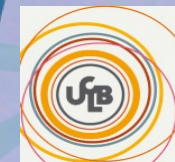


An introduction to the Planetary Boundary Framework from a chemistry point of view

Elsje Alessandra Quadrelli



MASTER 1– CHIMIE INORGANIQUE
Université Lyon1



Ircelyon

INSTITUT DE RECHERCHES
SUR LA CATALYSE
ET L'ENVIRONNEMENT

elsje.quadrelli@cnrs.fr



@ElsjeQuadrelli





Aboriginal midden China Walls archaeological site. Mungo National Park, New South Wales, Australia © Reg Morrison/AUSCAPE

<https://dreamtimesouthernx.com.au/>

https://www.tripadvisor.com.au/Attraction_Review-g255060-d3600969-Reviews-The_Rocks_Dreaming_Aboriginal_Heritage_Tour-Sydney_New_South_Wales.html#/media-atf/3600969/296304011:p/?albumid=-160&type=0&category=-160

Abbé Suger,
bâtitseur de
cathédrales

XIth C

"Together with all nations
we protect both land and
life, and hold the world in
balance."

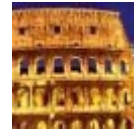
Hopi tribe



1789

"any one year,
no-one should
cut down more
trees than they
have planted"
**German Forest
Code**

Late 19th C.



1972

"The Limits to Growth" report

analyses the dynamic interactions
between industrial production,
population, environmental damage,
food consumption and the use of
natural resources.

Club of Rome (12Mio copies sold)

*Sustainable
Development* should
meet the needs of
the present without
compromising the
ability of future
generations to meet
their own needs
**Brundtland
Commission**

1986



1992

**World (UN)
Summit**



Stockholm
University

**Stockholm
Resilience Centre**

Planetary
boundaries
approach

2000



Anthropocene

P. Crutzen,
"Geology of
mankind"
Nature 415, 23
(2002).

2009

2015

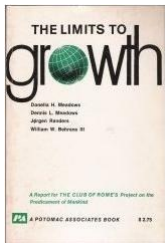


**Great
acceleration**
Will Steffen
Australian
National
University
*Stockholm
Resilience
Institute*

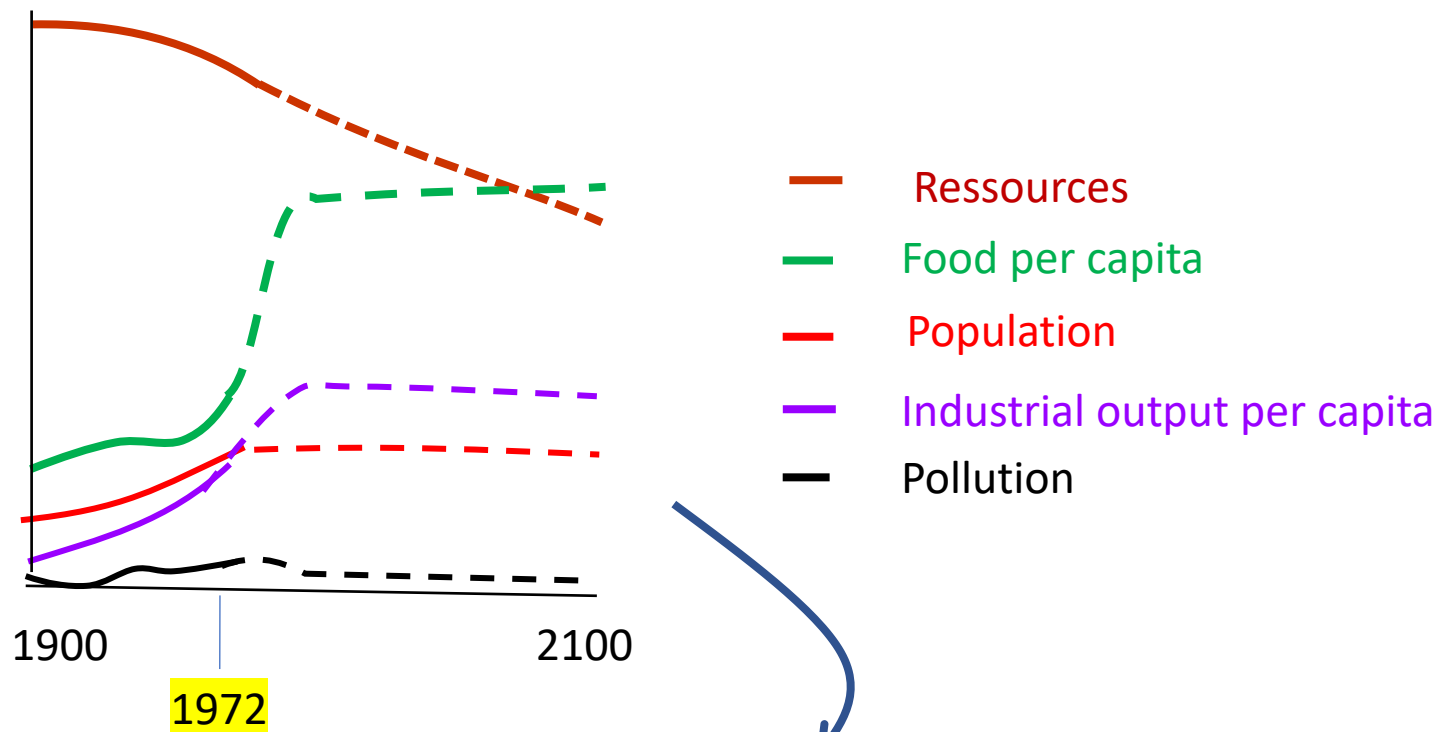
XVIth C

Corn myth
**Atzec and
mesoamerica**



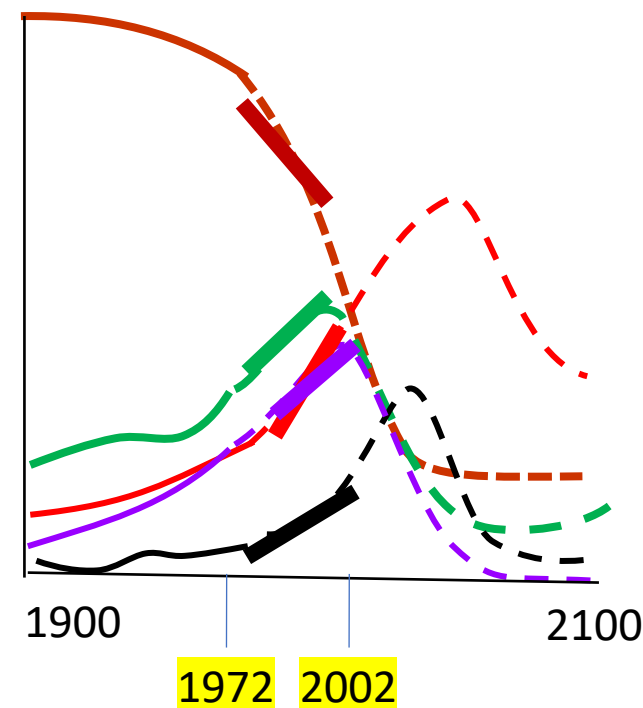


The Limits to Growth; A Report for the Club of Rome's Project on the Predicament* of Mankind.
New York: Universe Books. [ISBN 0876631650](https://doi.org/10.1016/j.gloenvcha.2008.05.001). (1972)



Sustainable Development

"Should meet the needs of the present without compromising the ability of future generations to meet their own needs" Brundtland Commission 1988



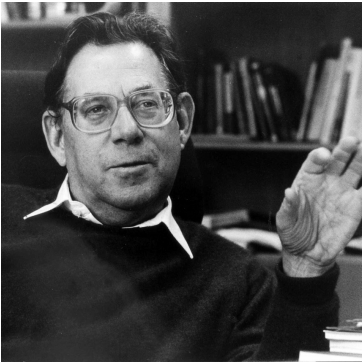
A comparison of The Limits to Growth with 30 years of reality

Graham M. Turner (CSIRO Sustainable Ecosystems)
Global Environmental Change 18 (2008) 397–411

<https://doi.org/10.1016/j.gloenvcha.2008.05.001>

Ca. 2000

Anthropocene



Paul Crutzen

P. Crutzen, "Geology of mankind" **Nature** 415, 23 (2002).

2009

Planetary Boundaries

Rockstrom, J., W. Steffen, P. Crutzen, and J. Foley. "*Planetary boundaries: exploring the safe operating space for humanity*" **Ecology and Society** 14(2): 32 (2009)

2015

Great Acceleration

Steffen, Will; Broadgate, Wendy; Deutsch, Lisa; Gaffney, Owen; Ludwig, Cornelia (April 2015). "*The trajectory of the Anthropocene: The Great Acceleration*". **The Anthropocene Review**. 2 (1): 81–98

Anthropocene

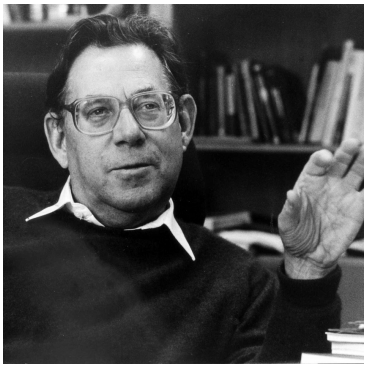
ἄνθρωπος (*anthropos*)

Humain 🖐️ « Anthropos »
n'existe pas...

καινός (*kainos*) meaning
New

Geological era

Ca. 2000



Paul Crutzen

Atmospheric Chemist
Ozone, stratosphere
(Chemistry Nobel Prize 1995)
Nobel Conférence :
« *My life with O₃, NO_x, and other YZO_x* »

Geology of mankind

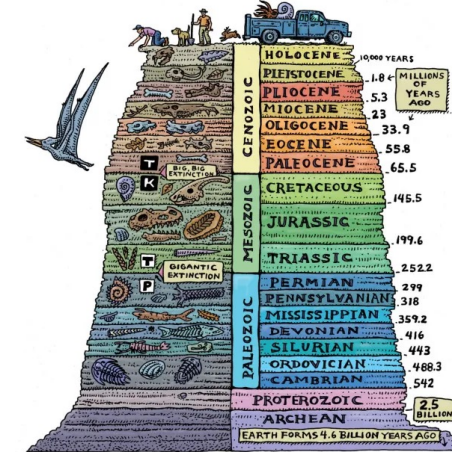
Paul J. Crutzen

For the past three centuries, the effects of humans on the global environment have escalated. Because of these anthropogenic emissions of carbon dioxide, global climate may depart significantly from natural behaviour for many millennia to come. It seems appropriate to assign the term 'Anthropocene' to the present, in many ways human-dominated, geological epoch, supplementing the Holocene — the warm period of the past 10–12 millennia. The Anthropocene could be said to have started in the latter part of the eighteenth century, when analyses of air trapped in polar ice showed the beginning of growing global concentrations of carbon dioxide and methane. This date also happens to coincide with James Watt's design of the steam engine in 1784.

referring to the “anthropozoic era”. And in 1926, V. I. Vernadsky acknowledged the increasing impact of mankind: “The direction in which the processes of evolution must proceed, namely towards increasing consciousness and thought, and forms having greater and greater influence on their surroundings.” Teilhard de Chardin and Vernadsky used the term ‘noösphere’ — the ‘world of thought’ — to mark the growing role of human brain-power in shaping its own future and environment.

The rapid expansion of mankind in numbers and per capita exploitation of Earth's resources has continued apace. During the past three centuries, the human population has increased tenfold to more than 6 billion and is expected to reach 10 billion in this century. The methane-producing cattle population has risen to 1.4 billion. About 30–50% of the planet's land surface

* Holocene: current geological period, which covers the last 12,000 years and which followed the last ice age



www.skeptical-science.com/science/holocene-climate-change-mystery-solved/

P. Crutzen, “*Geology of mankind*” **Nature** 415, 23 (2002).

The great acceleration

Socio-Economic Trend (12 entries, 3 examples ↓)

Ca. 2015



26 reserachers among whom

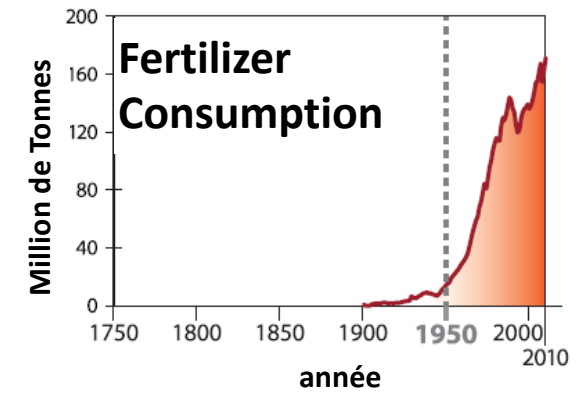
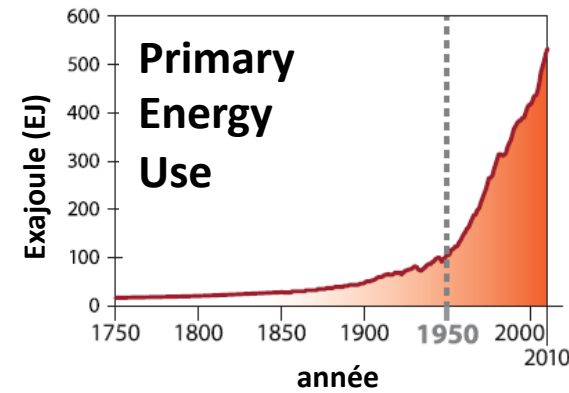
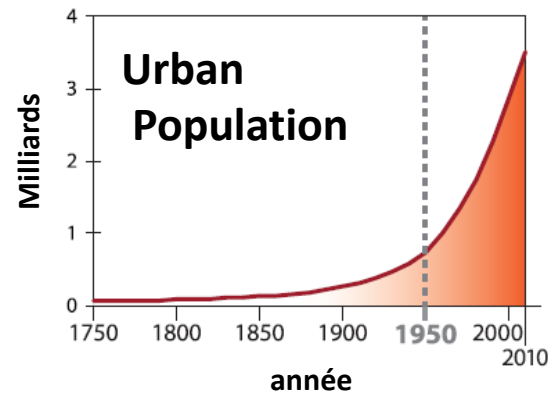
Will Steffen

