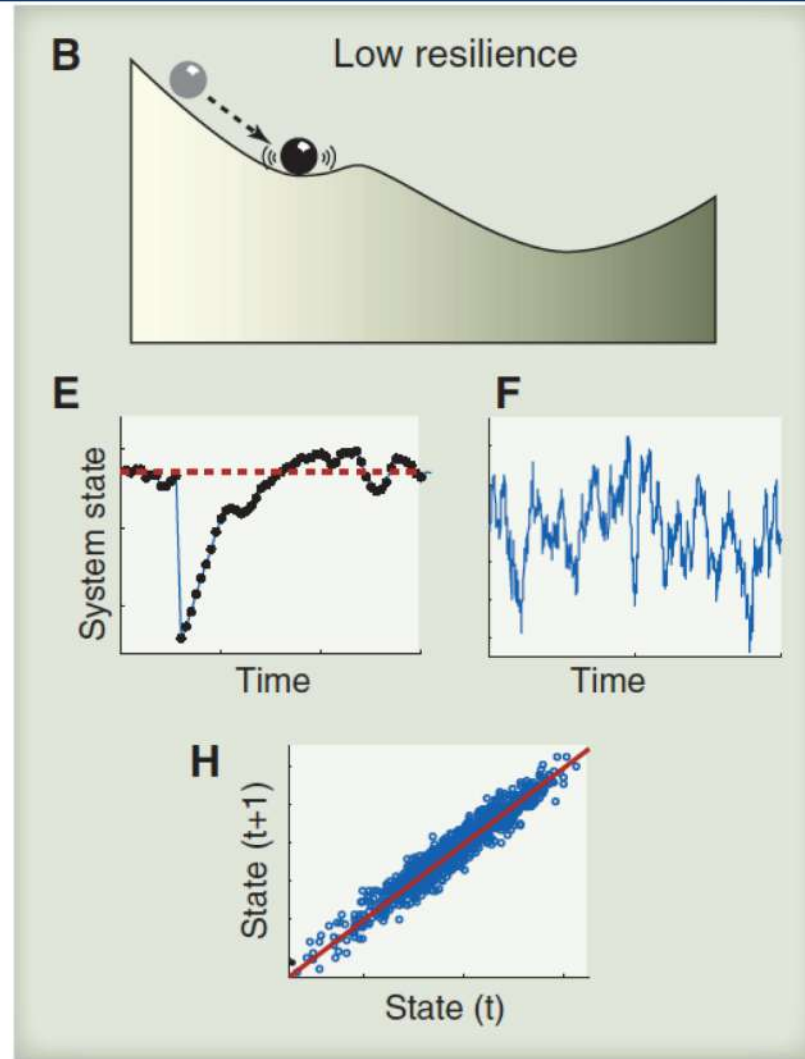
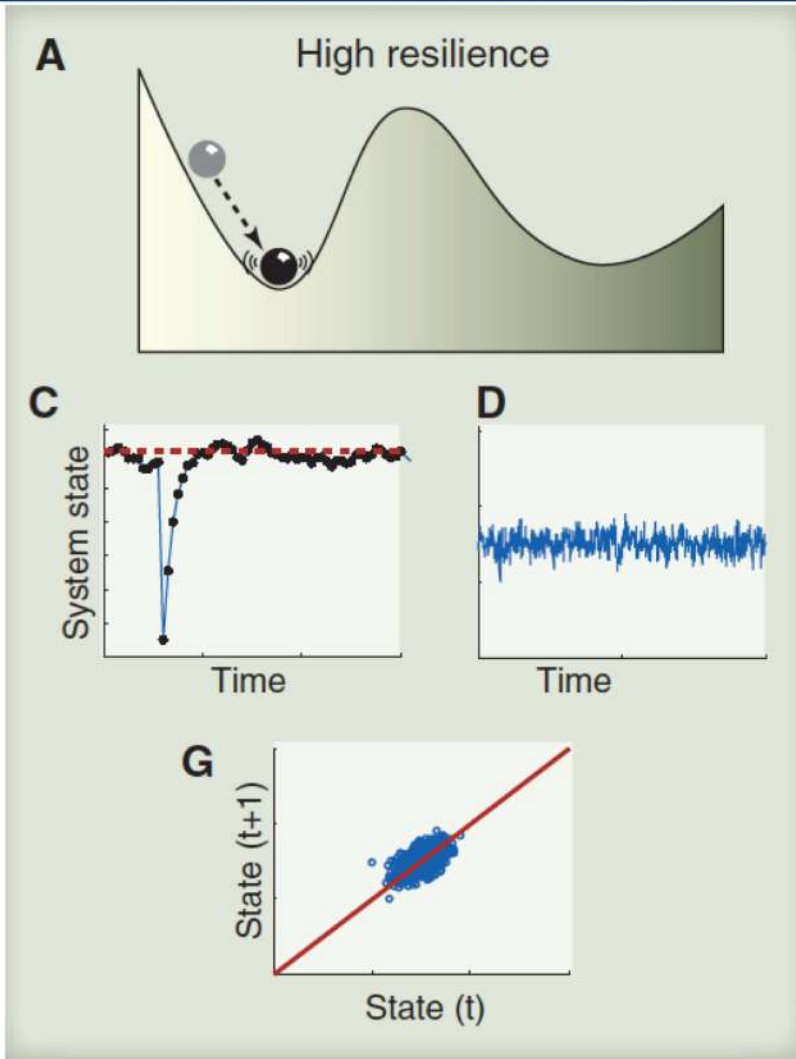
Architecture of fragility



