Cours « Planetary boundaries »

UE CERES Ecologie du développement durable
David Claessen

www.environnement.ens.fr
Ecole Normale Supérieure
24 rue Lhomond, 75005 Paris, Rez-de-chaussée, bureaux E026

Histoire des idées

- 1798 **Malthus** « *population, croissance exponentielle, limitation* »
- 1805 **Von Humboldt** « *géographie des plantes* »
- 1809 **Lamarck** « *individu, évolution, transmutation* »
- 1838 **Verhulst** « *fonction logistique* »
- 1859 **Darwin**, **Wallace** « *biocénose, lutte pour la vie, sélection naturelle, fitness* »
- 1866 **Haeckel** « *écologie* »
- 1875 **Suess, Vernadsky** « *biosphère* »
- 1910 **Lotka, Volterra** « *écologie mathématique, cycles prédateur-proie* »
- 1911 **Cowles, Clements** « *succession écologique* »
- 1927 **Charles Elton** « *niche écologique, chaine trophique, écologie animale* »
- 1932 **Gause** « *principe d'exclusion compétitive* »
- 1935 **Tansley, Lindeman, Odum** « *écosystème* »
- 1947 **Lack** « *écologie évolutive* »
- 1957 **Hutchinson** « *niche écologique* »
- 1962 **Rachel Carson** « *environnement, environmentalism, écologisme* »
- 1963 **Holling, McArthur**, **Rosenzweig** « *réponse fonctionnelle, paradox of enrichment* »
- 1973 **Maynard-Smith** « *théorie des jeux, stratégie évolutivement stable (ESS)* »
- 1976 **McArthur, Wilson** « *la biogéographie insulaire* »
- 1969 **Levins** « *métapopulations* »
- 1976 **May** « *chaos* »
- 1977 **Westman, Ehrlich, Mooney, Costanza** « *ecosystem services* »
- 1988 **Wilson** « *biodiversité* »
- 2009 **Rocktrom, Steffen** « *planetary boundaries* »

Rockstrom et al (2009)