Chemist

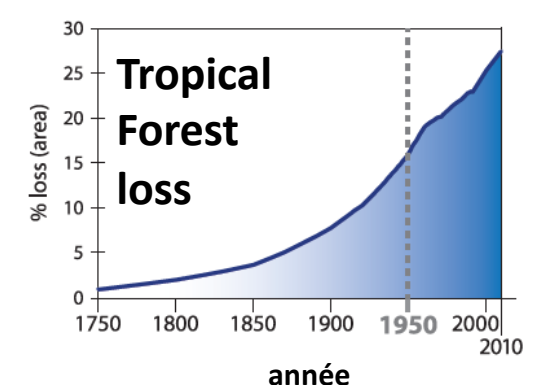
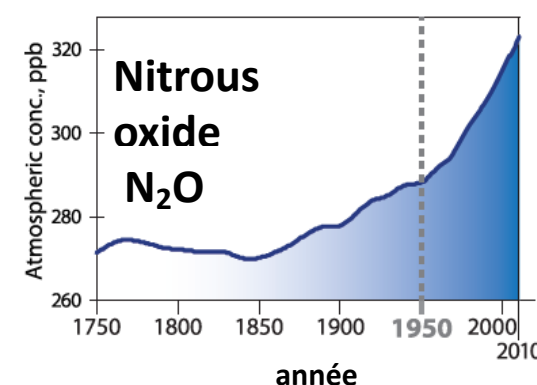
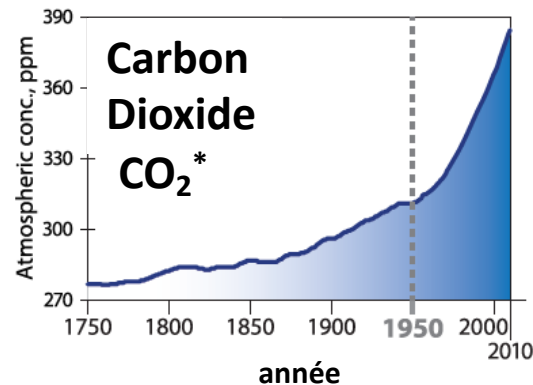
Earth system scientist

at Australian National University

Stockholm Resilience Institute



Earth System Trends (12 entries, 3 examples ↓)



Steffen, W., Broadgate, W., Deutsch, L., Gaffney, O., & Ludwig, C. (2015).

The trajectory of the Anthropocene: The Great Acceleration. *The Anthropocene Review*, 2(1), 81–98. <https://doi.org/10.1177>

The planetary approach

Ca. 2009



Stockholm
University

Stockholm
Resilience Centre

26 reserachers among whom

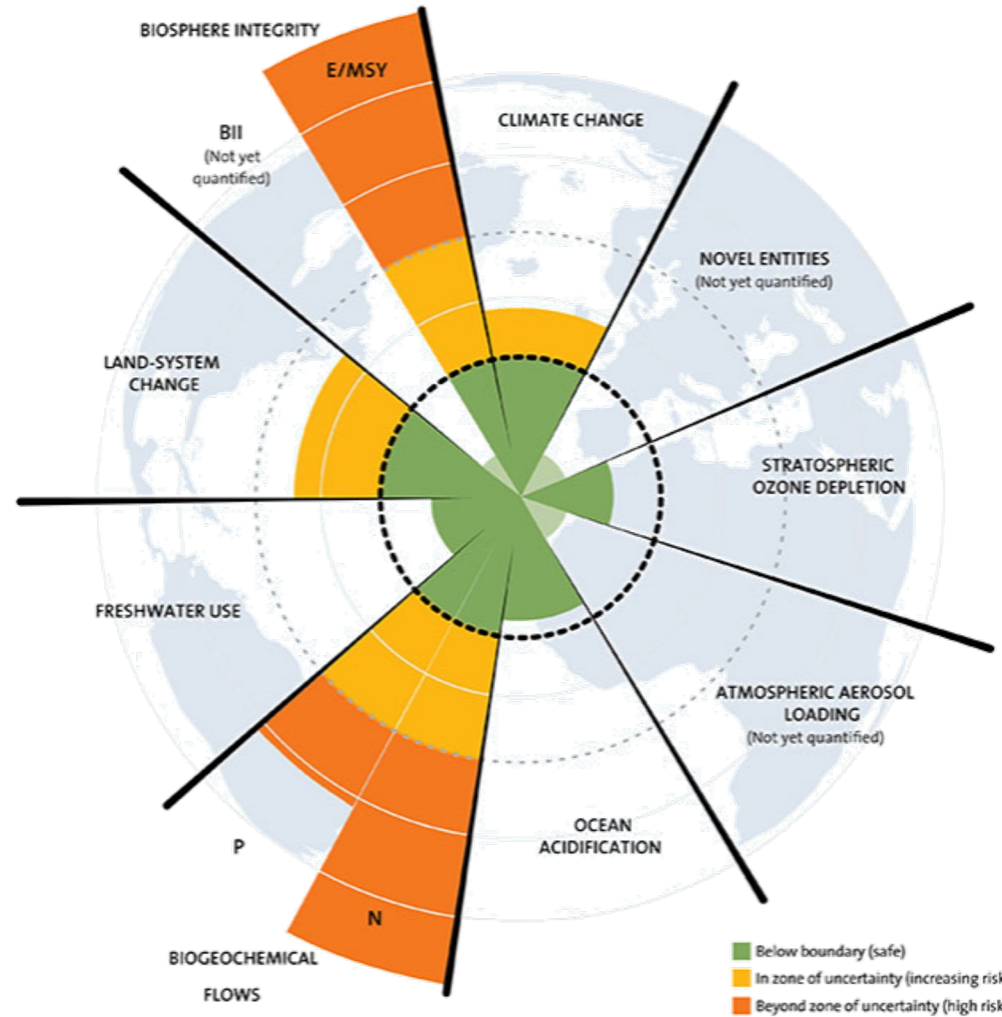
Will Steffen

Chemist

Earth system scientist

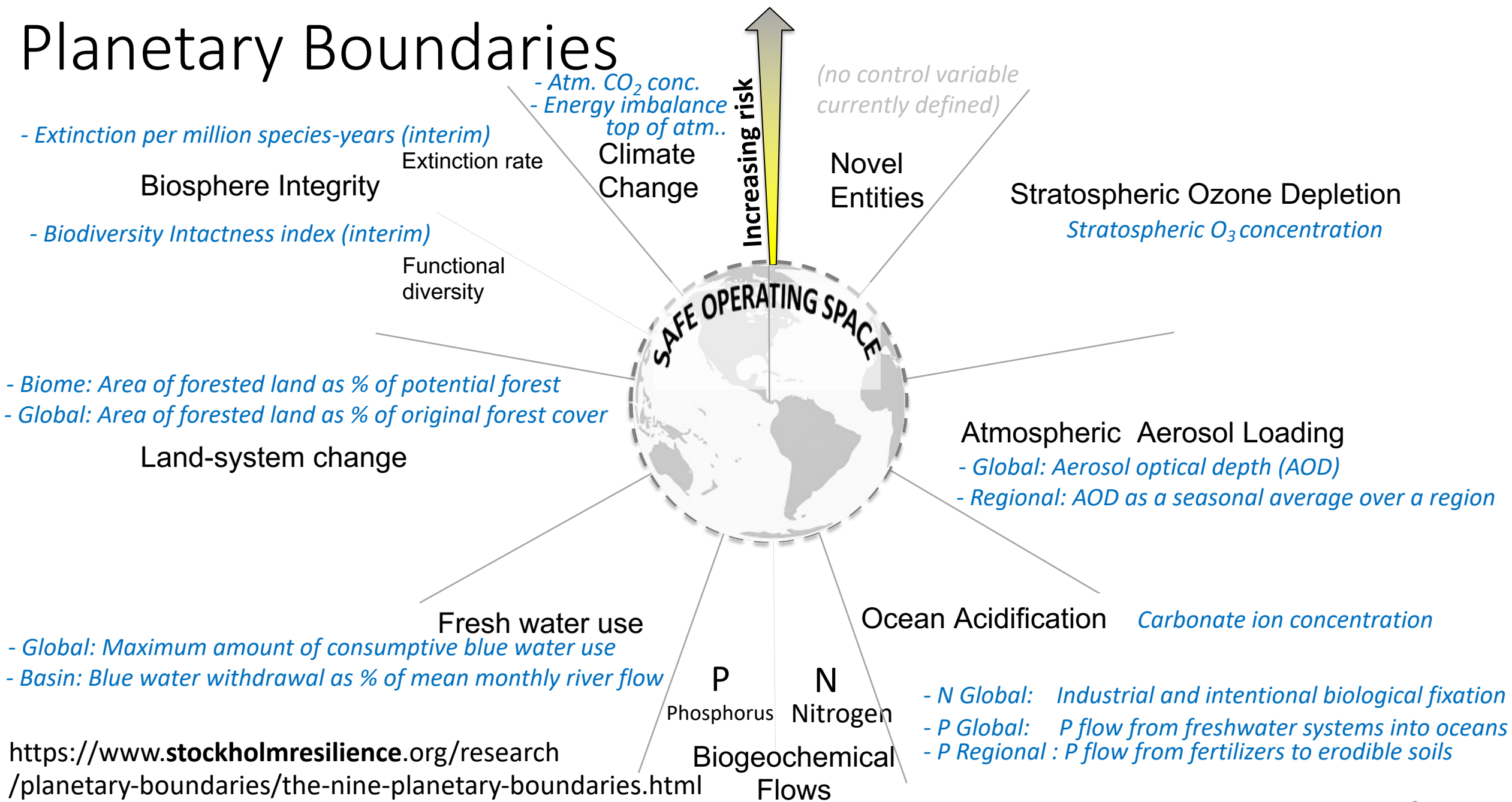
at Australian National University

Stockholm Resilience Institute



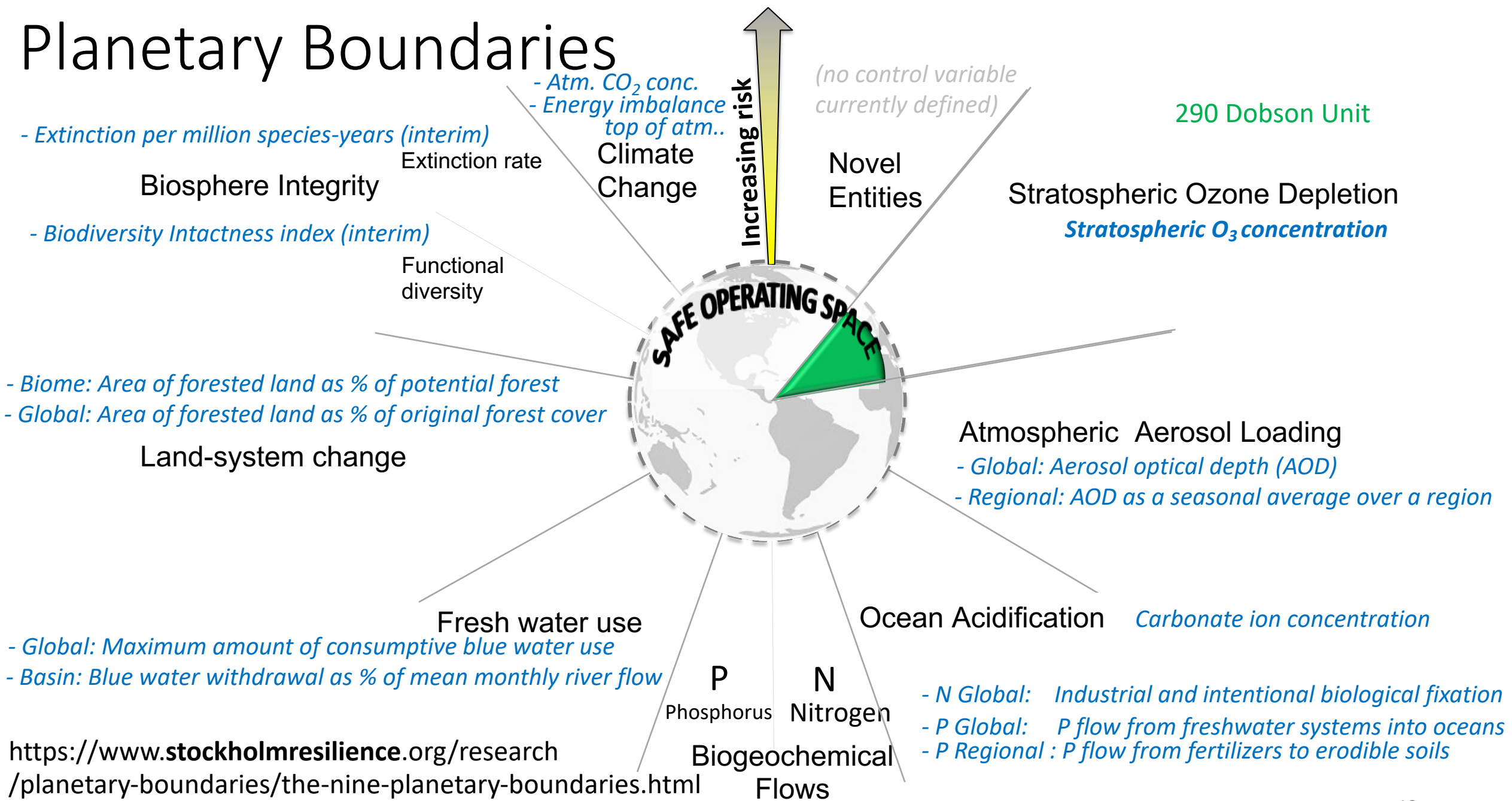
Rockstrom, J., W. Steffen, P. Crutzen, and J. Foley.
"Planetary boundaries: exploring the safe operating space for
humanity" **Ecology and Society** 14(2): 32 (2009)

