Plastics: A rapidly growing global challenge for Earth's life-support system and humanity

Hans-Peter Plag
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Norfolk, VA, USA

Plastics: A rapidly growing global challenge for Earth's life-support system and humanity

Our perception depends on the distance we have …

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Planetary Life-Support System

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Health Planetary Physiology: Homeostasis

Planetary Life-Support System

Health Planetary Physiology: Homeostasis

Homo sapiens: one of (still) many species of mammals

Planetary Life-Support System

Health Planetary Physiology: Homeostasis

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Syndrome of modern global change

Planetary Physiology

The Syndrome: Modern Global Change

Planetary Physiology

Earth: Life-Support System for many species

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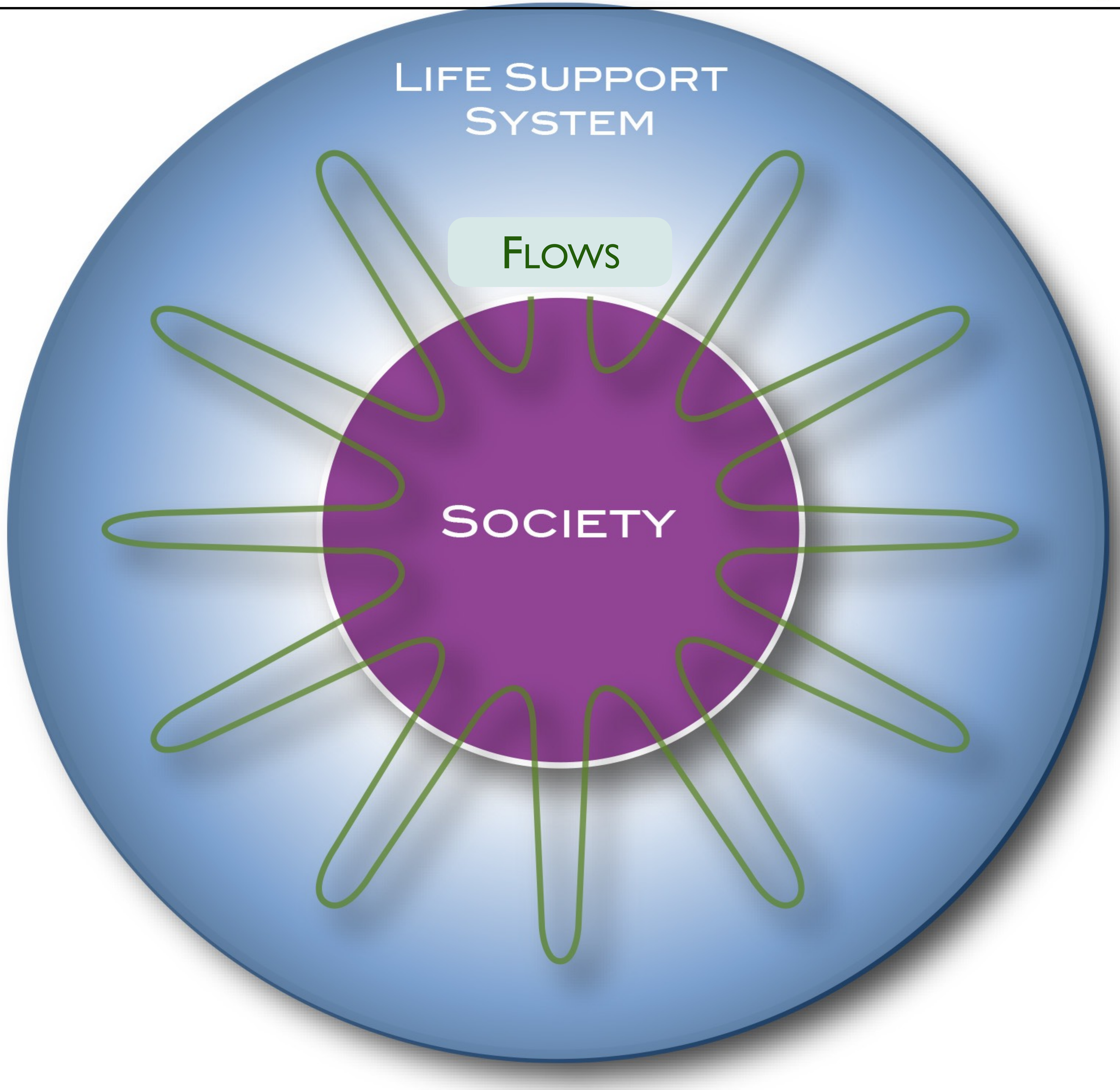
Earth: Life-Support System for many species

Everything is about Flows



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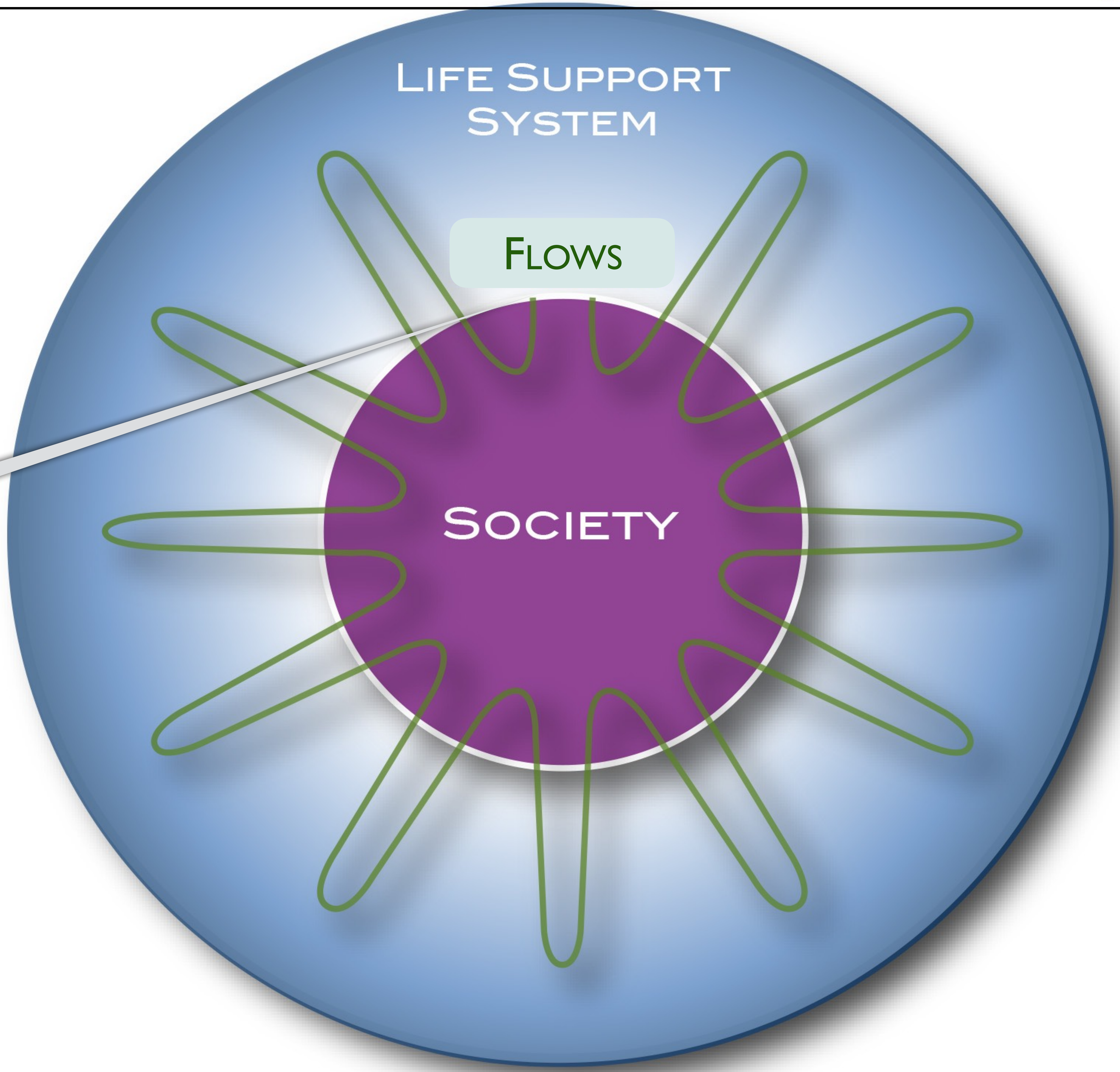
Everything is about Flows

Limitations in the flows between a community and its life-support system limit the growth of the community



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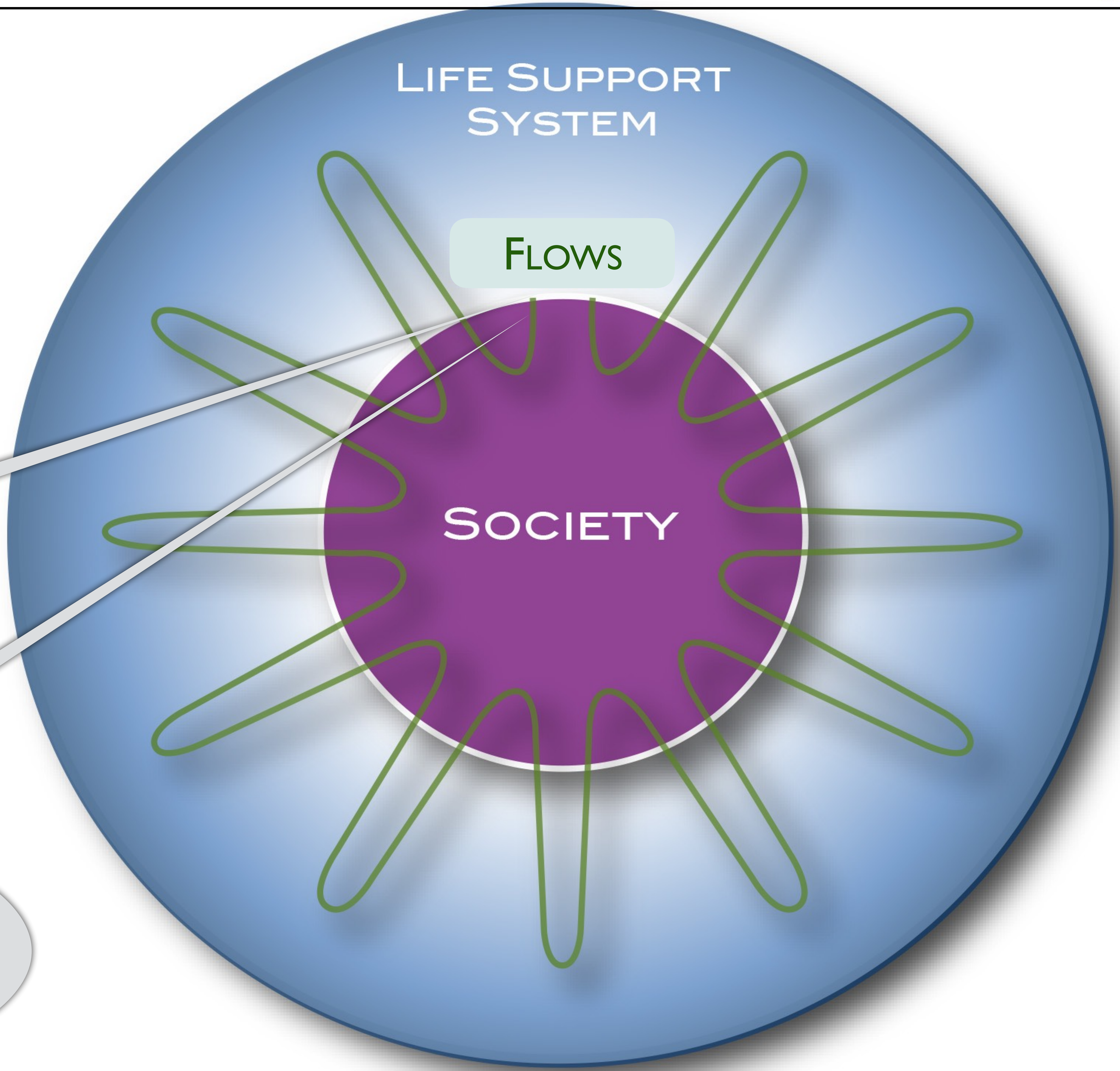


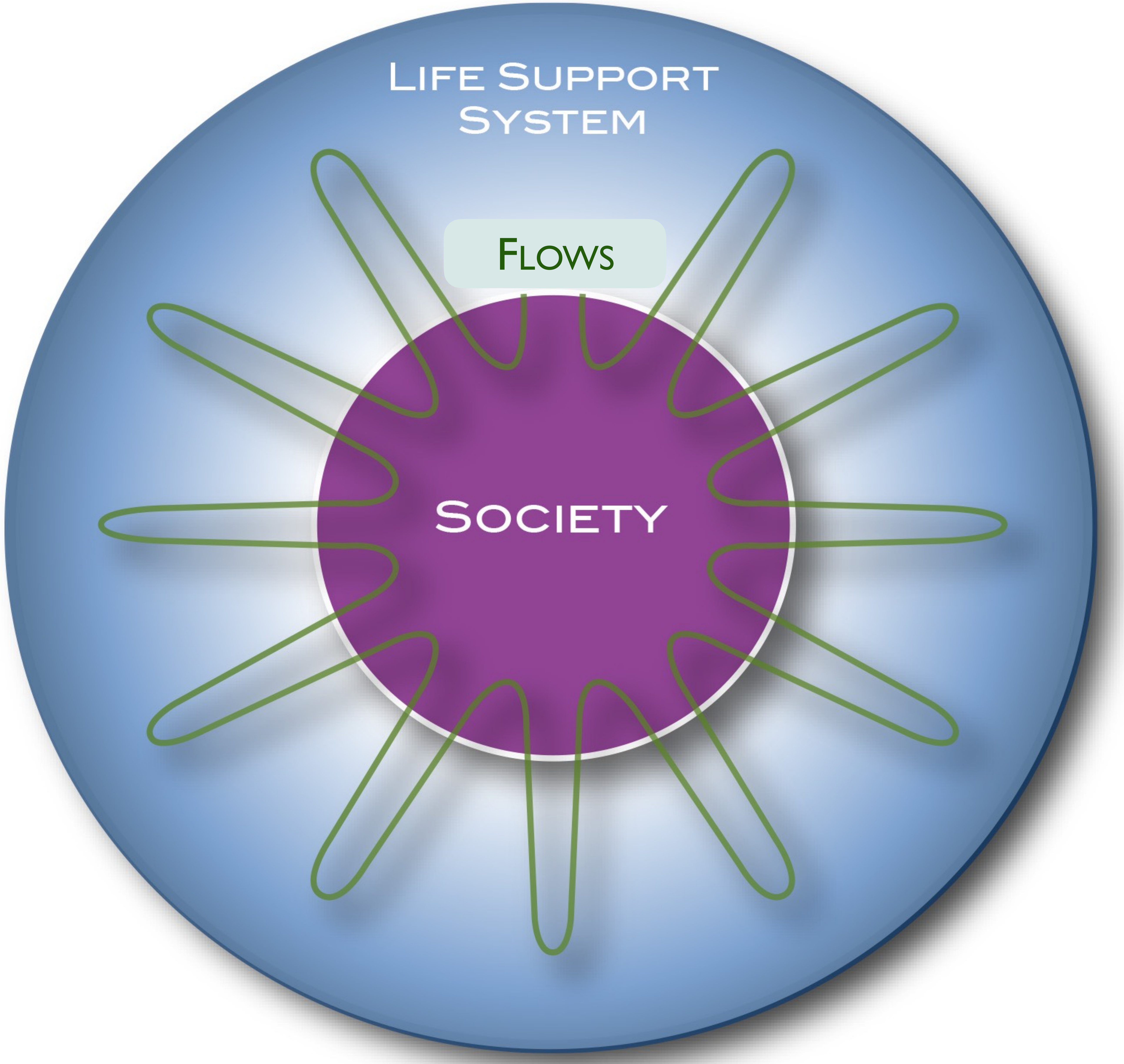
Limitations in the flows between a community and its life-support system limit the growth of the community

For Home sapiens, the flows are regulated by ethical, social, and - recently - economic rules

Planetary Physiology

Earth: Life-Support System for many species

Everything is about Flows

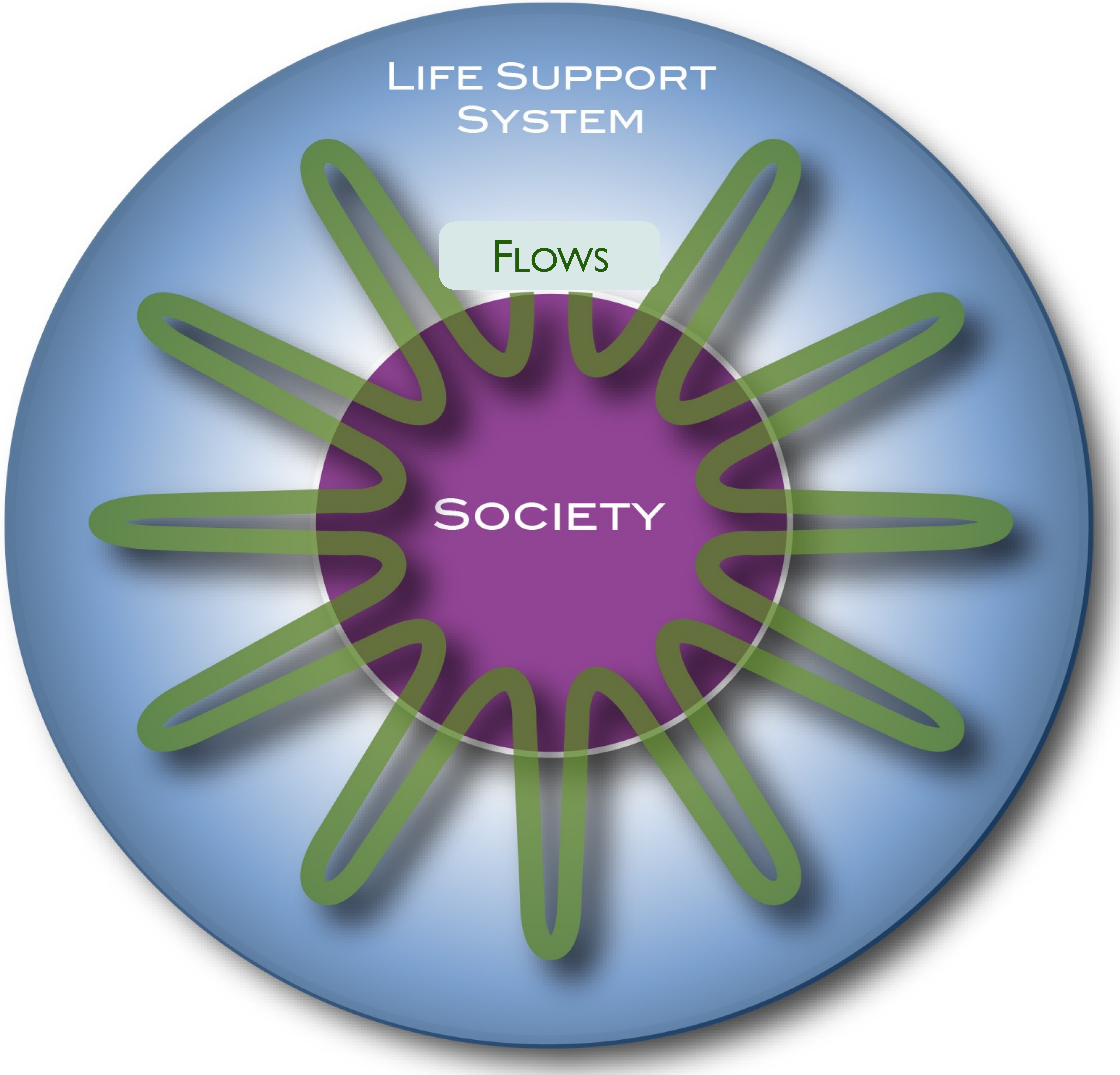


Planetary Physiology

Earth: Life-Support System for many species

Everything is about Flows

Flows have accelerated in the last 200 years; exploded in the last 70 years.