nature Vol 461|24 September 2009

FEATURE

A safe operating space for humanity

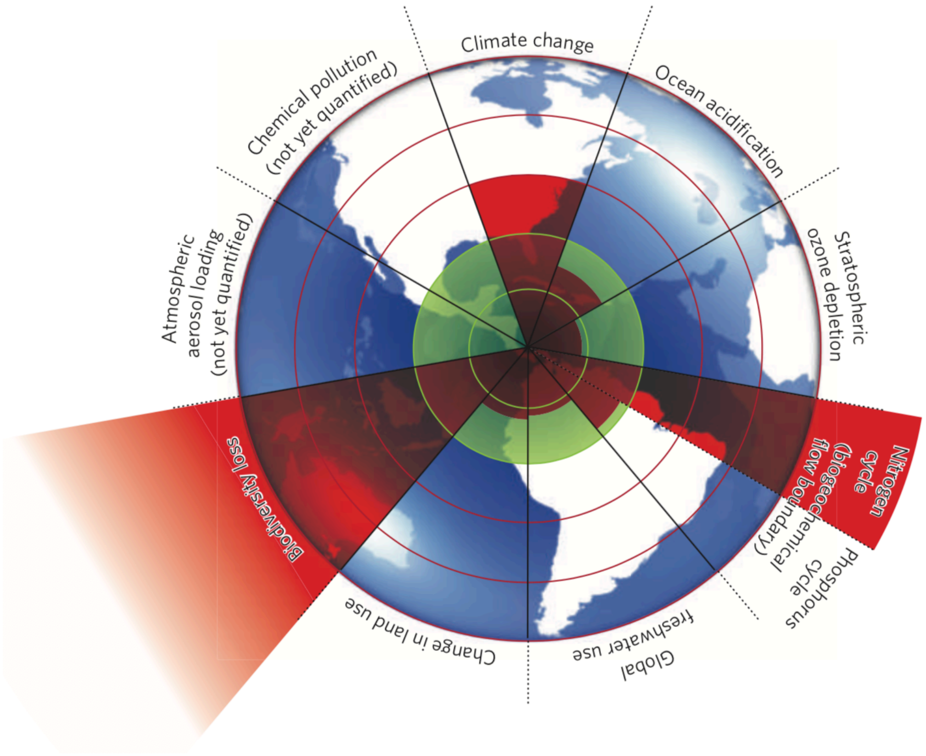


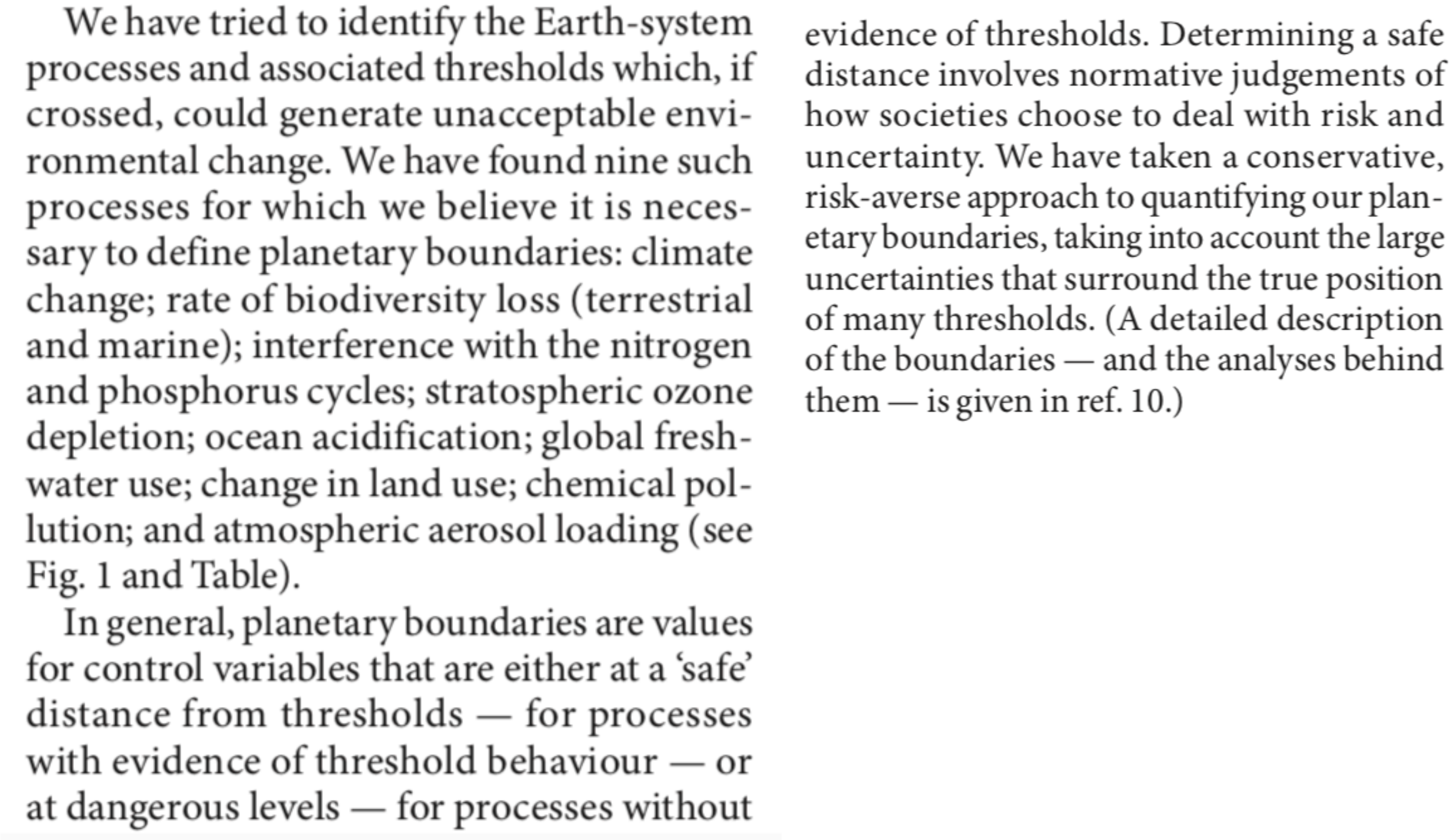
Figure 1 | Beyond the boundary. The inner green shading represents the proposed safe operating space for nine planetary systems. The red wedges represent an estimate of the current position for each variable. The boundaries in three systems (rate of biodiversity loss, climate change and human interference with the nitrogen cycle), have already been exceeded.

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].

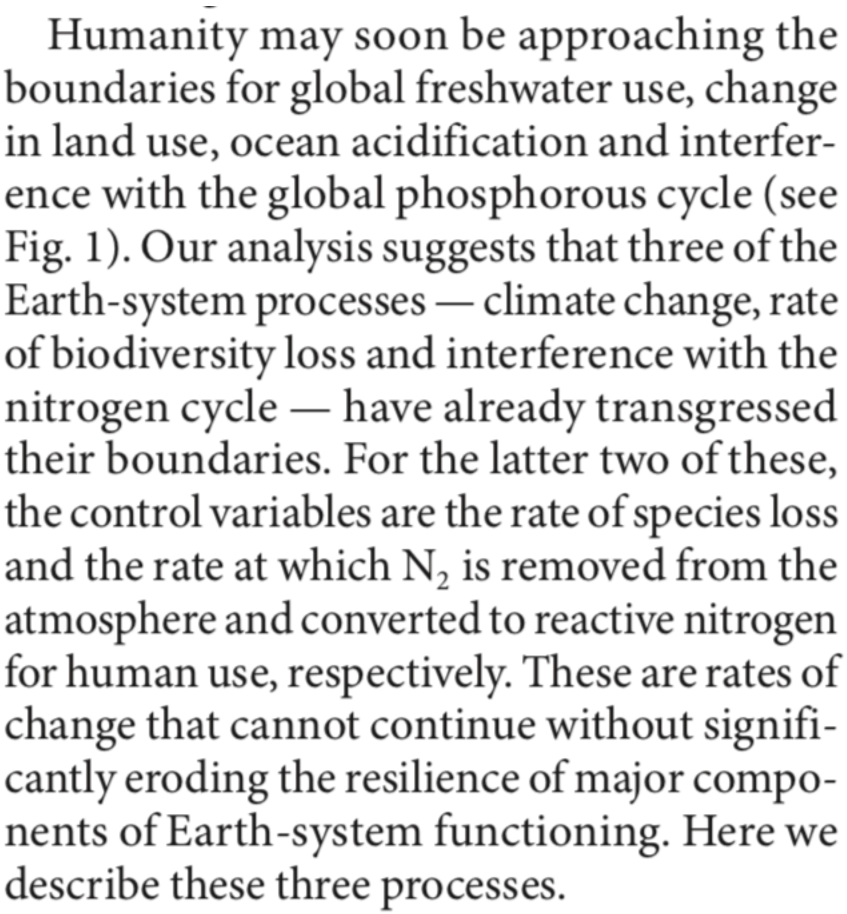
Most of these thresholds can be defined by a critical value for one or more control variables, such as carbon dioxide concentration. Not all processes or subsystems on Earth have well-defined thresholds, although human actions that undermine the resilience of such processes or subsystems — for example, land and water degradation — can increase the risk that thresholds will also be crossed in other processes, such as the climate system.