Planetary Boundaries

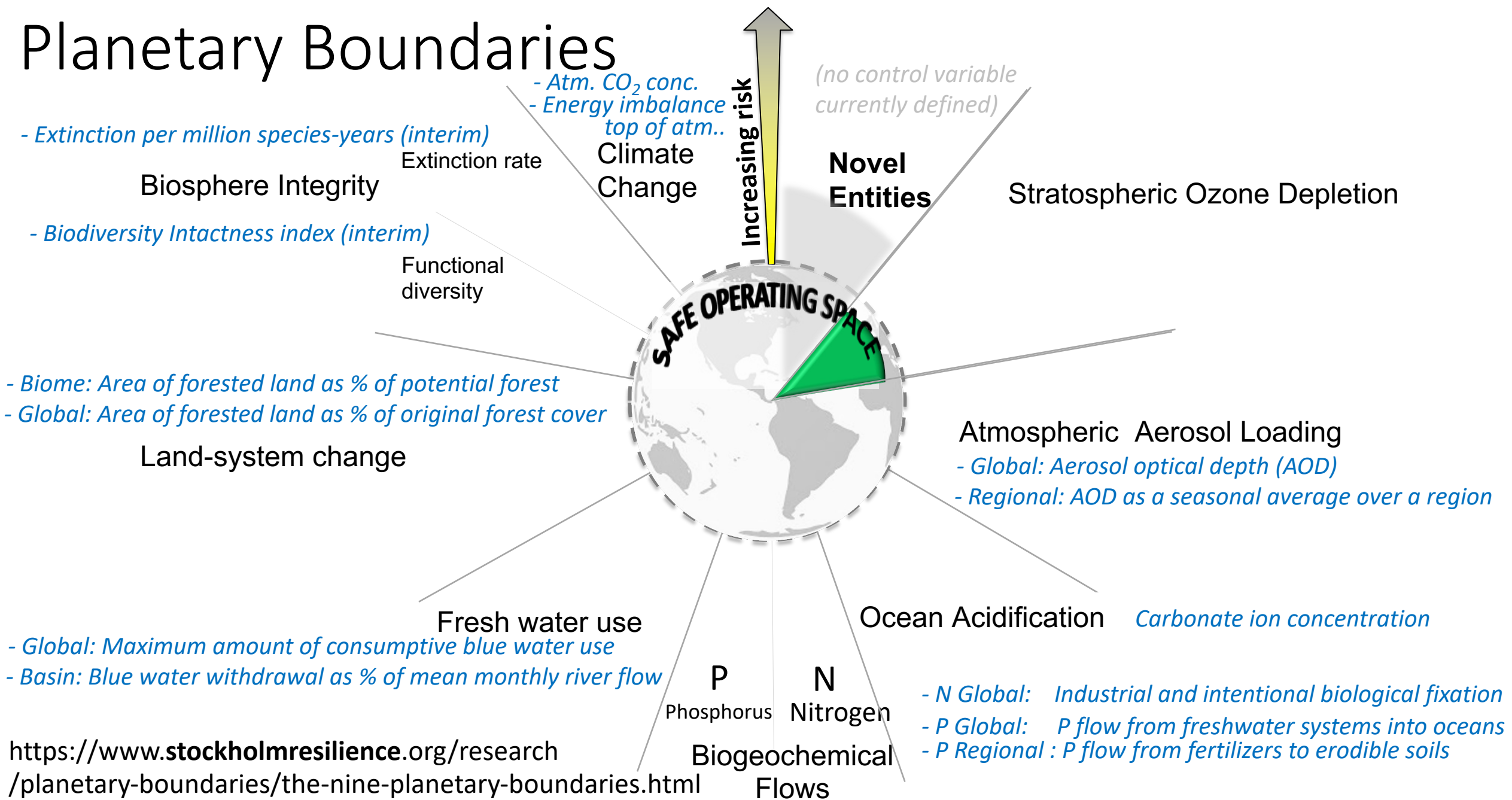


<https://www.stockholmresilience.org/research/planetary-boundaries/the-nine-planetary-boundaries.html>

Planetary Boundaries

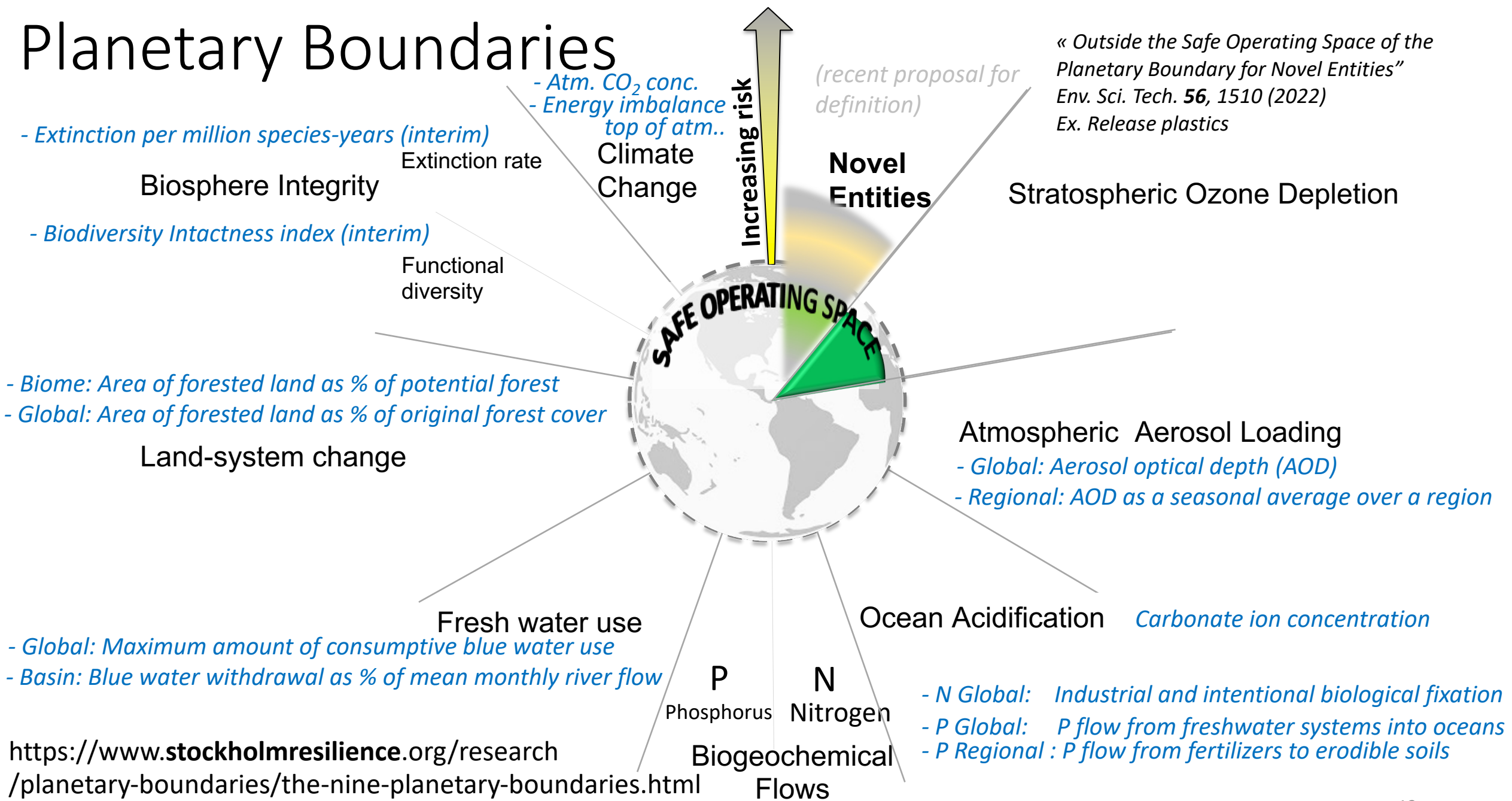


Planetary Boundaries

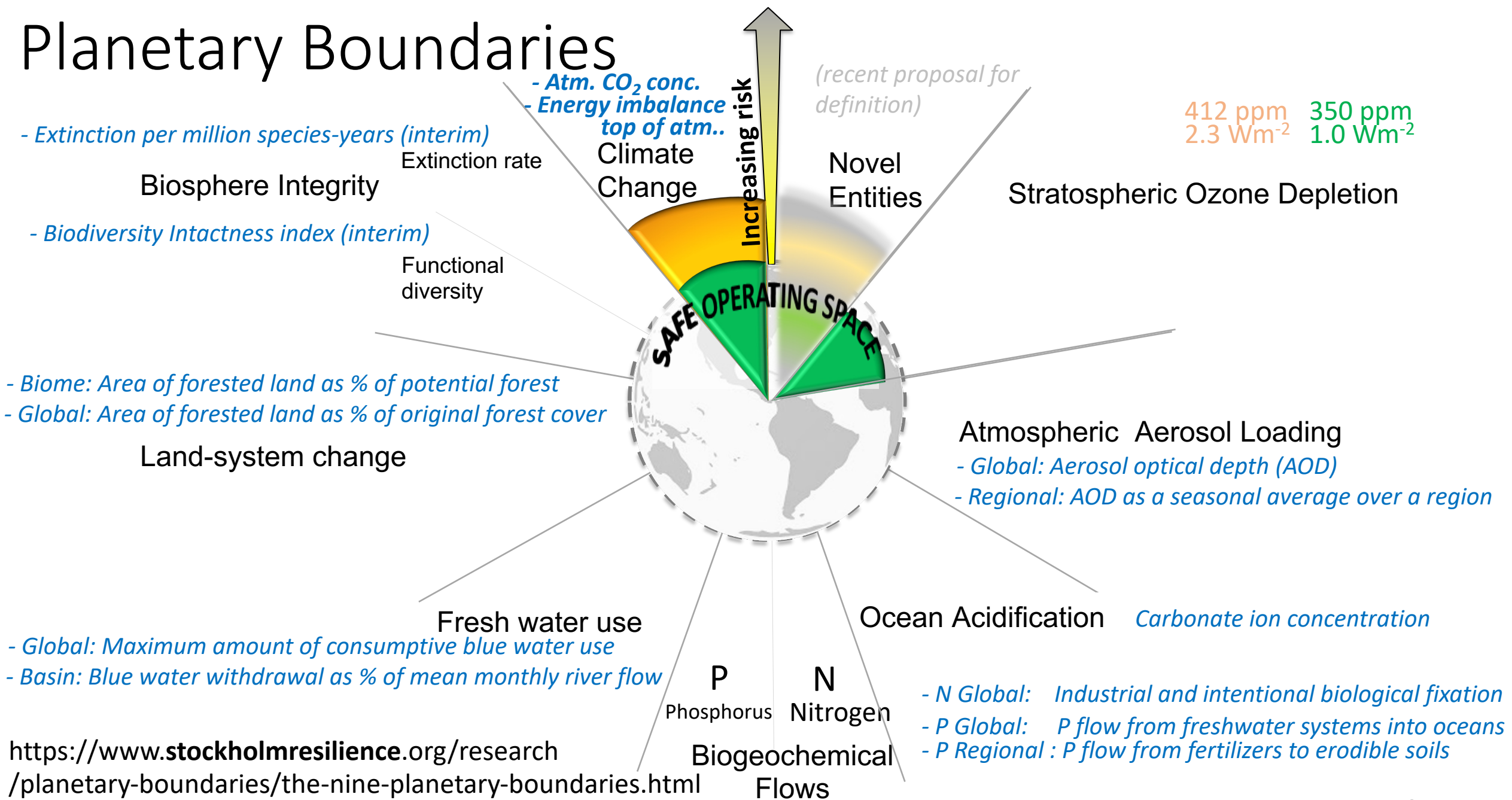


<https://www.stockholmresilience.org/research/planetary-boundaries/the-nine-planetary-boundaries.html>

Planetary Boundaries



Planetary Boundaries



Planetary Boundaries

- *Extinction per million species-years (interim)*

Biosphere Integrity

Extinction rate

- *Biodiversity Intactness index (interim)*

Functional diversity

Climate Change

Increasing risk

(recent proposal for definition)