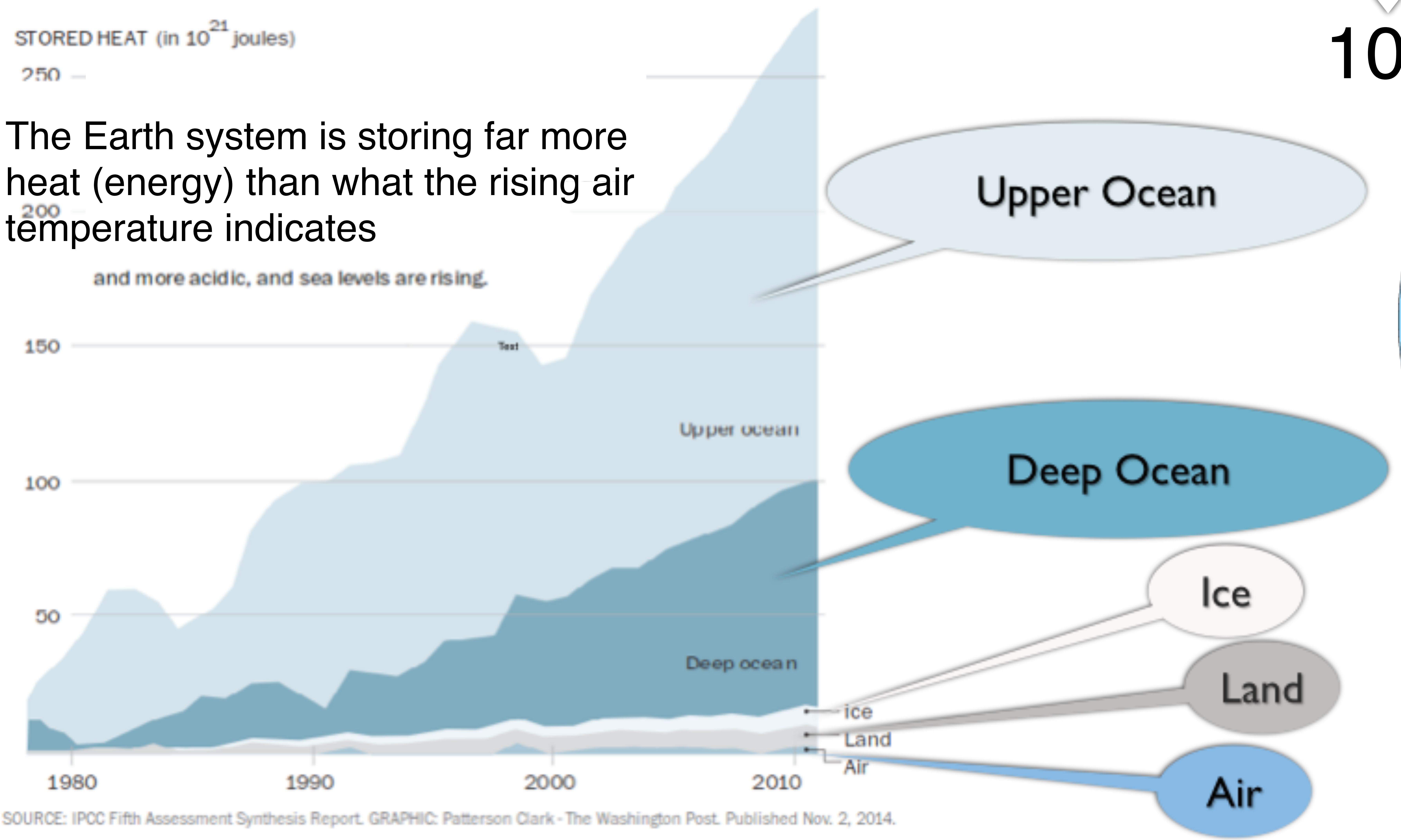
Earth’s Energy Imbalance

- Long-term due to photosynthesis: 10-100 MegaWatt
- Today: 300-320 TeraWatt

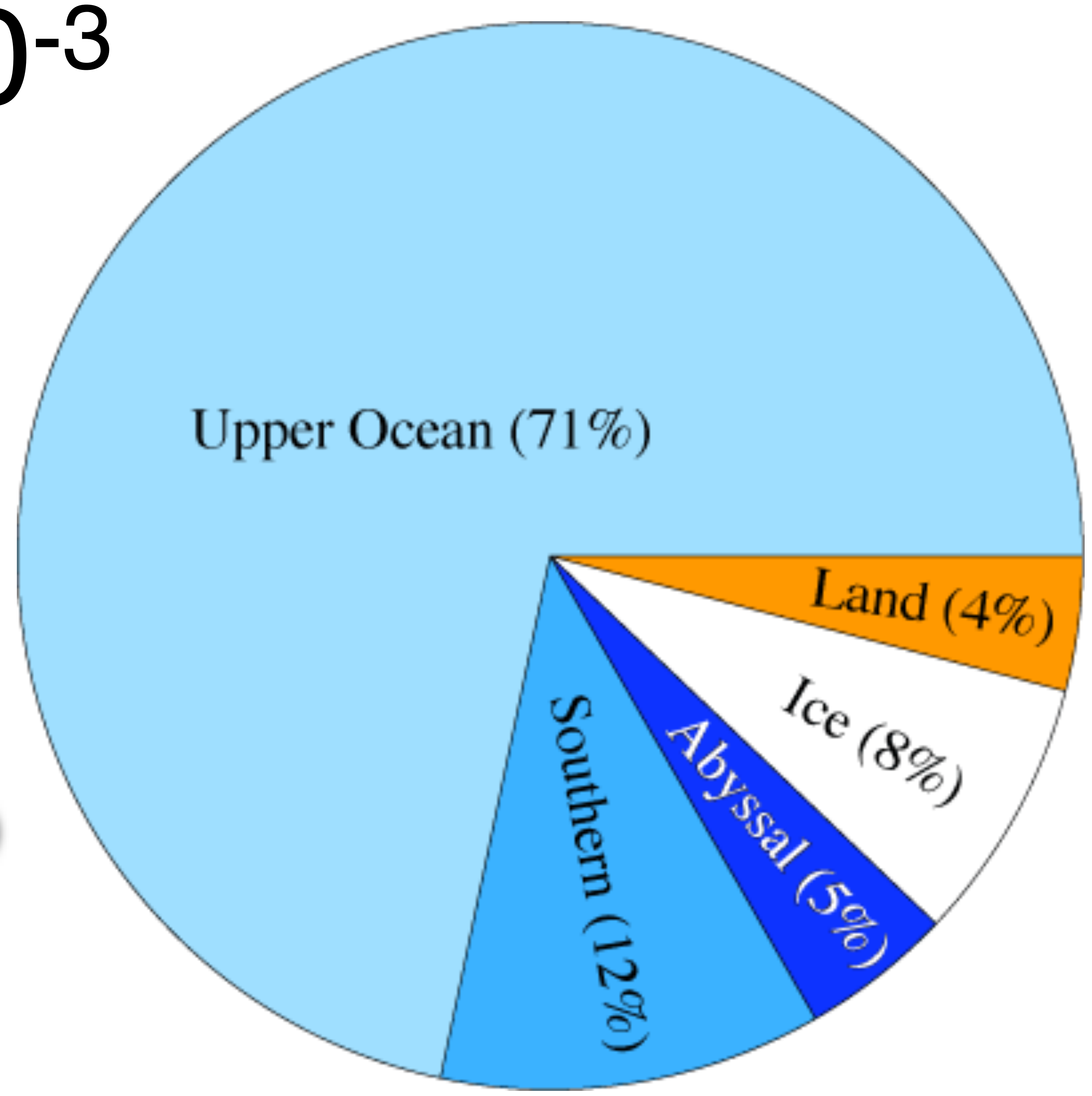
10^{-10} to 10^{-9}

10^{-3}

The Earth system is storing far more heat (energy) than what the rising air temperature indicates



SOURCE: IPCC Fifth Assessment Synthesis Report. GRAPHIC: Patterson Clark - The Washington Post. Published Nov. 2, 2014.



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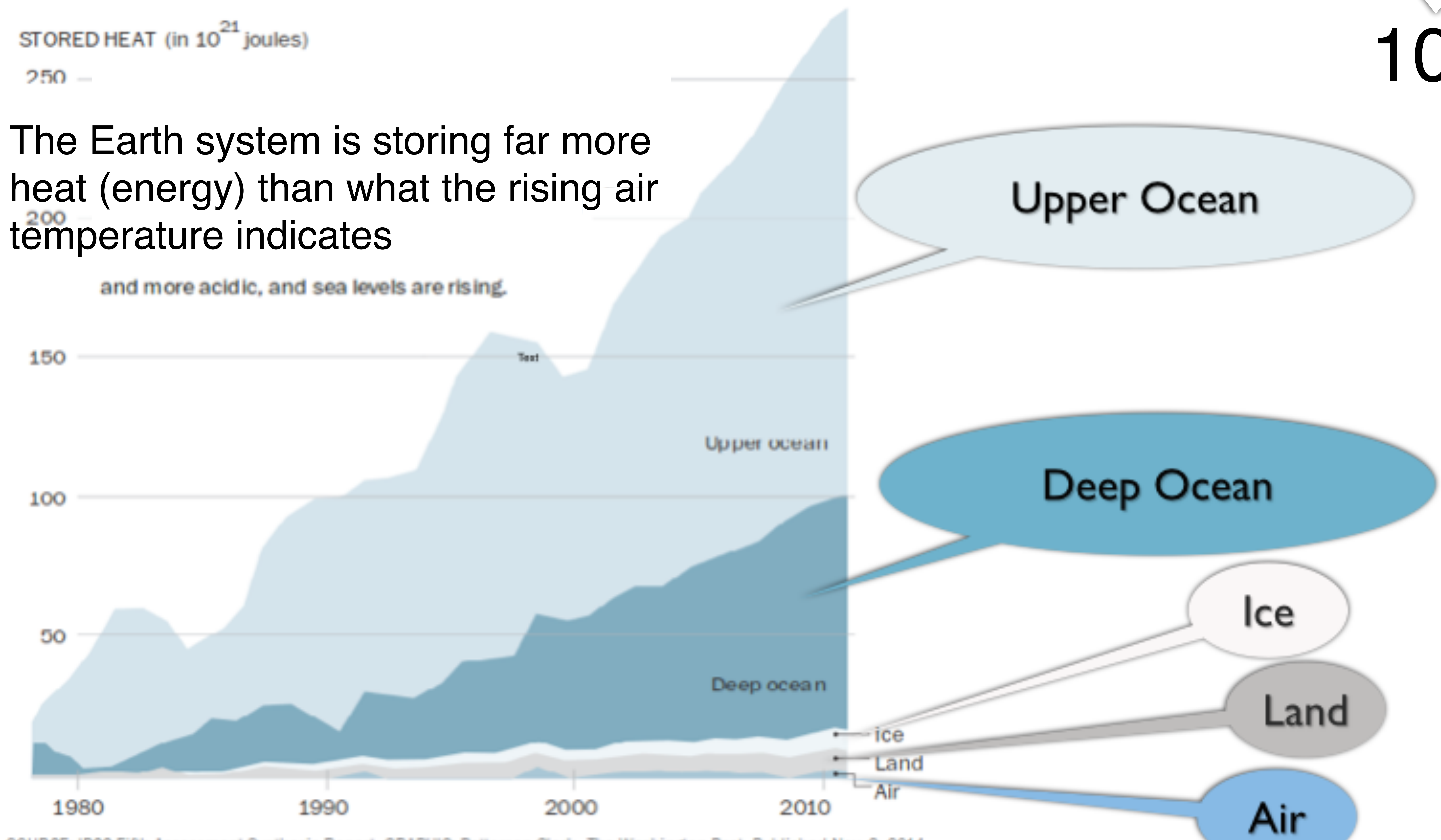

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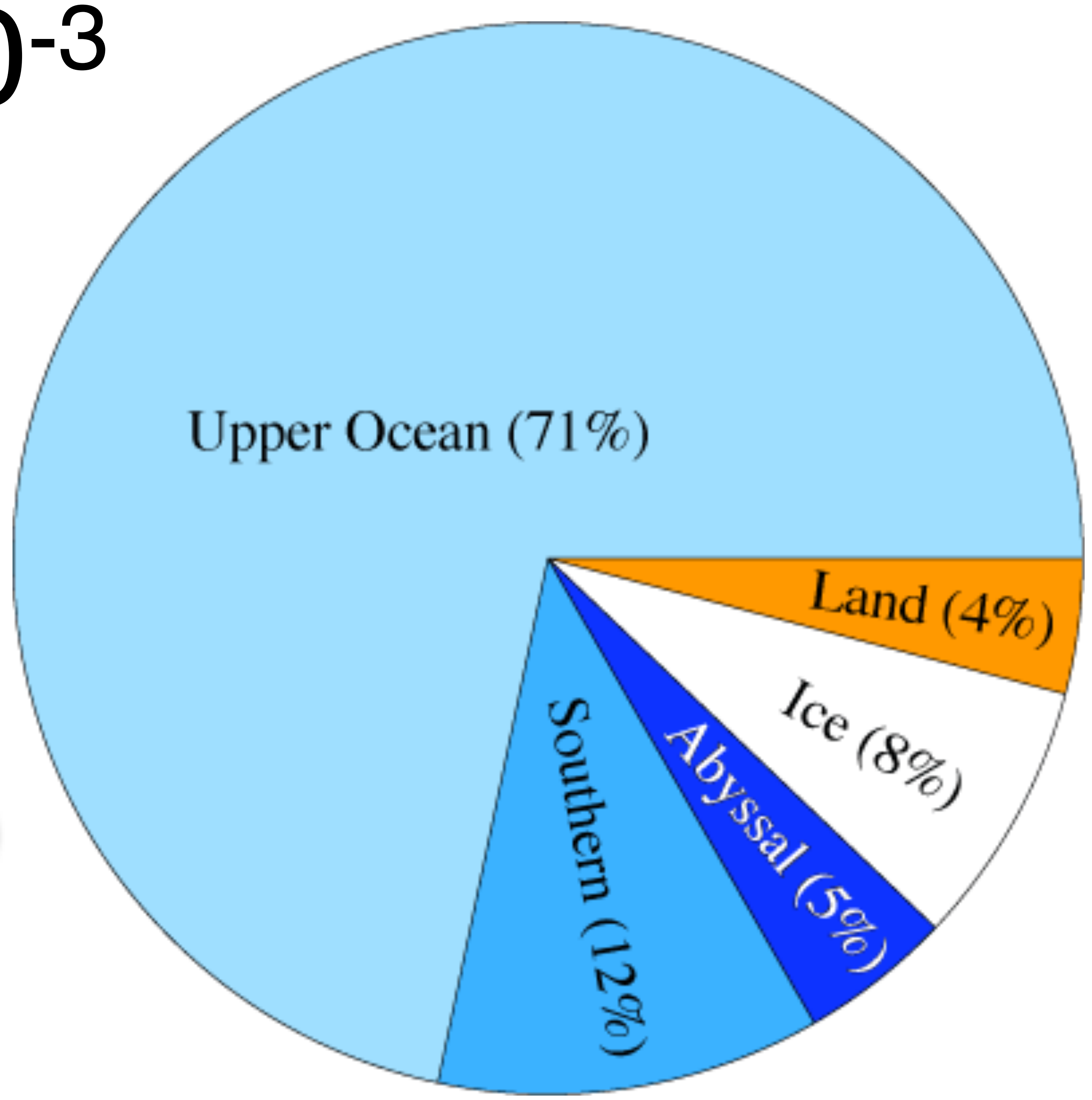
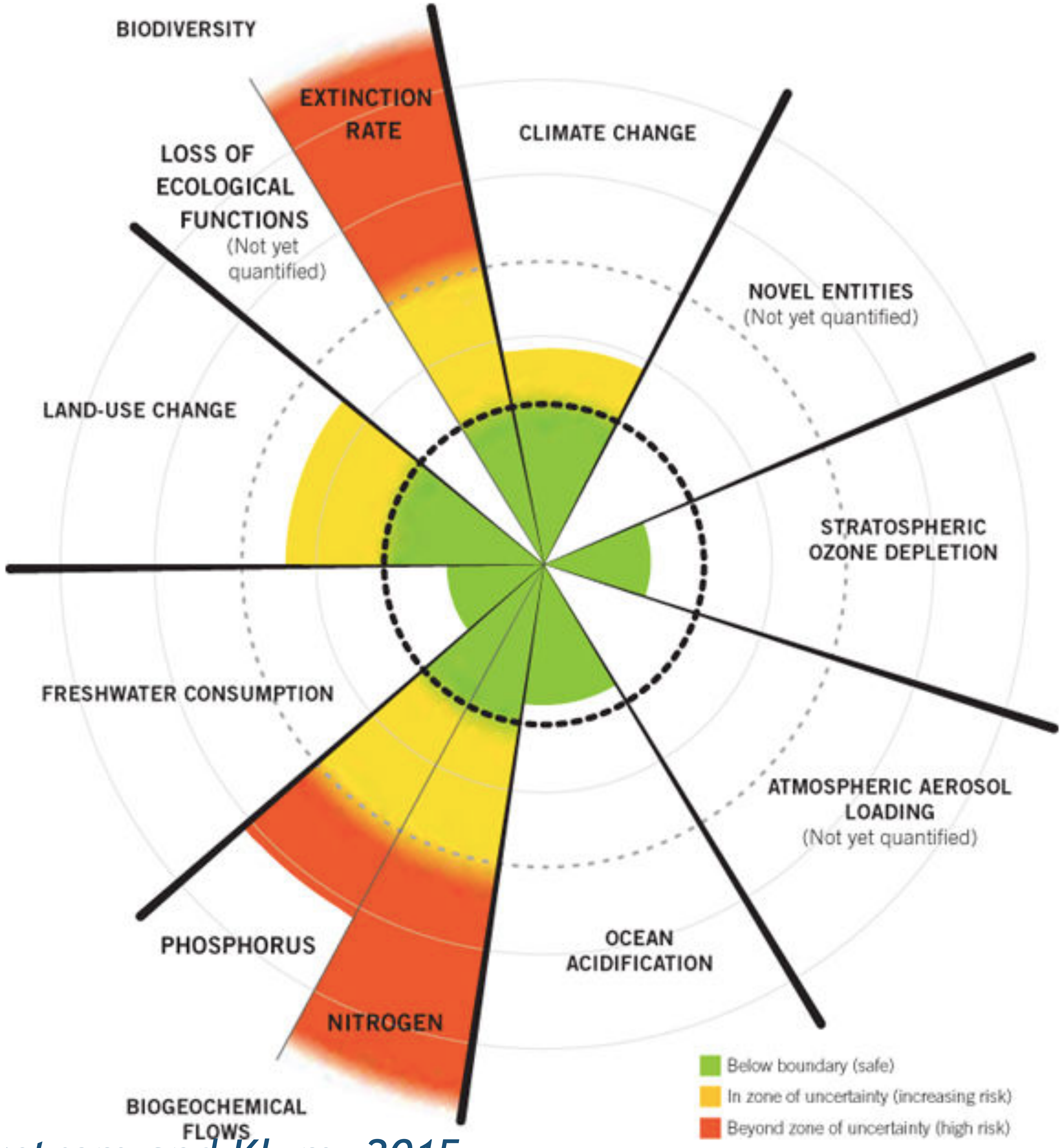