Rockstrom et al (2009)



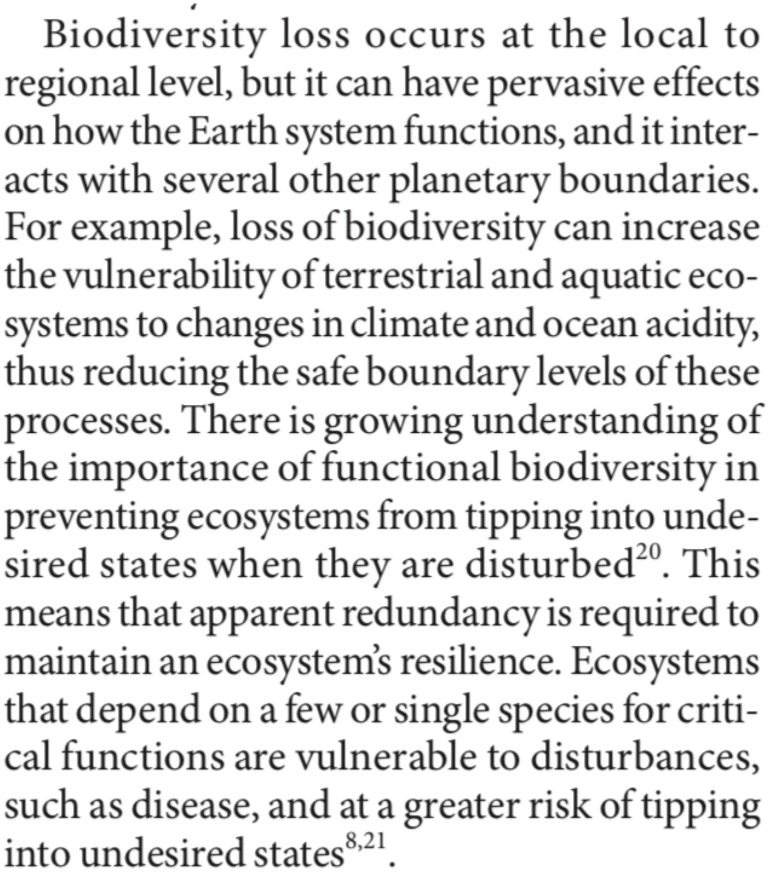
We have tried to identify the Earth-system processes and associated thresholds which, if crossed, could generate unacceptable environmental change. We have found nine such processes for which we believe it is necessary to define planetary boundaries: climate change; rate of biodiversity loss (terrestrial 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 evidence of thresholds. Determining a safe distance involves normative judgements of how societies choose to deal with risk and uncertainty. We have taken a conservative, risk-averse approach to quantifying our planetary boundaries, taking into account the large uncertainties that surround the true position of many thresholds. (A detailed description of the boundaries — and the analyses behind them — is given in ref. 10.)