Novel Entities

10-1000 E/MSY < 10 E/MSY
Not evaluated

Stratospheric Ozone Depletion

SAFE OPERATING SPACE

- *Biome: Area of forested land as % of potential forest*

- *Global: Area of forested land as % of original forest cover*

Land-system change

Atmospheric Aerosol Loading

- *Global: Aerosol optical depth (AOD)*

- *Regional: AOD as a seasonal average over a region*

Fresh water use

- *Global: Maximum amount of consumptive blue water use*

- *Basin: Blue water withdrawal as % of mean monthly river flow*

Ocean Acidification

Carbonate ion concentration

P

Phosphorus

N

Nitrogen

Biogeochemical
Flows

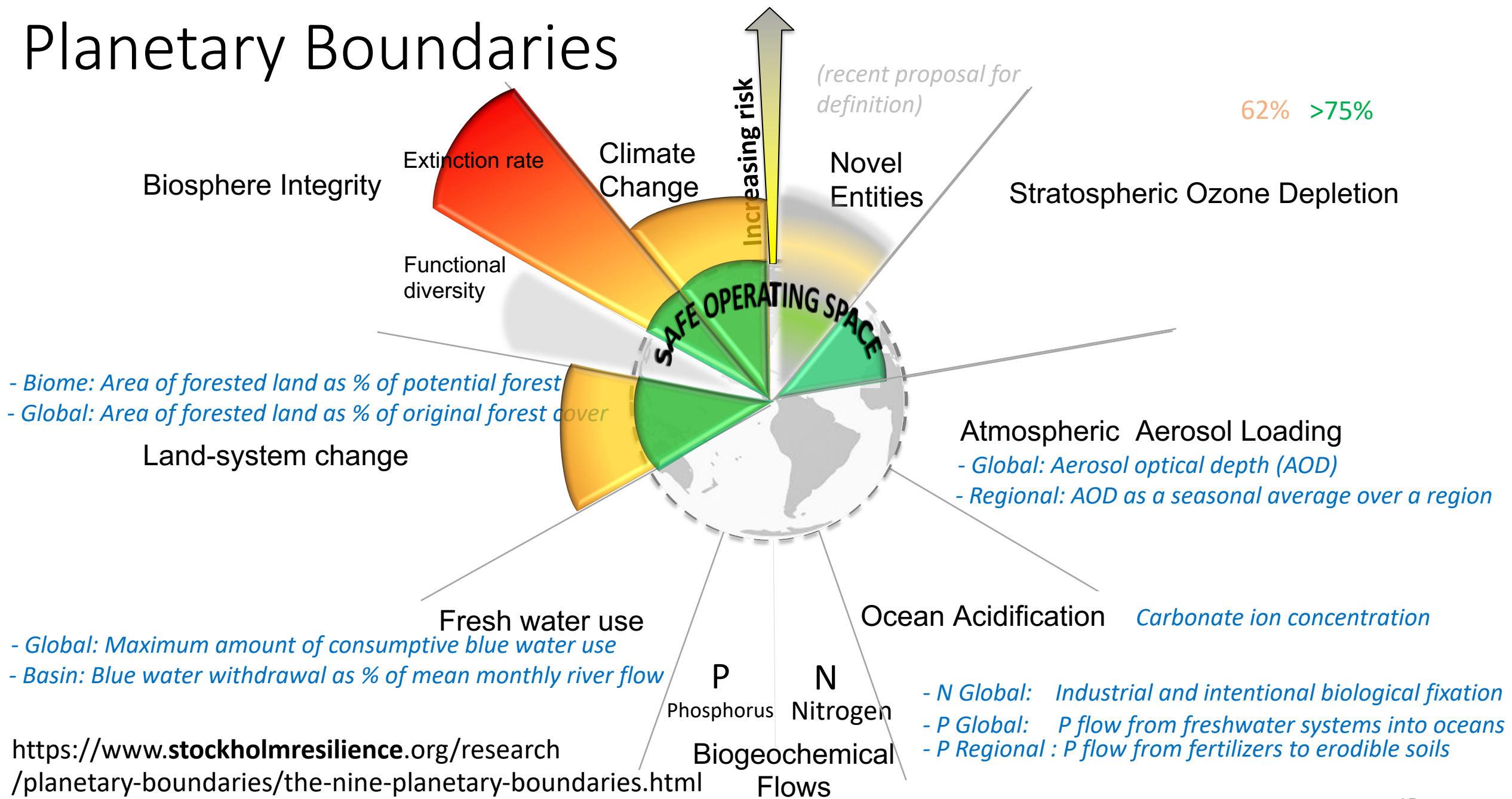
- *N Global: Industrial and intentional biological fixation*

- *P Global: P flow from freshwater systems into oceans*

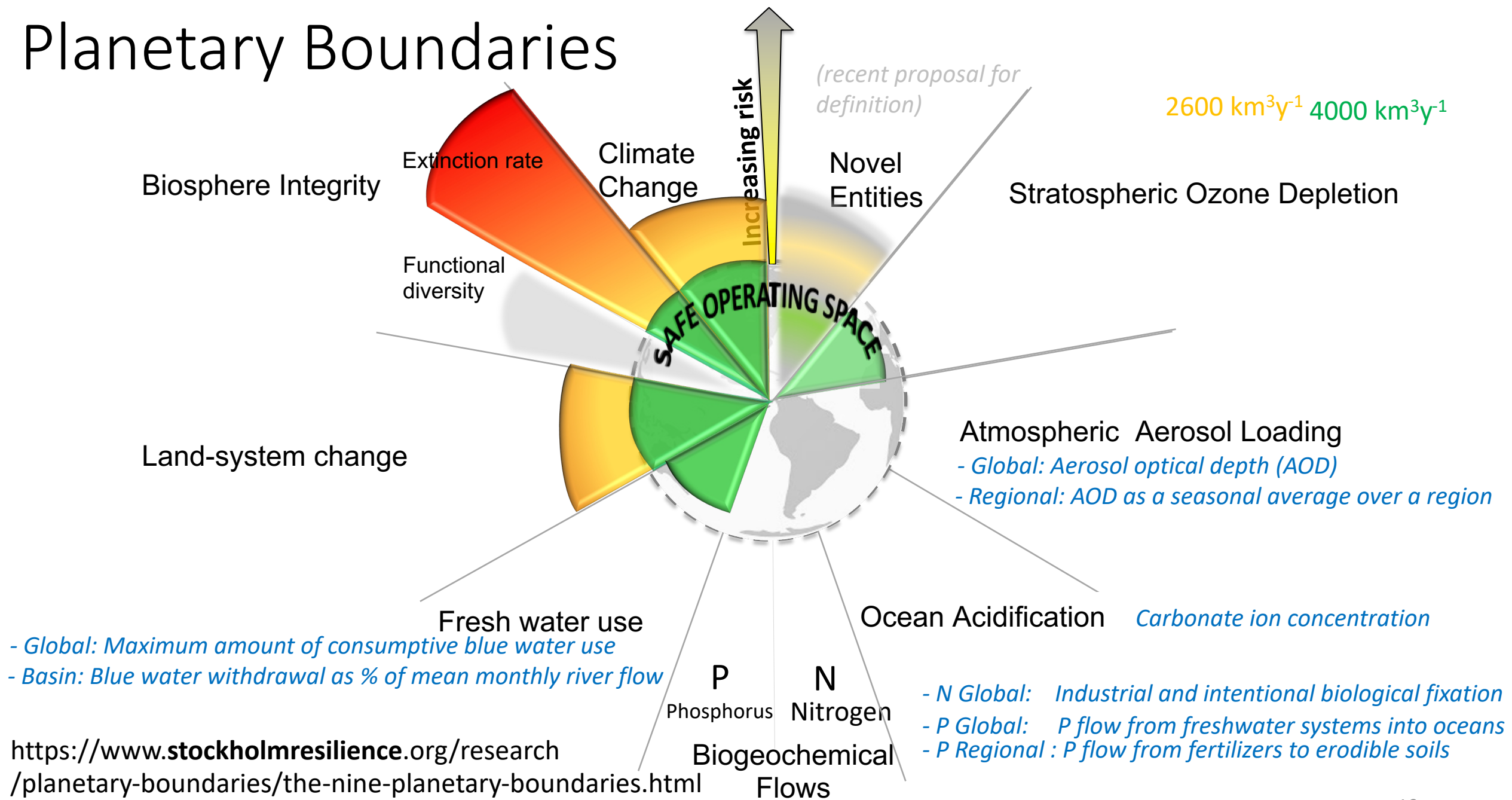
- *P Regional: P flow from fertilizers to erodible soils*

<https://www.stockholmresilience.org/research/planetary-boundaries/the-nine-planetary-boundaries.html>