The Pool-House Effect

Impacts on the Earth’s Life-Support System

The Syndrome: Modern Global Change

Impacts on the Earth's Life-Support System



Rockstrom and Klum, 2015

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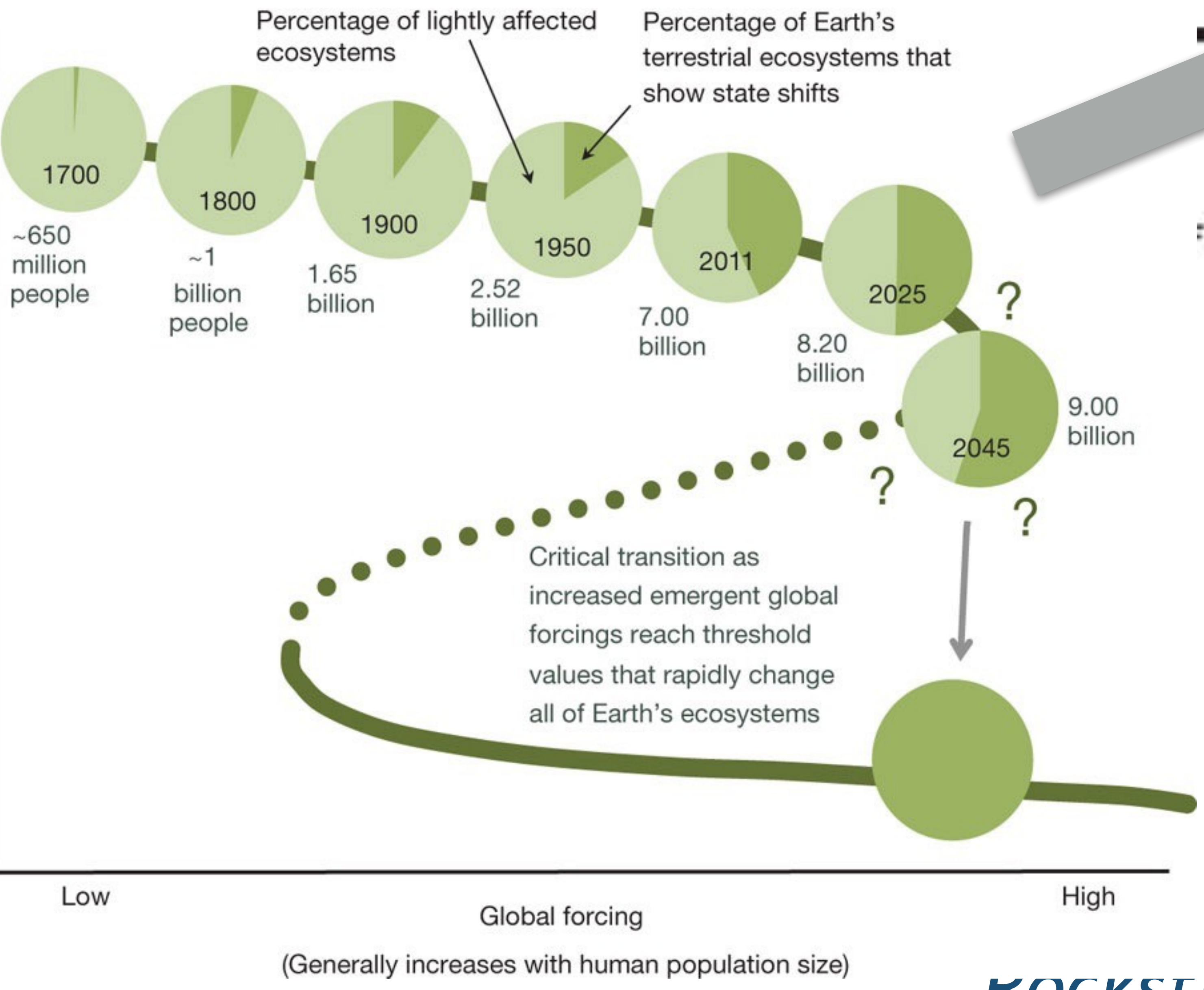

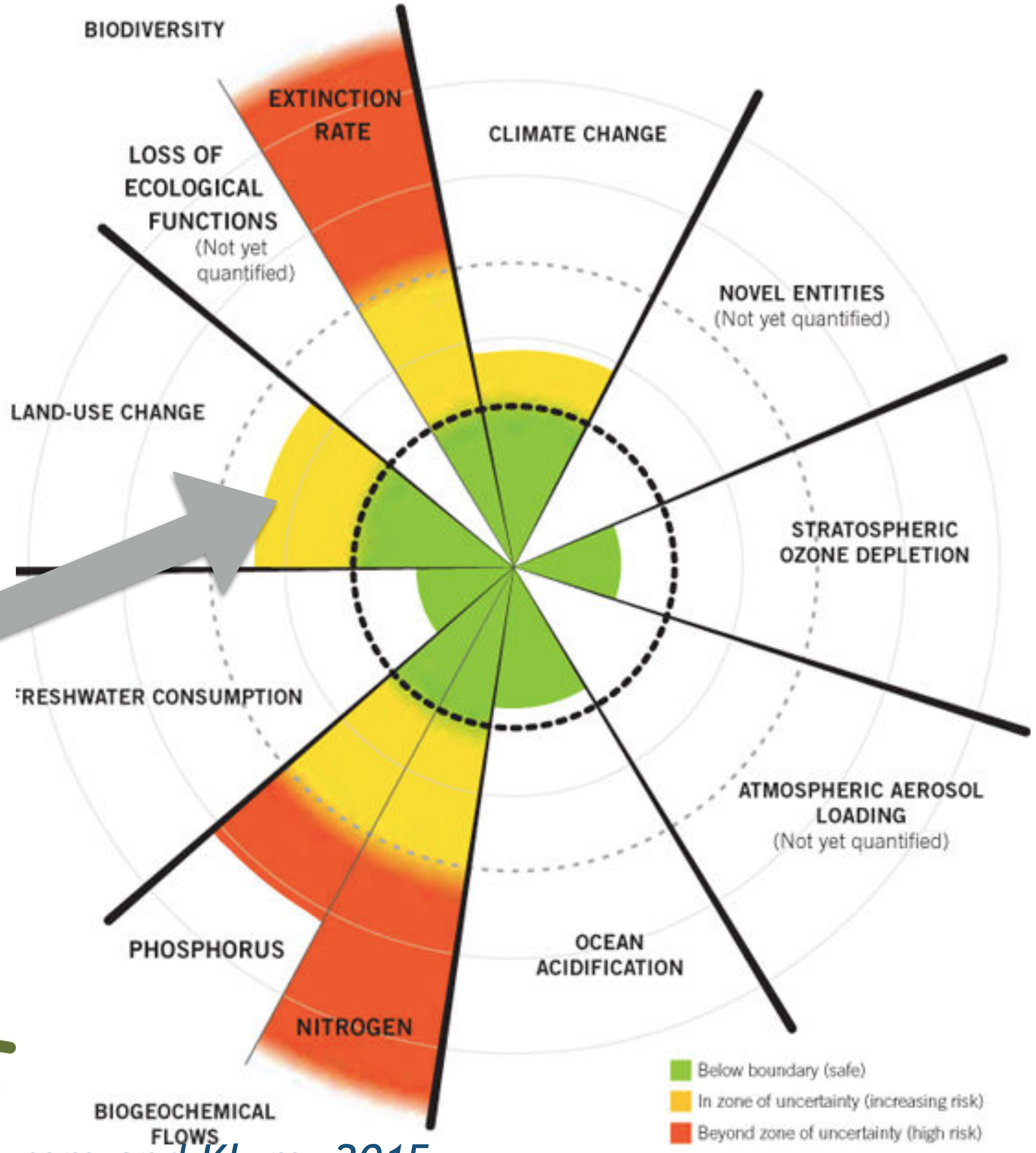

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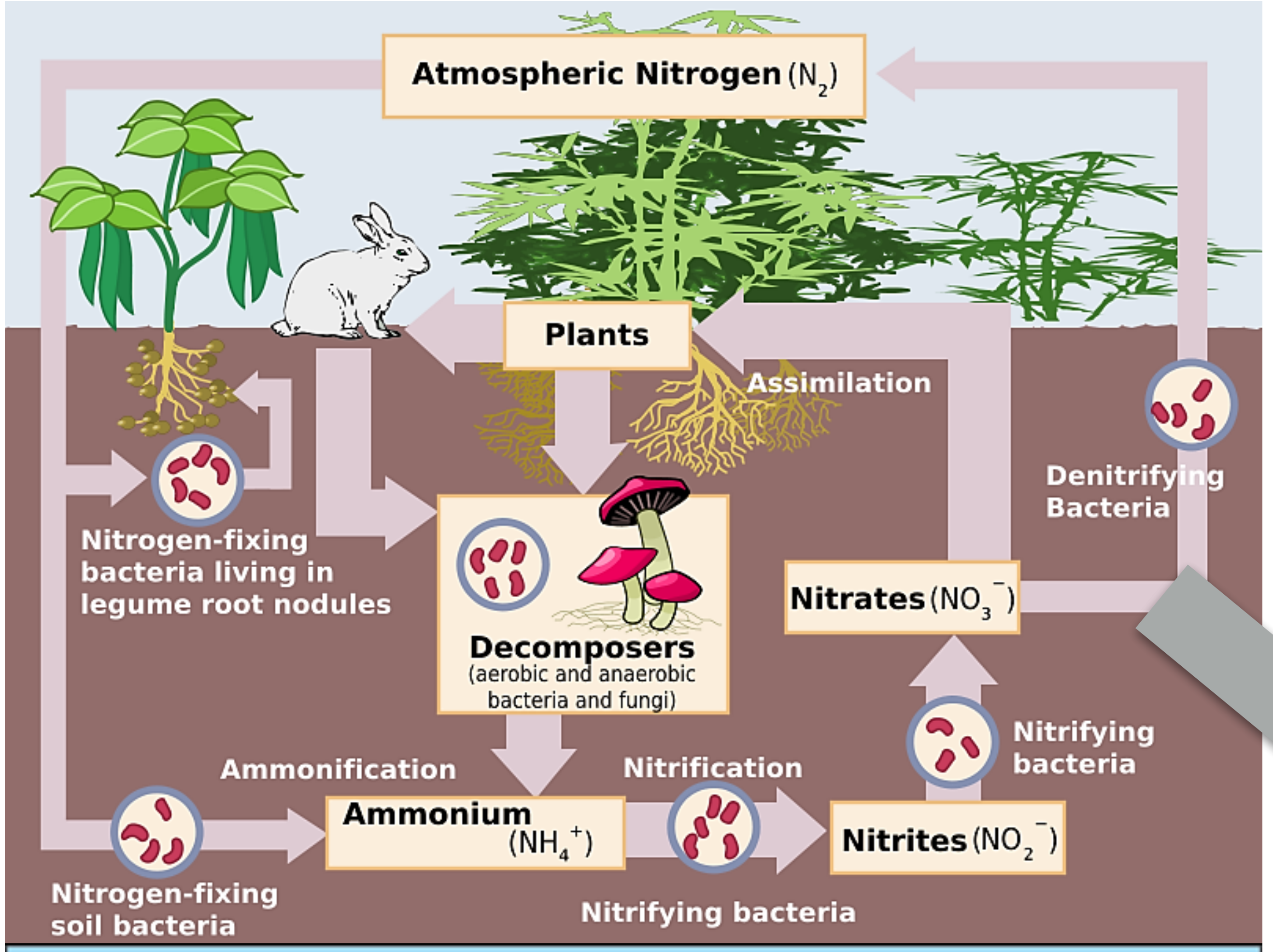