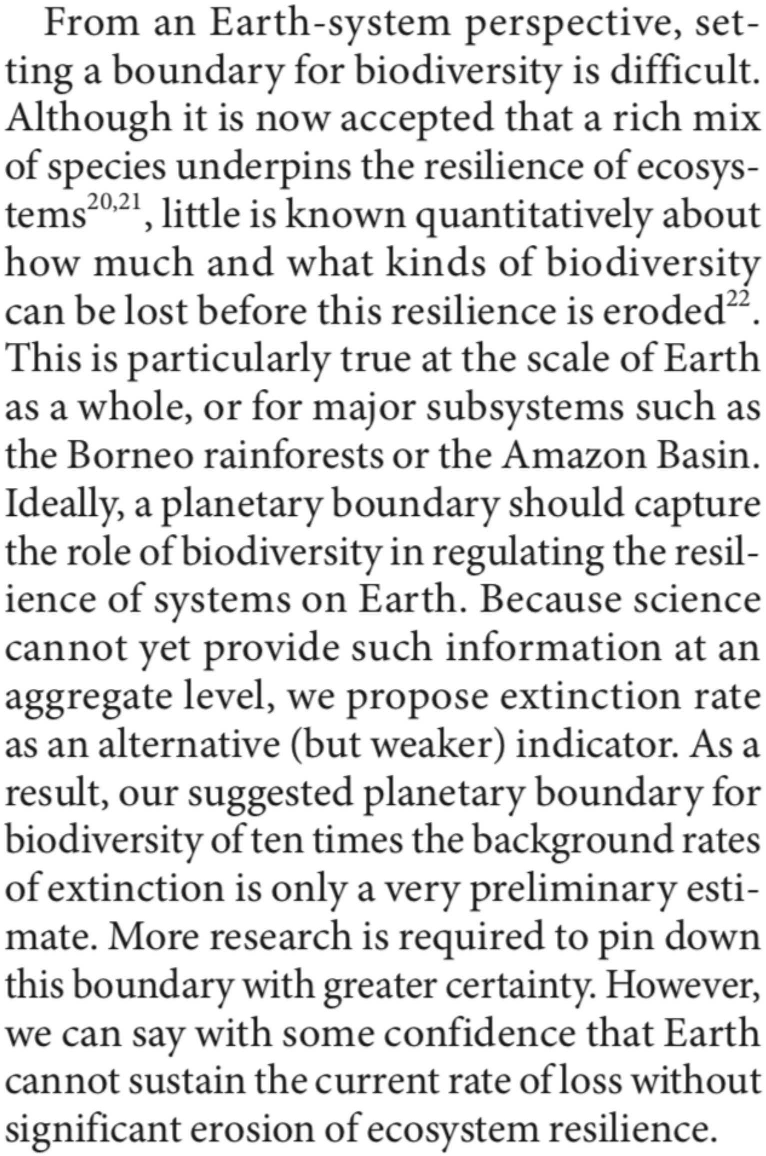


Humanity may soon be approaching the boundaries for global freshwater use, change in land use, ocean acidification and interference with the global phosphorous cycle (see Fig. 1). Our analysis suggests that three of the Earth-system processes — climate change, rate of biodiversity loss and interference with the nitrogen cycle — have already transgressed their boundaries. For the latter two of these, the control variables are the rate of species loss and the rate at which N_2 is removed from the atmosphere and converted to reactive nitrogen for human use, respectively. These are rates of change that cannot continue without significantly eroding the resilience of major components of Earth-system functioning. Here we describe these three processes.

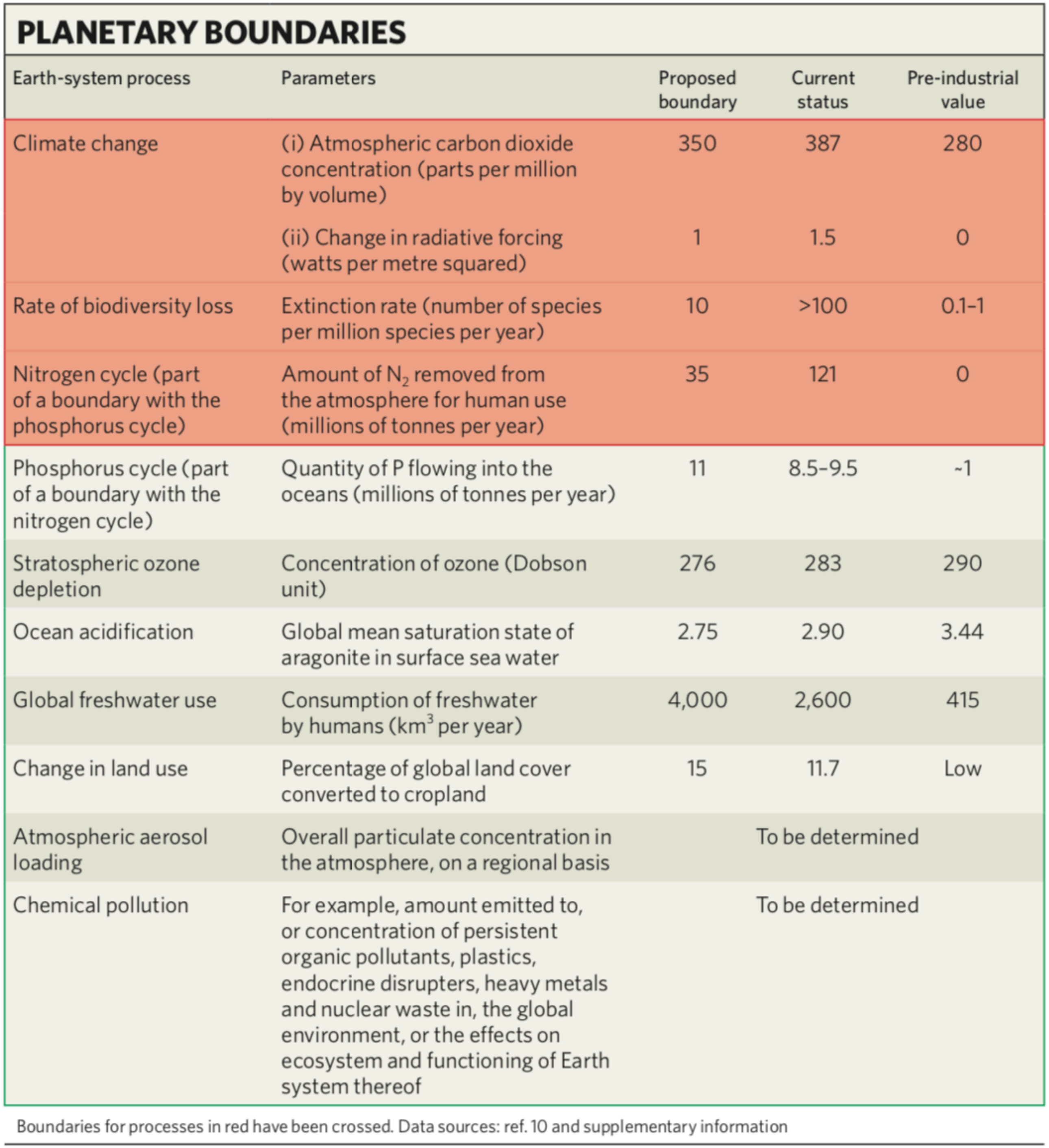
Biodiversity loss



Biodiversity loss occurs at the local to regional level, but it can have pervasive effects on how the Earth system functions, and it interacts with several other planetary boundaries. For example, loss of biodiversity can increase the vulnerability of terrestrial and aquatic ecosystems to changes in climate and ocean acidity, thus reducing the safe boundary levels of these processes. There is growing understanding of the importance of functional biodiversity in preventing ecosystems from tipping into undesired states when they are disturbed[20]. This means that apparent redundancy is required to maintain an ecosystem's resilience. Ecosystems that depend on a few or single species for critical functions are vulnerable to disturbances, such as disease, and at a greater risk of tipping into undesired states[8,21].