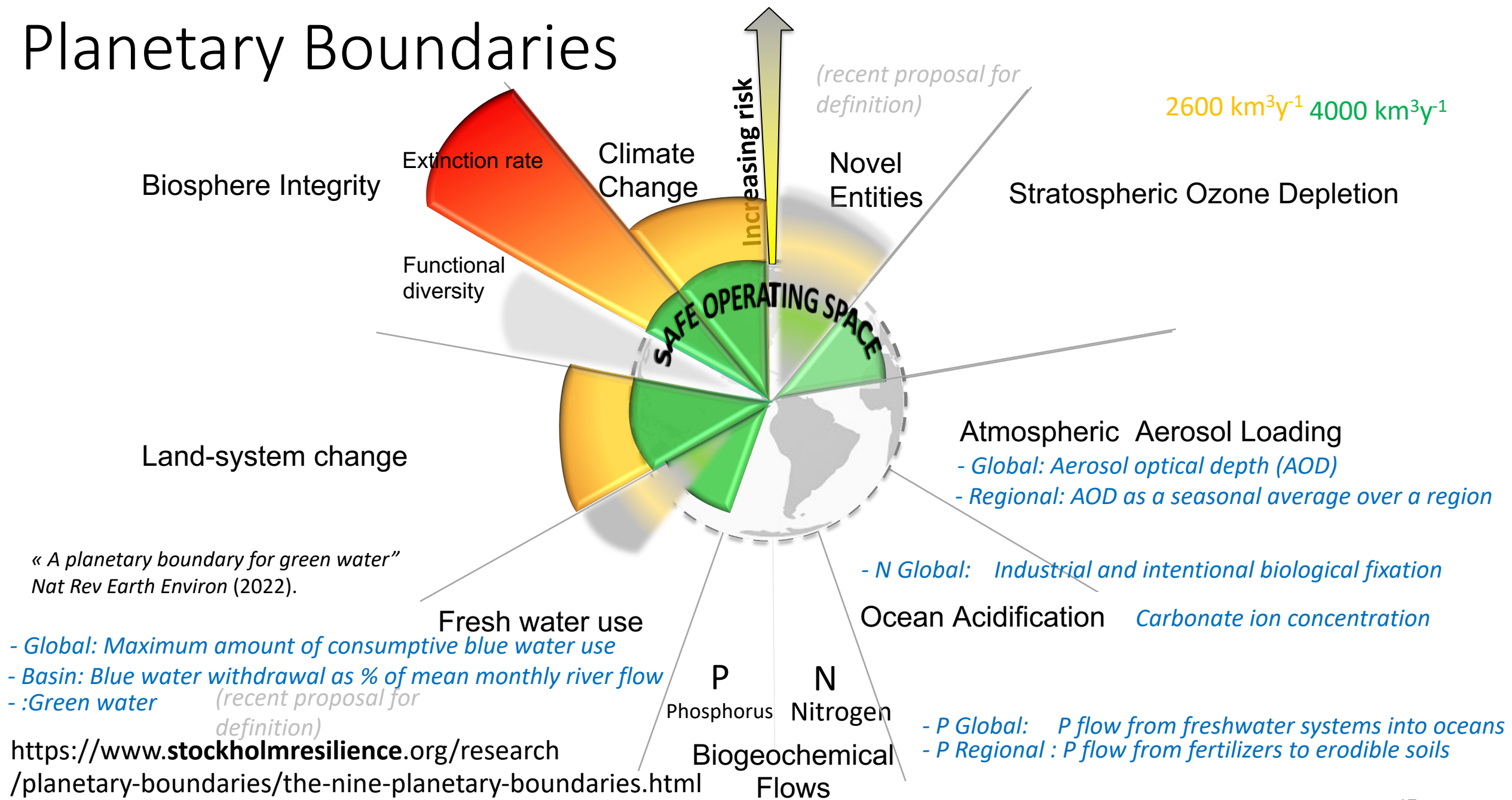
Planetary Boundaries



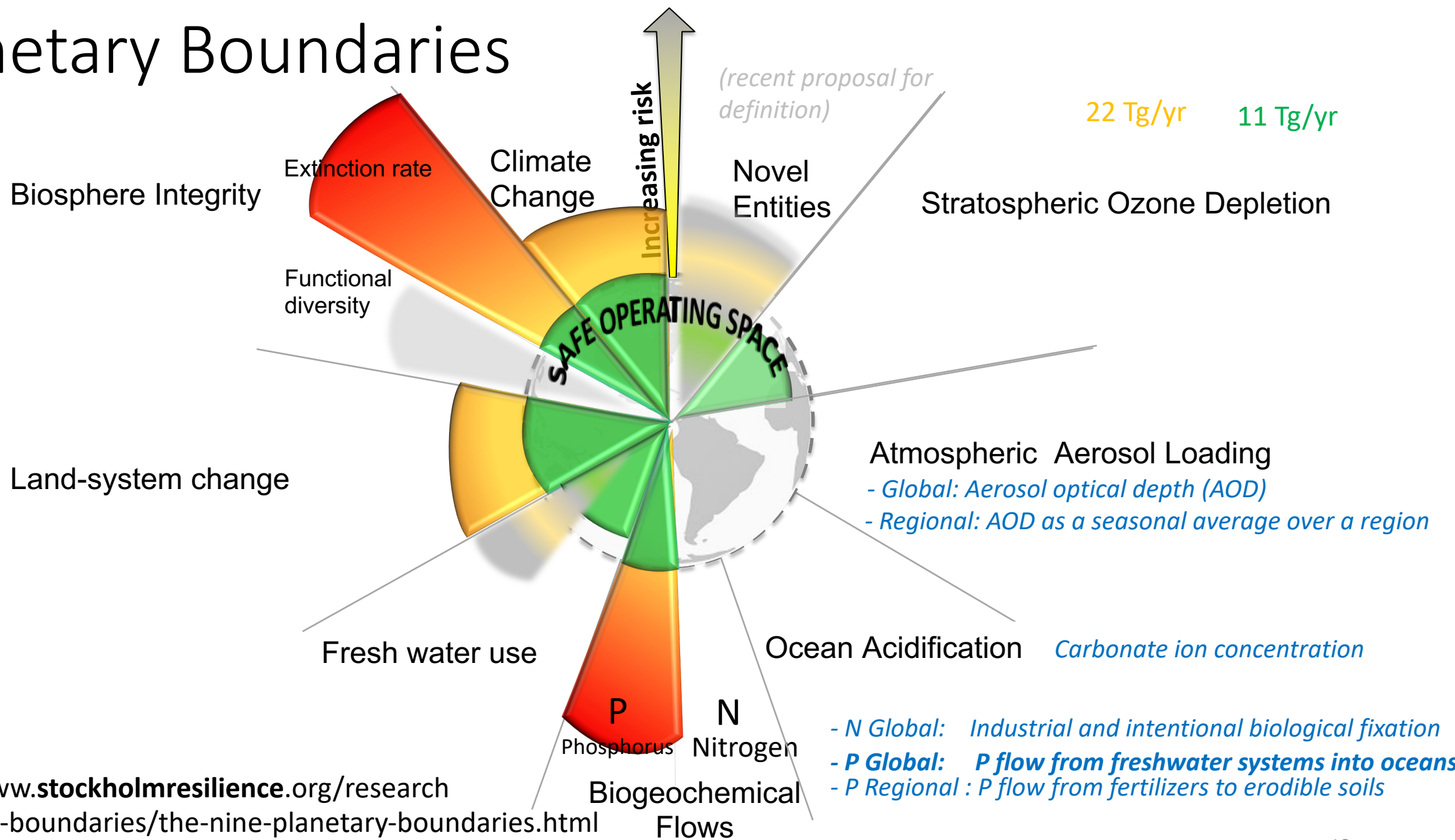
Planetary Boundaries



Planetary Boundaries

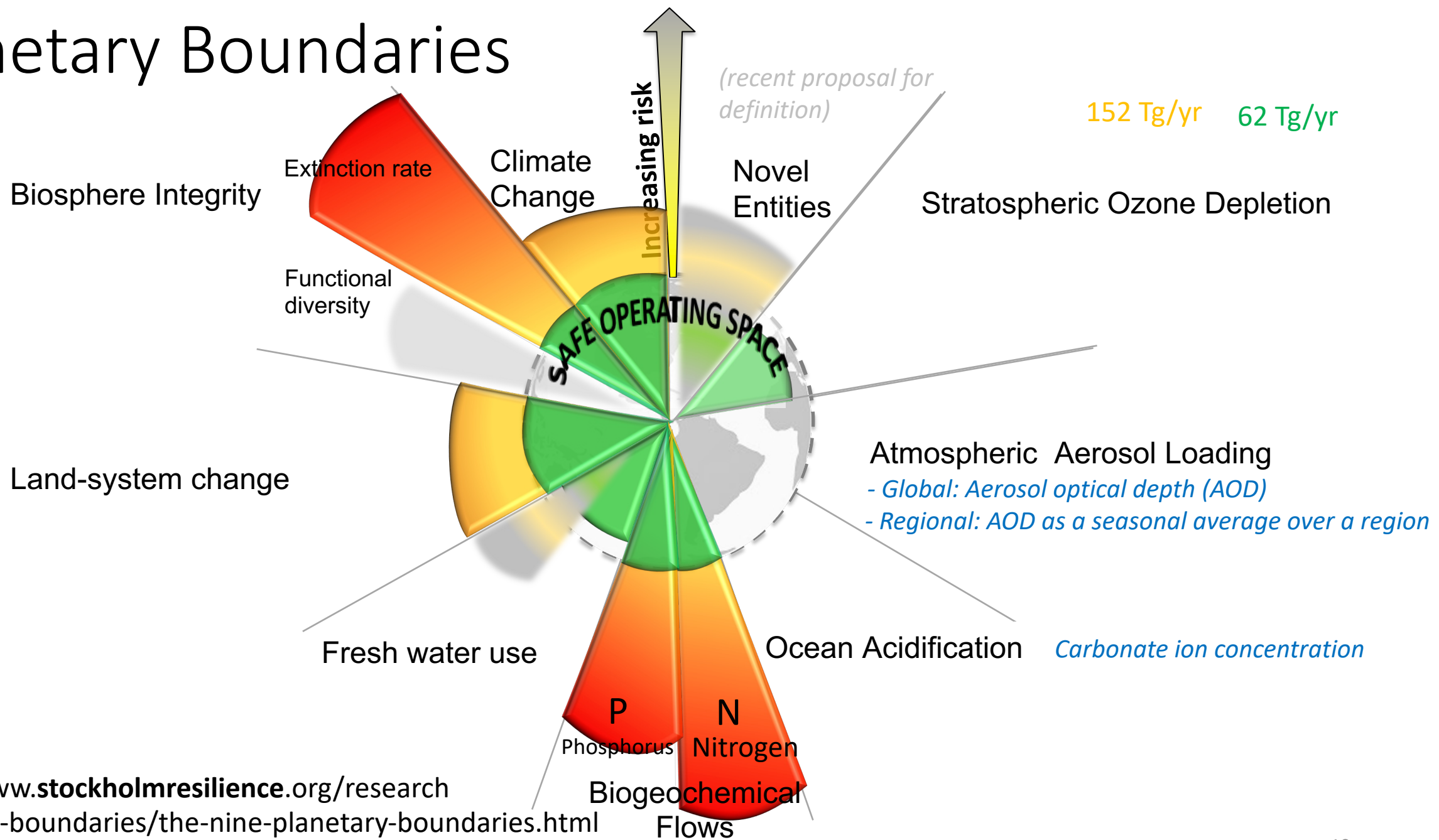


Planetary Boundaries



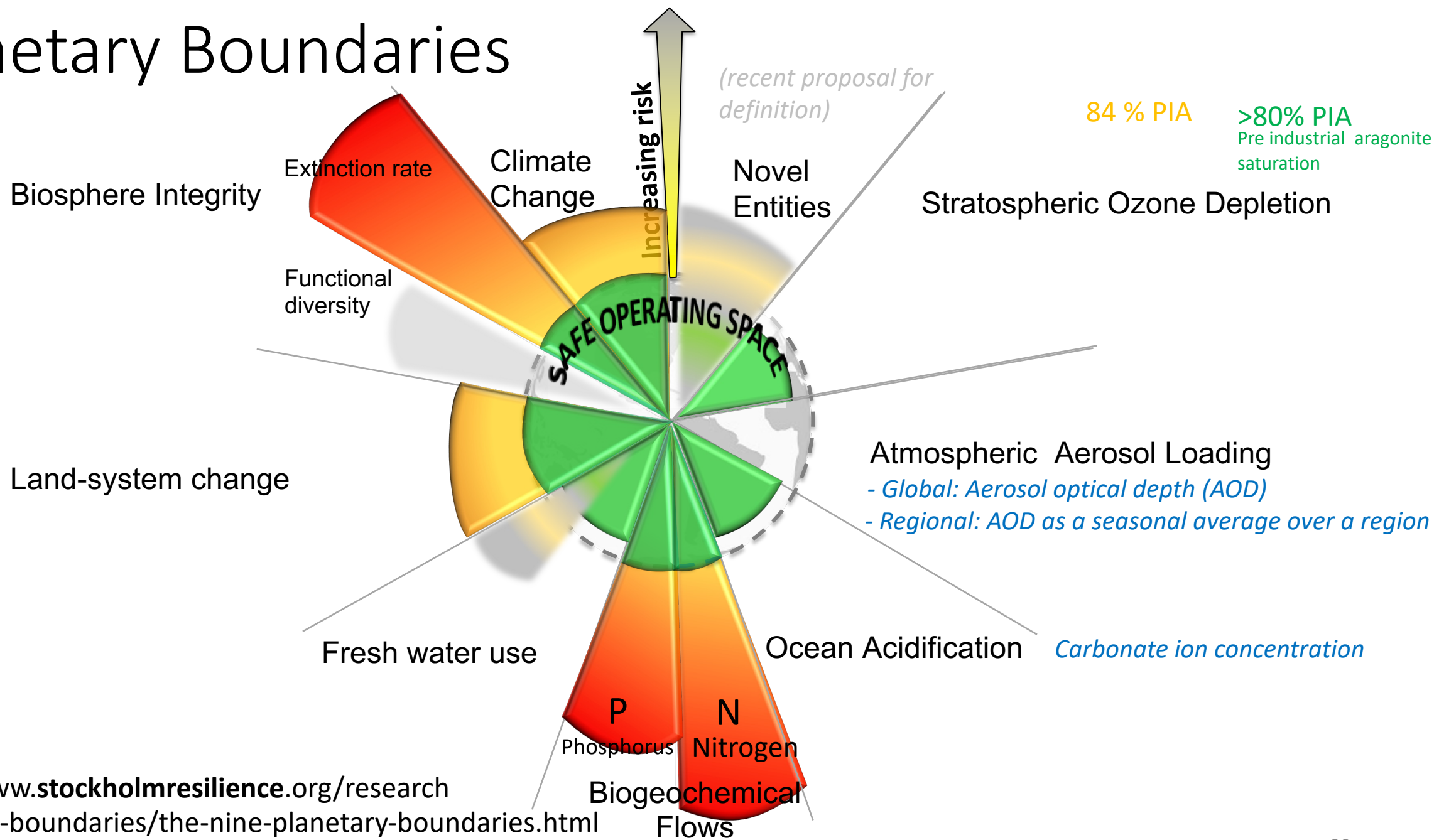
<https://www.stockholmresilience.org/research/planetary-boundaries/the-nine-planetary-boundaries.html>