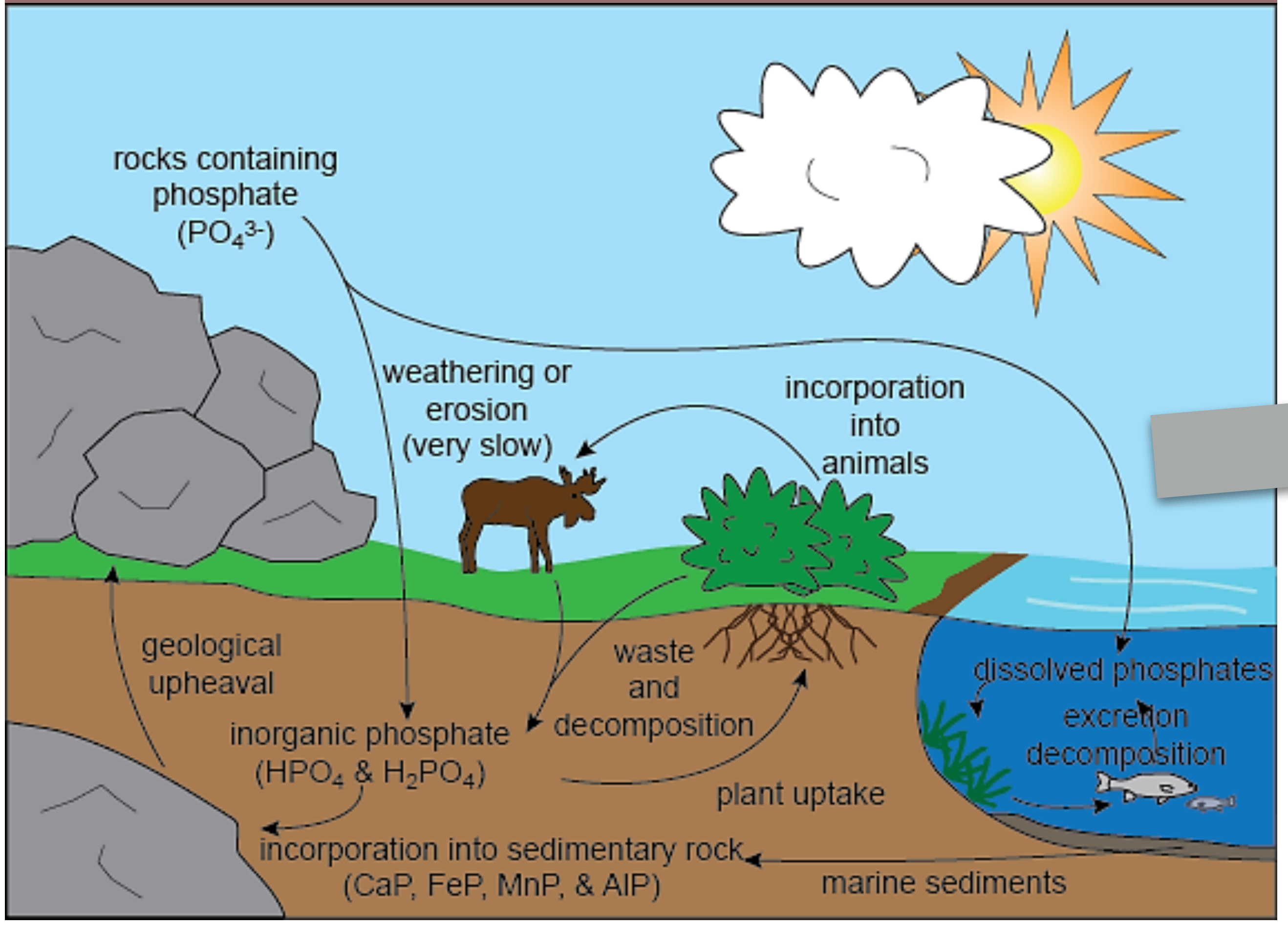

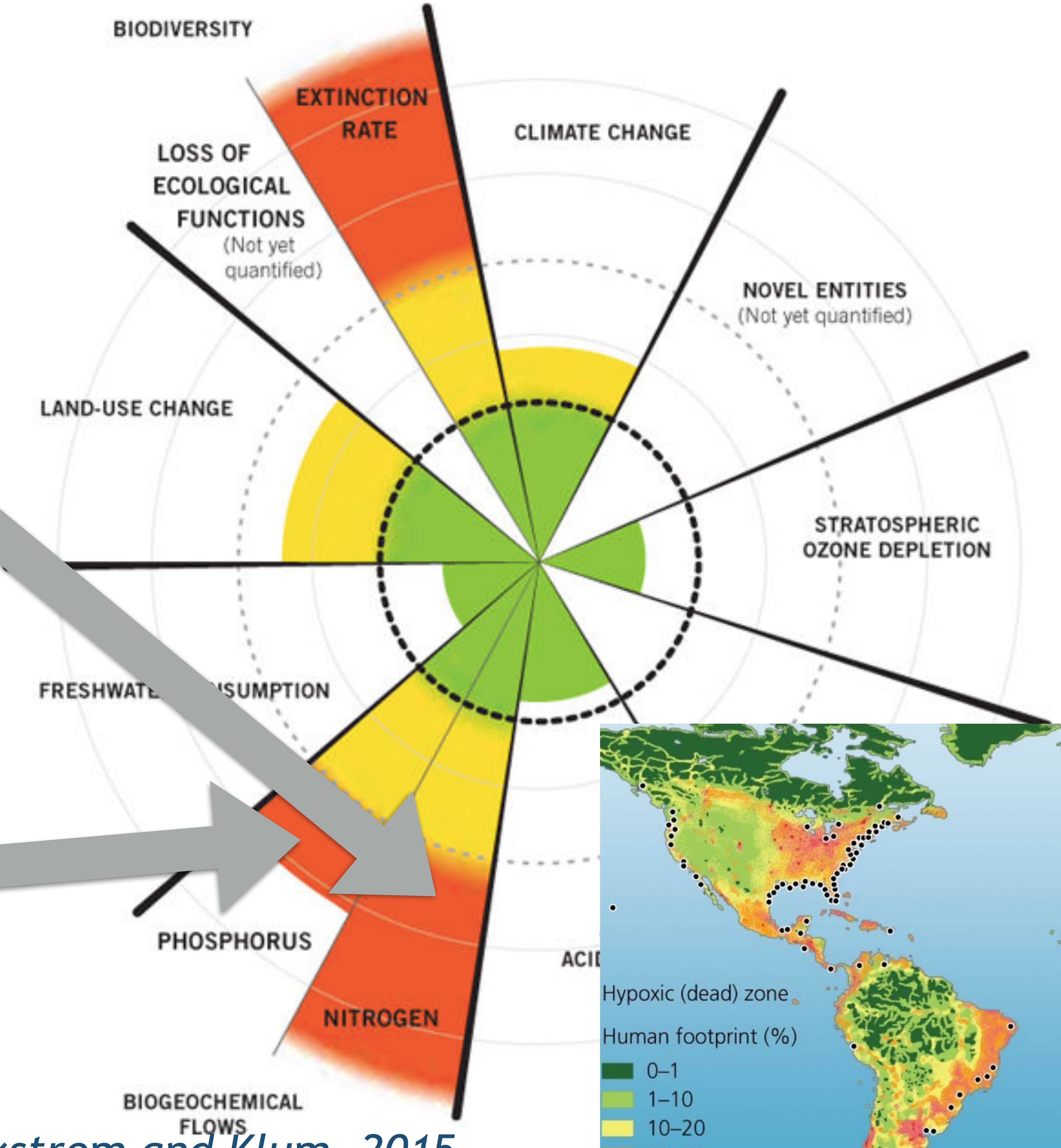

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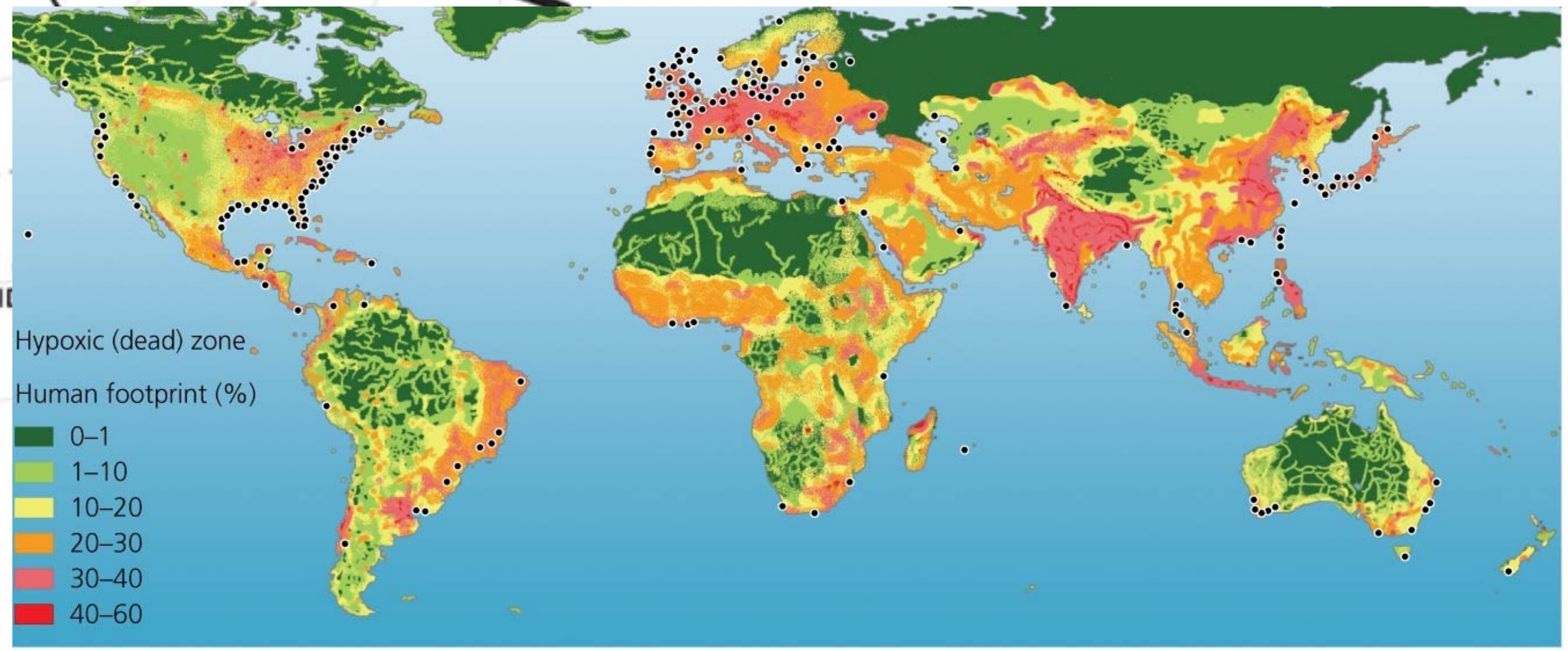
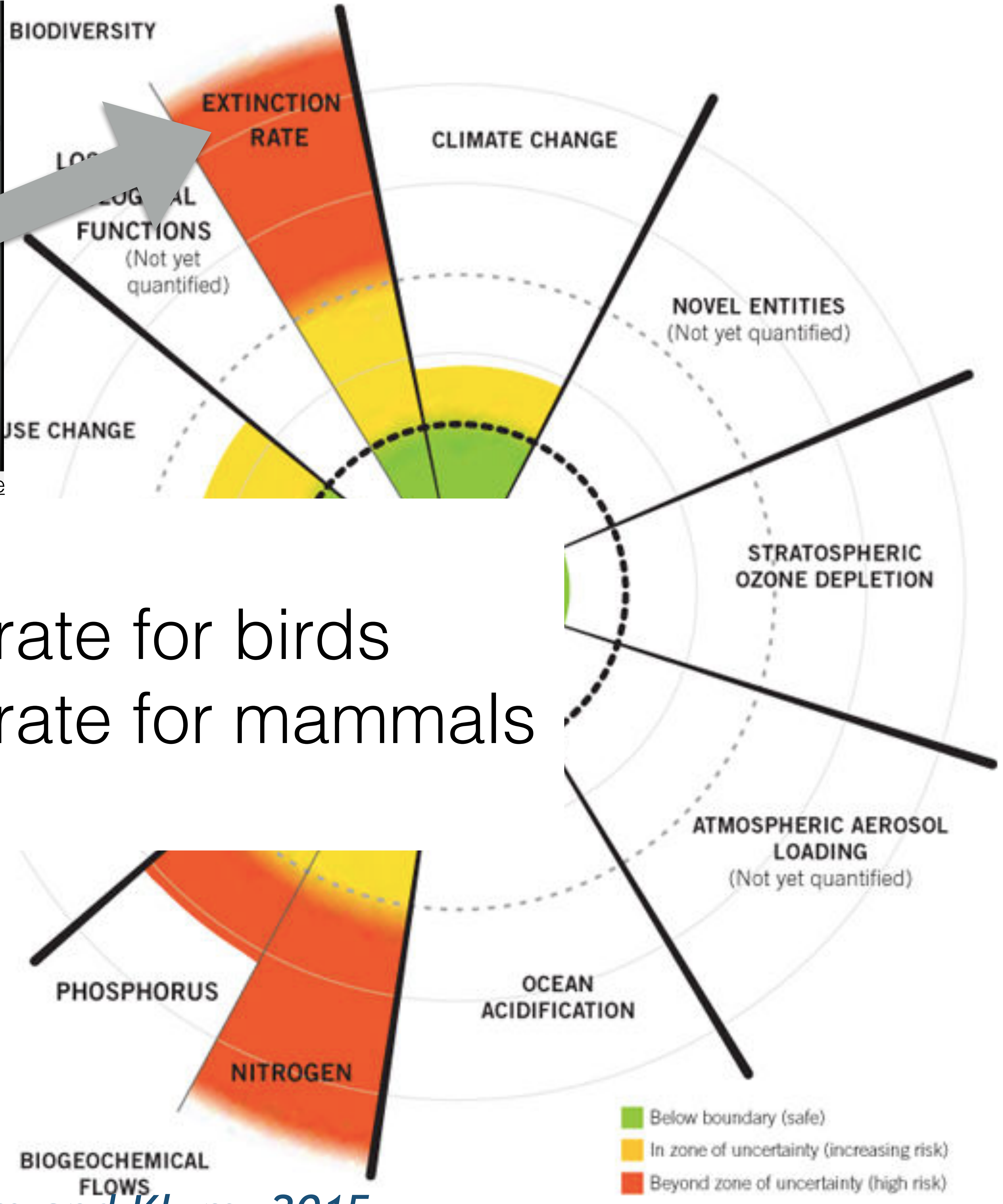


The Syndrome: Modern Global Change

Impacts on the Earth's Life-Support System

https://www.youtube.com/watch?v=gPq9YAg9mfc&feature=youtu.be



Current extinction rates:

300 times background rate for birds

80,000 times background rate for mammals

Rockstrom and Klum, 2015

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https://www.youtube.com/watch?v=gPq9YAg9mfc&feature=youtu.be

"We are the asteroid …"

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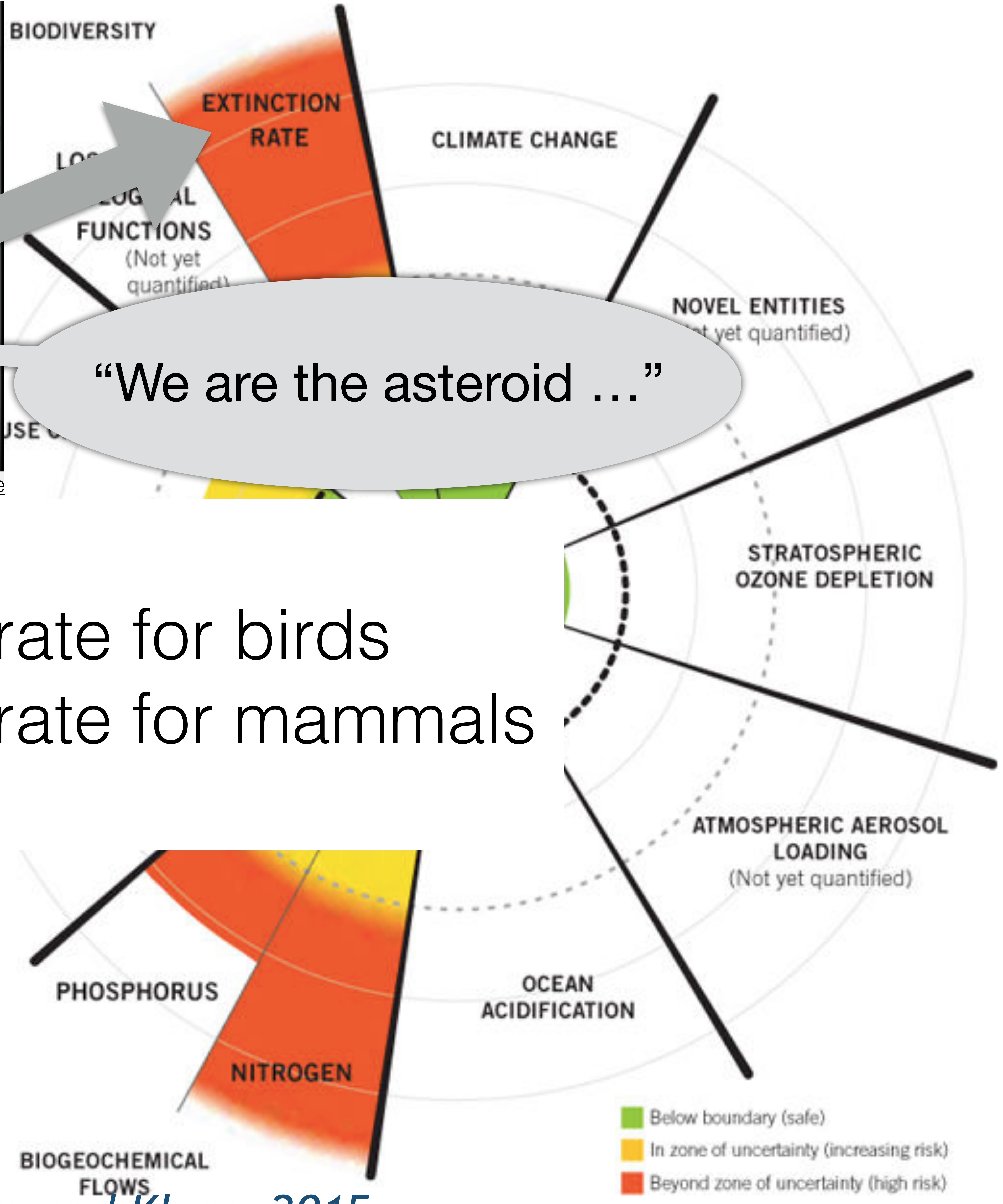

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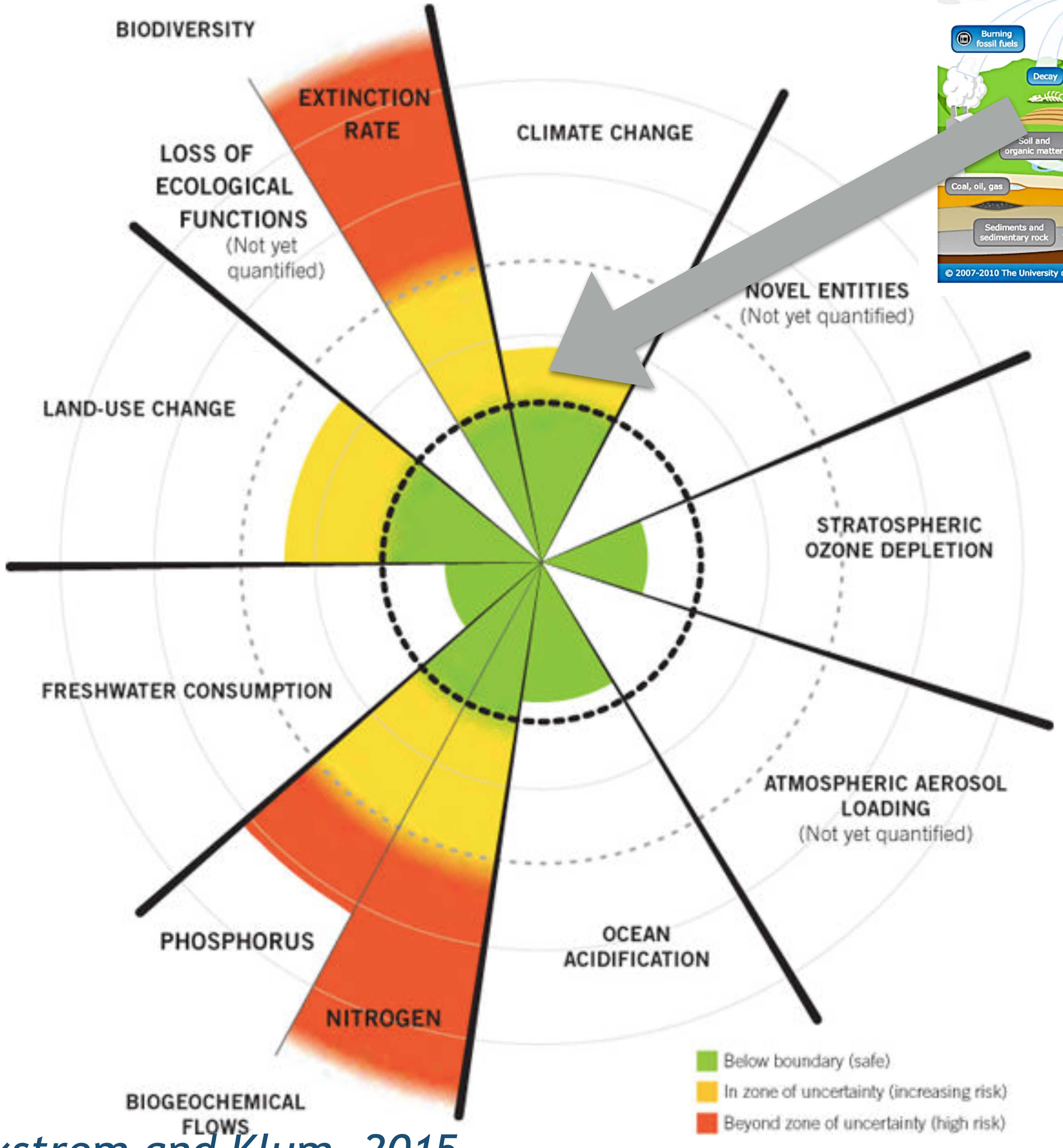

