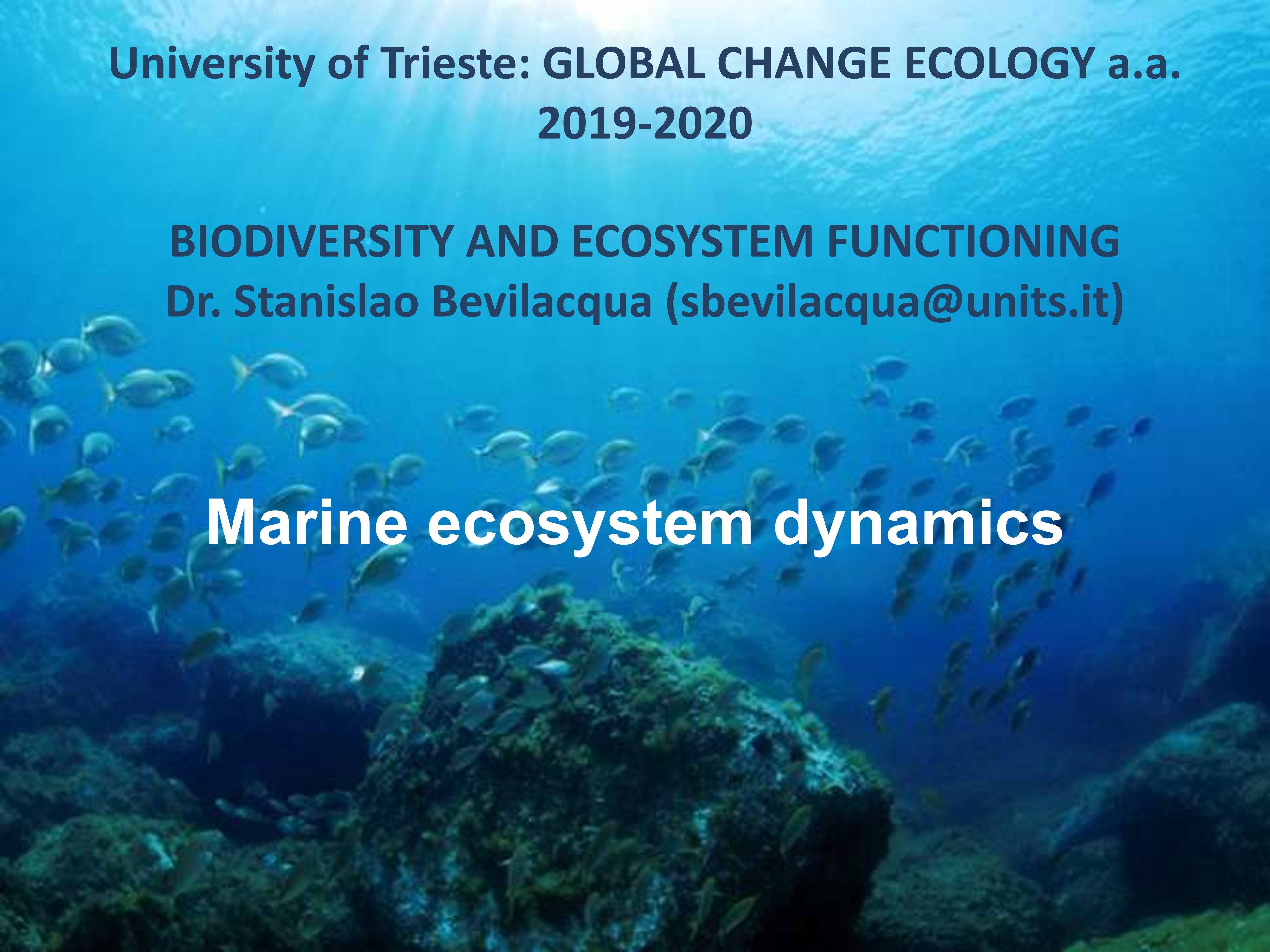


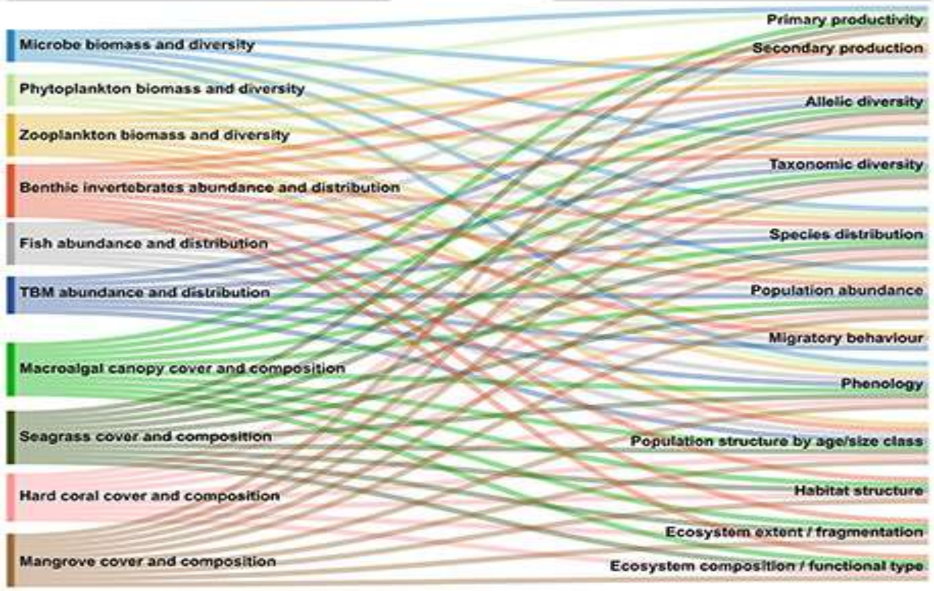
University of Trieste: GLOBAL CHANGE ECOLOGY a.a. 2019-2020

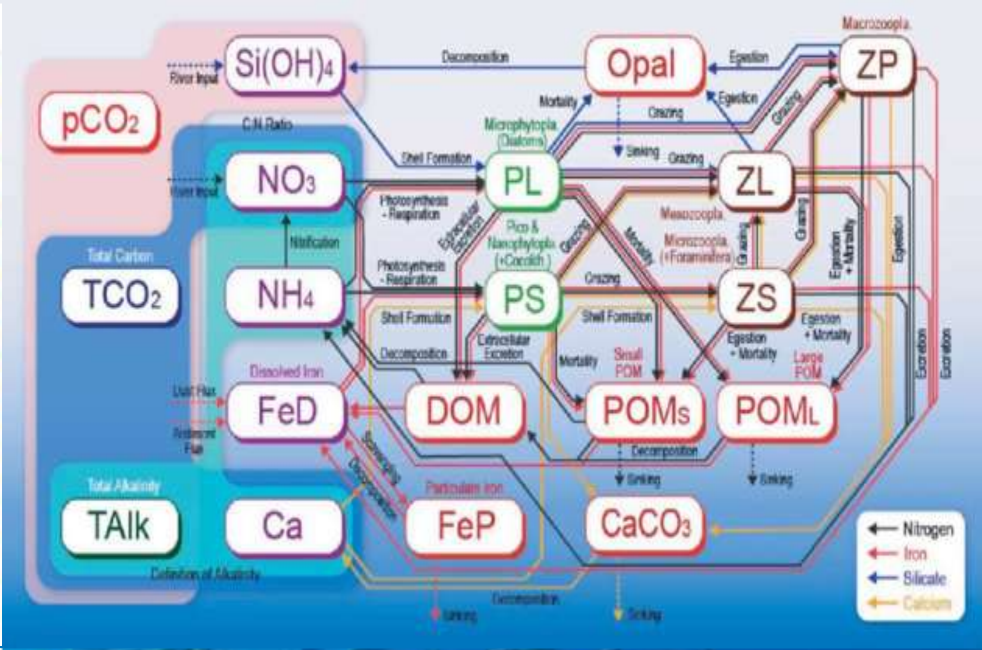
BIODIVERSITY AND ECOSYSTEM FUNCTIONING

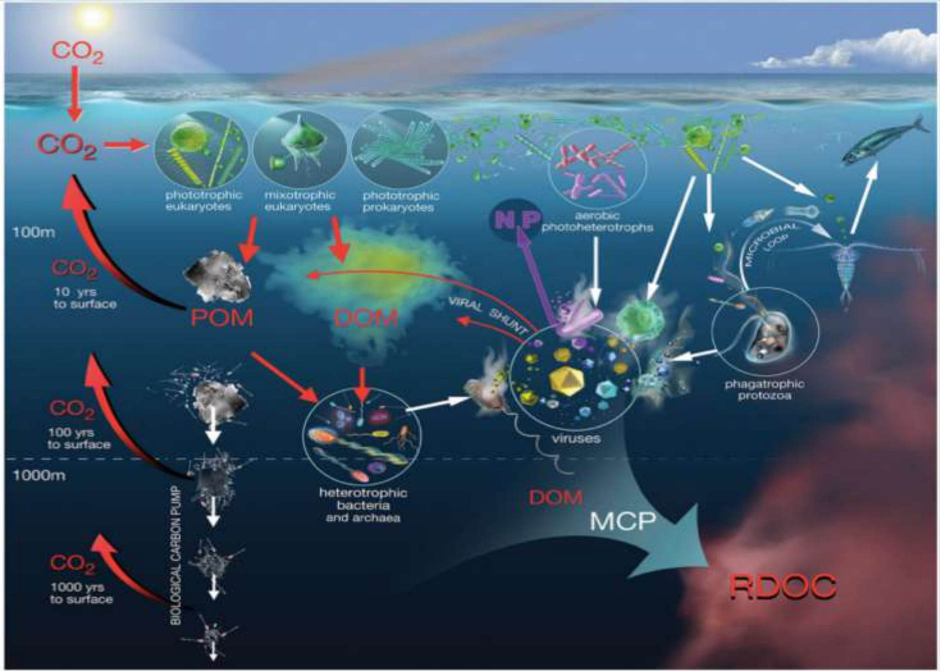
Dr. Stanislao Bevilacqua (sbevilacqua@units.it)

Marine ecosystem dynamics

Ecosystem complexity



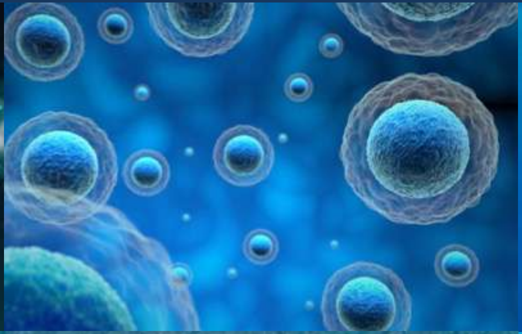




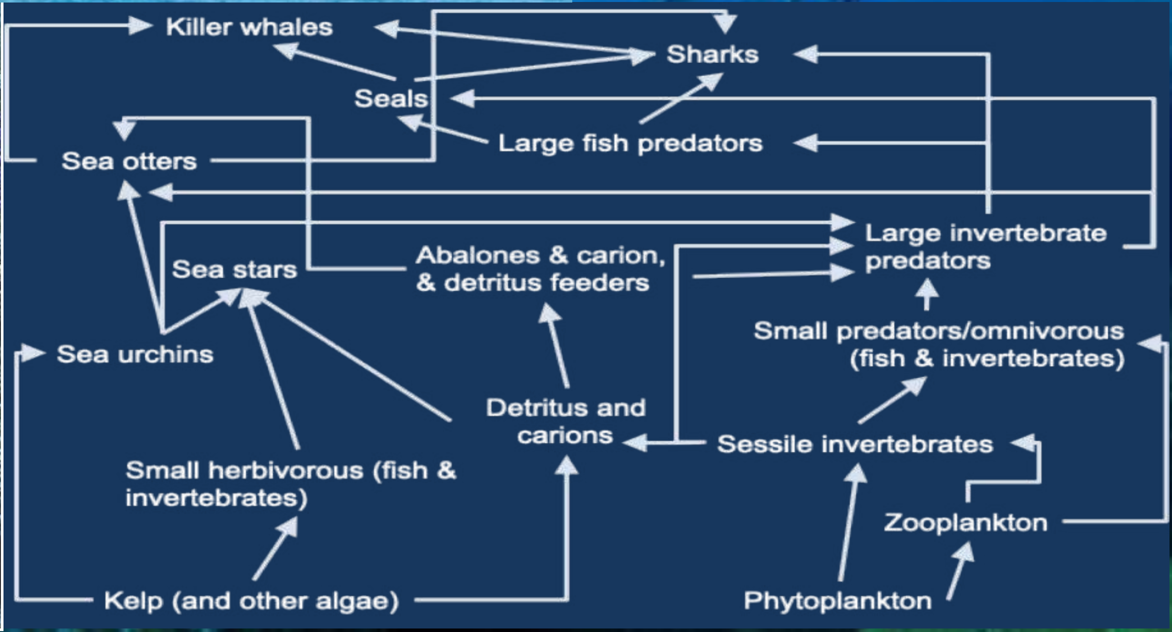
Ecosystems are complex. This stems from the huge number of components (abiotic and biological) and their respective interactions (predation, competition, parasitism, trophic relations, cycling of organic and inorganic matter, decomposition, and many others). Complexity is so high that generate emergent properties. These properties allow ecosystems to self-sustaining, self regulating, and self-repairing.