The connectivity and homogeneity of the units affect the way in which systems with local alternative states respond to changing conditions. Networks in which the components differ (are heterogeneous) and where incomplete connectivity causes modularity tend to have adaptive capacity in that they adjust gradually to change.

By contrast, in highly connected networks, local losses tend to be “repaired” by subsidiary inputs from linked units until at a critical stress level the system collapses.

Signals of potential transition



Scheffer et al 2012

Slowing down recovery

Autocorrelation

Increased variance

Flickering between alternative states

Shifts and drivers

regime shift name

Arctic sea ice

key drivers

atmospheric CO₂

global warming

greenhouse gases

temperature

ecosystem services impacted

water cycling

biodiversity

fisheries

wild animal and plant foods

climate regulation

water purification

water regulation

aesthetic values

knowledge and educational values

spiritual and religious



Shifts and drivers

regime shift name	key drivers	ecosystem services impacted
mangroves transitions	agriculture aquaculture atmospheric CO ₂ deforestation droughts erosion floods global warming hurricanes infrastructure development irrigation infrastructure landscape fragmentation ocean acidification rainfall variability sea-level rise sea surface temperature sediments sewage temperature urbanization	soil formation water cycling biodiversity fisheries wild animal and plant foods timber wood fuel climate regulation water purification regulation of soil erosion natural hazard regulation aesthetic values