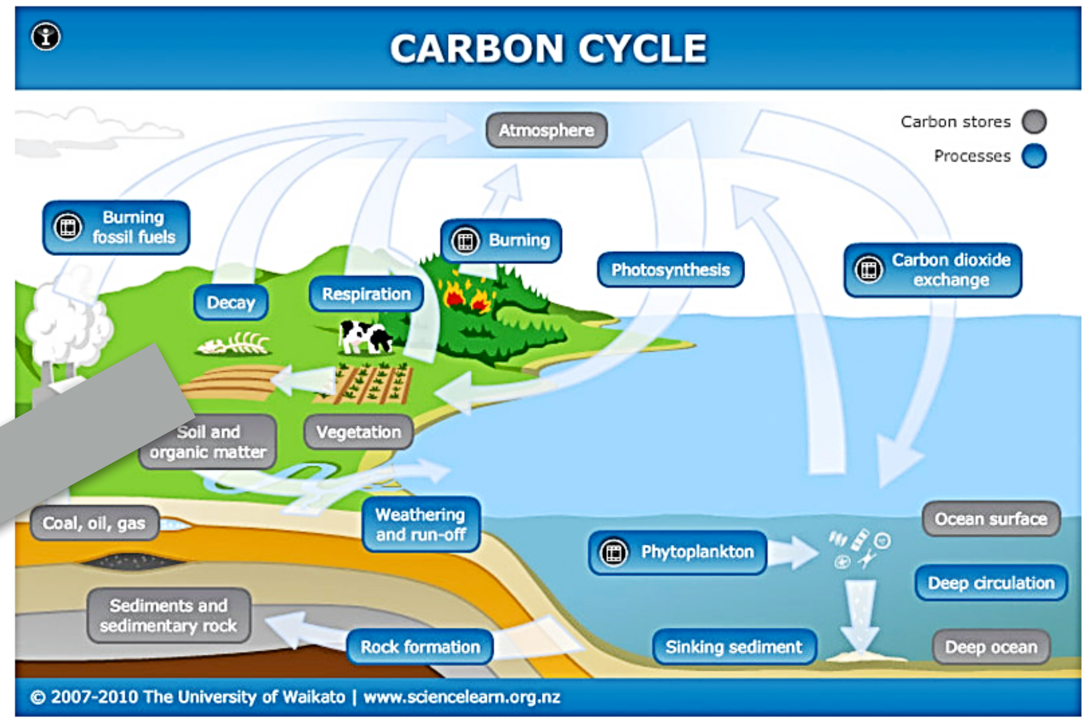

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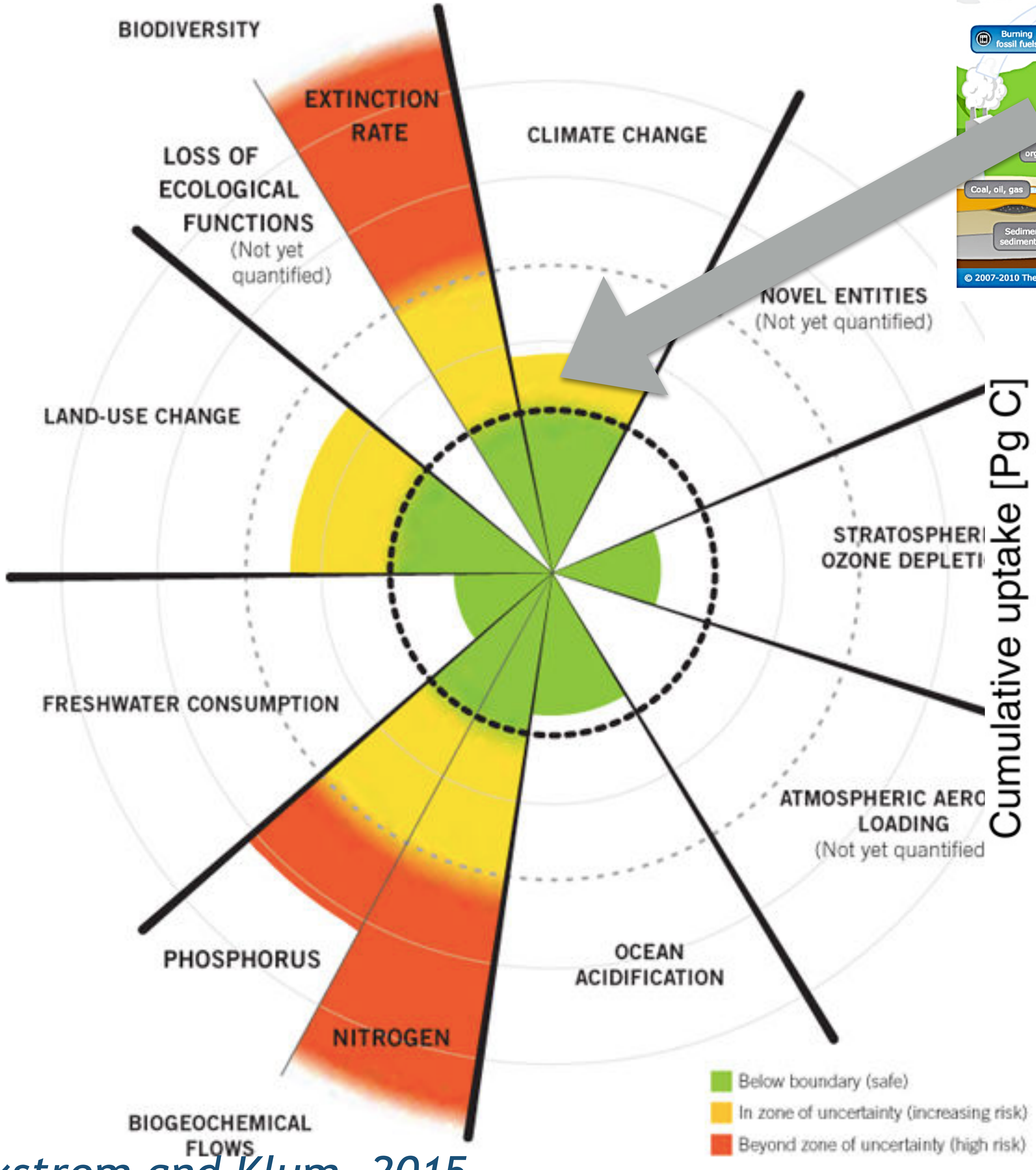

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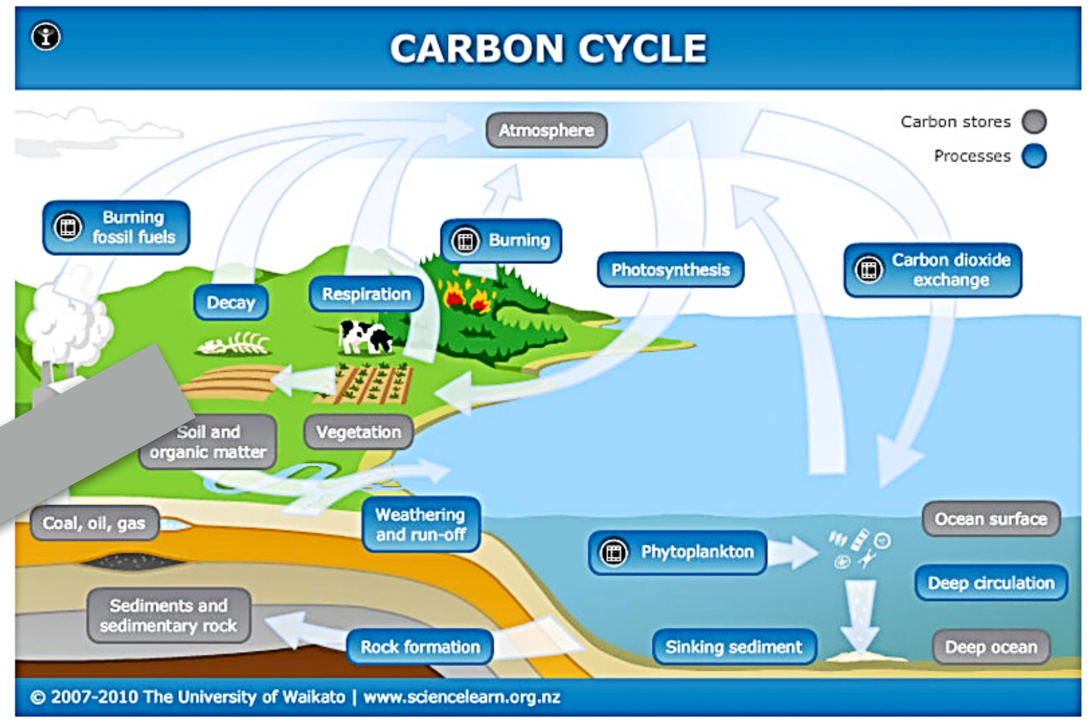

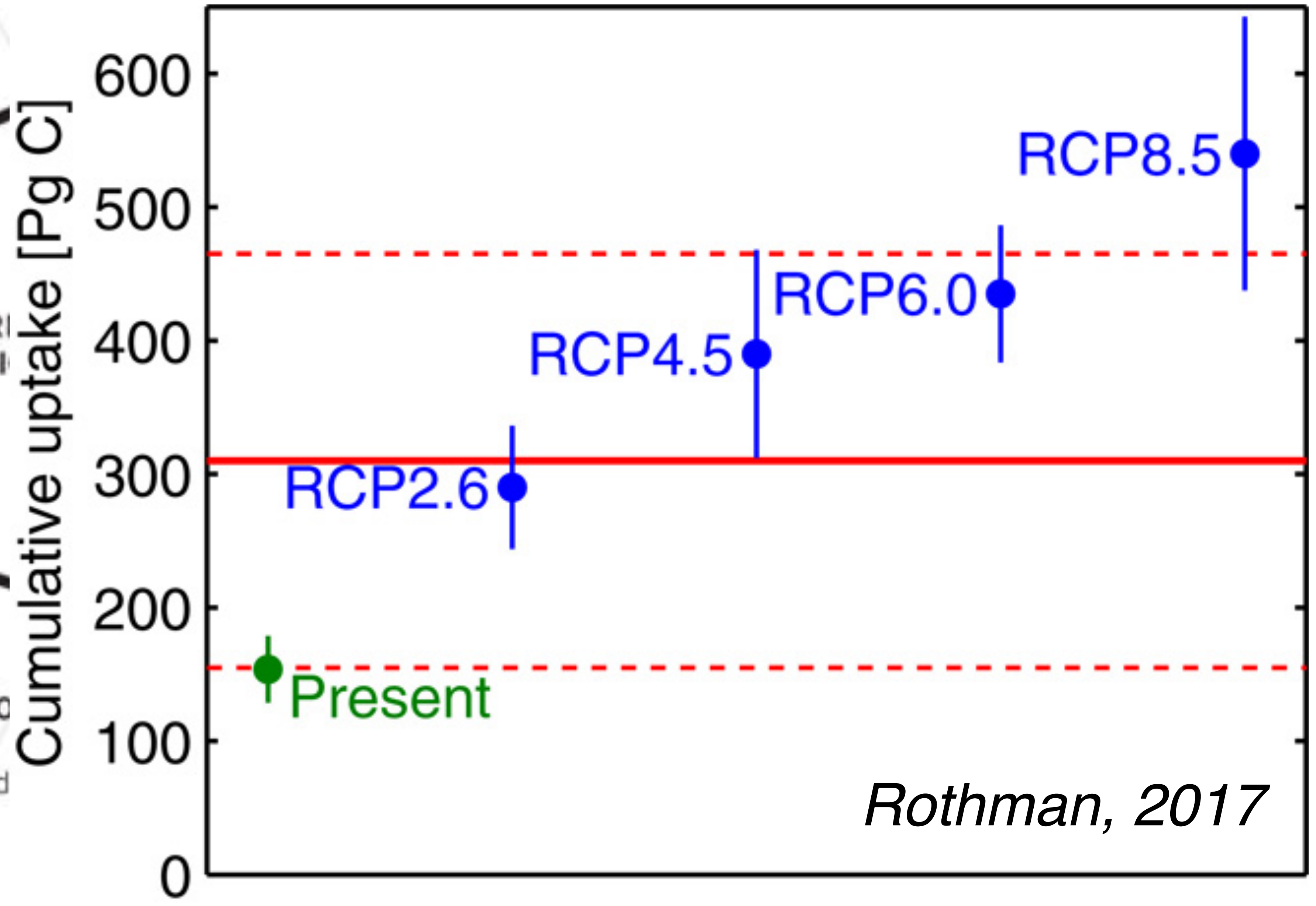

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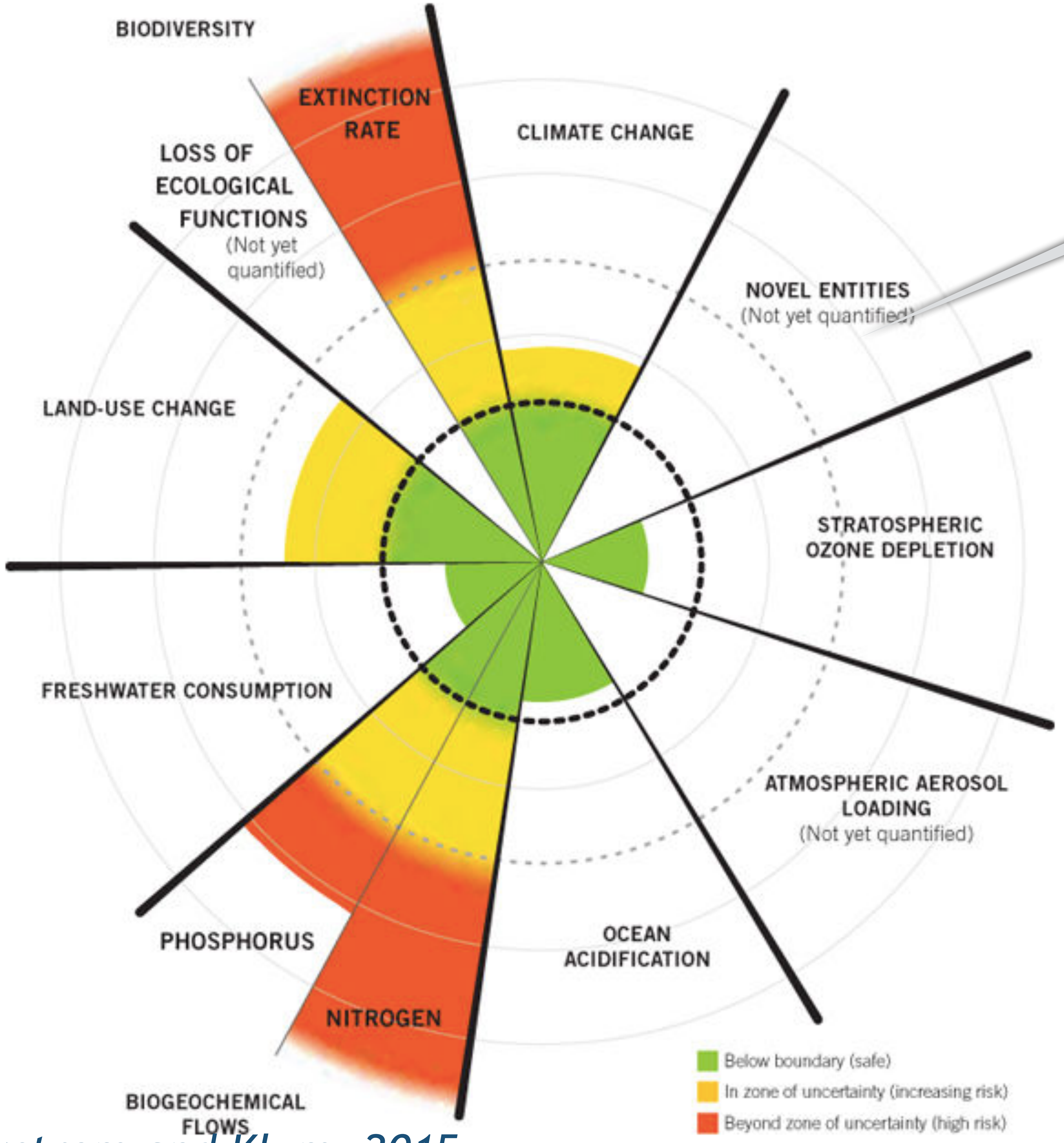