Emergent properties

C, H, O, N, P…



The whole is more than the sum of components



Killer whales

Sharks

Seals

Large fish predators

Sea otters

Large invertebrate predators

Sea stars

Abalones & carion, & detritus feeders

Small predators/omnivorous (fish & invertebrates)

Sea urchins

Detritus and carions

Sessile invertebrates

Small herbivorous (fish & invertebrates)

Zooplankton

Kelp (and other algae)

Phytoplankton

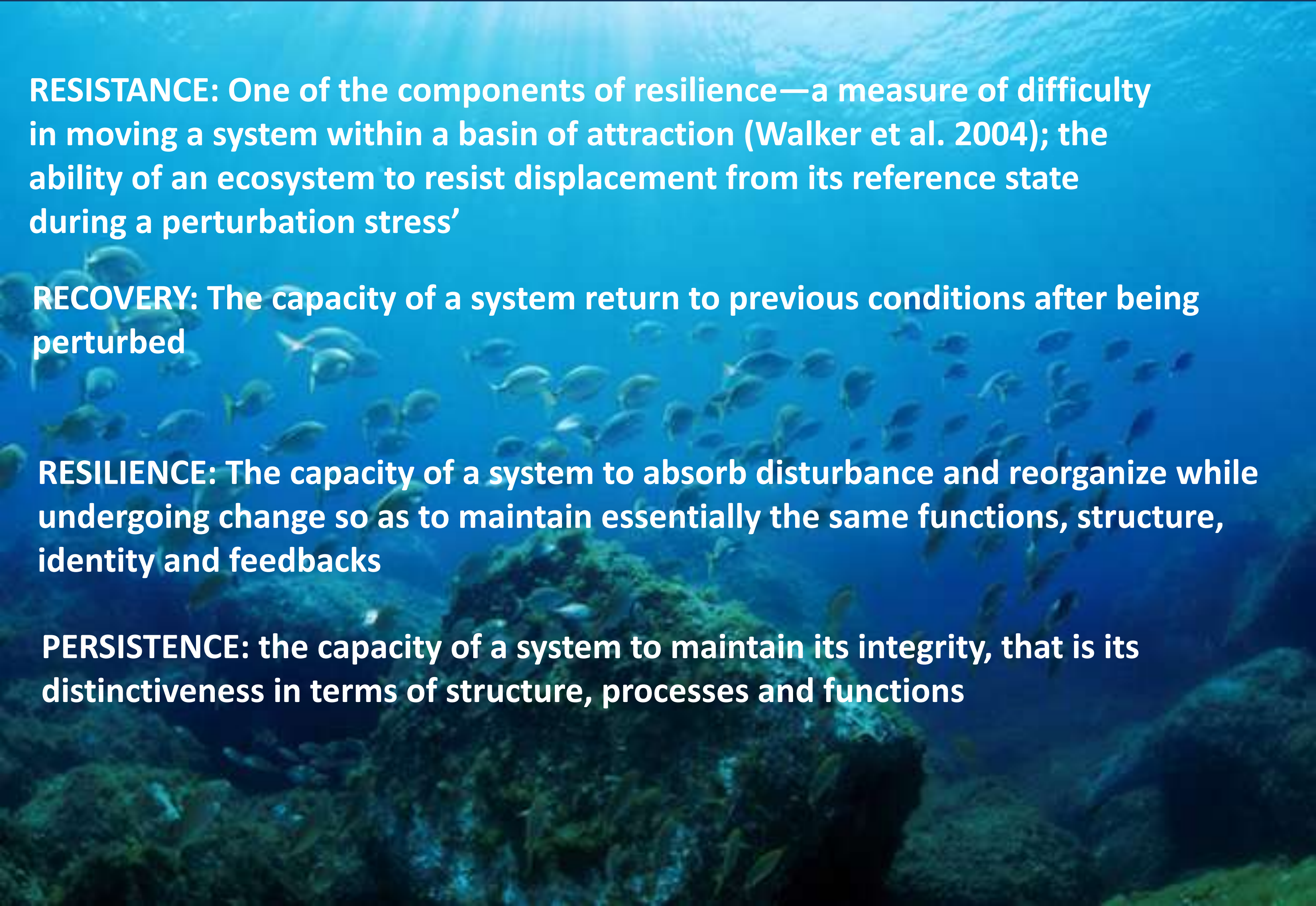
Ecosystem state(s)

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. 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. Also known as tipping point or bifurcation.

Resilience, resistance, persistence



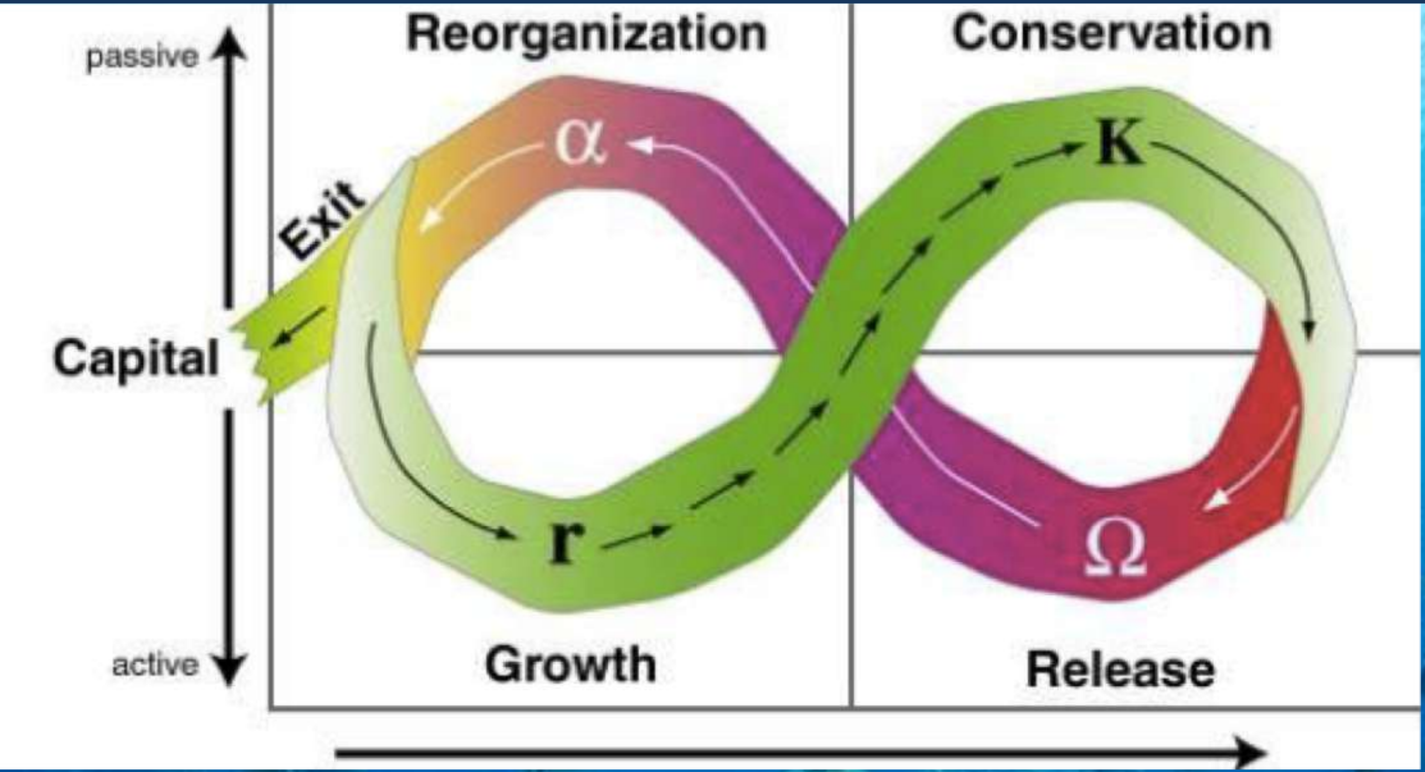
RESISTANCE: One of the components of resilience—a measure of difficulty in moving a system within a basin of attraction (Walker et al. 2004); the ability of an ecosystem to resist displacement from its reference state during a perturbation stress'

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

PERSISTENCE: the capacity of a system to maintain its integrity, that is its distinctiveness in terms of structure, processes and functions