Rocha et al. 2015

Shifts and drivers

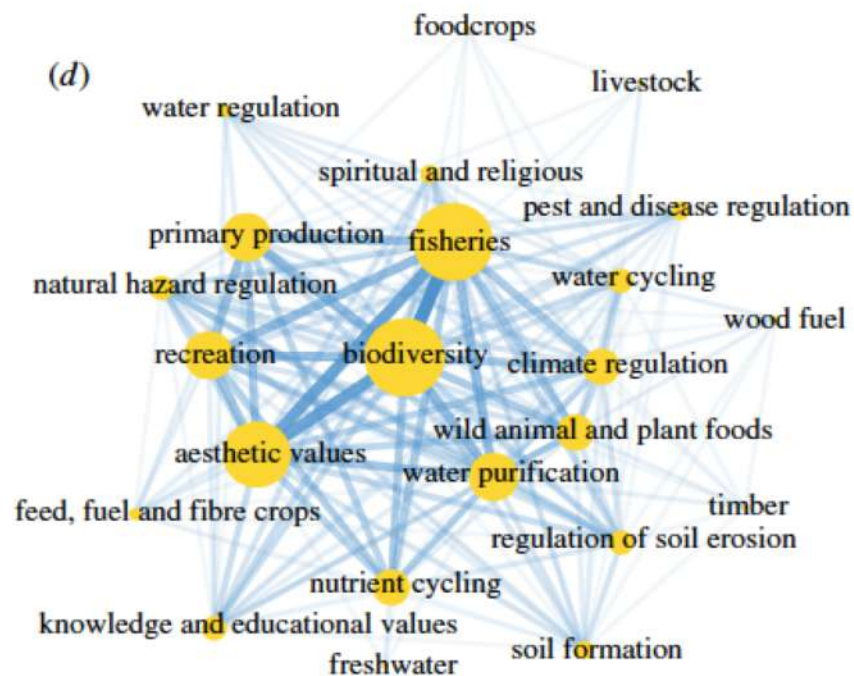
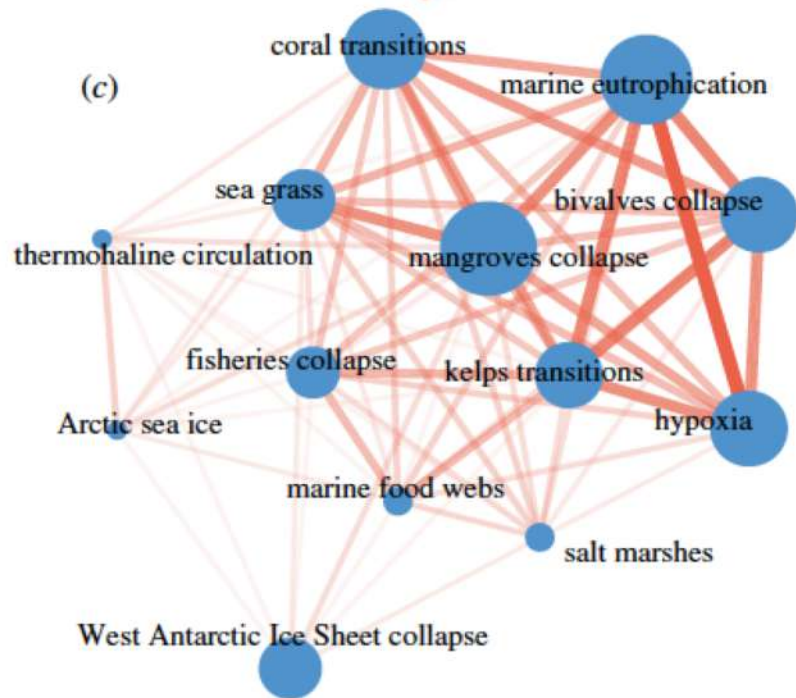