From an Earth-system perspective, setting a boundary for biodiversity is difficult. Although it is now accepted that a rich mix of species underpins the resilience of ecosystems[20,21], little is known quantitatively about how much and what kinds of biodiversity can be lost before this resilience is eroded[22]. This is particularly true at the scale of Earth as a whole, or for major subsystems such as the Borneo rainforests or the Amazon Basin. Ideally, a planetary boundary should capture the role of biodiversity in regulating the resilience of systems on Earth. Because science cannot yet provide such information at an aggregate level, we propose extinction rate as an alternative (but weaker) indicator. As a result, our suggested planetary boundary for biodiversity of ten times the background rates of extinction is only a very preliminary estimate. More research is required to pin down this boundary with greater certainty. However, we can say with some confidence that Earth cannot sustain the current rate of loss without significant erosion of ecosystem resilience.

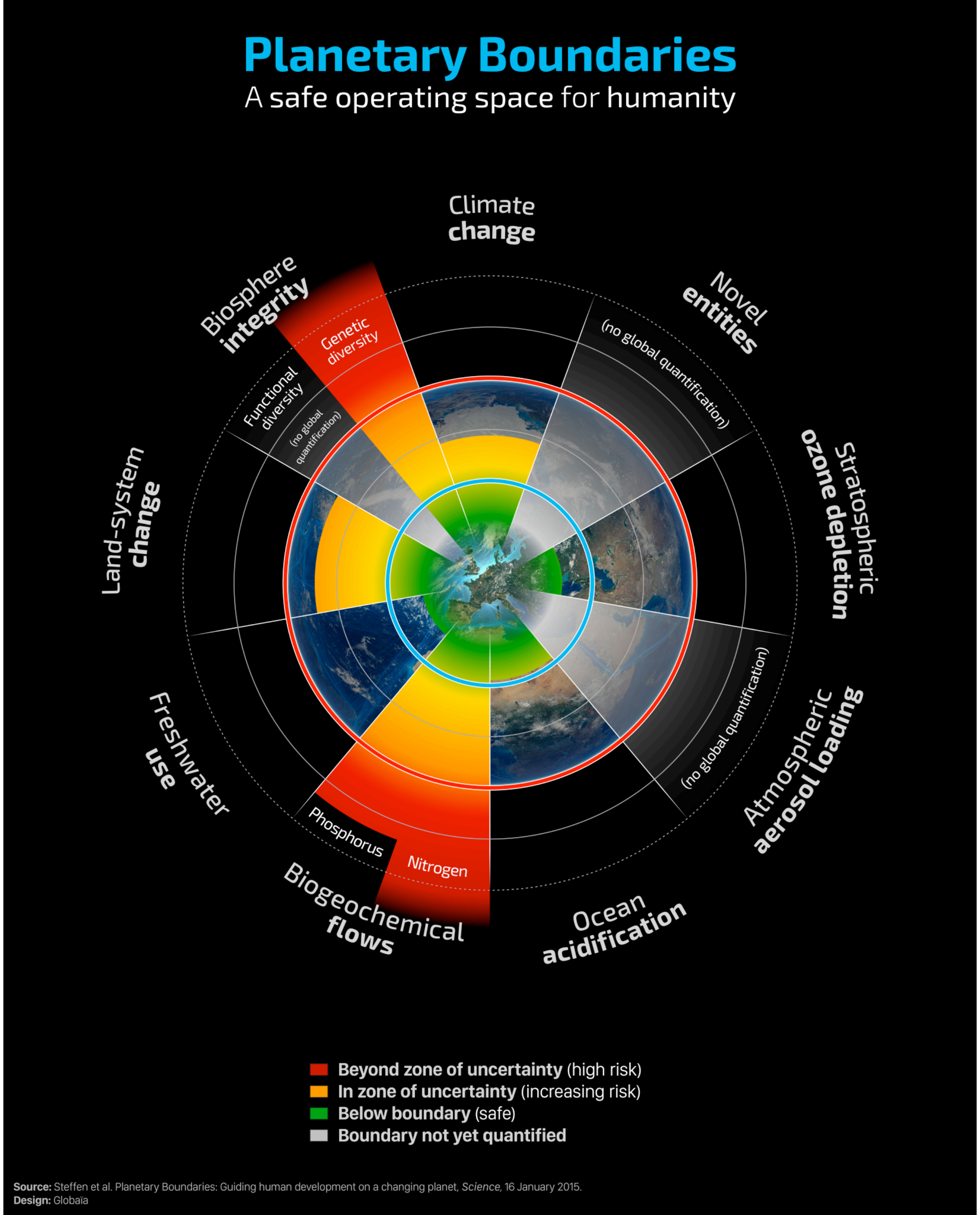


PLANETARY BOUNDARIES

Earth-system process	Parameters	Proposed boundary	Current status	Pre-industrial value
Climate change	(i) Atmospheric carbon dioxide concentration (parts per million by volume)	350	387	280
	(ii) Change in radiative forcing (watts per metre squared)	1	1.5	0
Rate of biodiversity loss	Extinction rate (number of species per million species per year)	10	>100	0.1–1