Cycle of Holling

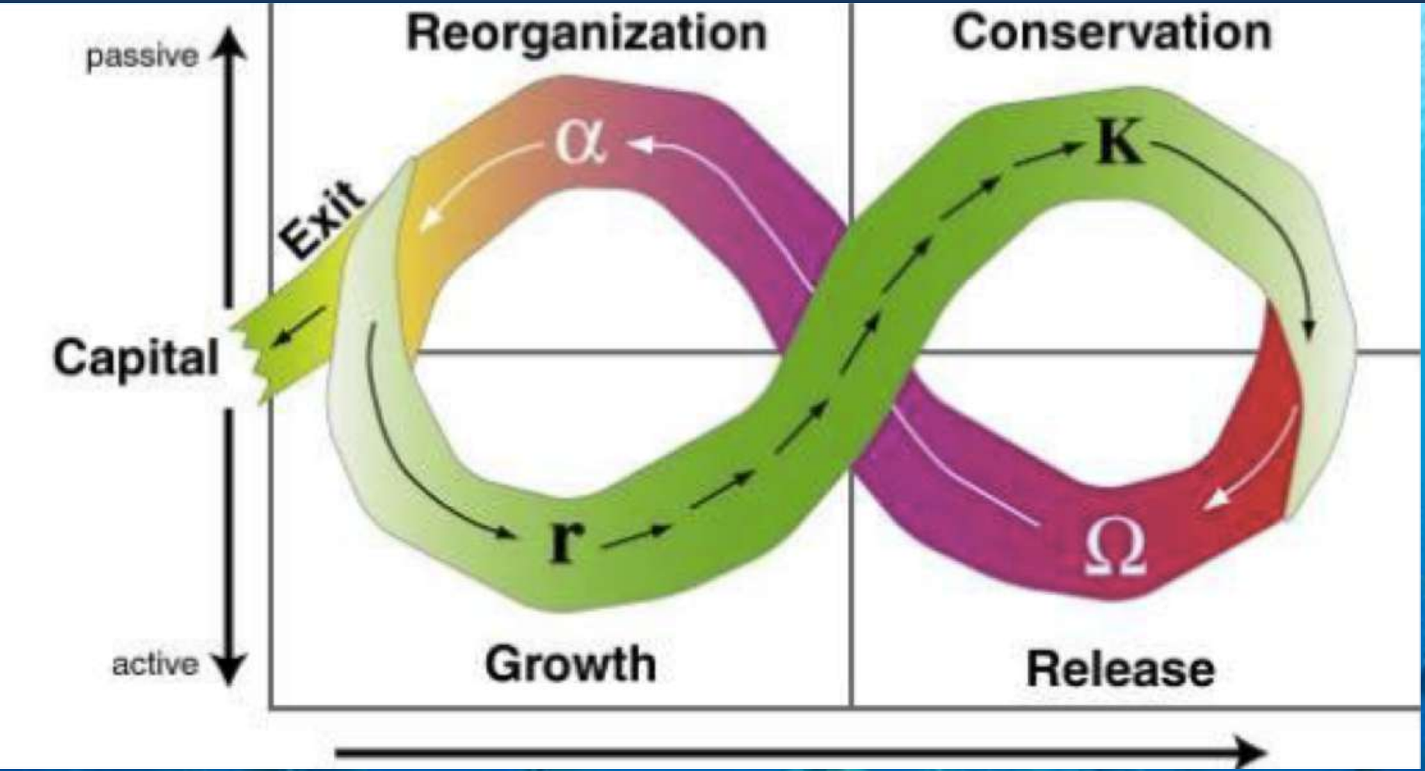


Gunderson e Holling, 2002

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

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

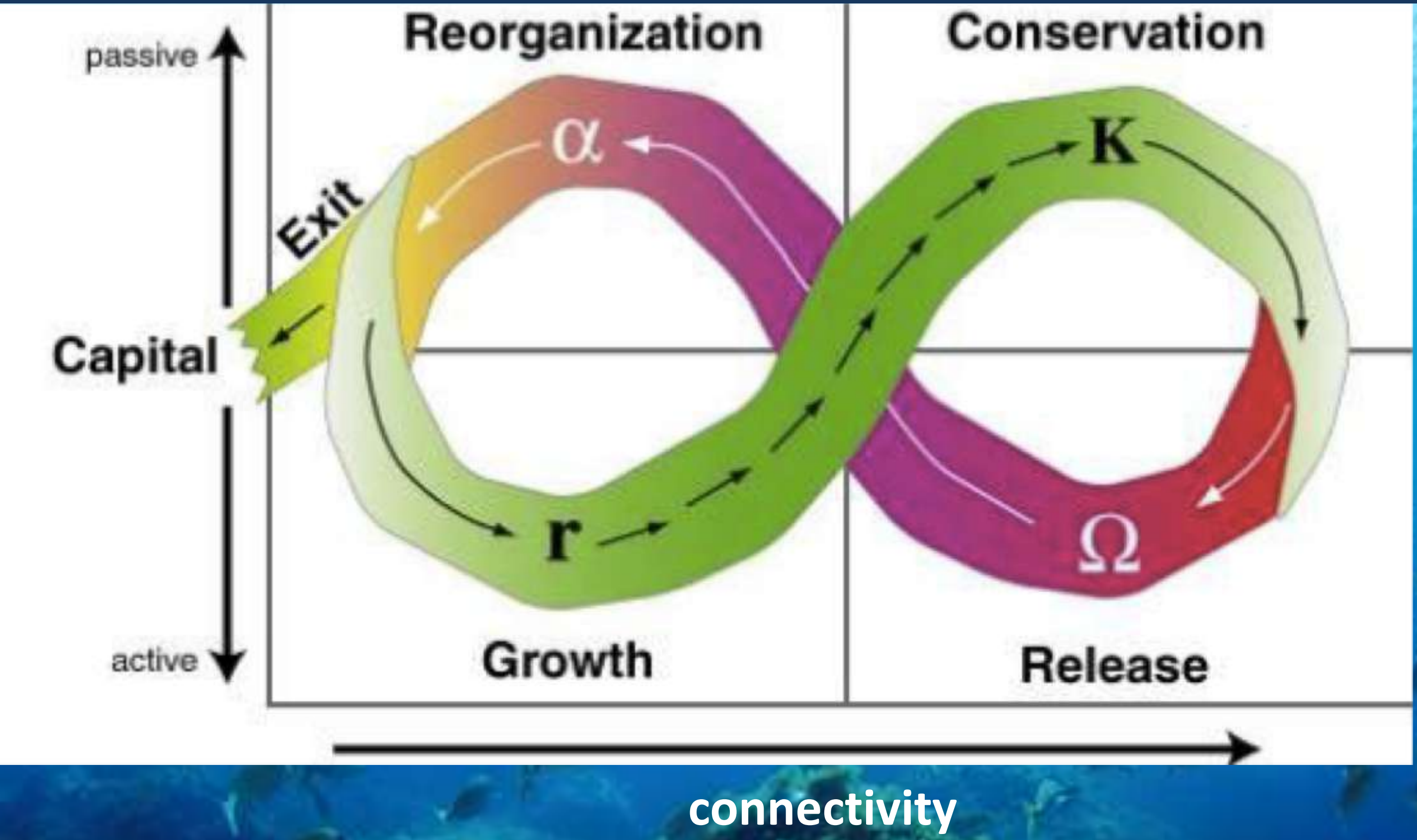
Growth



connectivity

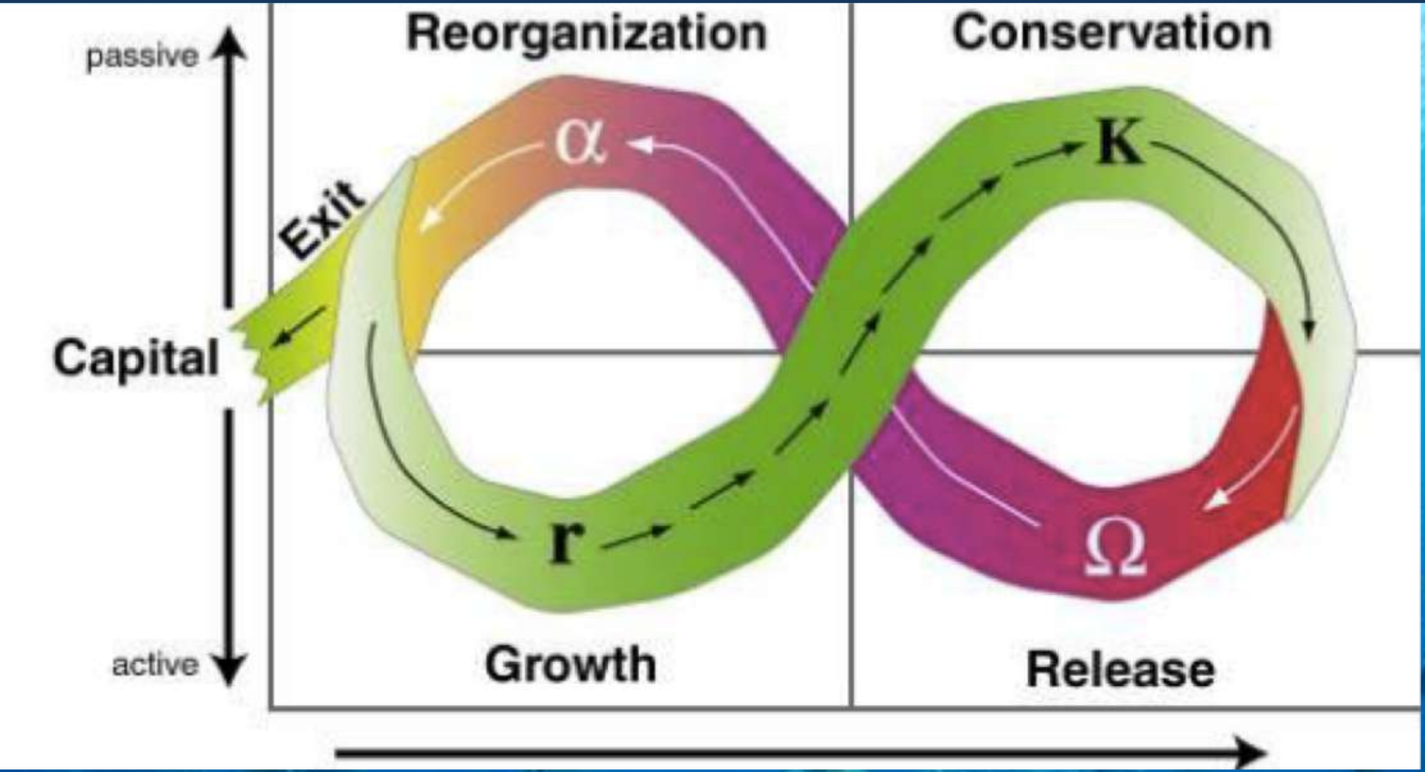
Rapid growth with r species, resources are available and not capitalized. Connection among species are limited. This is the phase in which the system is forming and structuring.

Conservation



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

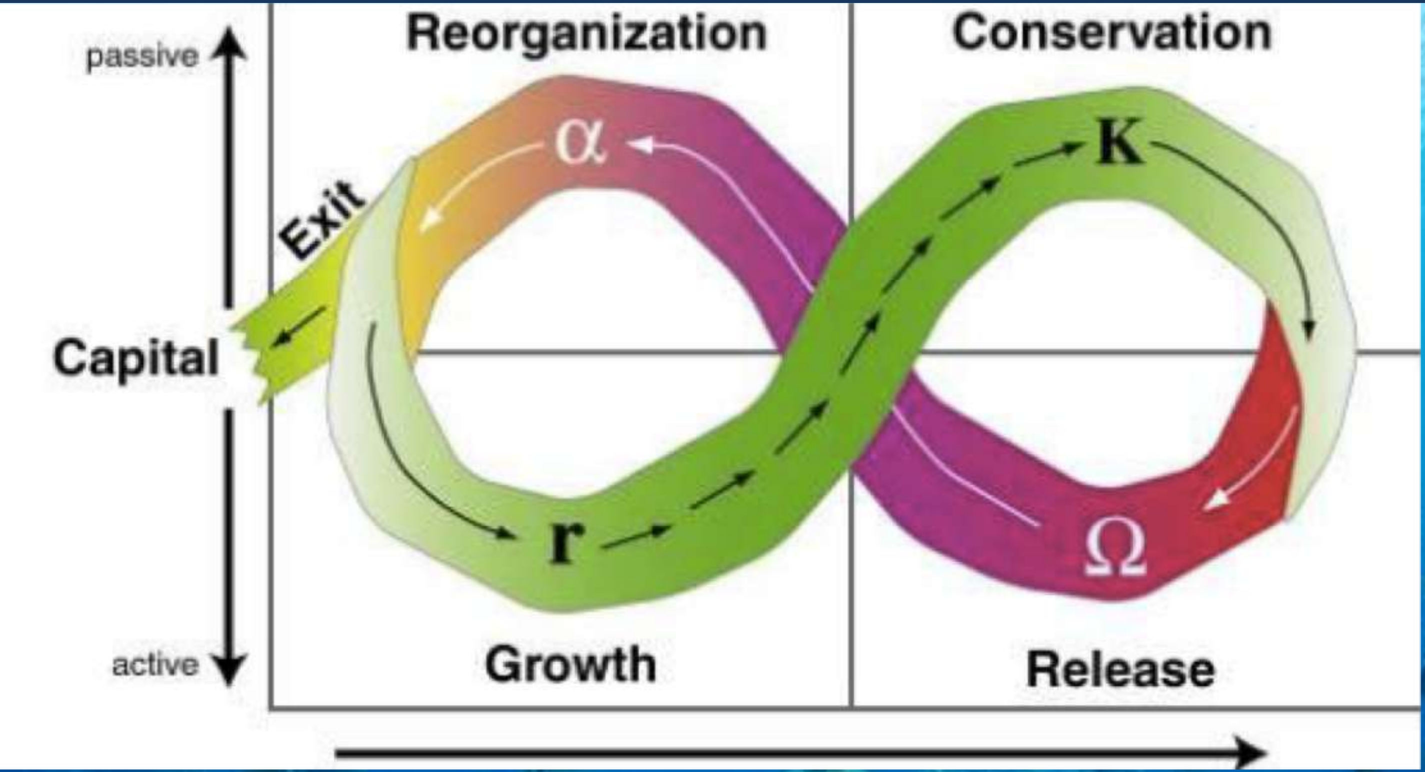
Release



connectivity

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

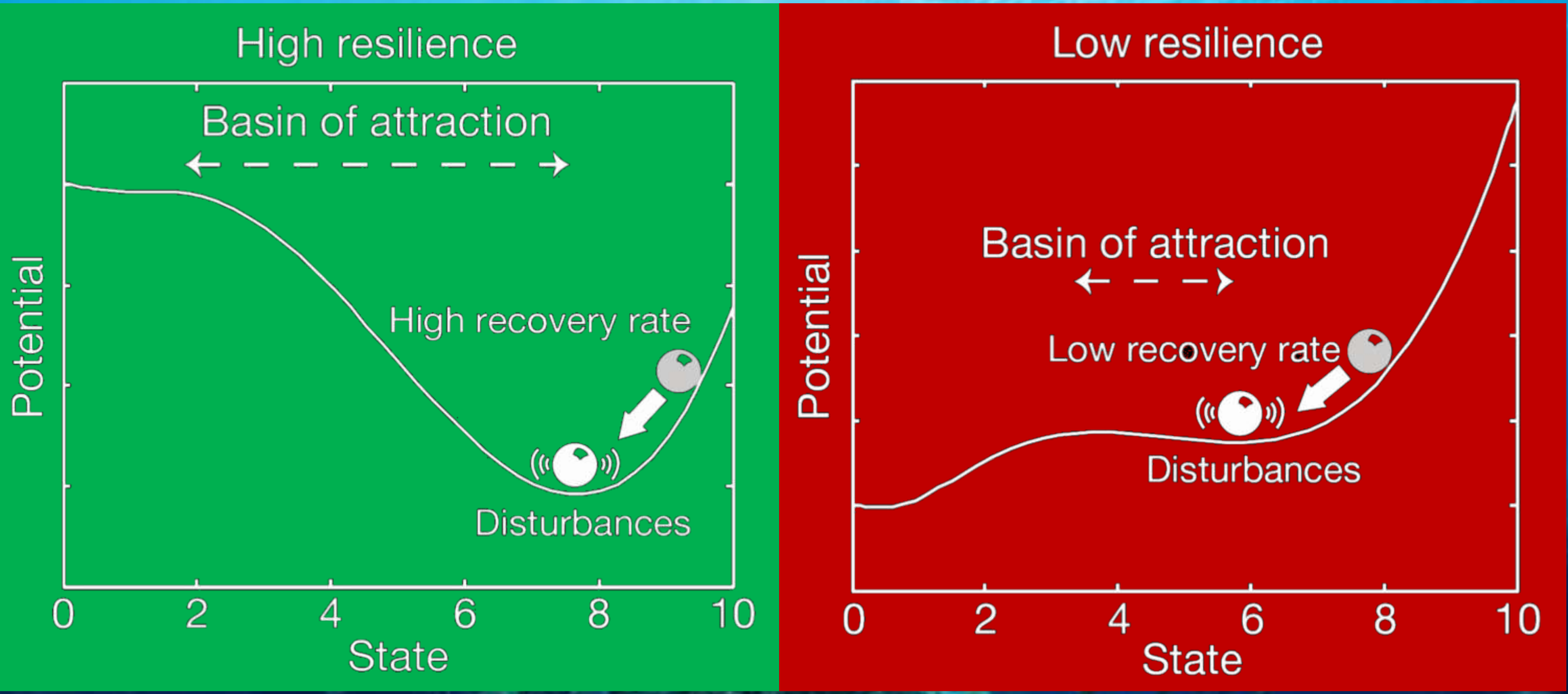
Reorganization



Resources are available for reorganizing the system, to restablish the original structure and connections passing by a new growth phase…or shifitng towards a different regime

Ecosystem stability

Modified from Scheffer et al., 2009



Decreasing stability

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*.