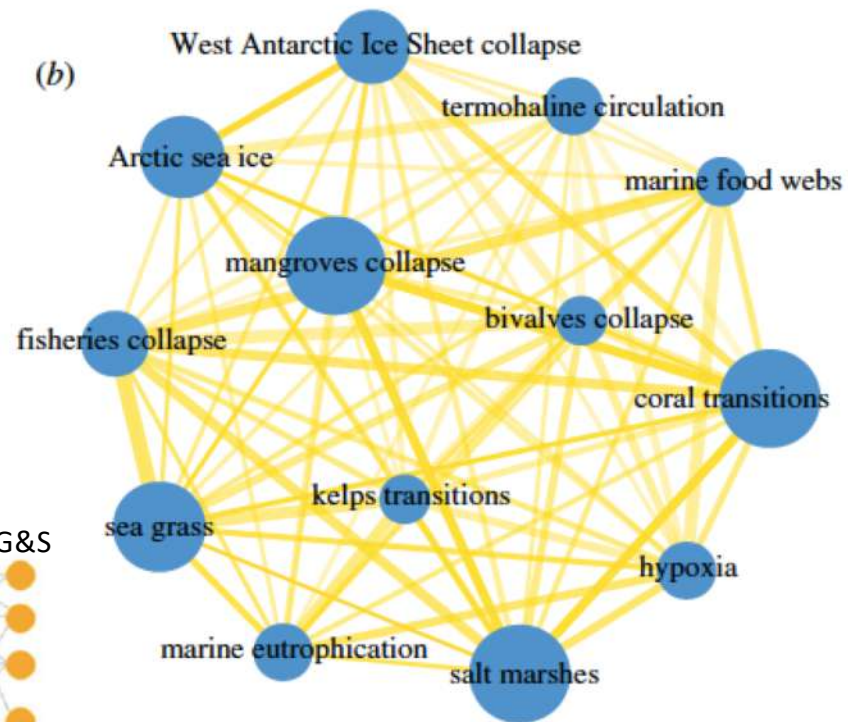
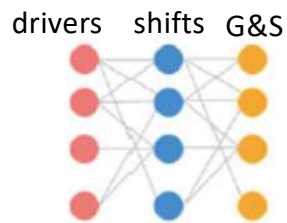
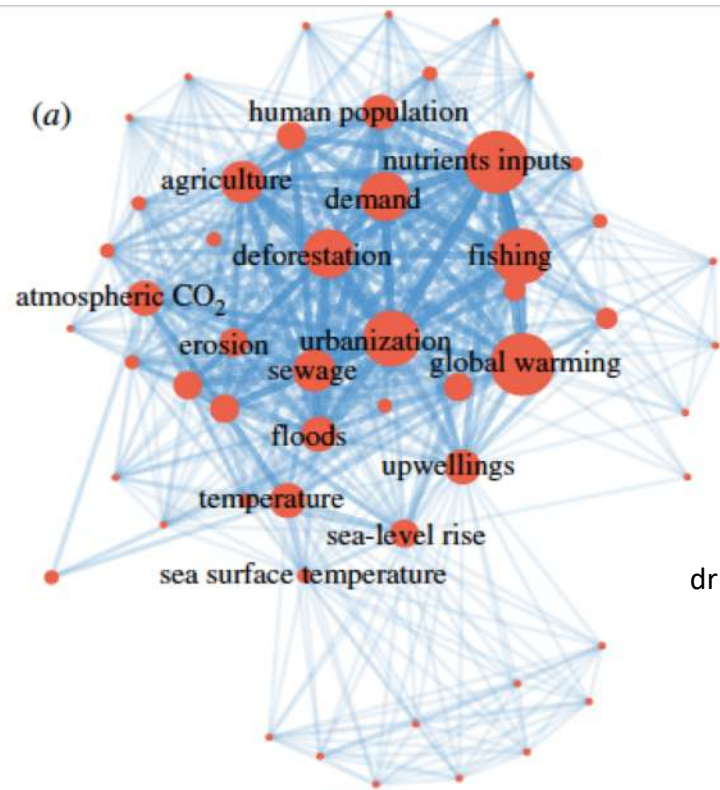
key drivers