Nitrogen cycle (part of a boundary with the phosphorus cycle)	Amount of N_2 removed from the atmosphere for human use (millions of tonnes per year)	35	121	0
Phosphorus cycle (part of a boundary with the nitrogen cycle)	Quantity of P flowing into the oceans (millions of tonnes per year)	11	8.5–9.5	~1
Stratospheric ozone depletion	Concentration of ozone (Dobson unit)	276	283	290
Ocean acidification	Global mean saturation state of aragonite in surface sea water	2.75	2.90	3.44
Global freshwater use	Consumption of freshwater by humans (km^3 per year)	4,000	2,600	415
Change in land use	Percentage of global land cover converted to cropland	15	11.7	Low
Atmospheric aerosol loading	Overall particulate concentration in the atmosphere, on a regional basis		To be determined	
Chemical pollution	For example, amount emitted to, or concentration of persistent organic pollutants, plastics, endocrine disrupters, heavy metals and nuclear waste in, the global environment, or the effects on ecosystem and functioning of Earth system thereof		To be determined	

Boundaries for processes in red have been crossed. Data sources: ref. 10 and supplementary information

Steffen et al (2015)



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

Source: Steffen et al. Planetary Boundaries: Guiding human development on a changing planet, *Science*, 16 January 2015.
Design: Globaïa

RESEARCH | *RESEARCH ARTICLE*

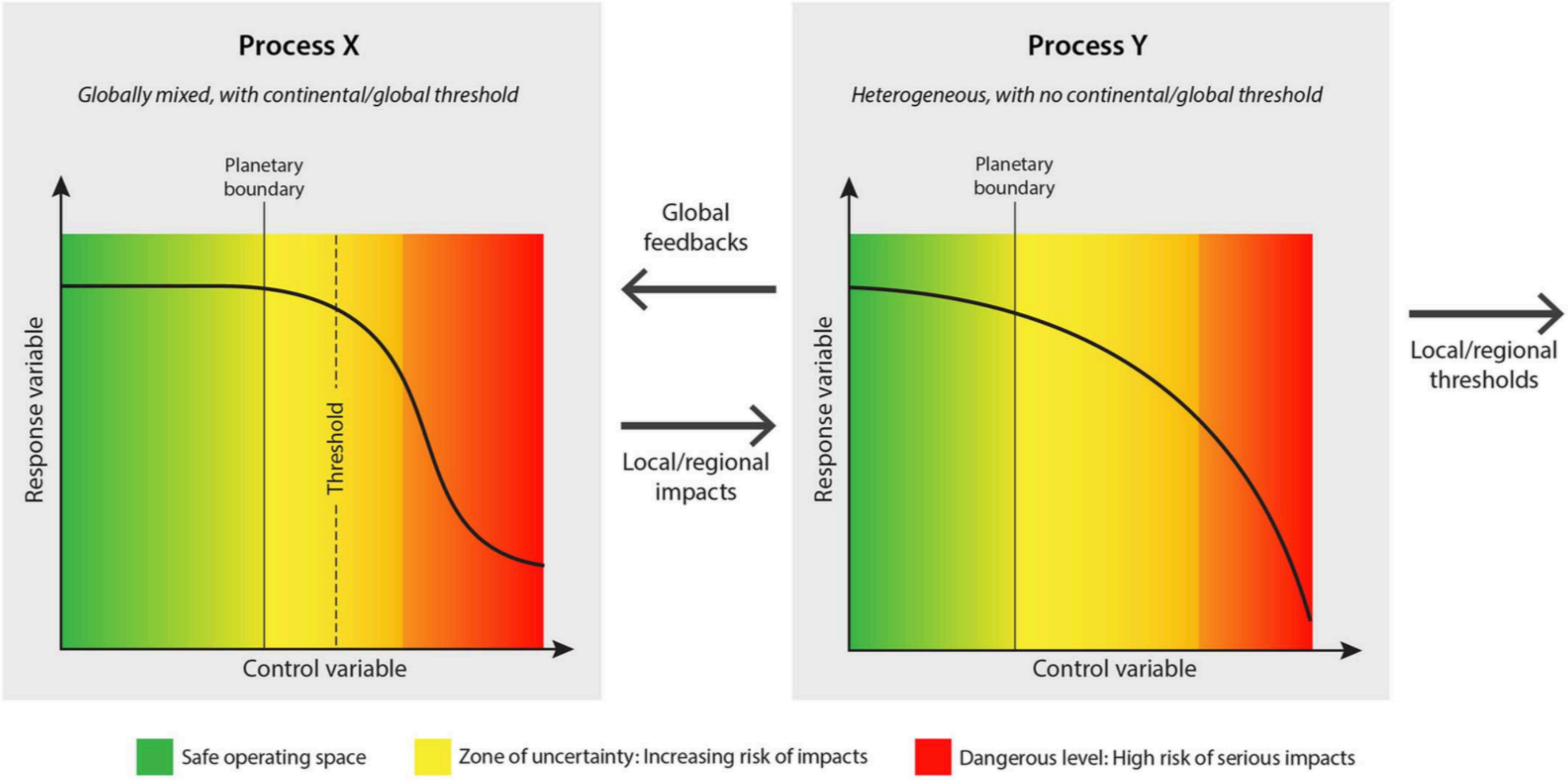
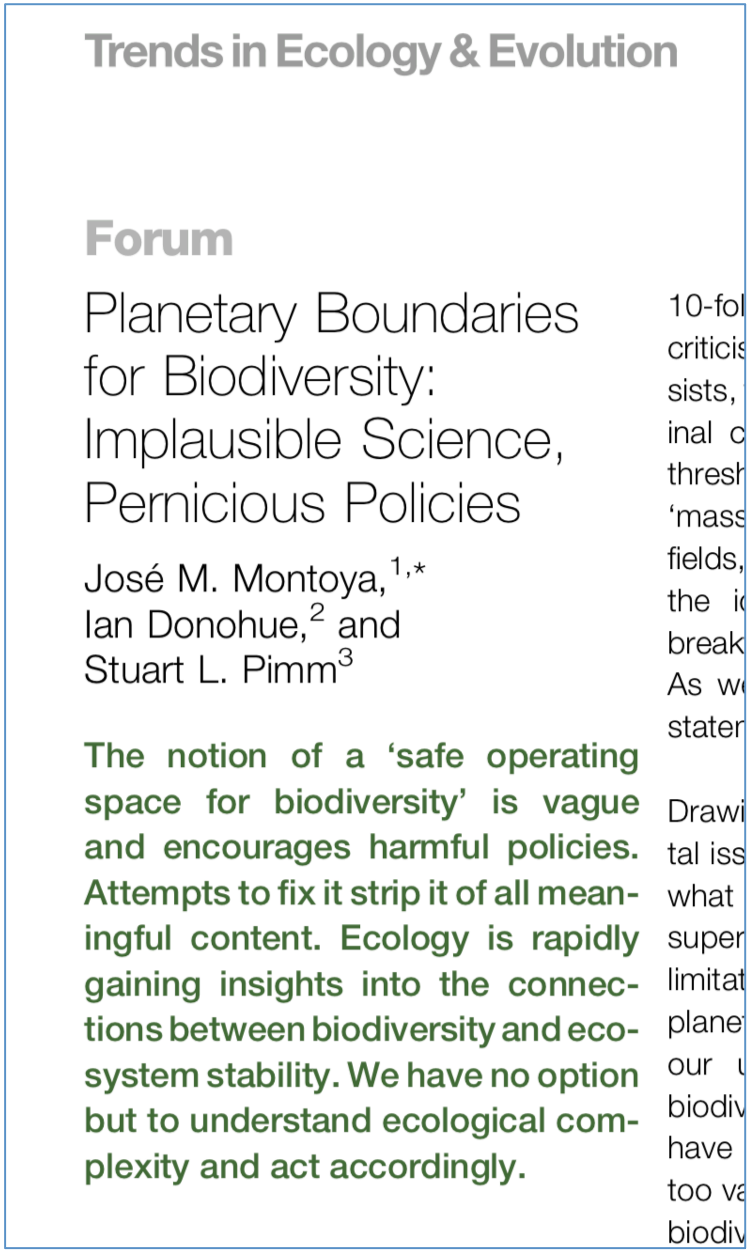