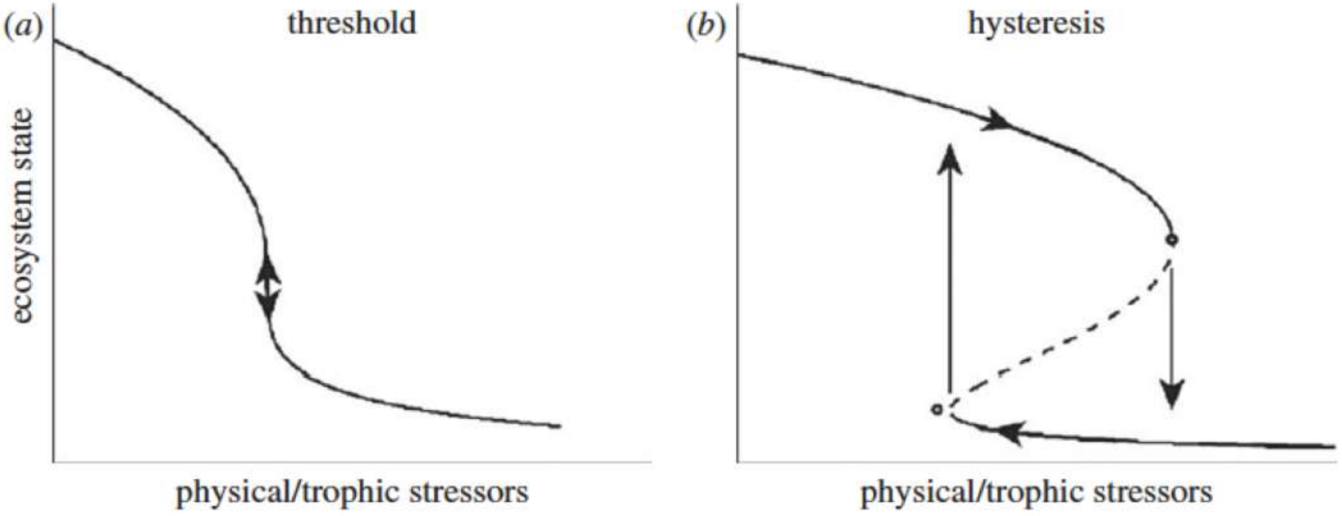
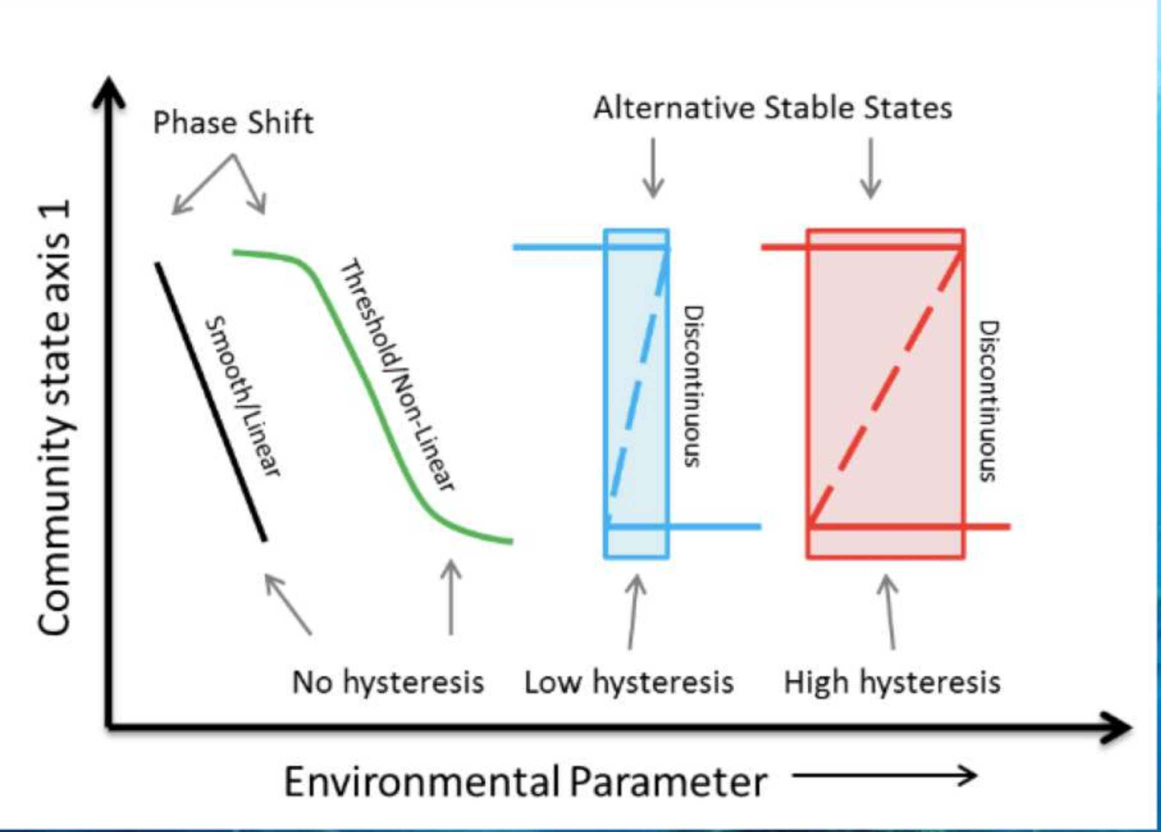


Figure 1. Examples of regime shift. Two different responses are shown, one without (*a*), and the other with hysteresis (*b*), both of which are encompassed by our working definition of regime shifts (adapted from [5]).

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

Phase shifts

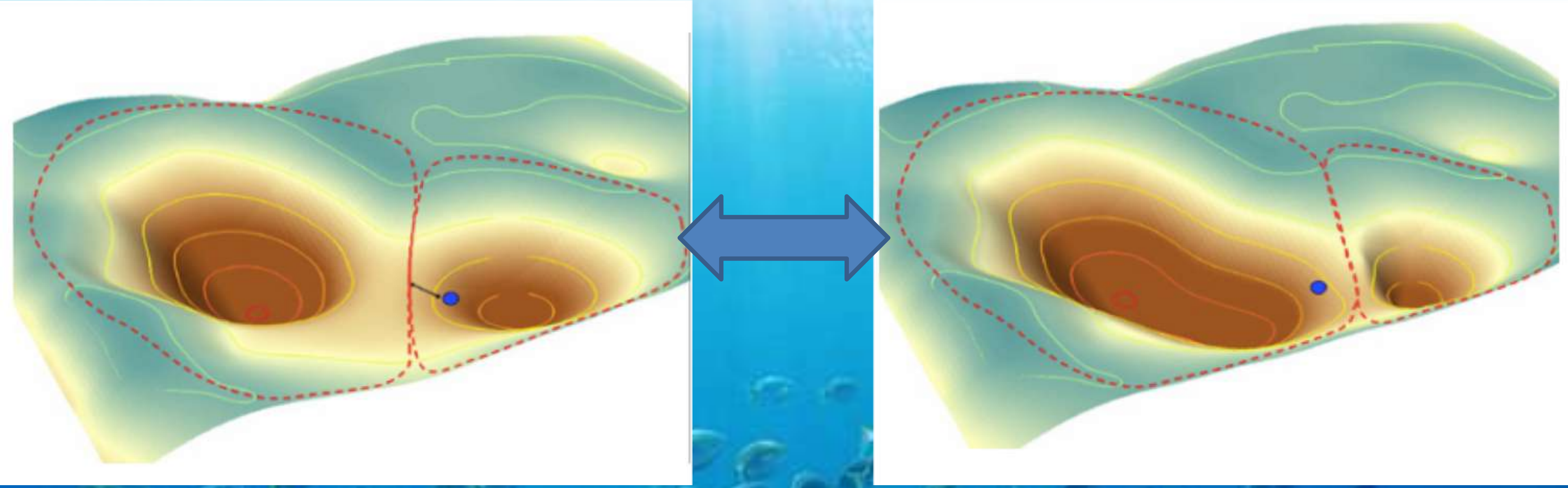


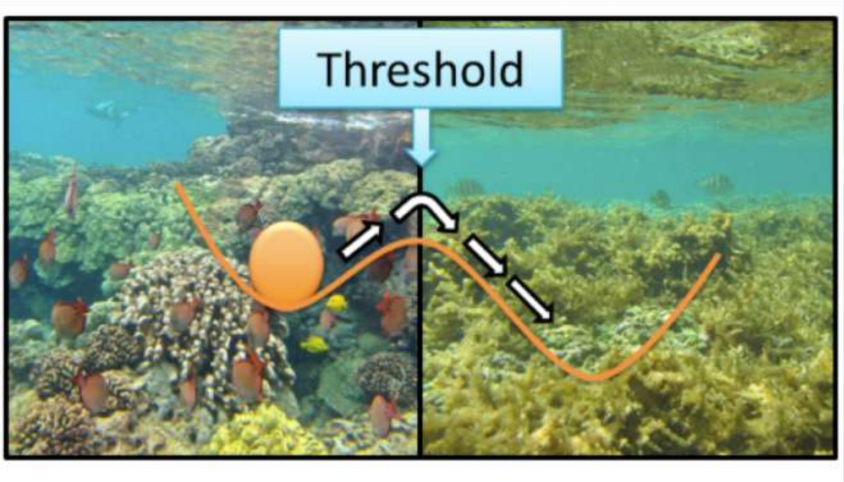
Smooth or Linear- characterized by a linear or nearly linear relationship between the stressor (e.g. fishing effort) and the ecosystem state (e.g. fish abundance) variables