Planetary Boundaries

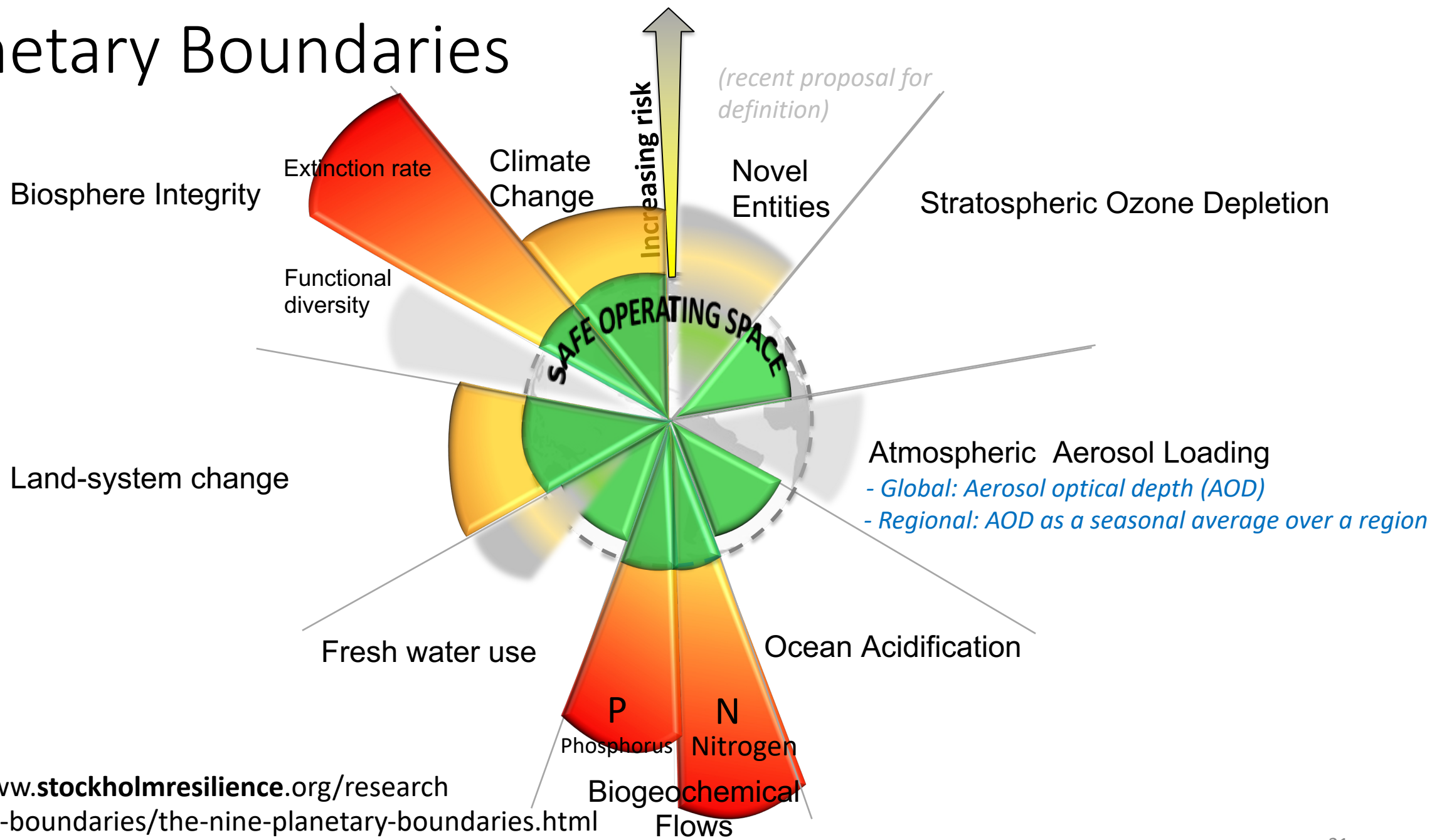


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Planetary Boundaries

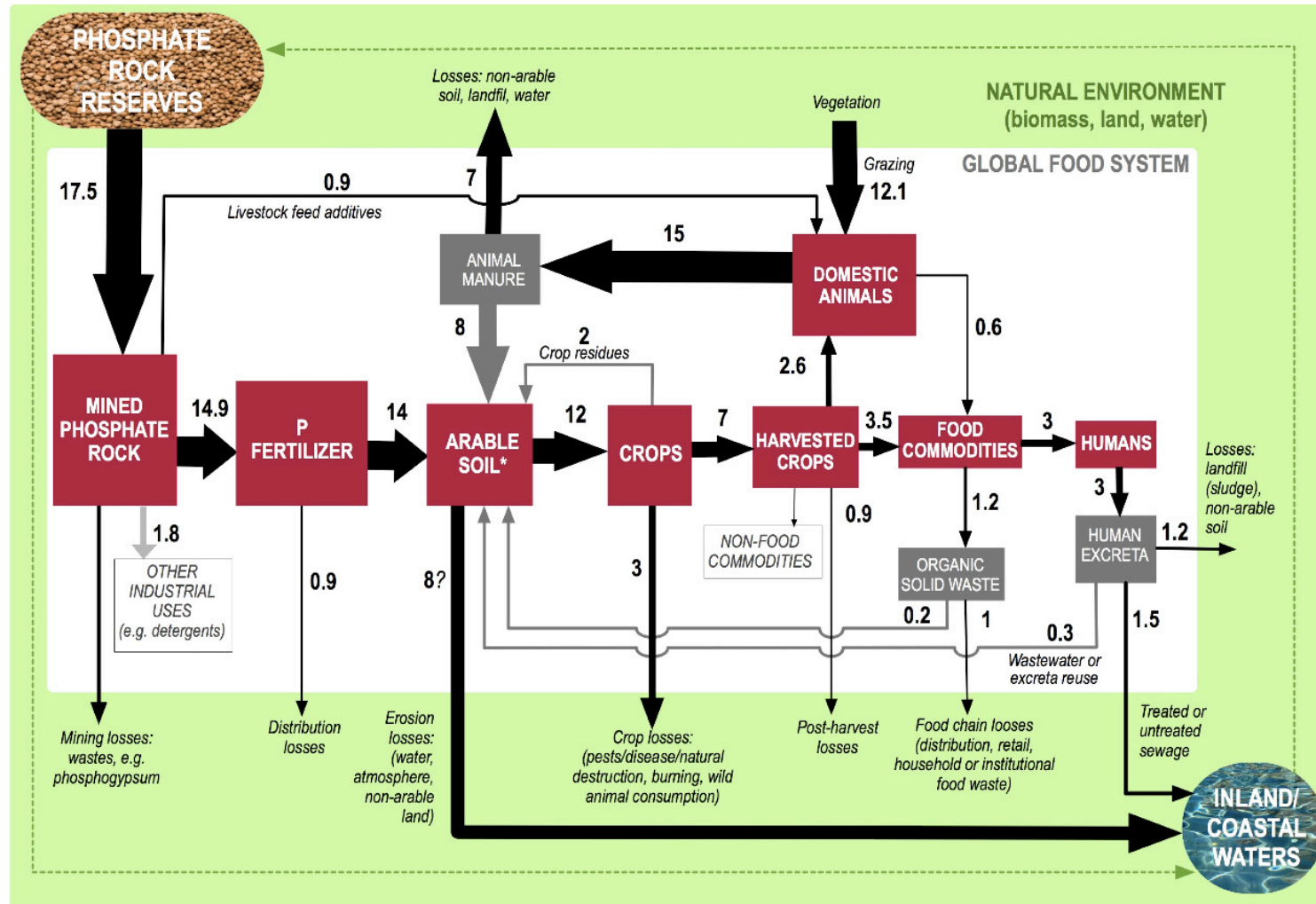


Planetary Boundaries



<https://www.stockholmresilience.org/research/planetary-boundaries/the-nine-planetary-boundaries.html>

80% P LOSS mine-to-fork



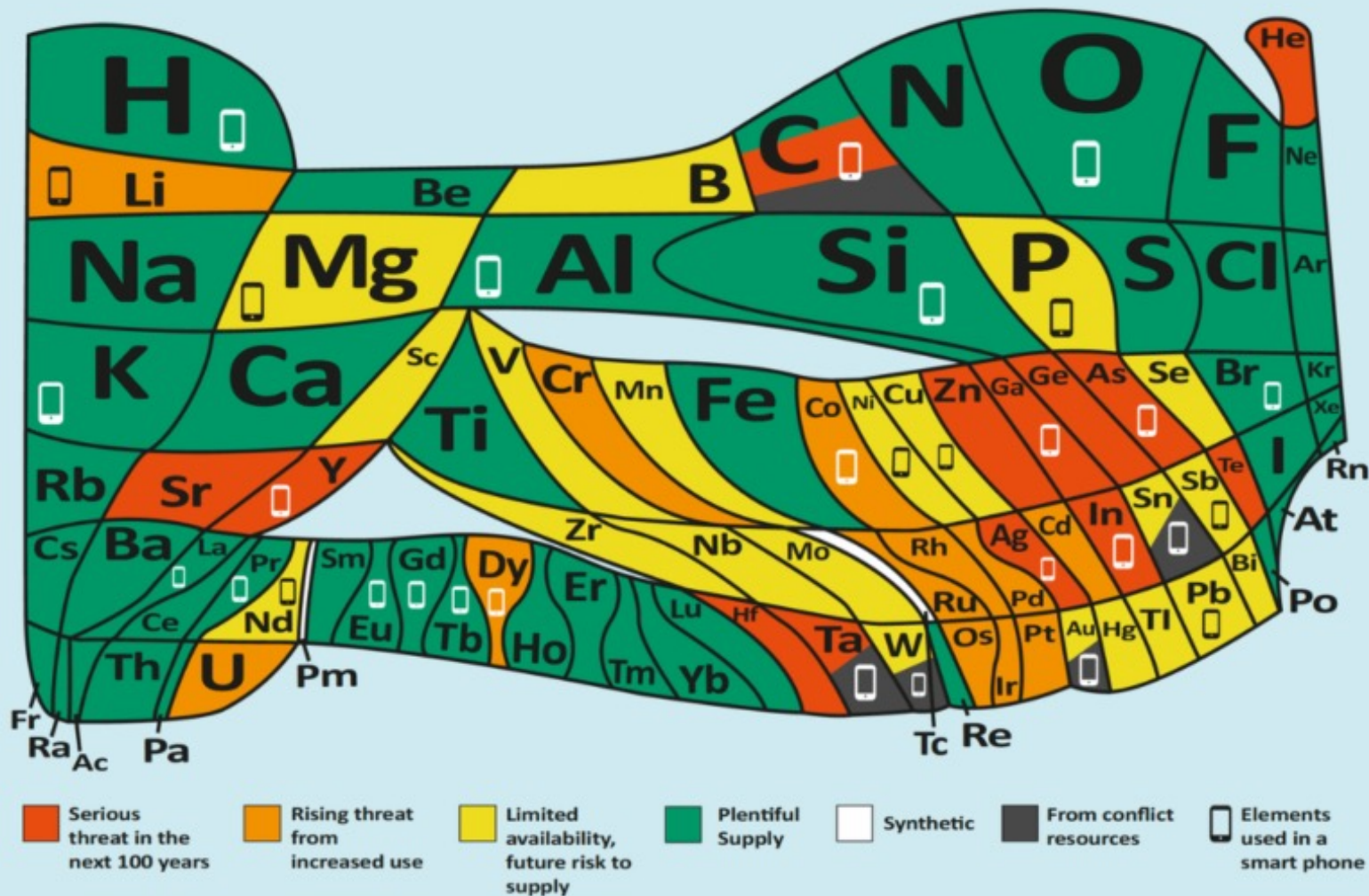
“The story of phosphorus: Global food security and food for thought”
Dana Cordell,* Jan-Olof Drangert , Stuart White

Global Environmental Change **19** (2009) 292–305.

Fig. 3. Key phosphorus flows through the global food production and consumption system, indicating phosphorus usage, losses and recovery at each key stage of the process. Units are in Million Tonnes per year (Only significant flows are shown here, relevant to modern food production and consumption systems.). Calculations based on data in IFA (2006) and Smil (2000a,b).

The 90 natural elements that make up everything

How much is there? Is that enough? Is it sustainable?

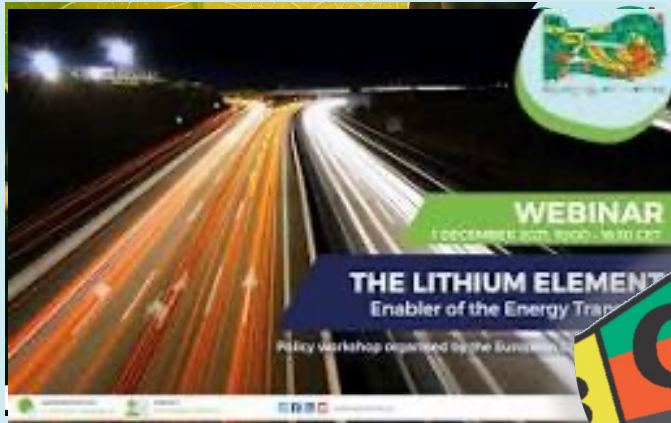


Inspired by WF Sheehan's 'A Periodic Table with Emphasis' published in Chemistry, 1976, 49, 17-18'

Read Support Notes and play the video game <http://bit.ly/euchems-pt>

The 90 natural elements that make up everything

How much is there? Is that enough? Is it sustainable?



APRIL 22nd, 2021



Global availability
on Earth

Supply from
main
current
sources



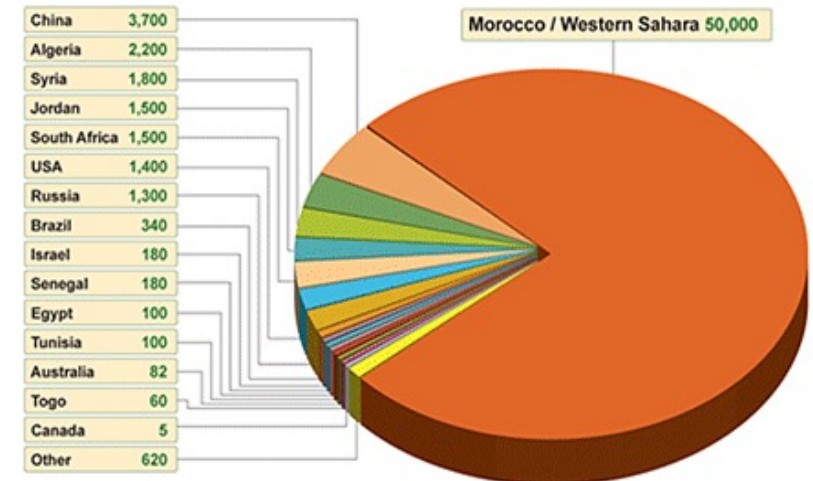
- The concentration of P is 0.09% of the solid earth crust
- P is the 10-12 most abundant element on the planet

Serious threat in the next 100 years

Rising threat from increased use

What quality? lower P concentration, Cd, U, Th, clay)
Access? more difficult (deeper, remote mines – no rail, below seabed)
Energy demand? increasing (to mine, process, transport)
Cost? Wastes ?

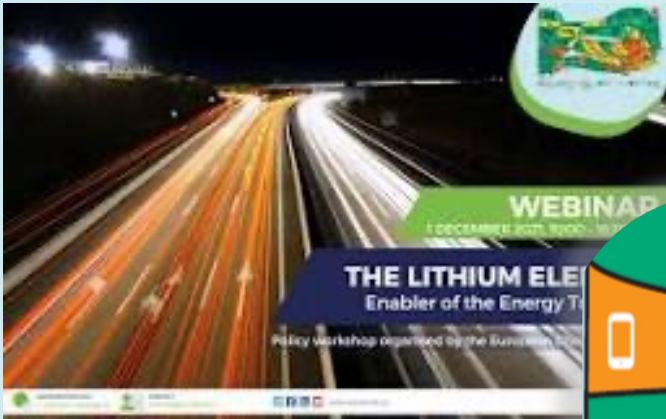
World Phosphate Rock Reserves 65,000 million tonnes*



The 90 natural elements that make up everything

How much is there? Is that enough? Is it sustainable?