atmospheric CO₂
deforestation
disease
fishing
infrastructure development
nutrient input
rainfall variability
sea-level rise
sediments
sewage
temperature
urbanization

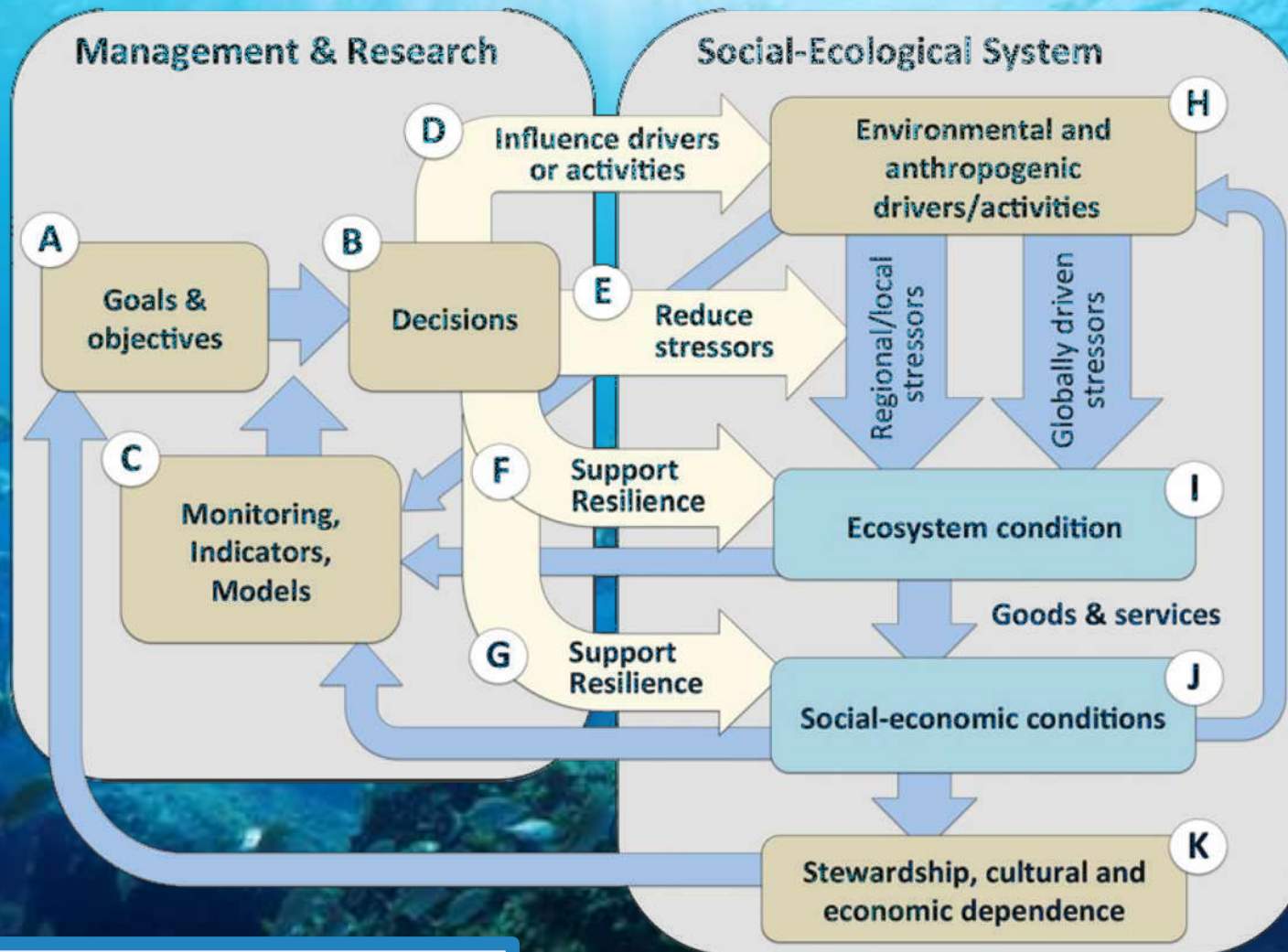
ecosystem services impacted

primary production
nutrient cycling
biodiversity
fisheries
wild animal and plant foods
climate regulation
water purification
regulation of soil erosion
natural hazard regulation
recreation
aesthetic values





Management



Reduce anthropogenic stressors

Support system's resilience

Monitoring the state of systems

Management

Example	D: Influence drivers and/or activities	E: Reduce stressors	F: Support ecosystem resilience	G: Support social-economic resilience
Great Barrier Reef	Influence national emissions policies through education and awareness-raising around climate change and linkages between land use and run-off	Improve land-use management to reduce pollution in receiving waters; maintained fisheries management	Networks of no-take areas (spatial planning for connectivity and population viability of key species); control CoTS at local scales	Work with fishers and tourism operators to help build resilience in their industries