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

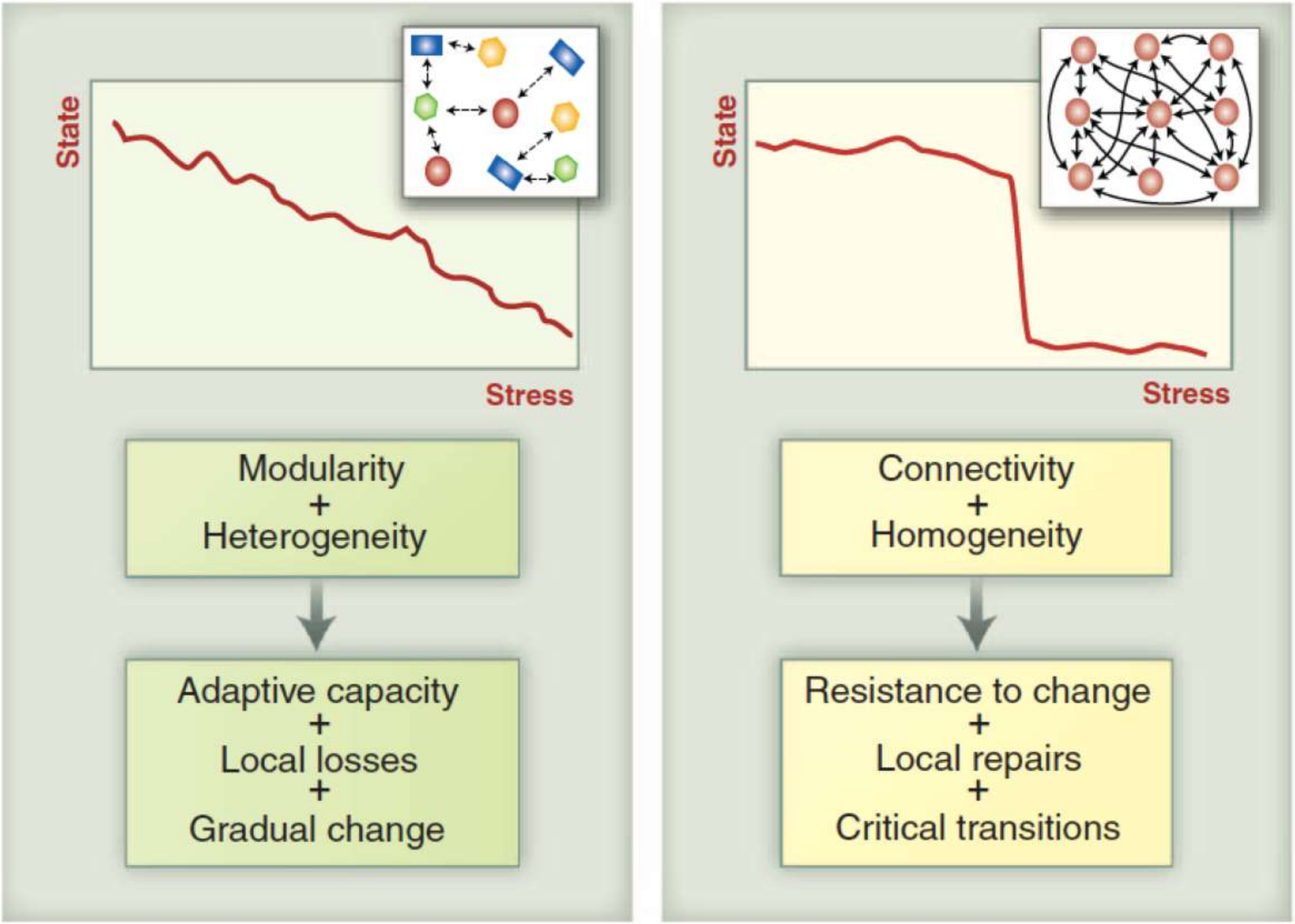
Phase shifts





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

Architecture of fragility



Modularity
+
Heterogeneity

Adaptive capacity
+
Local losses
+
Gradual change

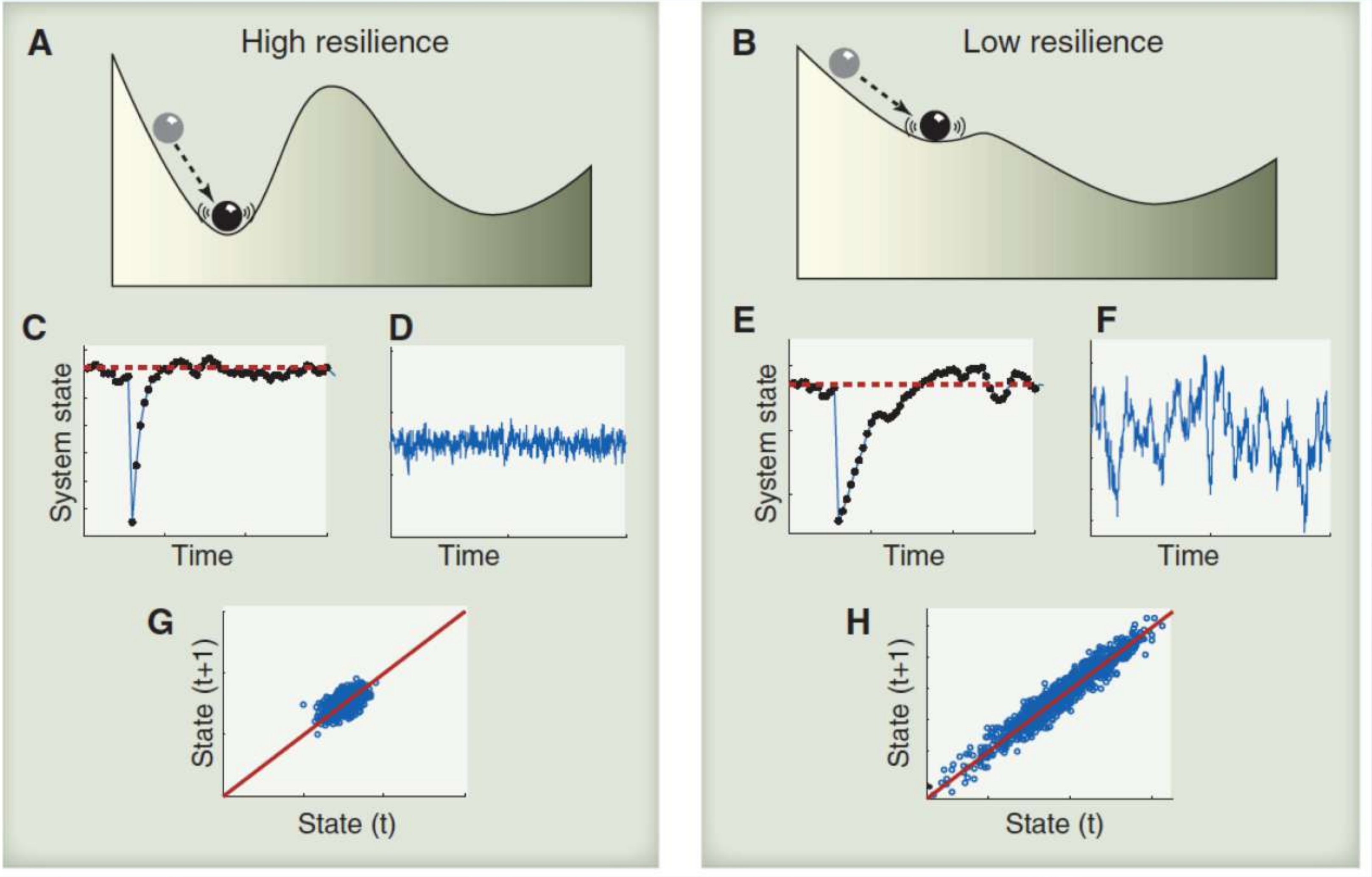
Connectivity
+
Homogeneity

Resistance to change
+
Local repairs
+
Critical transitions

The connectivity and homogeneity of the units affect the way in which distributed 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



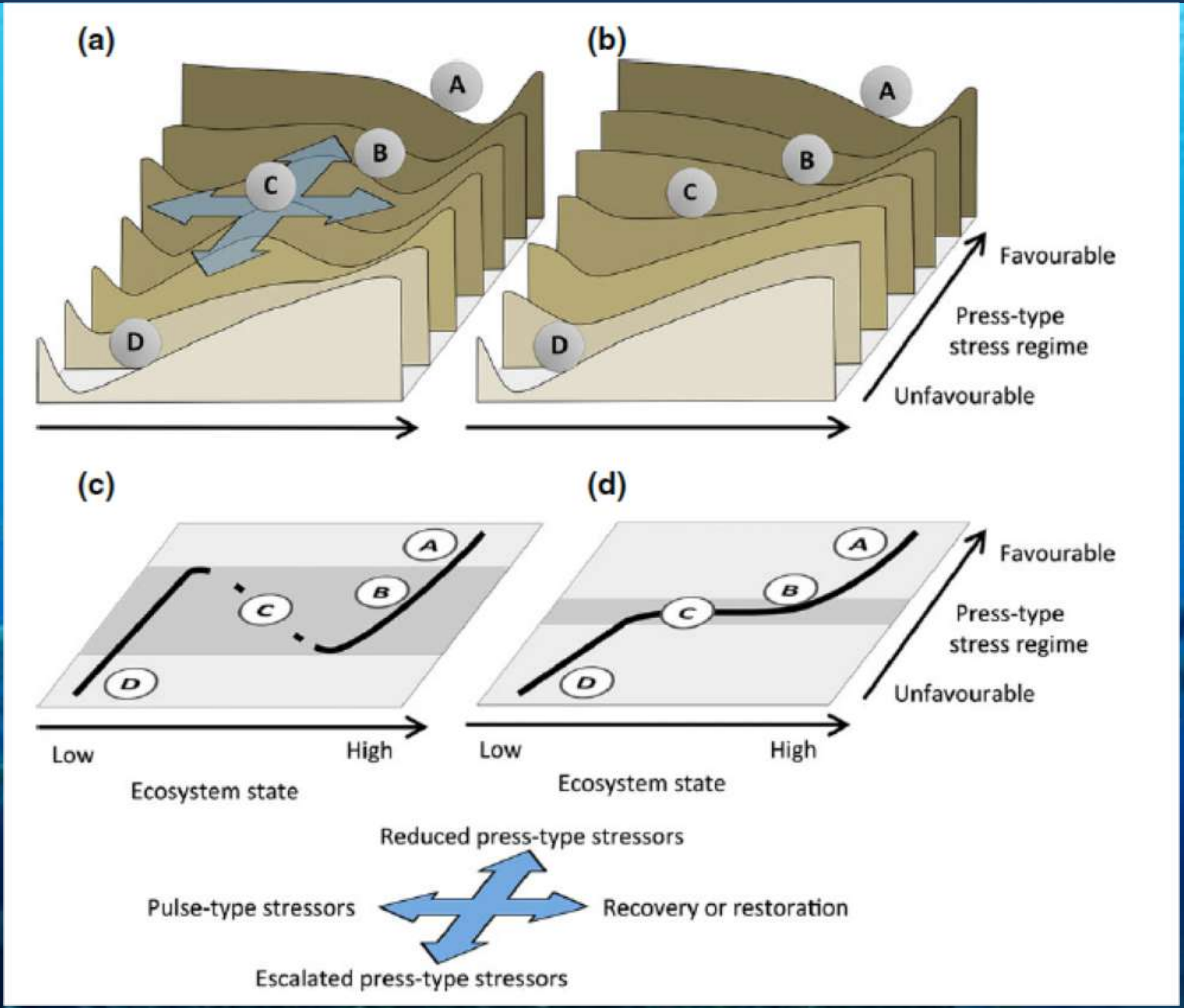
Scheffer et al 2012

Slowing down recovery **Autocorrelation** **Increased variance**

Flickering between alternative states

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



As the case on the left. However, no bifurcation. The system gradually change from A to the worse state

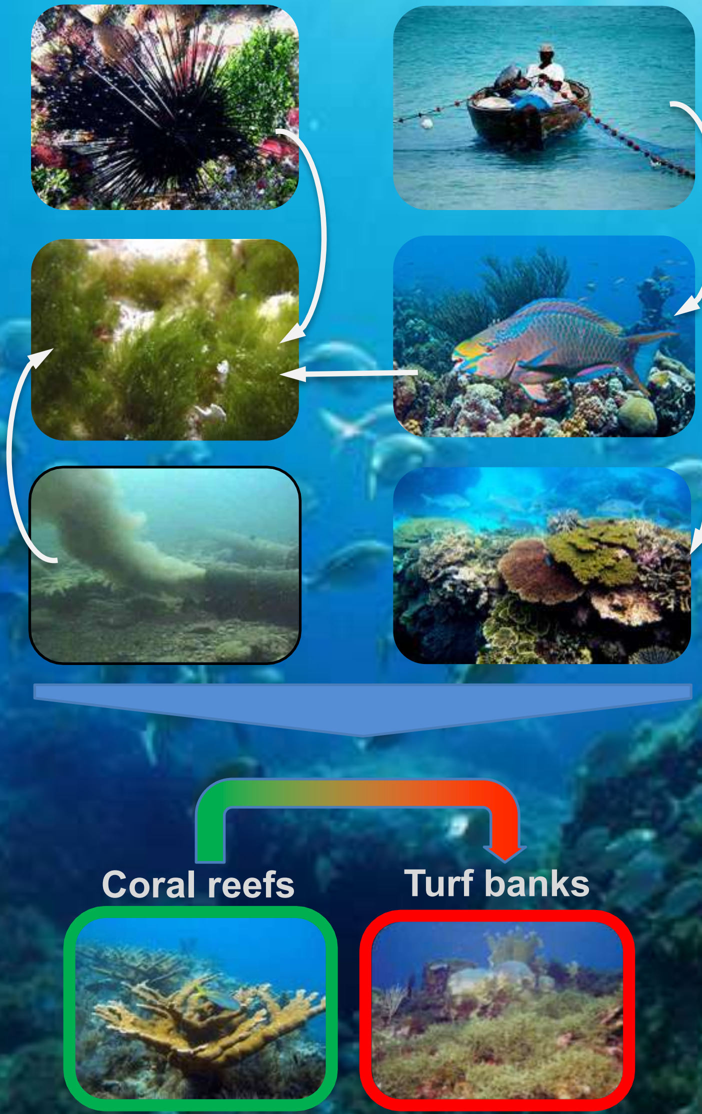
Anthony et al., 2015

Regime shifts: Aleutian Archipelago

Potential effects of warming period at the end of 70s. Decrease in phytoplankton and consequently of zooplankton. Bottom up effects on herrings and planktivore fish, reduction of marine mammals. Increase in salmon, attracting sharks.

This copupled with overfishing, and reduction of marine mammals. Attracting orcas towards otters. Predation release on sea urchins that increased their population. Grazing pressure increased with consequent collapse of kelp forests

Regime shifts: Caribbean reefs



Coral reefs

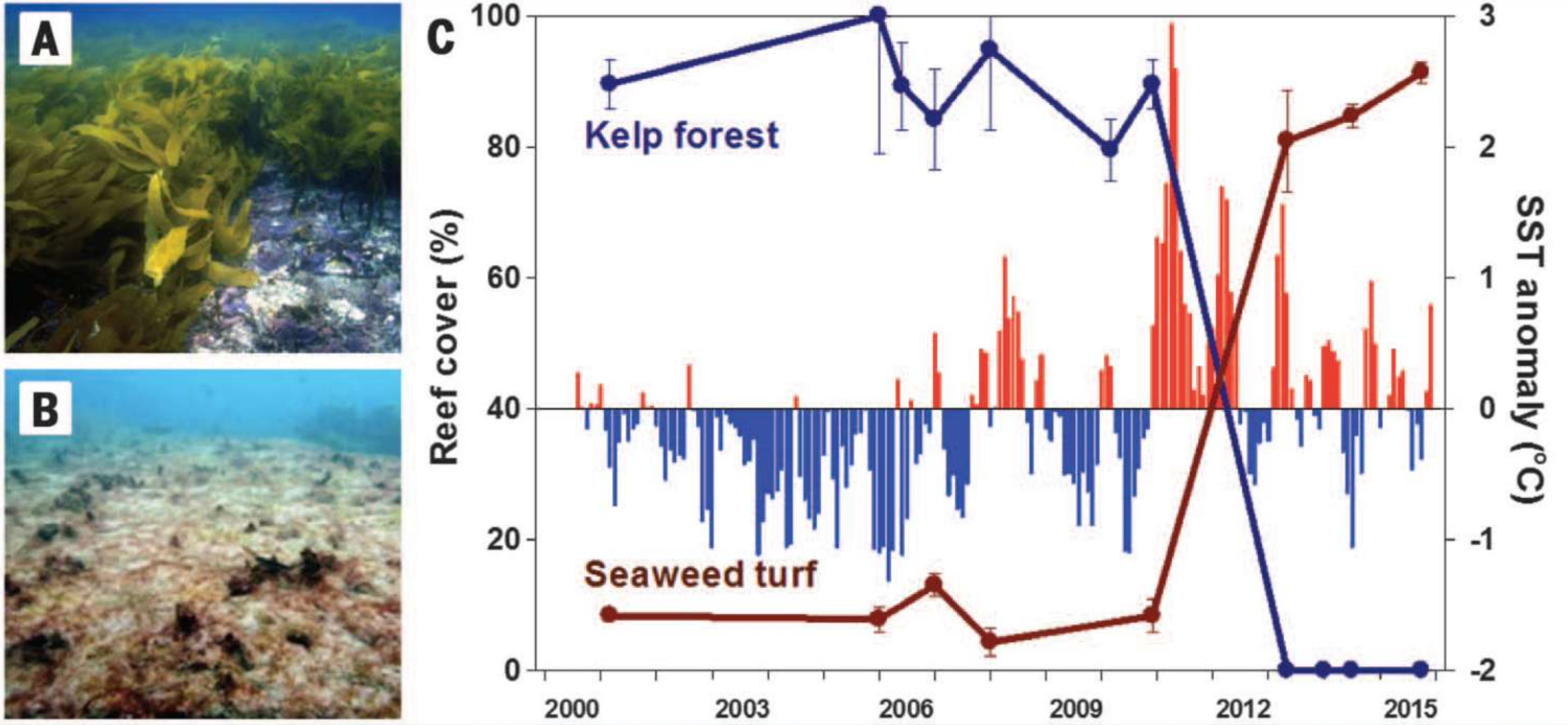
Turf banks

Caribbean Sea, from the 70s until now. Again, overfishing and exploitation of corals damaged the reef. Herbivore fish were exploited as commercial targets. These species controls turf algae on the reefs avoiding excessive proliferation of these competitors of corals. Fortunately, reduction of fish population and their herbivory was compensated by sea urchins, which allowed to maintain low abundance of turf forming algal species. However, extreme atmospheric events further damaged the reefs, and also nutrient enrichment from human discharge stimulate algal production. Finally, a disease drastically reduced sea urchin populations and algal blooms were out of control.