18



DEC 1st, 2021



Revisited
Because of
Major role in
Energy transition



Lithium Ion Battery
Phosphate!

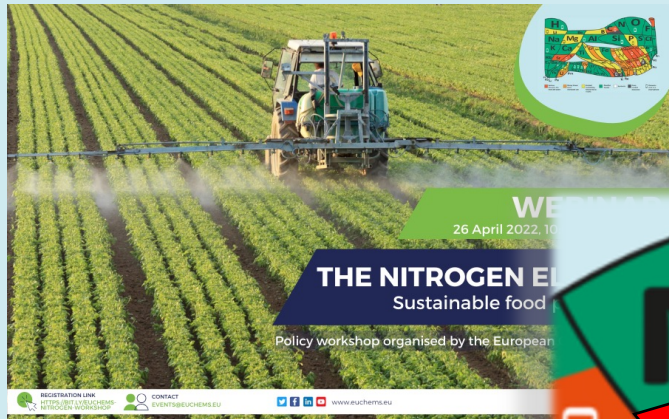


Inspired by V

The 90 natural elements that make up everything

How much is there? Is that enough? Is it sustainable?

18



Global availability

Environmental impacts



Air: N_2O (3-5% 298 GHG!), NH_3 (PM2.5)

Water:
anoxia

Abysmal Nitrogen Utilization
Efficiency (NUE) – 4-14%

Water ?

Phosphate Utilization efficiencies
Other externalities?

Serious threat in the next 100 years

Rising threat from increased use

Limited availability, future risk to supply

Plentiful Supply

Synthetic

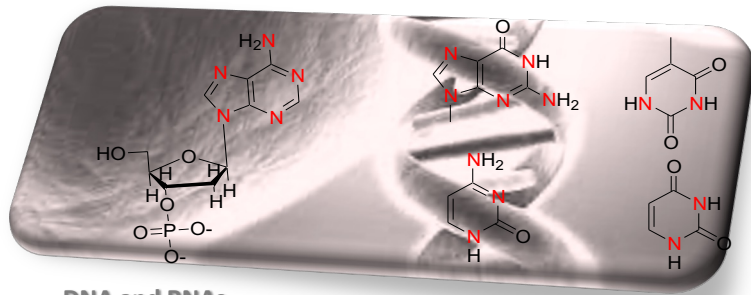
From conflict resources

Elements used in a smart phone

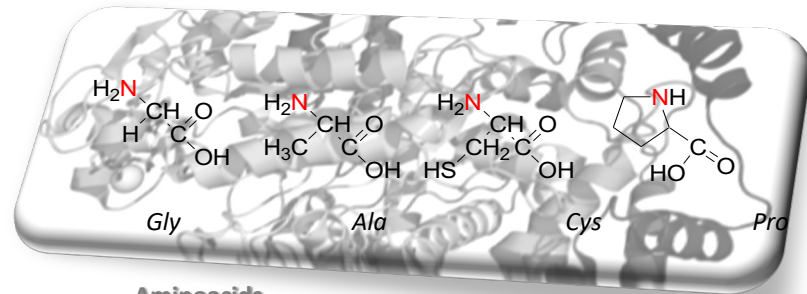
Inspired by V

Vital CHNOPS

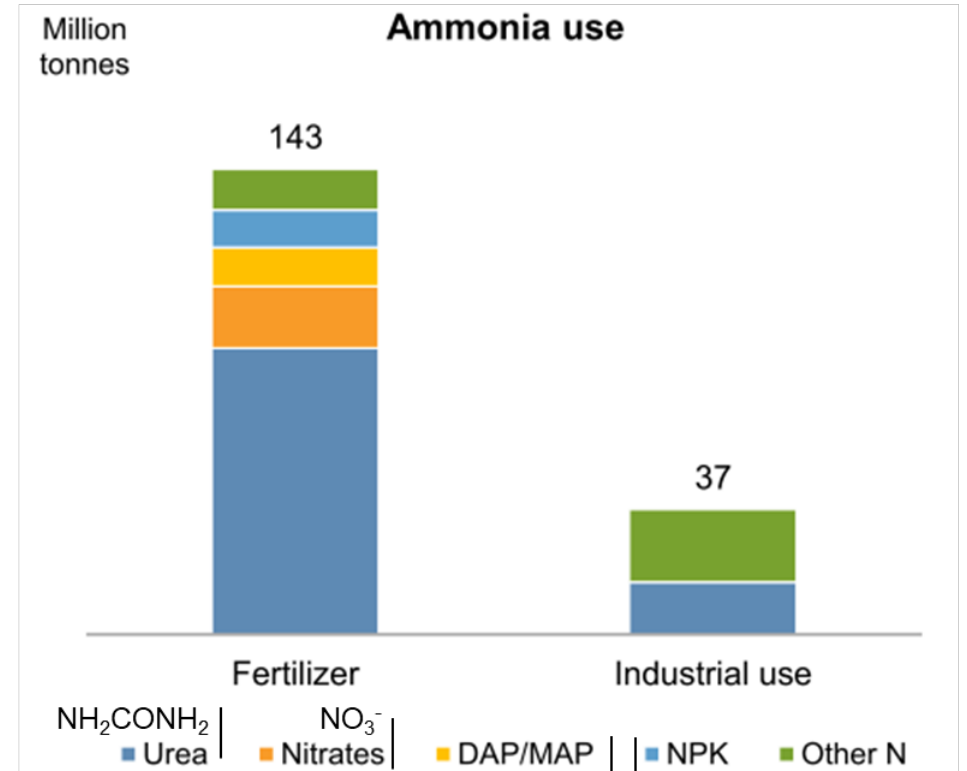
FERTILIZERS



DNA and RNAs



Aminoacids

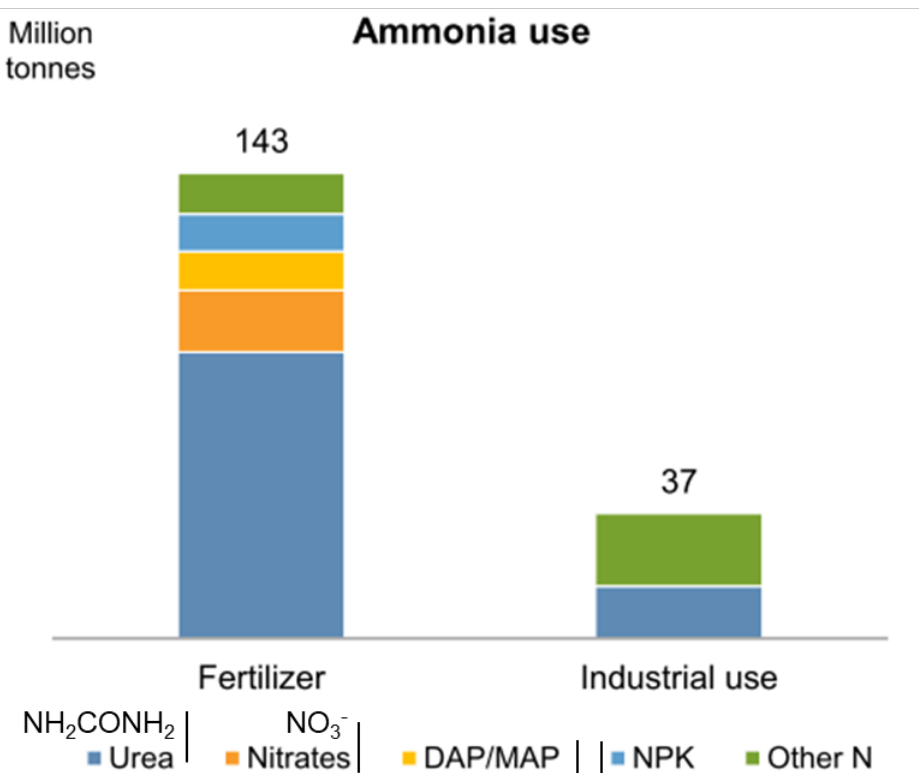


diammonium phosphate fertilizer $(\text{NH}_4)_2\text{HPO}_4$
 monoammonium phosphate fertilizer $(\text{NH}_4\text{H}_2\text{PO}_4)$ | $\ll (\text{N}-\text{P}_2\text{O}_5-\text{K}_2\text{O}) \gg$
 NH_4^+ , NO_3^- , NH_2CO^- , H_2PO_4^- , K^+

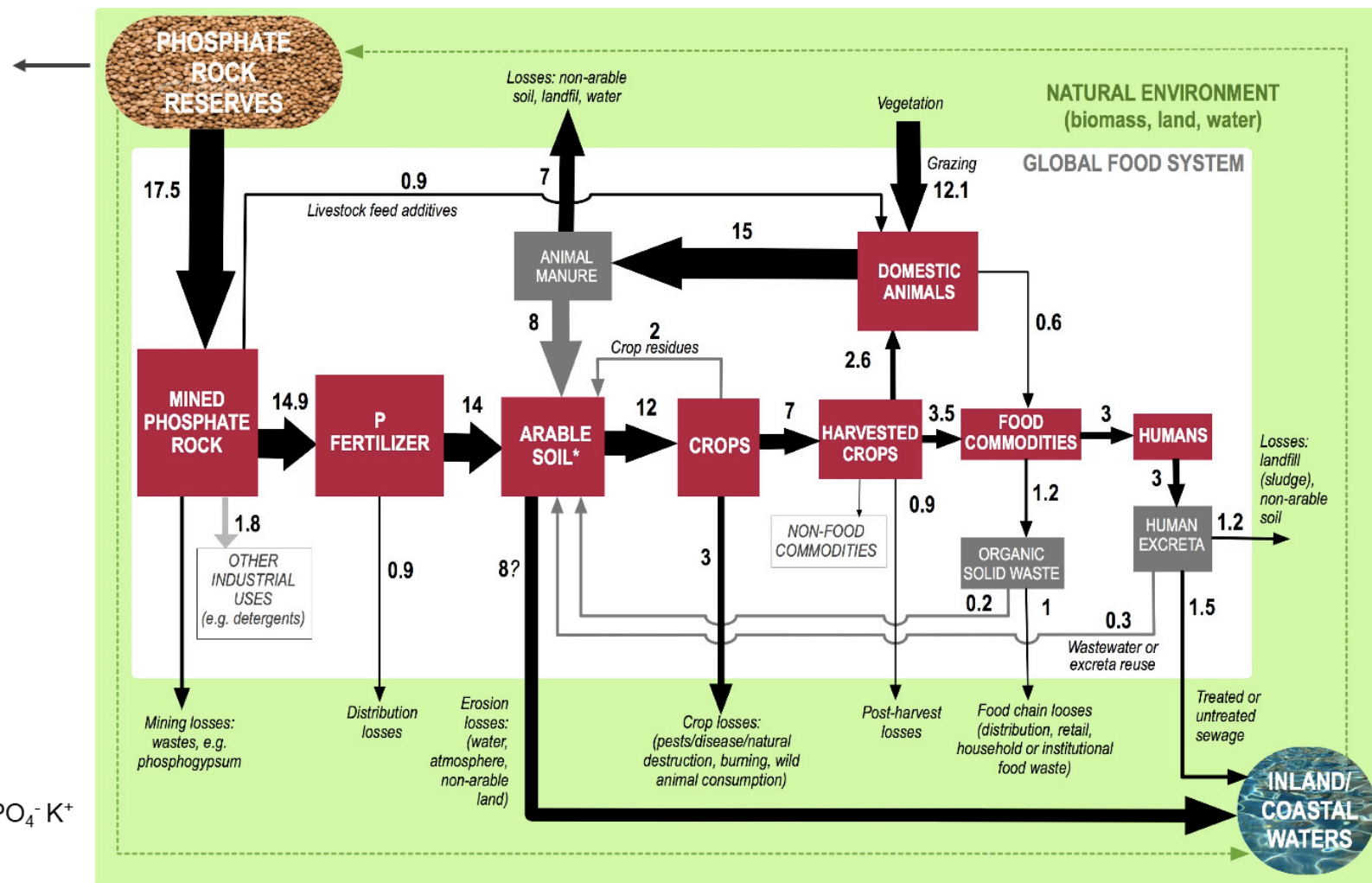
Source: IFA, Fertecon (via Haldor Topsoe)

FERTILIZERS

80% P LOSS mine-to-fork



Ammonium phosphate fertilizer $(\text{NH}_4)_2\text{HPO}_4$
 Ammonium phosphate fertilizer $(\text{NH}_4\text{H}_2\text{PO}_4)$



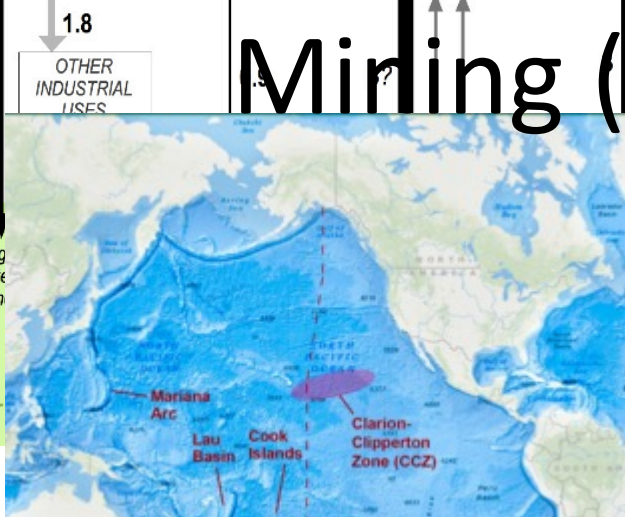
Mining (current) issues?