Management

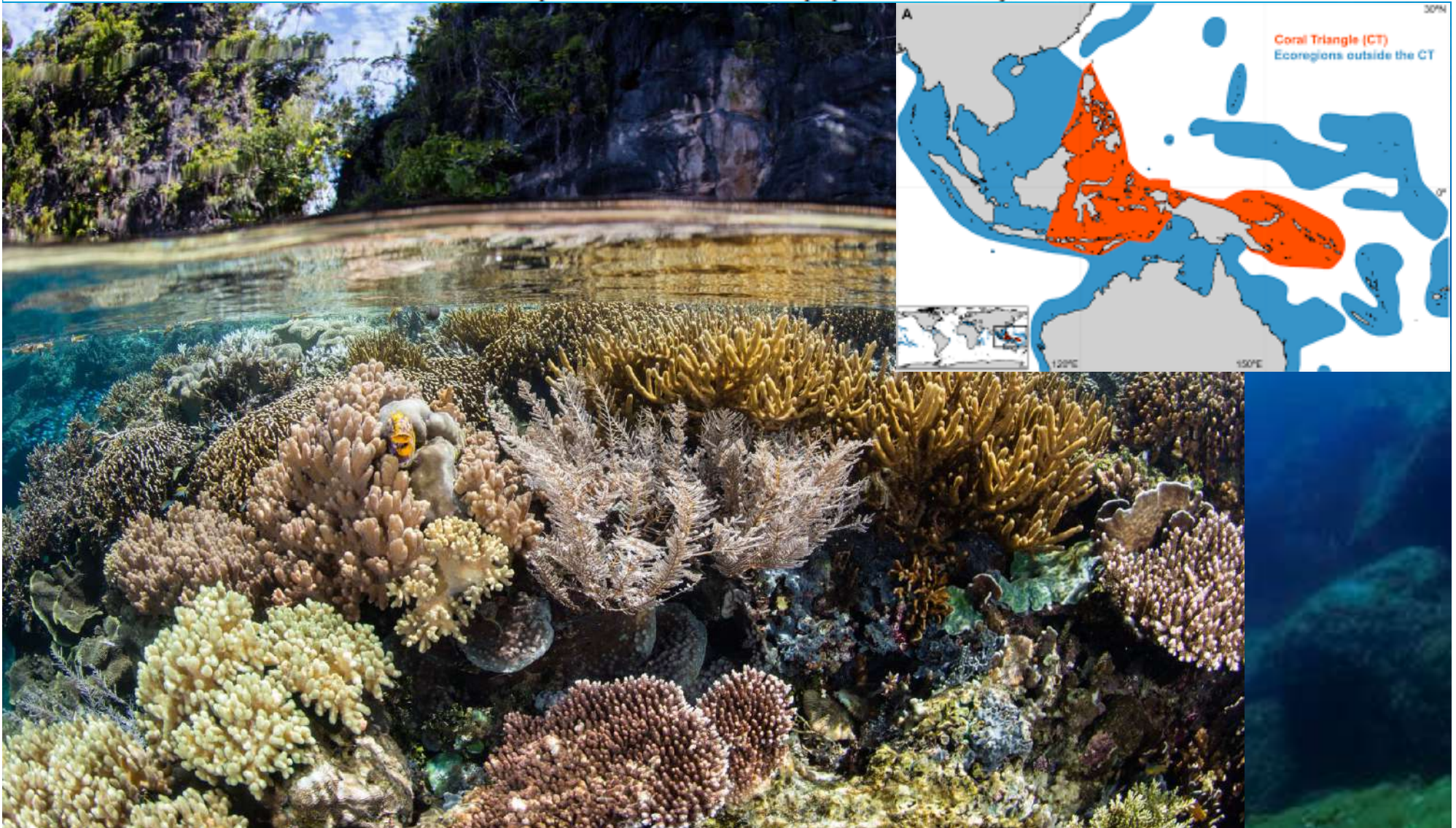
Coral Triangle

Education of local communities and regional government bodies

Reduce fishing of herbivores; stop destructive fishing practices; reduce pollution

Networks of no-take areas (spatial planning for connectivity and population viability)

Capacity-building of local communities and regional government bodies, support alternative livelihoods



Management

Florida Reef System

Education and awareness-raising around climate change and linkages between land use and land run-off

Reduce nutrient and sediment loads; reduce fishing pressure; manage pressures from recreational use

Coral and reef habitat restoration in combination with networks of no-take areas

Work with local communities and the tourism industry to develop adaptation strategies including livelihood transitioning