Fig. 1. The conceptual framework for the planetary boundary approach, showing the safe operating space, the zone of uncertainty, the position of the threshold (where one is likely to exist), and the area of high risk. Modified from (*1*).



Trends in Ecology & Evolution

Forum

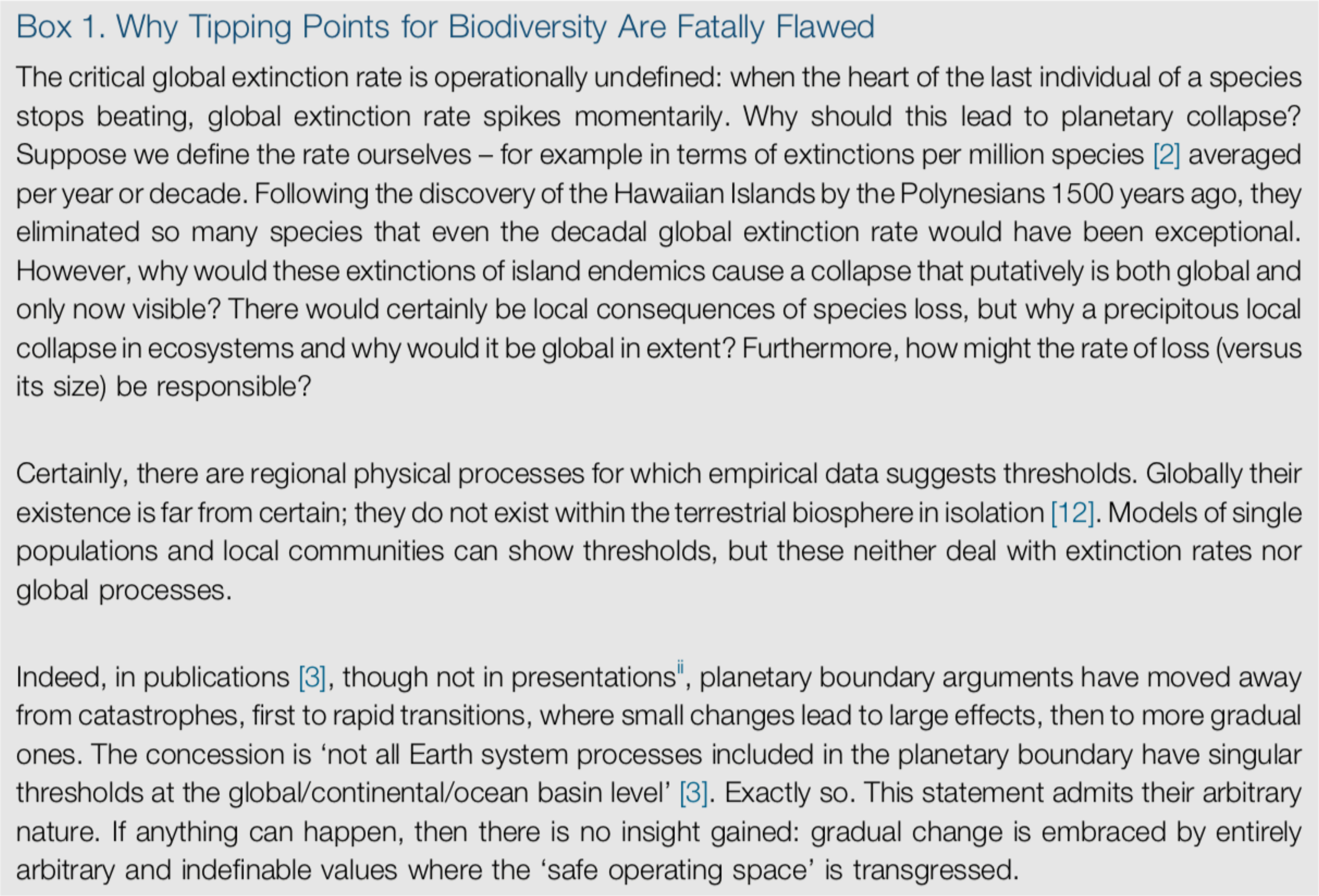
Planetary Boundaries for Biodiversity: Implausible Science, Pernicious Policies