Novel Entities include Plastics

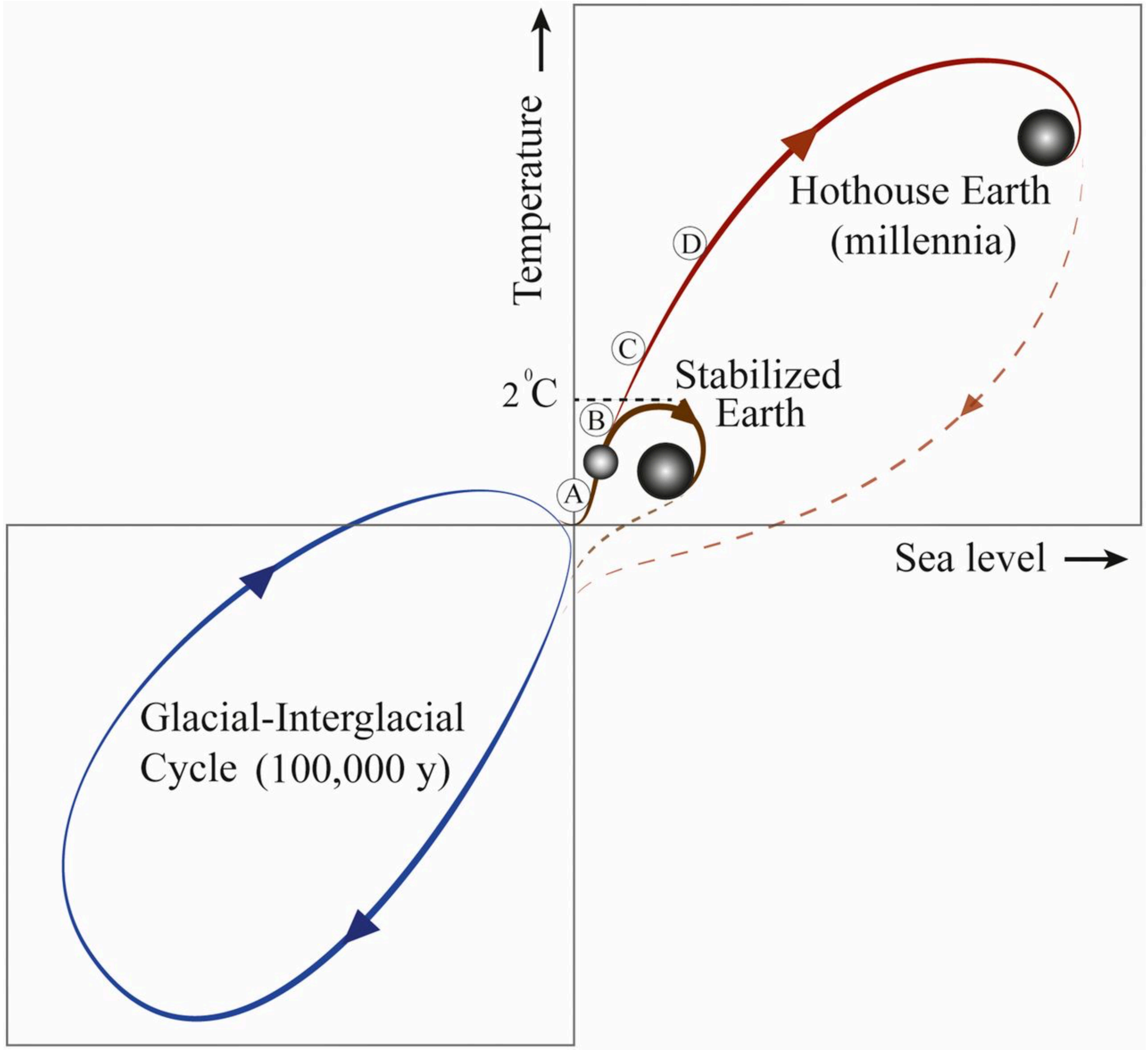
Rockstrom and Klum, 2015

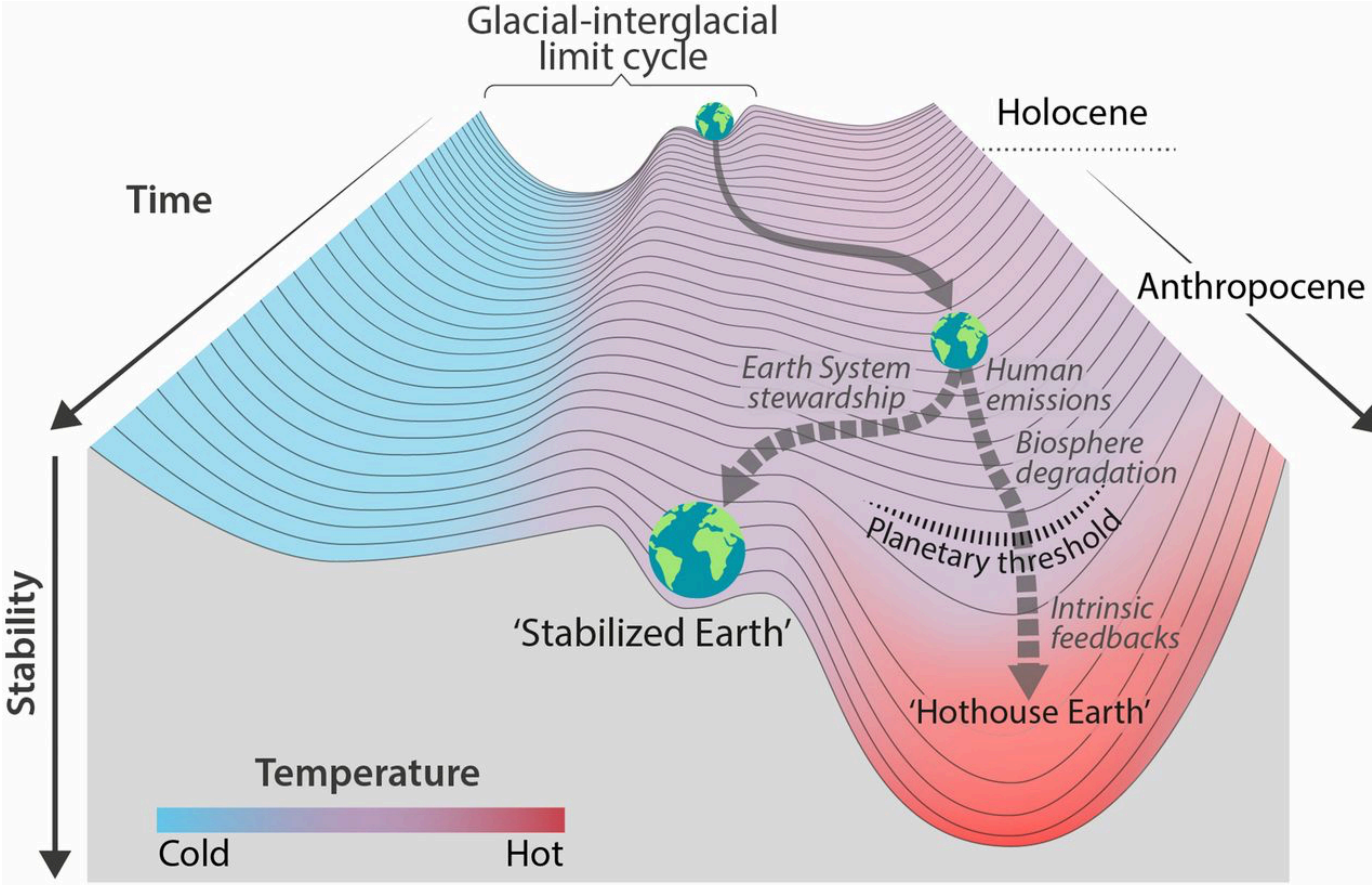
Prognosis: Earth Needs Intensive Care

Trajectories of the Earth System in the Anthropocene

Will Steffen, Johan Rockström, Katherine Richardson, Timothy M. Lenton, Carl Folke, Diana Liverman, Colin P. Summerhayes, Anthony D. Barnosky, Sarah E. Cornell, Michel Crucifix, Jonathan F. Donges, Ingo Fetzer, Steven J. Lade, Marten Scheffer, Ricarda Winkelmann, and Hans Joachim Schellnhuber

PNAS published ahead of print August 6, 2018 https://doi.org/10.1073/pnas.1810141115





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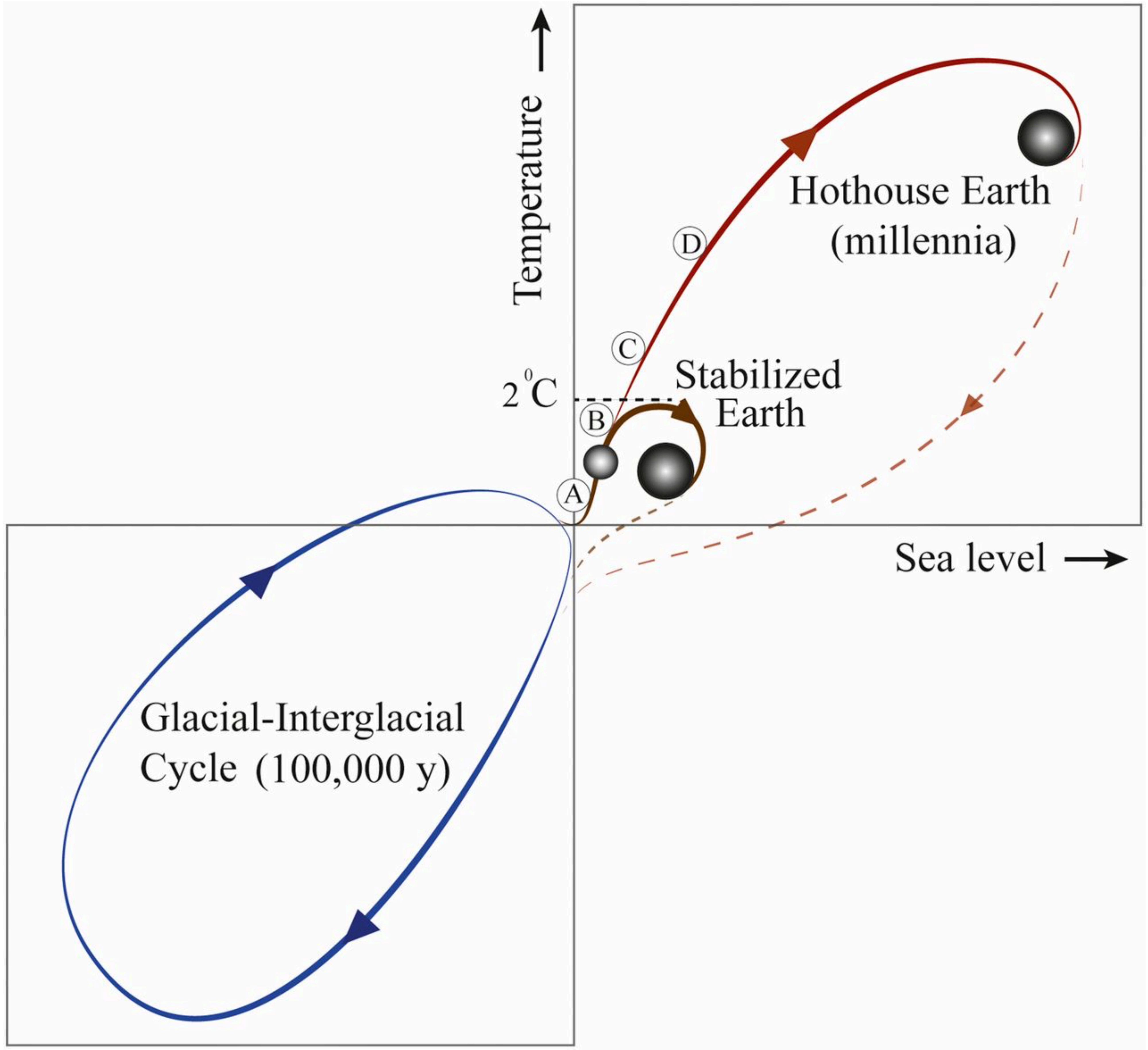
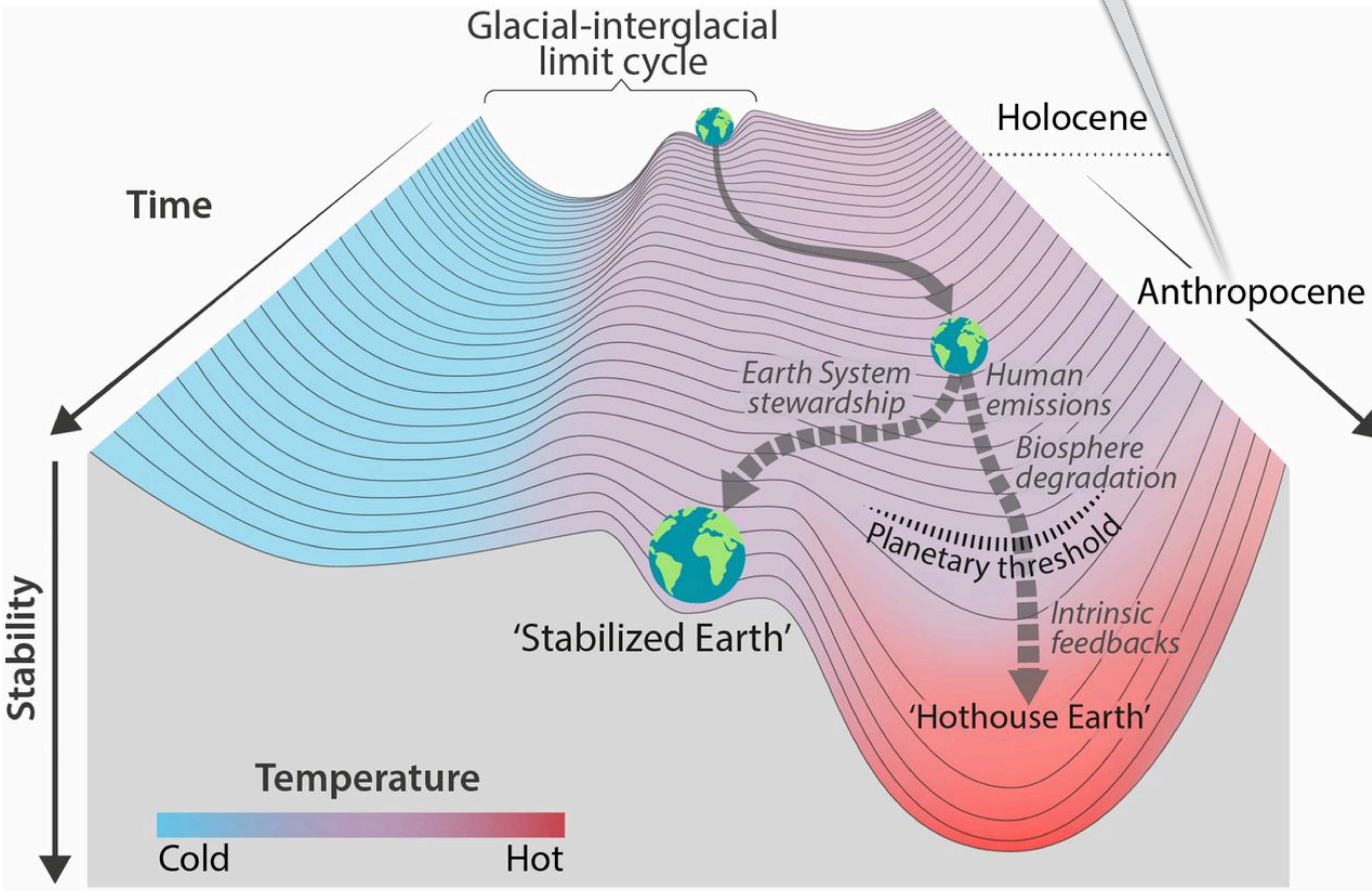
Anthropocene or Post-Holocene?





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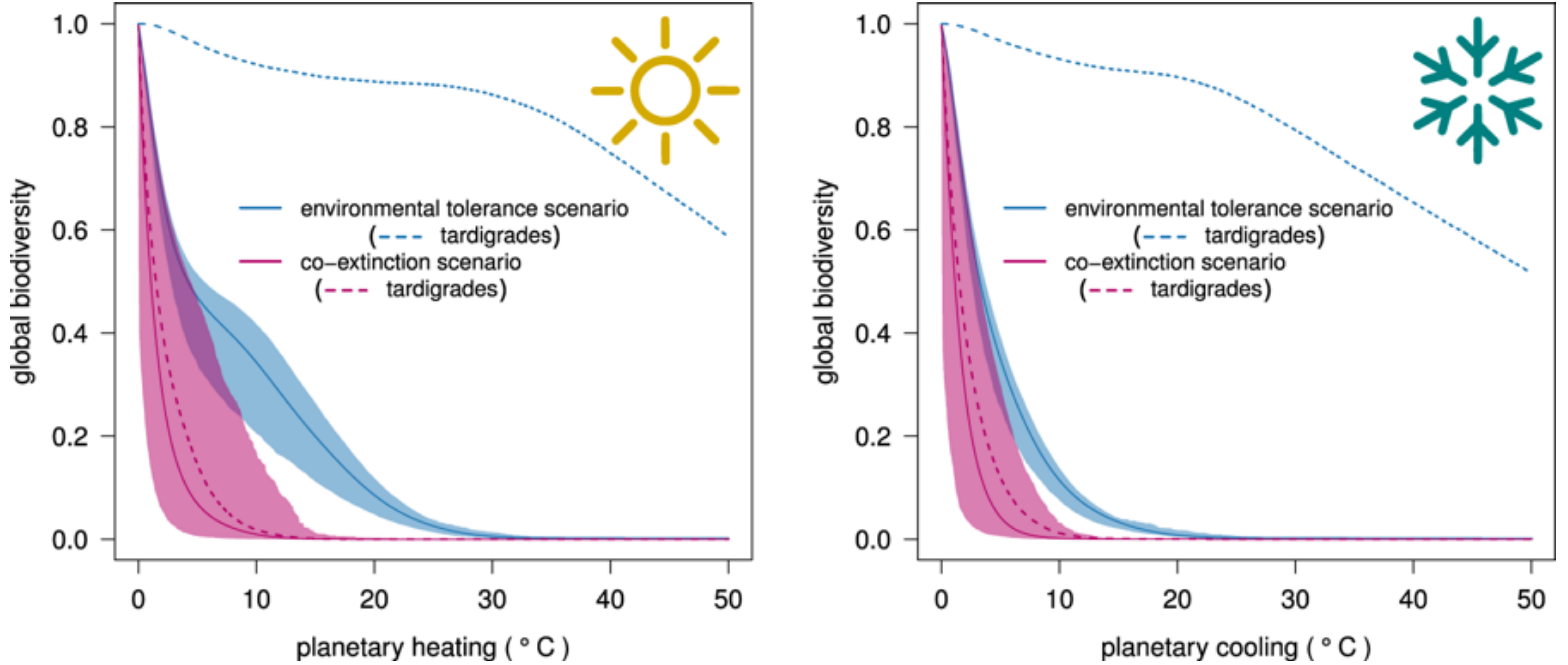

Co-extinctions reduce the robustness of planetary life to catastrophe. Response of global diversity to environmental change: progressive, monotonic increase (‘planetary heating’; left panel) or decrease (‘planetary cooling’; right panel) trajectories in local temperature. Species either go extinct based only on their tolerance to environmental conditions (‘environmental tolerance’ scenarios = blue curves), or where species go extinct not only when unable to cope with changed environmental conditions, but also following the depletion of their essential resources (‘co-extinction’ scenarios = magenta curves). Solid lines represent mean values, and shaded areas indicate the system boundaries (minimum-maximum) arising from 1000 randomly parametrized models (see Methods for details). Dotted lines show the decline in ‘tardigrade’ (extremophile) species richness in the environmental tolerance (blue) and in the co-extinction scenario (magenta) for both temperature trajectories.