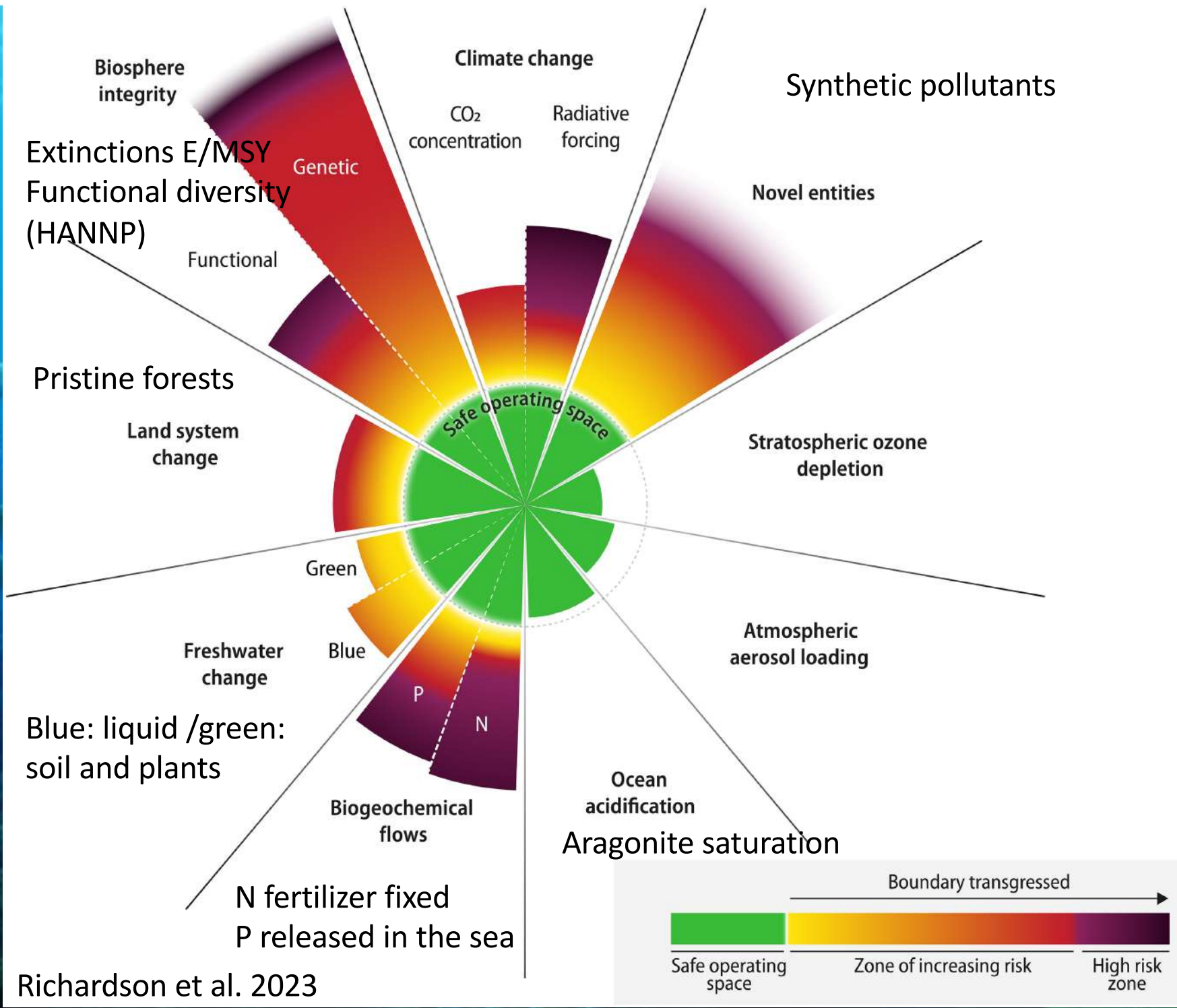
Final remarks

Complex systems are difficult to understand, and even more difficult to project. Previsions are largely uncertain.

Ecosystem can be assumed as chaotic systems, so their dynamics are extremely sensitive to initial conditions and unpredictable on the long run. There are too many variables... (Theory of chaos)

Could we manage to predict trajectories of ecosystems? Or it could be easier to reduce our pressure?





Richardson et al. 2023