Regime shifts: SW Australia kelp

Extreme marine heat waves forced a 100-kilometer range contraction of extensive kelp forests and saw temperate species replaced by seaweeds, invertebrates, corals, and fishes characteristic of subtropical and tropical waters.

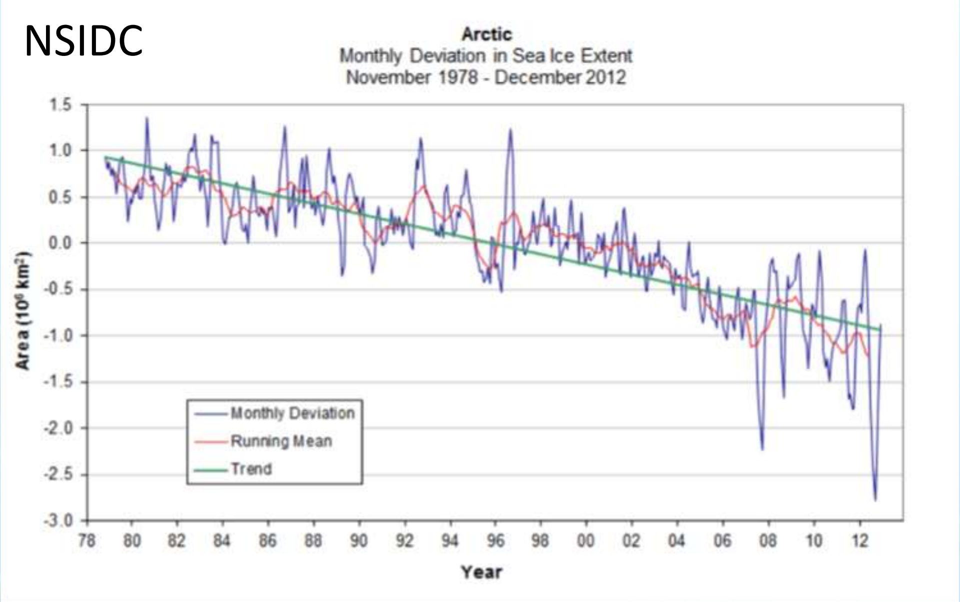
Wernberg et al. 2016

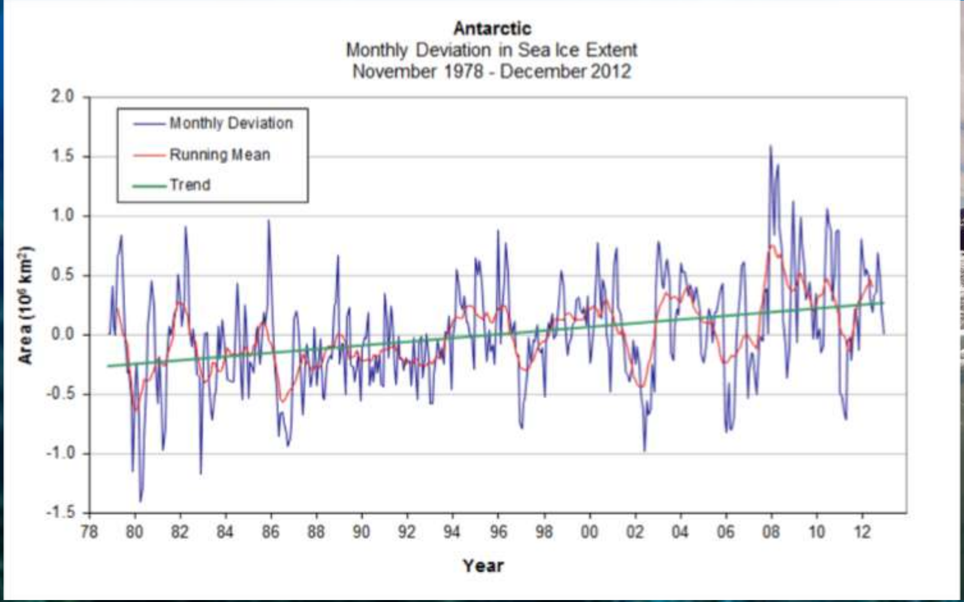


Shifts and drivers

regime shift name	key drivers	ecosystem services impacted
Arctic sea ice	atmospheric CO_2	water cycling
	global warming	biodiversity
	greenhouse gases	fisheries
	temperature	wild animal and plant foods
		climate regulation
		water purification
		water regulation
		aesthetic values
		knowledge and educational values
		spiritual and religious

Major threats to polar ecosystems


NSIDC



Global warming

Global warming is causing a fast reduction in ice cover especially in northern polar region. Antarctic ice seems more stable, or slighly increasing. However, some areas in the southern ocean are experiencing a decreasing trend.

Habitat destruction for seals and bears with consequent loss of feeding grounds and refuge

Decrease in primary productivity and risk of cascading effects

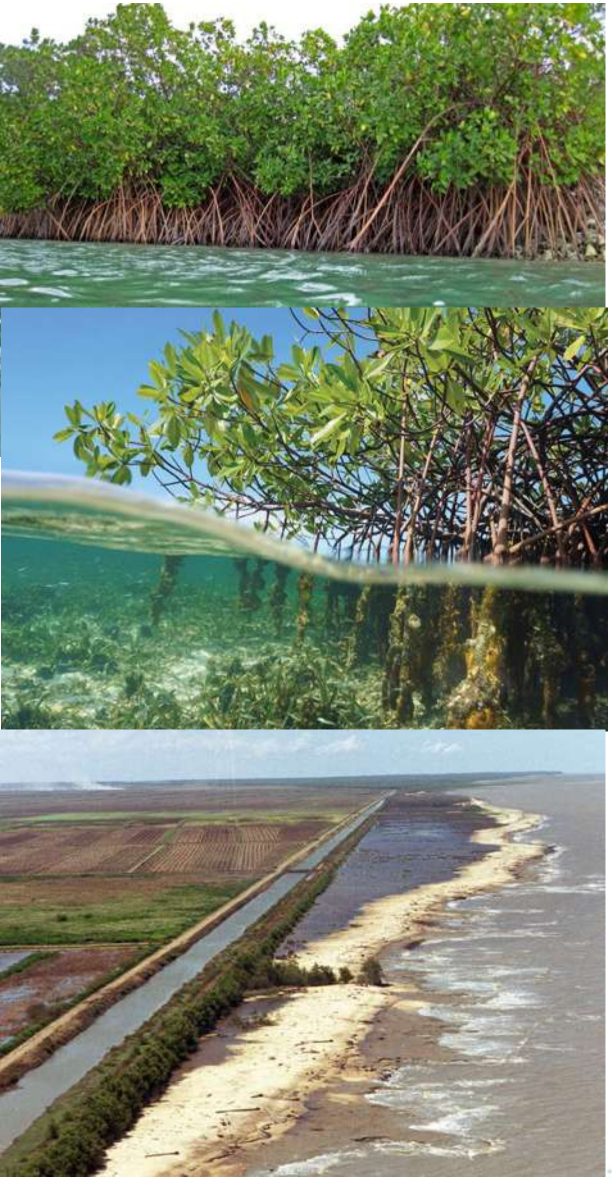
Earlier spring sea ice retreat and later fall sea ice formation

Shifts in species composition and northward faunal range expansions

Grebmeier 2012

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

Consequences

Loss of biodiversity due to habitat destruction. Moreover, without a barrier of mangroves low lying countries (e.g. Bangladesh) are more susceptible to flooding and devastation by cyclones. Loss of mangroves could severely impact economies that rely on tourism and fisheries.

Mangrove forests was estimated at 137,760 km^2 in the year 2000, marking an approximate decrease of 35% from 1980 estimates (Giri et al. 2011). Moreover, the rate of decrease of global mangrove forests was larger than or equal to the rates measured for coral reefs or tropical rainforests (Duke et al. 2007).

A sad story

Indonesia’s mangrove area shrank from about 41,000 km^2 in 1800 to 31,000 km^2 today, mostly because of shrimp aquaculture (Joffre et al. 2015)

How unsustainable economy turns into ecological disaster and social deprivation

Shifts and drivers

key drivers

- atmospheric CO_2
- deforestation
- disease
- fishing
- infrastructure development
- nutrient input
- rainfall variability
- sea-level rise
- sediments
- sewage
- temperature
- urbanization