José M. Montoya,[1,*]
Ian Donohue,[2] and
Stuart L. Pimm[3]

The notion of a ‘safe operating space for biodiversity’ is vague and encourages harmful policies. Attempts to fix it strip it of all meaningful content. Ecology is rapidly gaining insights into the connections between biodiversity and ecosystem stability. We have no option but to understand ecological complexity and act accordingly.

10-fol
criticis
sists,
inal c
thresh
‘mass
fields,
the i
break
As w
state

Drawi
tal iss
what
super
limitat
plane
our
biodiv
have
too va
biodiv



Box 1. Why Tipping Points for Biodiversity Are Fatally Flawed

The critical global extinction rate is operationally undefined: when the heart of the last individual of a species stops beating, global extinction rate spikes momentarily. Why should this lead to planetary collapse? Suppose we define the rate ourselves – for example in terms of extinctions per million species [2] averaged per year or decade. Following the discovery of the Hawaiian Islands by the Polynesians 1500 years ago, they eliminated so many species that even the decadal global extinction rate would have been exceptional. However, why would these extinctions of island endemics cause a collapse that putatively is both global and only now visible? There would certainly be local consequences of species loss, but why a precipitous local collapse in ecosystems and why would it be global in extent? Furthermore, how might the rate of loss (versus its size) be responsible?

Certainly, there are regional physical processes for which empirical data suggests thresholds. Globally their existence is far from certain; they do not exist within the terrestrial biosphere in isolation [12]. Models of single populations and local communities can show thresholds, but these neither deal with extinction rates nor global processes.

Indeed, in publications [3], though not in presentations[ii], planetary boundary arguments have moved away from catastrophes, first to rapid transitions, where small changes lead to large effects, then to more gradual ones. The concession is ‘not all Earth system processes included in the planetary boundary have singular thresholds at the global/continental/ocean basin level’ [3]. Exactly so. This statement admits their arbitrary nature. If anything can happen, then there is no insight gained: gradual change is embraced by entirely arbitrary and indefinable values where the ‘safe operating space’ is transgressed.

Histoire des idées

- 1798 **Malthus** « *population, croissance exponentielle, limitation* »
- 1805 **Von Humboldt** « *géographie des plantes* »
- 1809 **Lamarck** « *individu, évolution, transmutation* »
- 1838 **Verhulst** « *fonction logistique* »
- 1859 **Darwin**, **Wallace** « *biocénose, lutte pour la vie, sélection naturelle, fitness* »
- 1866 **Haeckel** « *écologie* »
- 1875 **Suess, Vernadsky** « *biosphère* »
- 1910 **Lotka, Volterra** « *écologie mathématique, cycles prédateur-proie* »
- 1911 **Cowles, Clements** « *succession écologique* »
- 1927 **Charles Elton** « *niche écologique, chaine trophique, écologie animale* »
- 1932 **Gause** « *principe d'exclusion compétitive* »
- 1935 **Tansley, Lindeman, Odum** « *écosystème* »
- 1947 **Lack** « *écologie évolutive* »
- 1957 **Hutchinson** « *niche écologique* »
- 1962 **Rachel Carso**n « *environnement, environmentalism, écologisme* »
- 1963 **Holling, McArthur**, **Rosenzweig** « *réponse fonctionnelle, paradox of enrichment* »
- 1973 **Maynard-Smith** « *théorie des jeux, stratégie évolutivement stable (ESS)* »
- 1976 **McArthur, Wilson** « *la biogéographie insulaire* »
- 1969 **Levins** « *métapopulations* »
- 1976 **May** « *chaos* »
- 1977 **Westman, Ehrlich, Mooney, Costanza** « *ecosystem services* »
- 1988 **Wilson** « *biodiversité* »
- 2009 **Rocktrom, Steffen** « planetary boundaries »