Algae Bloom

Food security?




Mining (future)





The 90 natural elements that make up everything

How much is there? Is it enough? Is it sustainable?




 Serious threat in the next 100 years


 Rising threat from increased use

 Limited availability, future risk to supply

 Plentiful Supply

 Synthetic

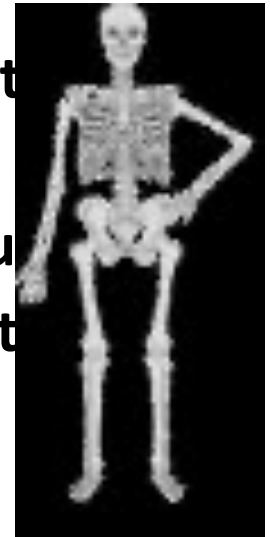
 From conflict resources

 Elements used in a smart phone

Inspired by V

Phosphorus - P

- The concentration of P is 0.09% of the solid earth crust
 - P is the 10-12 most abundant element on the planet
- More than 300 phosphate minerals is known in the nature
- Apatite is the most common phosphate mineral on earth
 - 87% of bone substance is consisting of $\text{Ca}_3(\text{PO}_4)_2$
 - 4% of the bone substance is P



Phosphates
Arne Åsheim

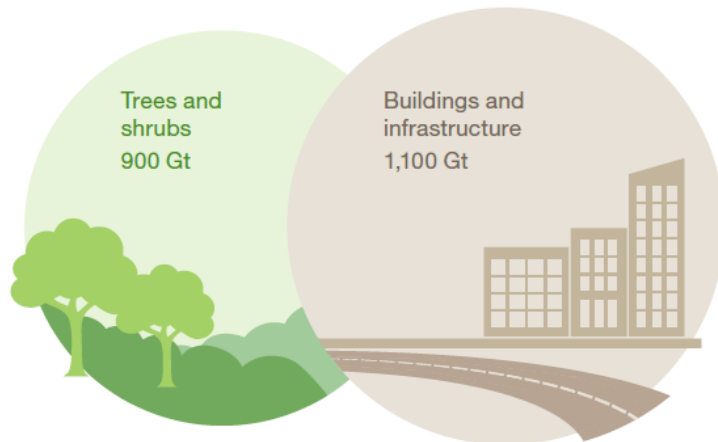
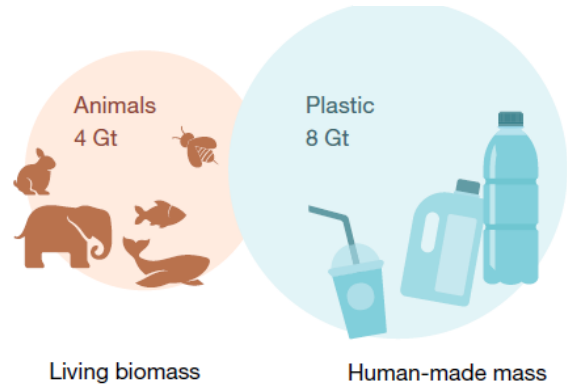
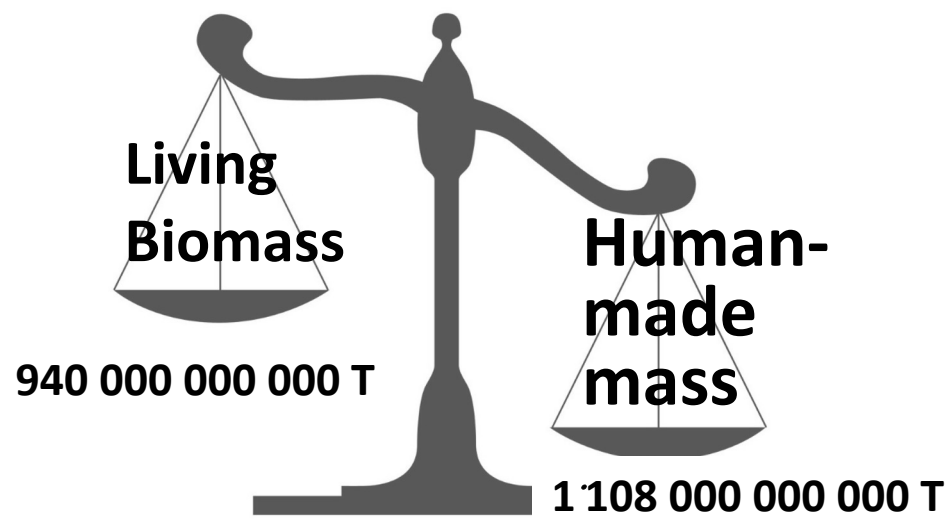
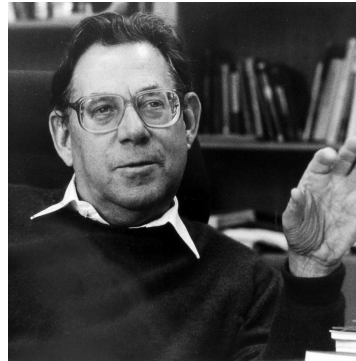


Figure from Nature 588, 442–444 (2020).

P. Crutzen, “*Geology of mankind*” **Nature** 415, 23 (2002).

Ca. 2000

Anthropocene



Paul Crutzen

Chimie de l’atmosphère
Ozone, stratosphère

2009

Planetary Boundaries

Rockstrom, J., W. Steffen, P. Crutzen, and J. Foley. “*Planetary boundaries: exploring the safe operating space for humanity*” **Ecology and Society** 14(2): 32 (2009)

2015

Great Acceleration

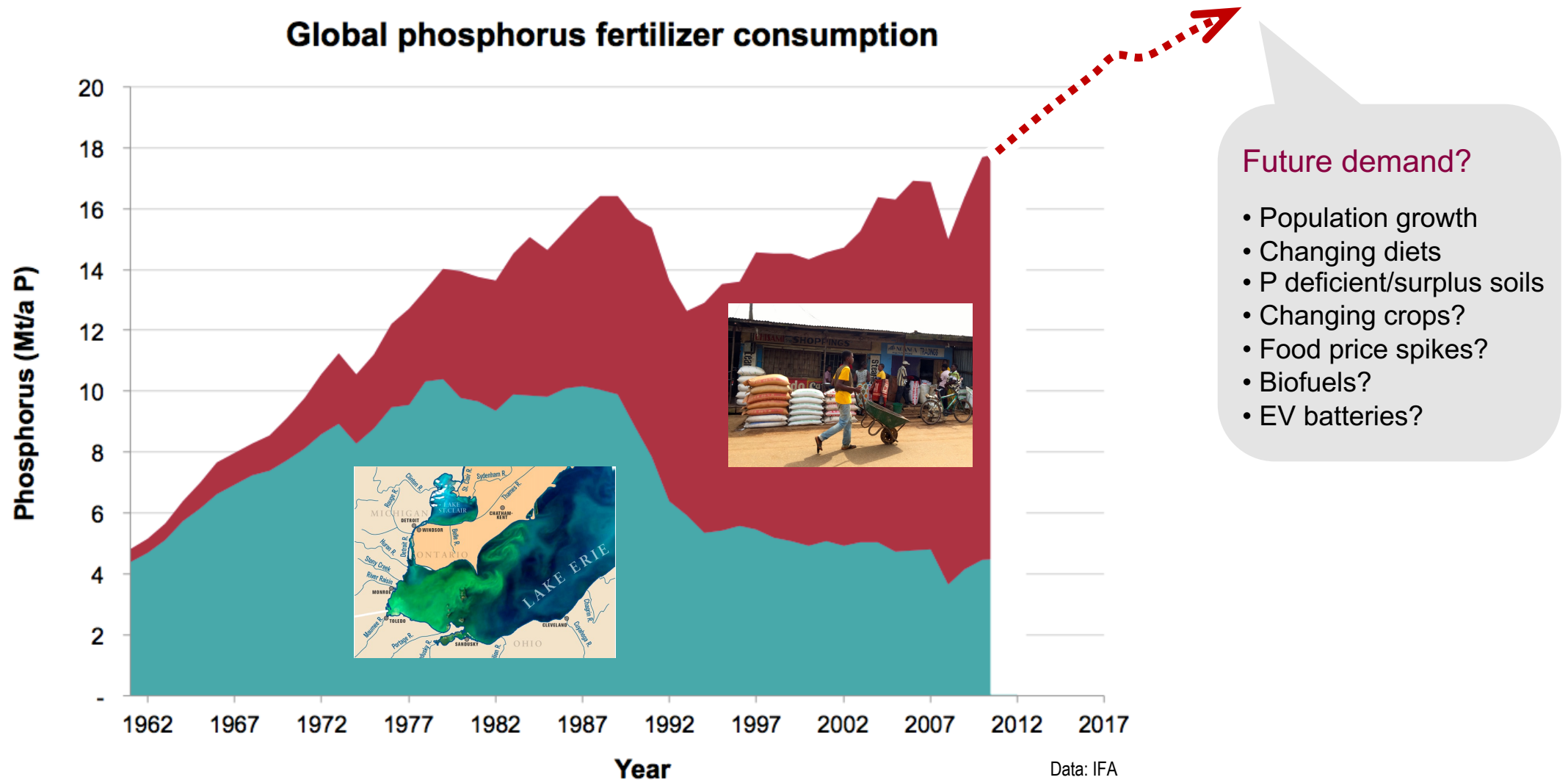
Steffen, Will; Broadgate, Wendy; Deutsch, Lisa; Gaffney, Owen; Ludwig, Cornelia (April 2015). “*The trajectory of the Anthropocene: The Great Acceleration*”. **The Anthropocene Review**. 2 (1): 81–98

2022

Crossover Point

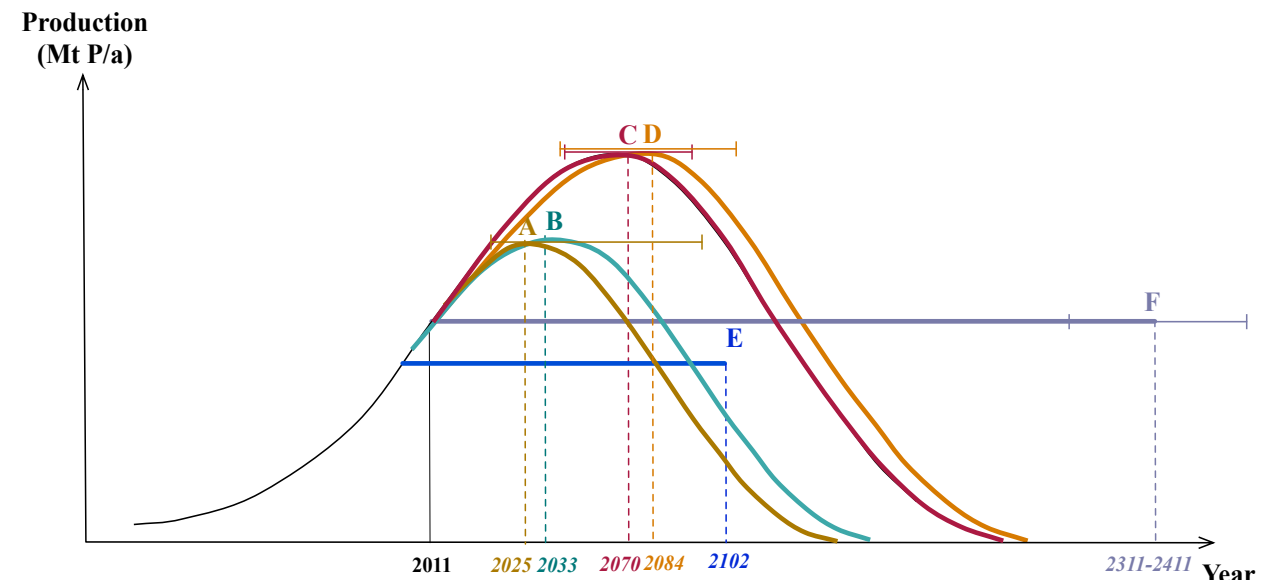
Emily Elhacham, Liad Ben-Uri, Jonathan Grozovski, Yinon M Bar-On, Ron Milo «*Global human-made mass exceeds all living biomass* » **Nature** 588, 442–444 (2020).

FUTURE PHOSPHORUS DEMAND?



FUTURE PHOSPHORUS SUPPLY?

- **Long-term availability** of phosphate rock? Depends on demand assumptions! Demand is increasing...
- Global demand for phosphorus fertilisers may surpass supply of phosphorus this century, estimated between 2035-2075
- Timing of peak uncertain, but widely recognised that phosphate rock:
 - **quality** is declining (lower P concentration, Cadmium, Uranium, Thorium,, clay)
 - **access** is more difficult (digging deeper, more remote mines – no rail, below seabed)
 - **energy** increasing (to mine, process, transport)
 - **costs** increasing
 - **wastes** increasing



LEGEND:

A=Mohr & Evans (2013); B=Cordell et al (2009a); C=GPRI, 2010; Cordell et al, 2011b; D=Walan (2013); E=Fixen (2009); F=IFDC (2010)