Strona and Bradshaw, 2018

https://www.nature.com/articles/s41598-018-35068-1

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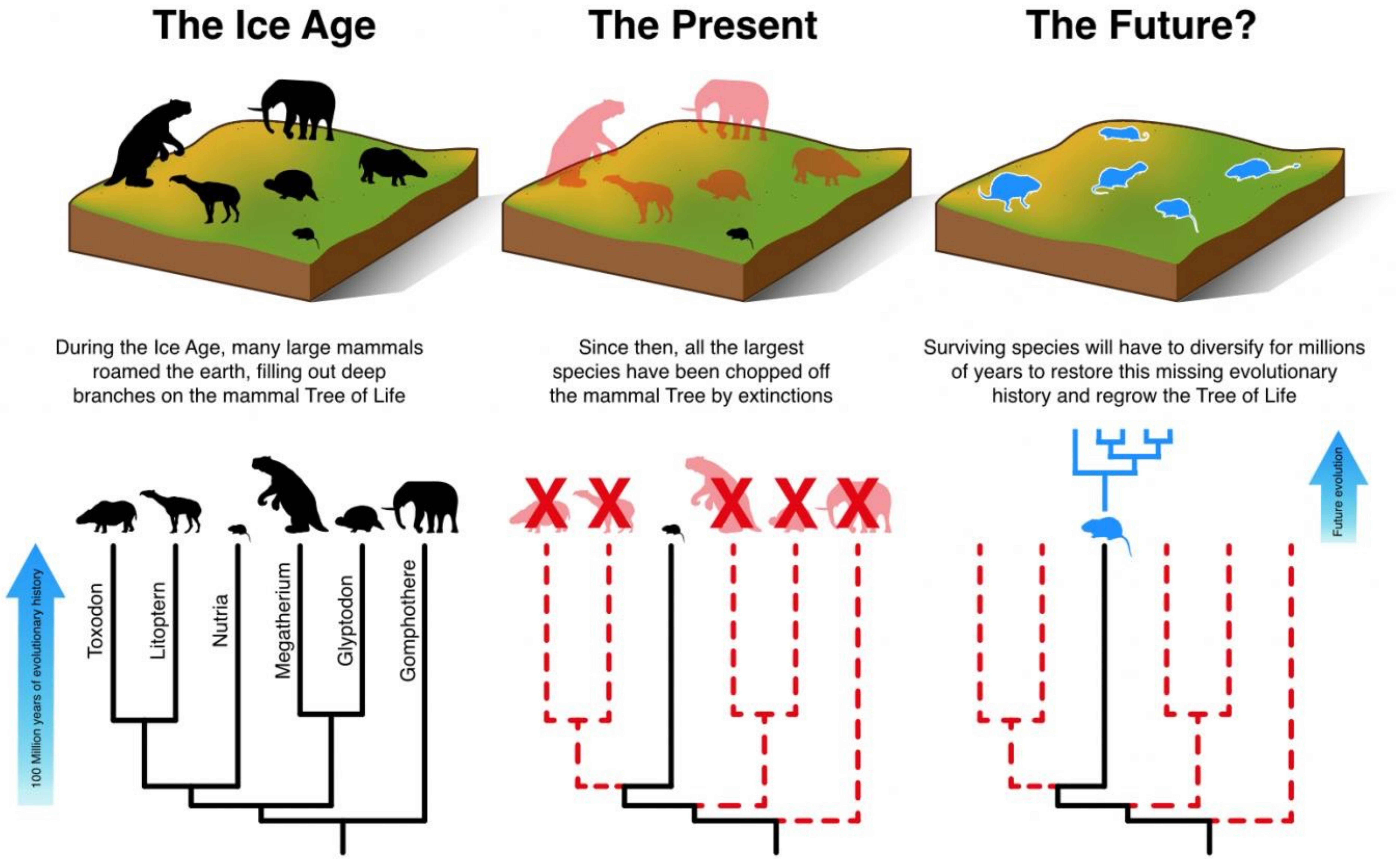

Davis et al., 2018

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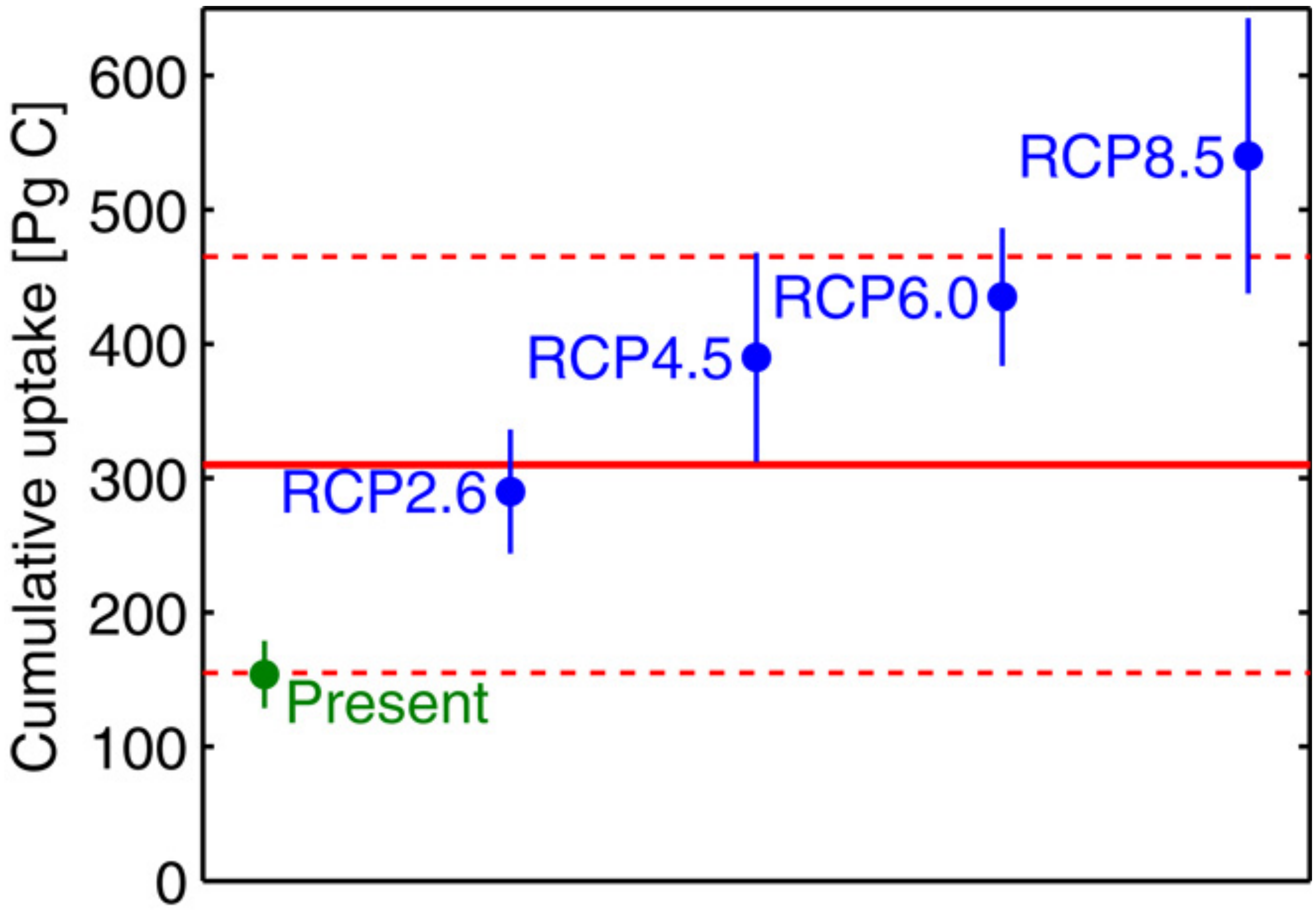

Rothman, 2017

Prognosis: Earth Needs Intensive Care

Assessing the risk …

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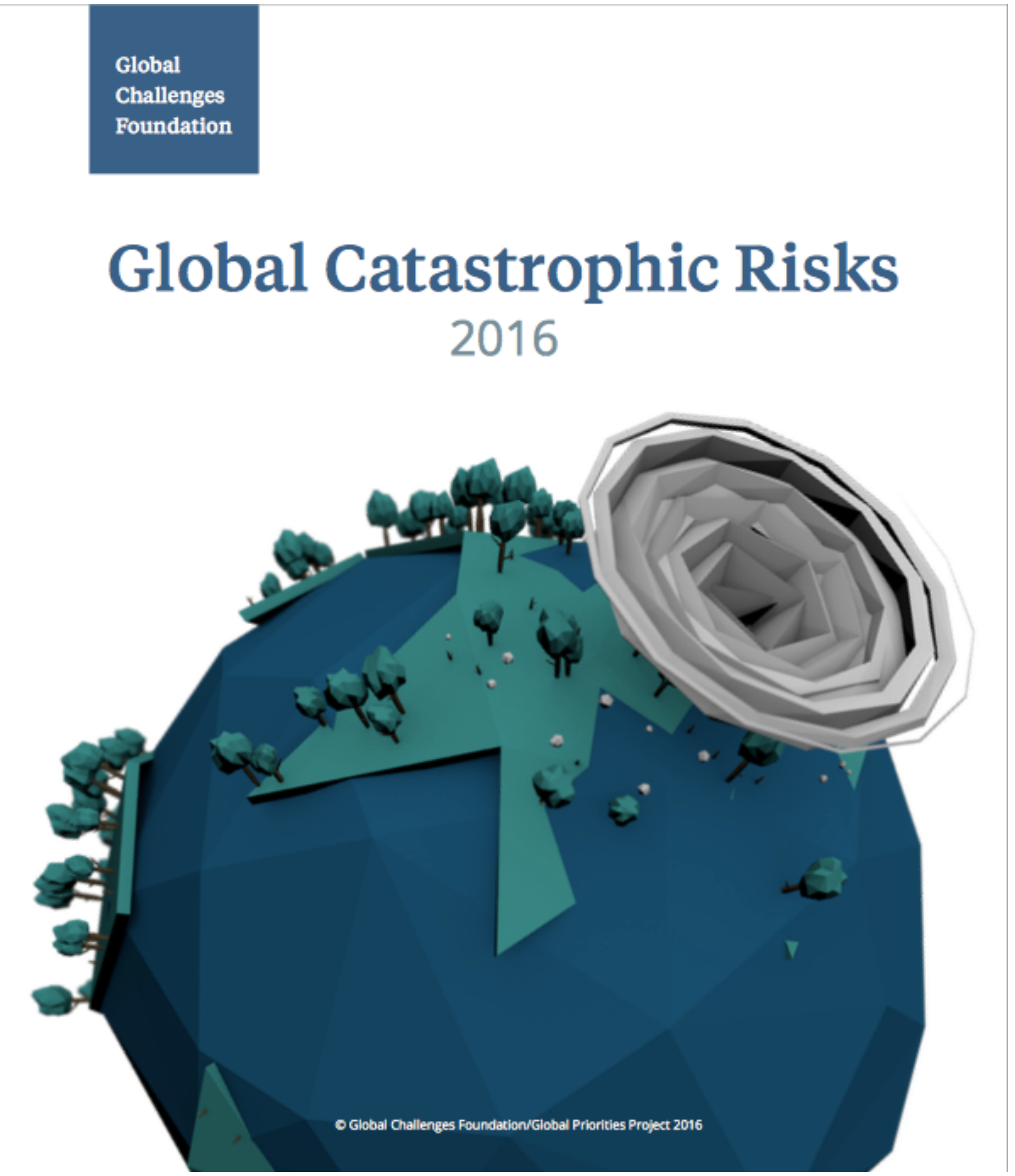