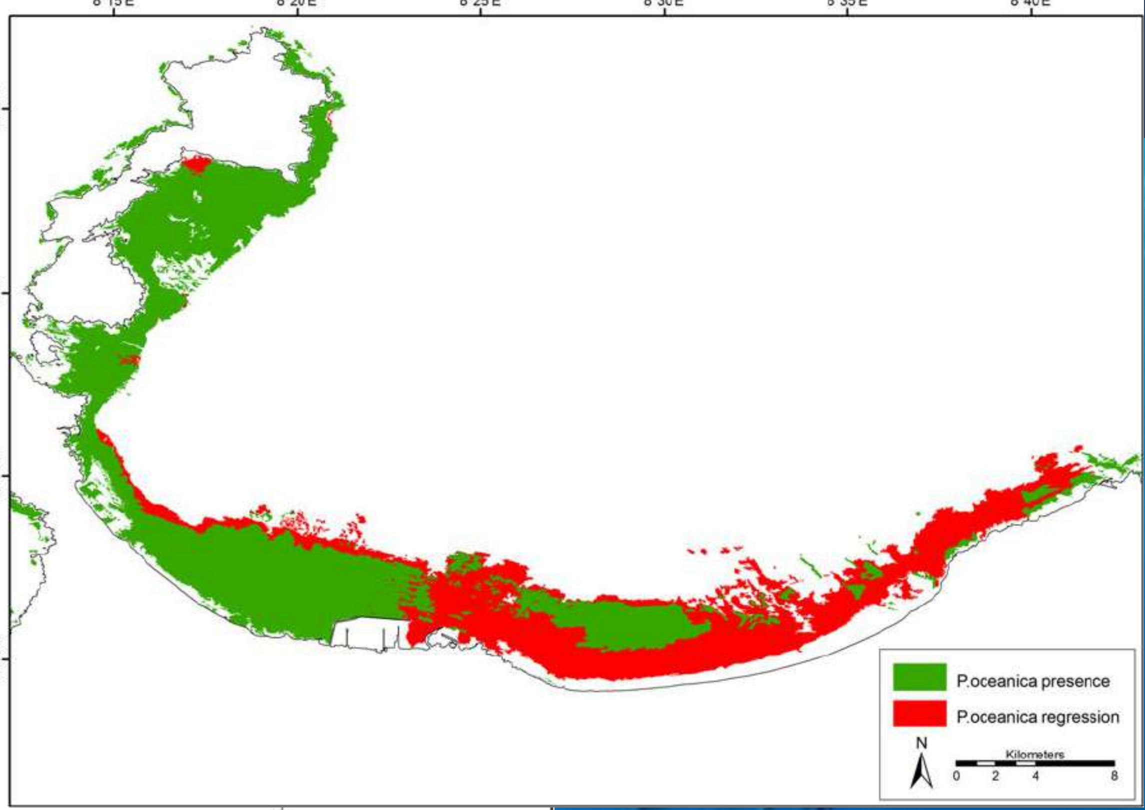
ecosystem services impacted

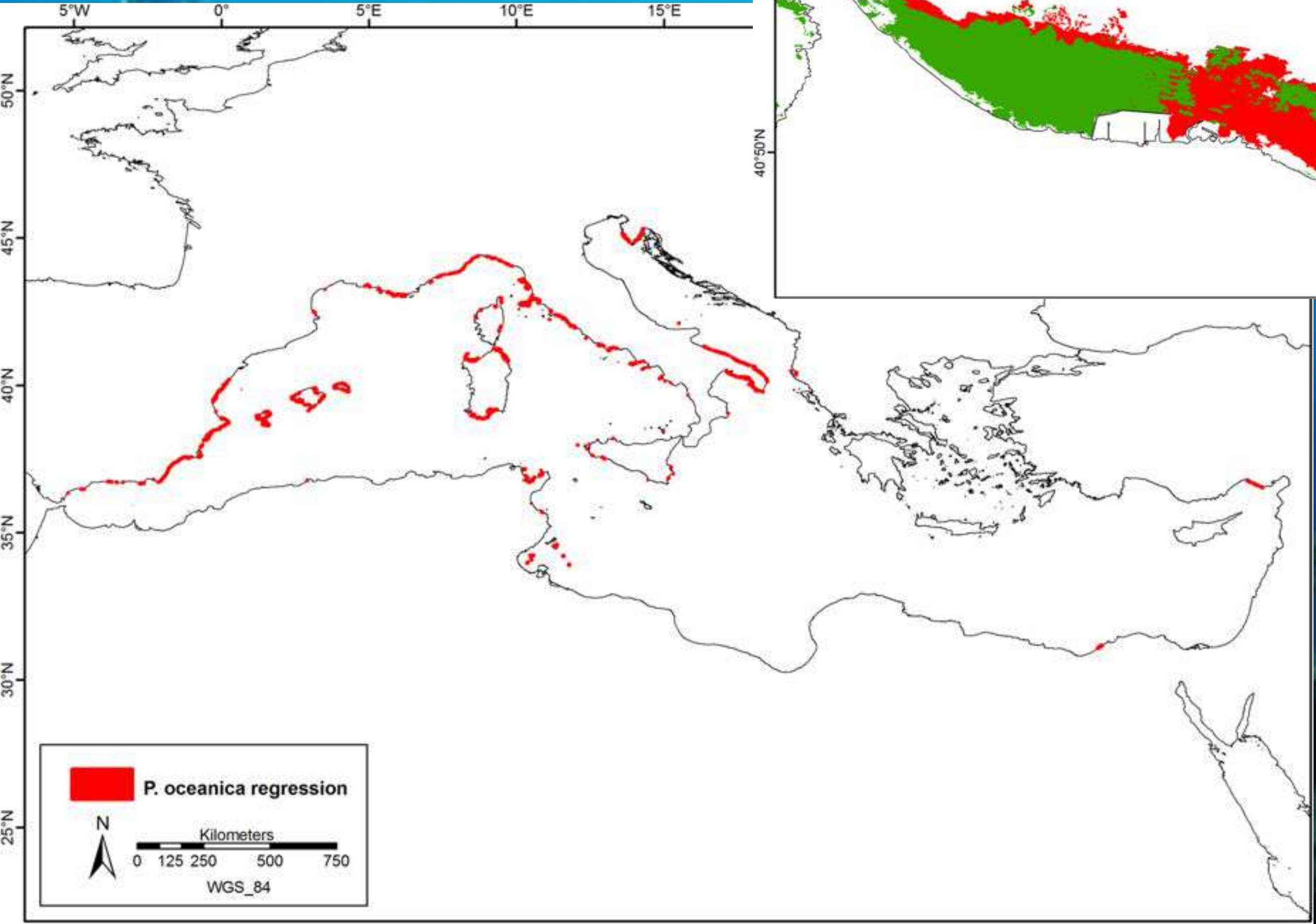
- primary production
- nutrient cycling
- biodiversity
- fisheries
- wild animal and plant foods
- climate regulation
- water purification
- regulation of soil erosion
- natural hazard regulation
- recreation
- aesthetic values


rossella baldacconi

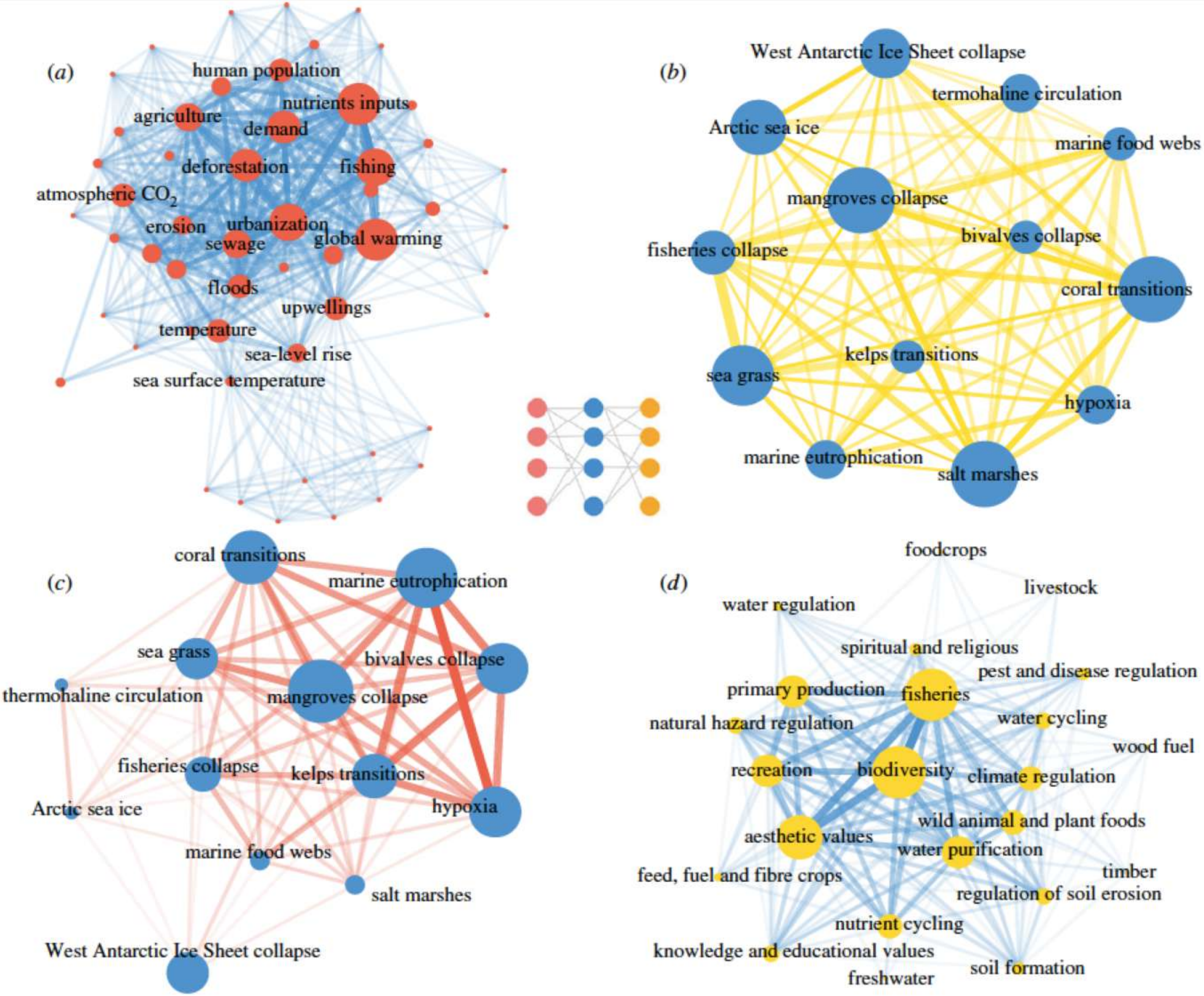
Current status

Seagrass regression may be due to natural processes and/or natural or anthropogenic disturbances and stress.
It can also be due to long-term climate trends.

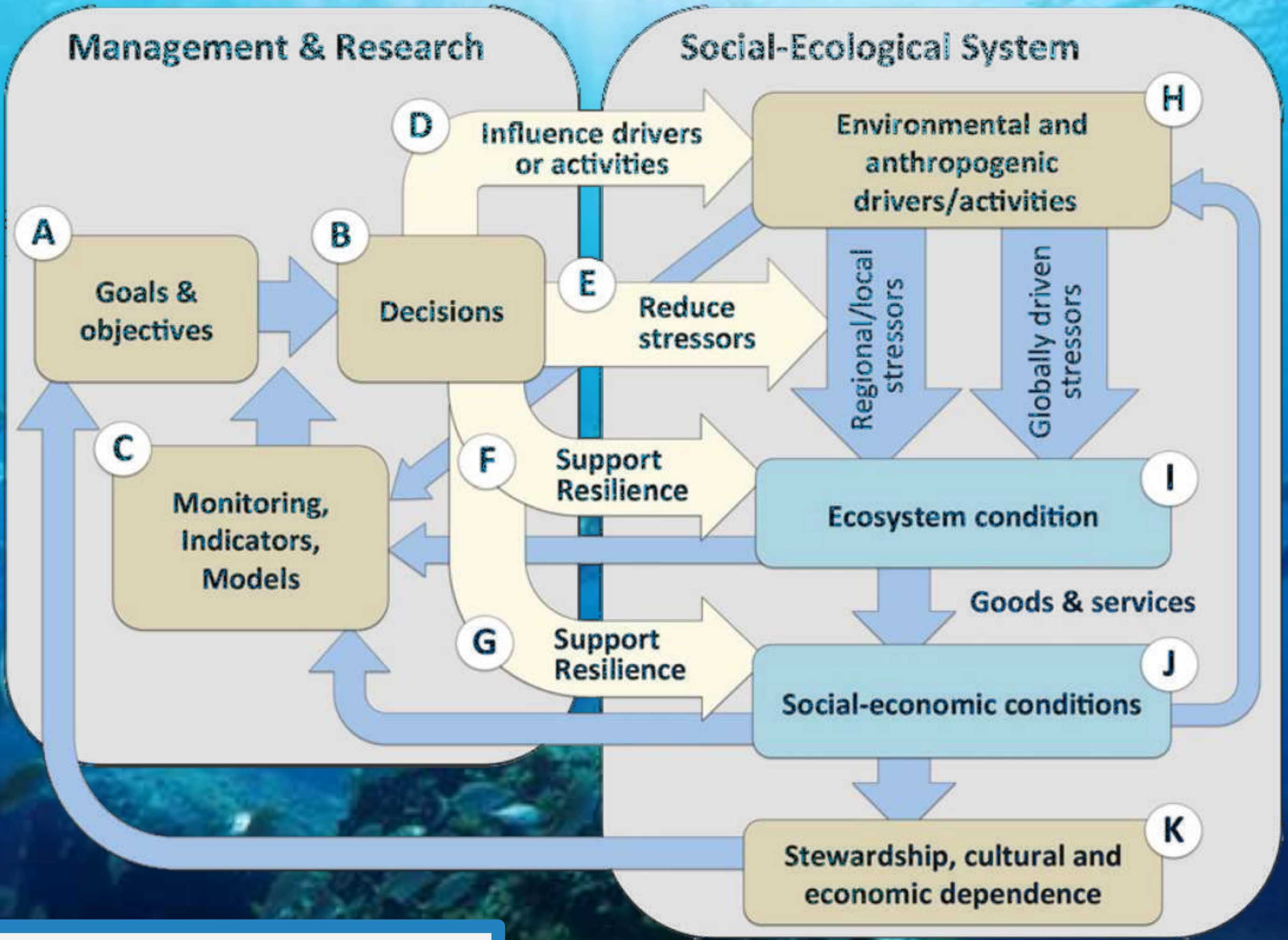




Human-induced losses of *P. oceanica* have been mainly related to coastal development, pollution, trawling, fish farming, moorings, dredging, dumping and introduced species.


(a)
human population
nutrients inputs
agriculture
demand
deforestation
fishing
atmospheric CO_2
erosion
urbanization
sewage
global warming
floods
upwellings
temperature
sea-level rise
sea surface temperature
(b)
West Antarctic Ice Sheet collapse
termohaline circulation
Arctic sea ice
marine food webs
mangroves collapse
bivalves collapse
fisheries collapse
coral transitions
kelps transitions
sea grass
hypoxia
marine eutrophication
salt marshes
(c)
coral transitions
marine eutrophication
sea grass
bivalves collapse
thermohaline circulation
mangroves collapse
fisheries collapse
kelps transitions
Arctic sea ice
hypoxia
marine food webs
salt marshes
West Antarctic Ice Sheet collapse
(d)
foodcrops
livestock
water regulation
spiritual and religious
pest and disease regulation
primary production
fisheries
natural hazard regulation
water cycling
wood fuel
recreation
biodiversity
climate regulation
wild animal and plant foods
aesthetic values
water purification
timber
feed, fuel and fibre crops
regulation of soil erosion
nutrient cycling
knowledge and educational values
freshwater
soil formation

Management



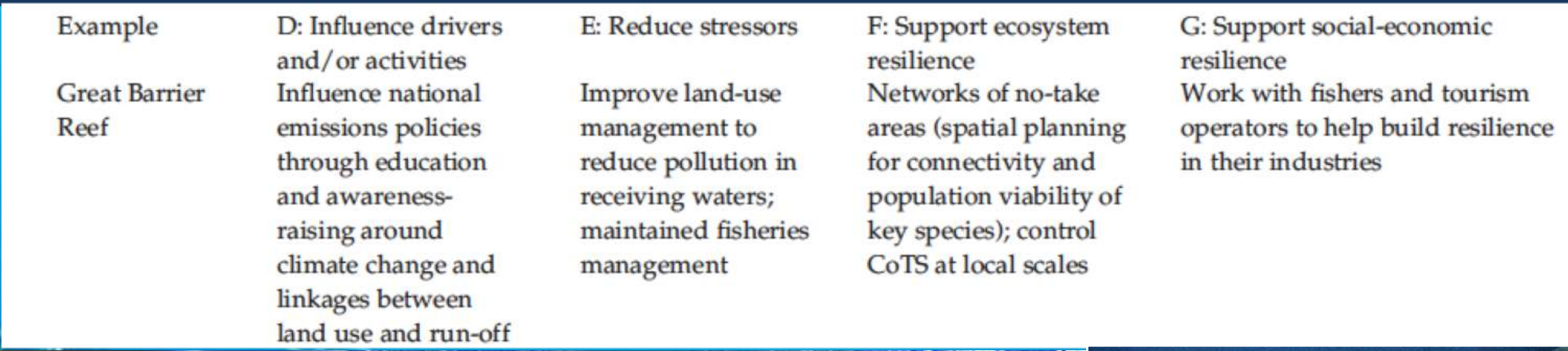
Reduce anthropogenic stressors

Support system’s resilience

Monitoring the state of systems

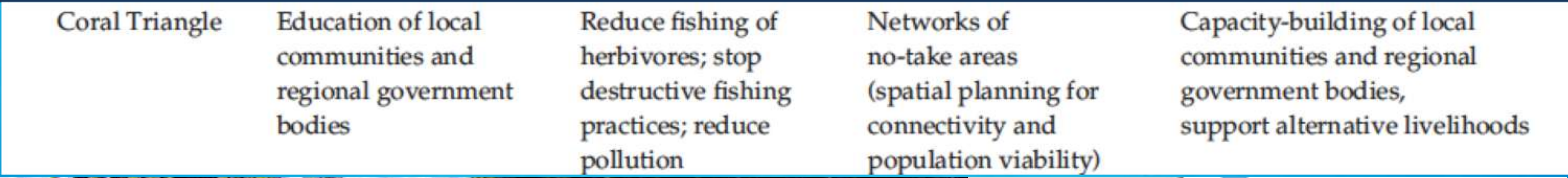
Anthony et al., 2015

Management

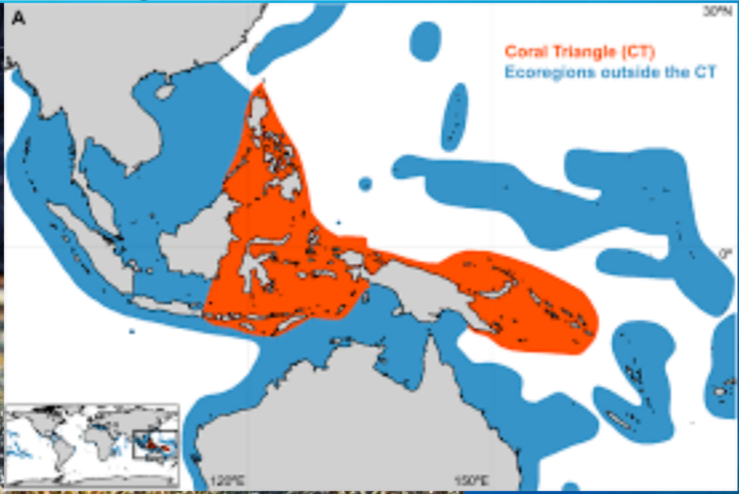


Example	D: Influence drivers and/or activities	E: Reduce stressors	F: Support ecosystem resilience	G: Support social-economic resilience
Great Barrier Reef	Influence national emissions policies through education and awareness-raising around climate change and linkages between land use and run-off	Improve 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

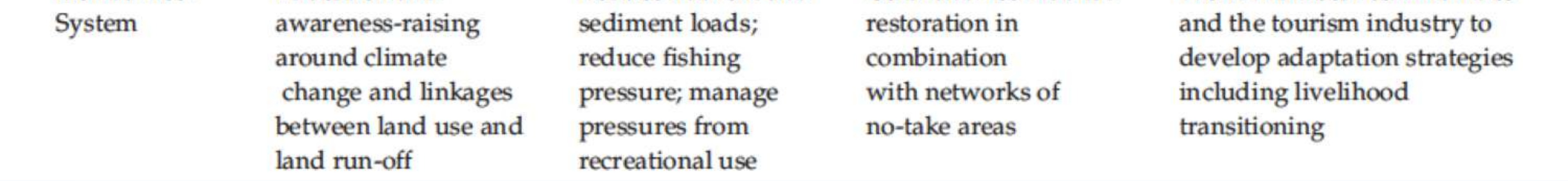
Management



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

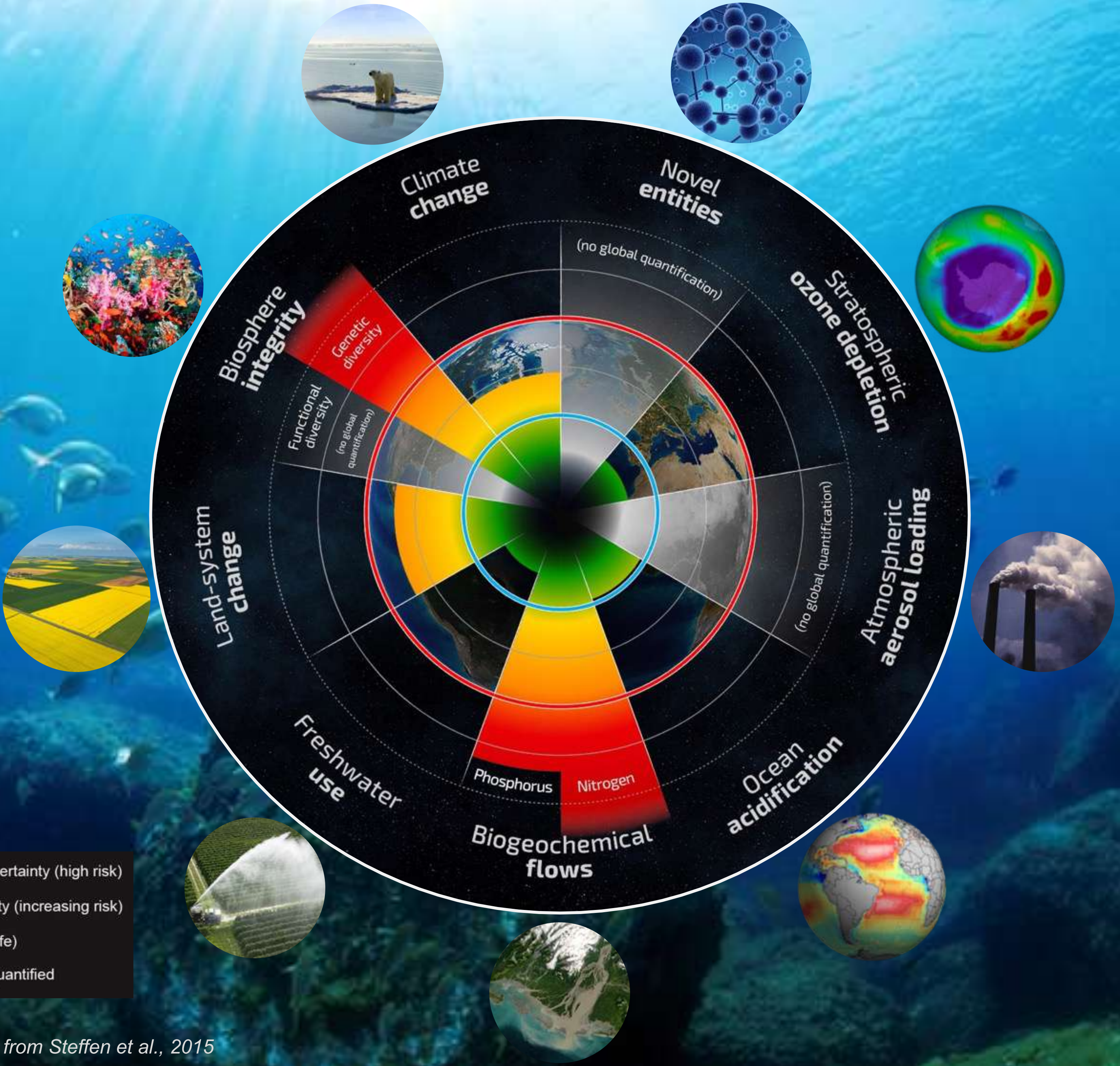


Management



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

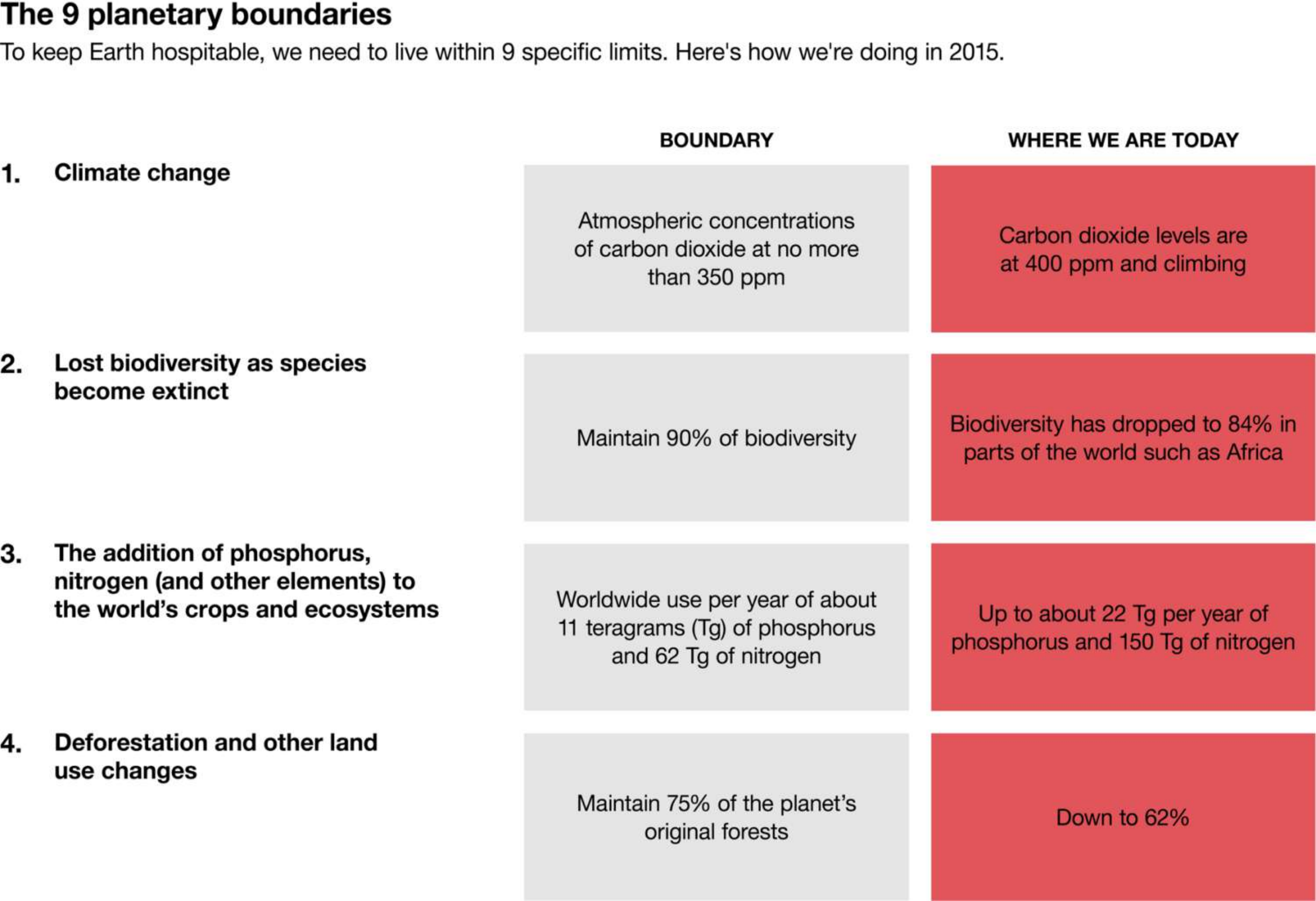
Planetary boundaries



🟥 Beyond zone of uncertainty (high risk)
🟧 In zone of uncertainty (increasing risk)
🟩 Below boundary (safe)
⬜ Boundary not yet quantified

Modified from Steffen et al., 2015

Status



The 9 planetary boundaries

To keep Earth hospitable, we need to live within 9 specific limits. Here's how we're doing in 2015.

		BOUNDARY	WHERE WE ARE TODAY
1.	**Climate change**	Atmospheric concentrations of carbon dioxide at no more than 350 ppm	Carbon dioxide levels are at 400 ppm and climbing
2.	**Lost biodiversity as species become extinct**	Maintain 90% of biodiversity	Biodiversity has dropped to 84% in parts of the world such as Africa
3.	**The addition of phosphorus, nitrogen (and other elements) to the world's crops and ecosystems**	Worldwide use per year of about 11 teragrams (Tg) of phosphorus and 62 Tg of nitrogen	Up to about 22 Tg per year of phosphorus and 150 Tg of nitrogen
4.	**Deforestation and other land use changes**	Maintain 75% of the planet's original forests	Down to 62%

Status

5.	**Emission of aerosols (microscopic particles) into the atmosphere that affect climate and living organisms**	Global boundary unknown, but regional effects (such as on the South Asian Monsoon) occur when Aerosol Optical Depth (AOD) is more than 0.25	Up to 0.30 AOD over South Asia, but probably well inside (or below) the boundary over most of the globe
6.	**Stratospheric ozone depletion**	Less than 5% below pre-industrial level of about 290 Dobson Units (DU)	Still safely inside the boundary except over Antarctica during spring, when levels drop to 200 DU
7.	**Ocean acidification**	When the oceans become acidic enough that the minerals sea creatures need to make shells, such as aragonite, begin to dissolve	Still within the boundary, which won't be crossed if we can stay within the climate boundary of 350ppm of CO2 in the atmosphere
8.	**Freshwater use**	Can use up to 4000km^3 of freshwater a year	We use around 2600 km^3 of freshwater per year
9.	**Dumping of organic pollutants, radioactive materials, nanomaterials, micro-plastics, and other novel or man-made substances into the world's environment**	Unknown	Unknown

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?