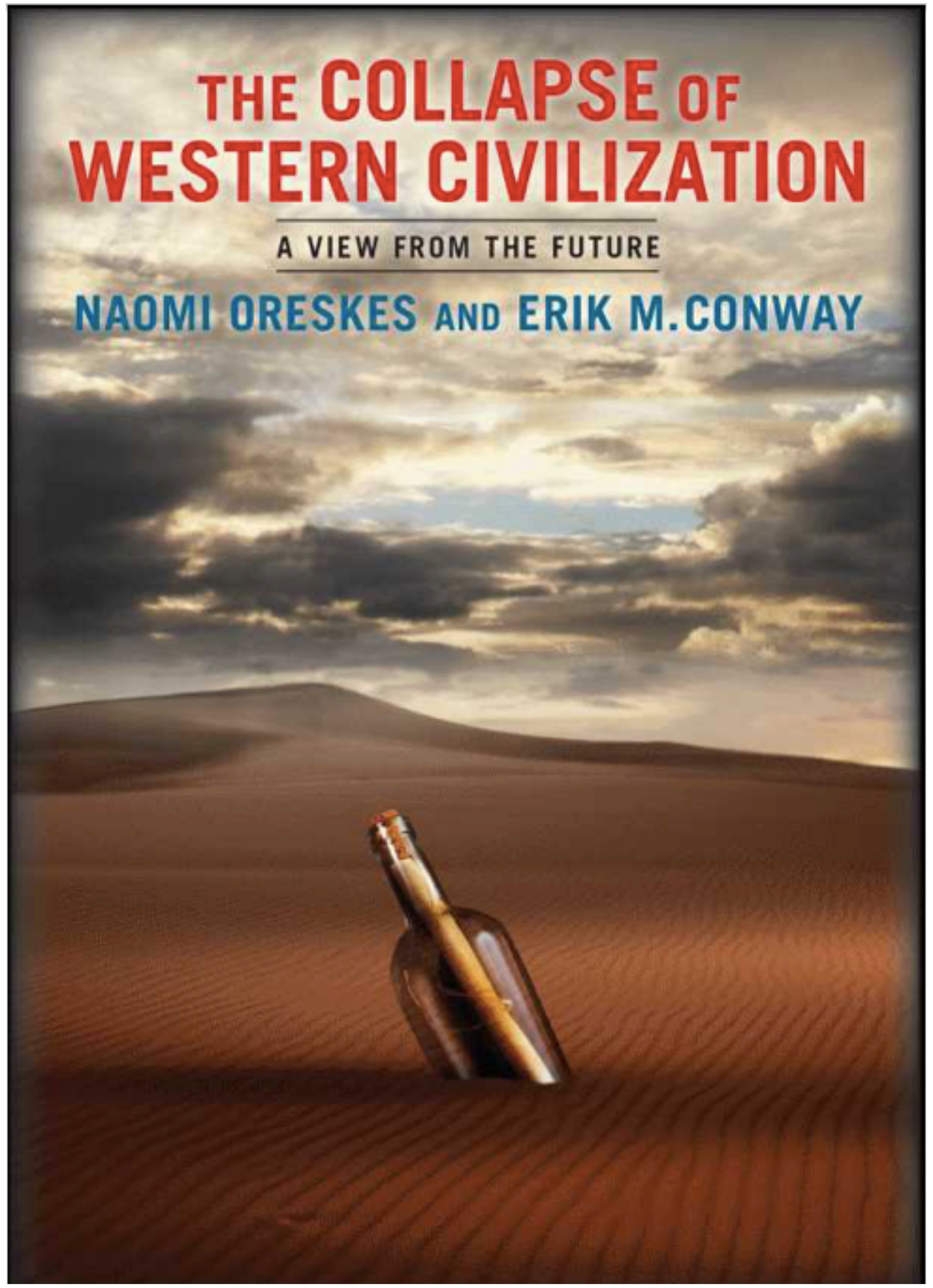

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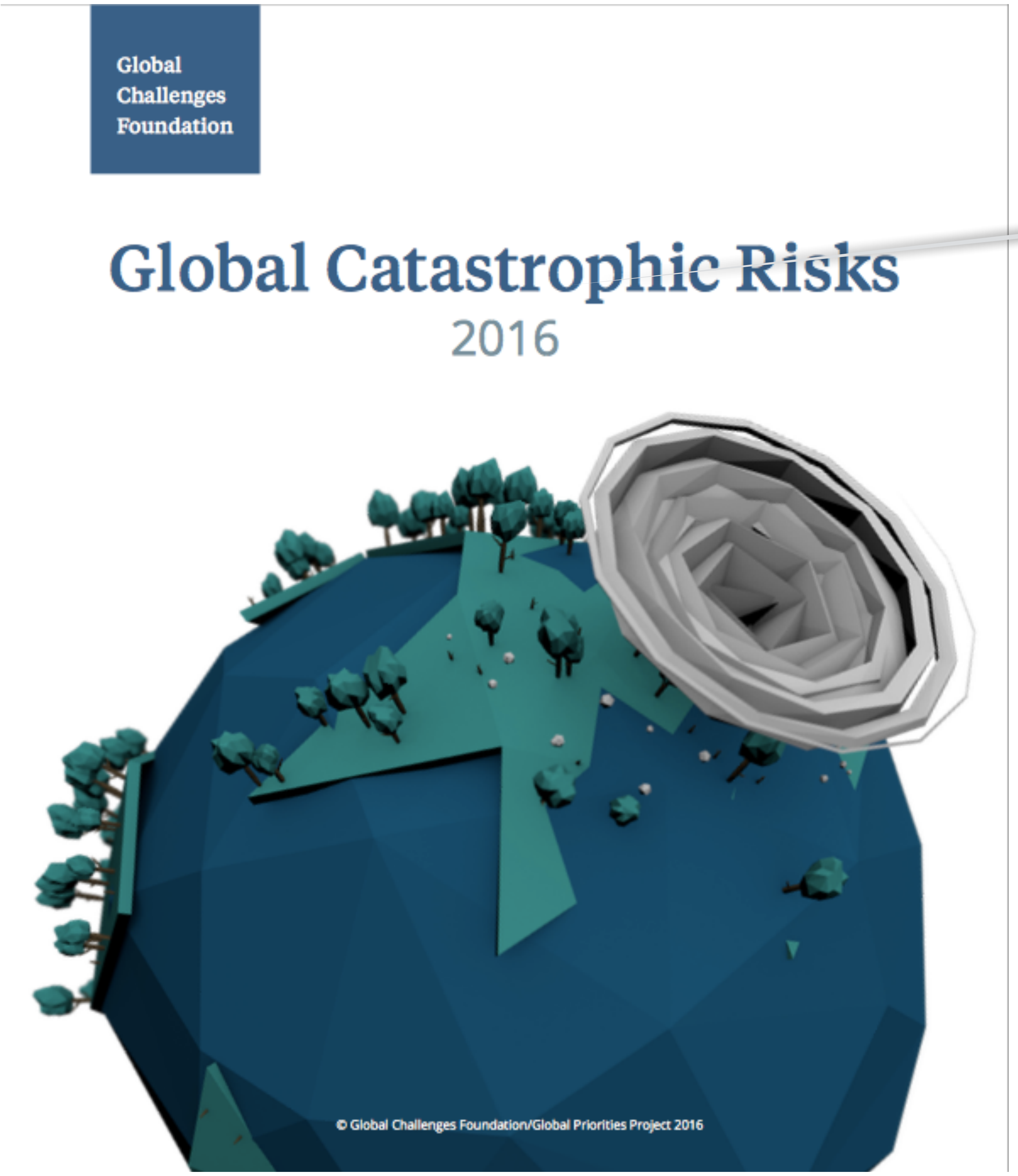
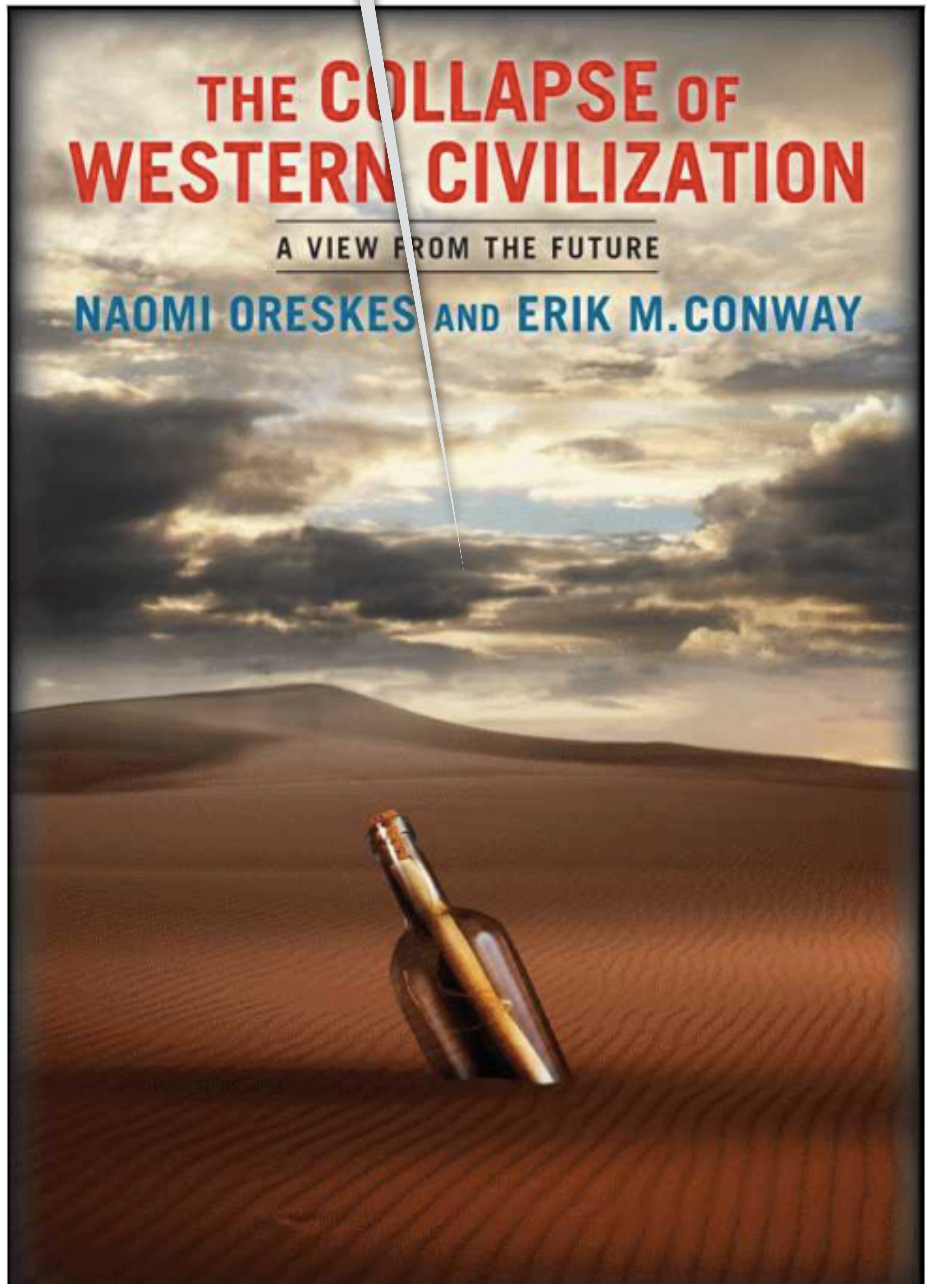


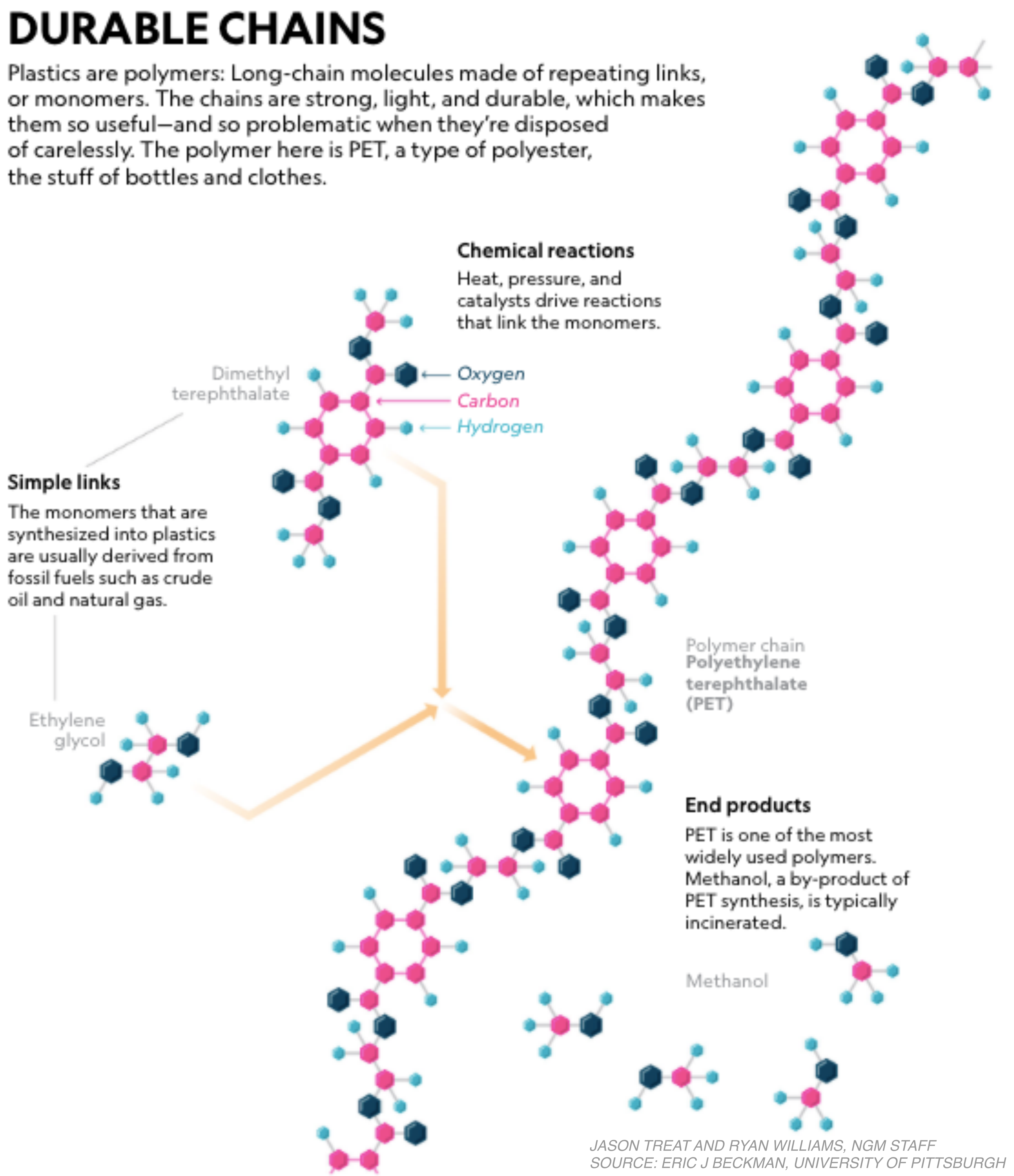


Plastics are missing

Plastics

What are Plastics:

- Any of numerous organic synthetic or processed materials that may be shaped when soft and then hardened;
- This property of plasticity, often in combination with other special properties such as low density, low electrical conductivity, transparency, and toughness, allows plastics to be made into a great variety of products.
- Many types of resins, resinoids, polymers, cellulose derivatives, casein materials, and proteins;
- Used in place of other materials, such as glass, wood, and metals,
- Mostly thermoplastic or thermosetting polymers of high molecular weight that can be made into many objects, films, or filaments.
- Polymeric material that has the capability of being molded or shaped, usually by the application of heat and pressure.



https://www.nationalgeographic.com/magazine/2018/06/plastic-planet-waste-pollution-trash-crisis/

Plastics

Commodity resins:

- Plastics that are produced at high volume and low production cost for the most common disposable items and durable goods.
- They are represented chiefly by polyethylene, polypropylene, polyvinyl chloride, and polystyrene.

Specialty resins:

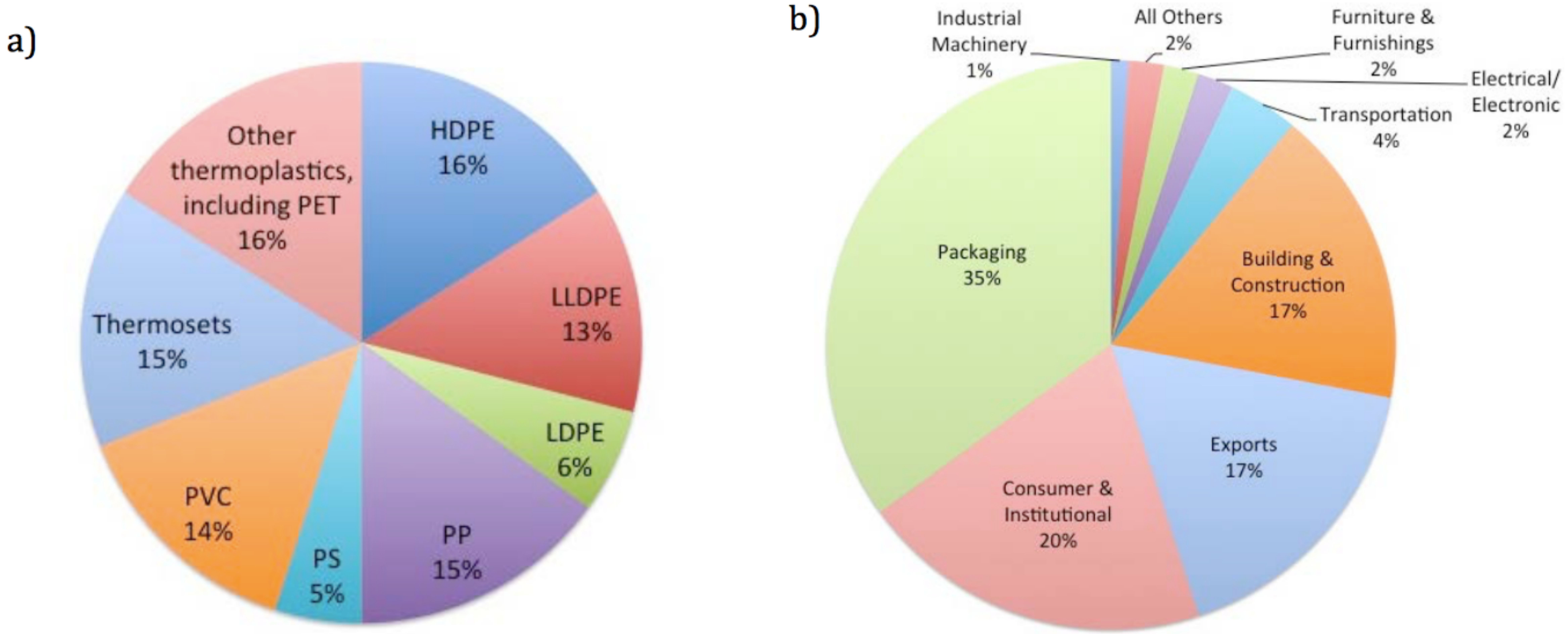
- Plastics whose properties are tailored to specific applications and that are produced at low volume and higher production cost.
- Engineering plastics: plastics that can compete with die-cast metals in plumbing, hardware, and automotive applications.
- Important engineering plastics, less familiar to consumers than the commodity plastics listed above, are polyacetal, polyamide, polytetrafluoroethylene, polycarbonate, polyphenylene sulfide, epoxy, and polyetheretherketone.
- Thermoplastic elastomers: polymers that have the elastic properties of rubber yet can be molded repeatedly upon heating.

Making Plastics

The process of making plastic is complicated (but low production cost):

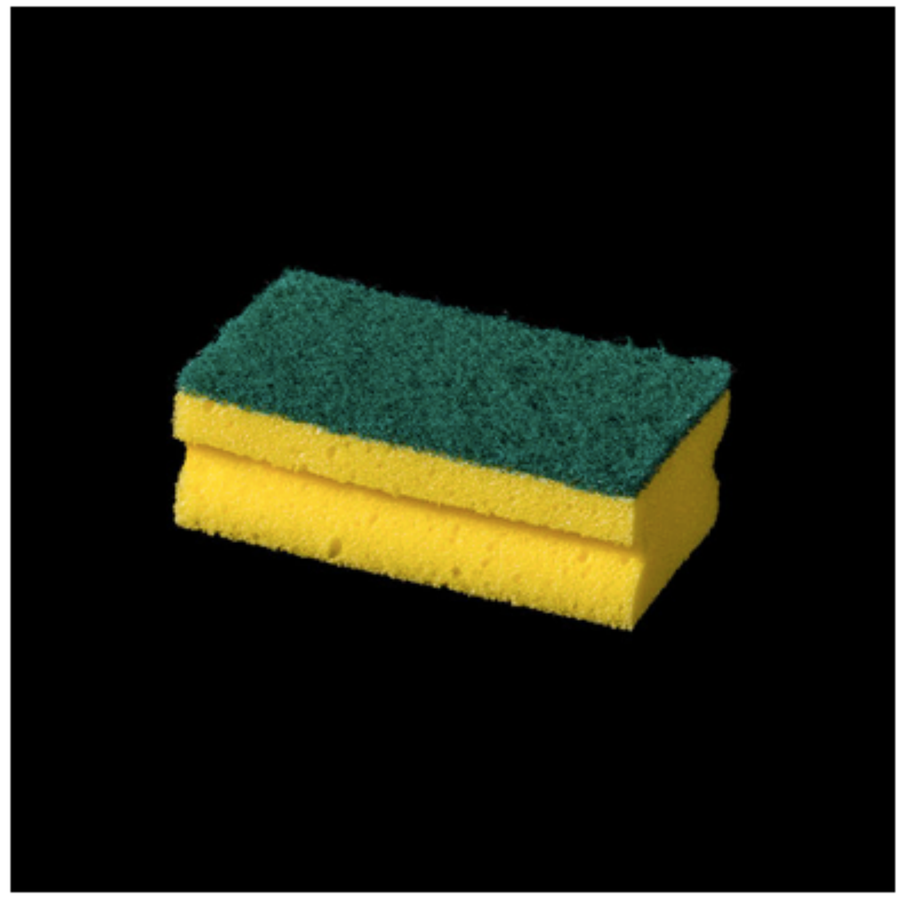
- It begins with carbon from petroleum, natural gas, coal, or biological sources.
- The elements can be combined in various combinations in order to achieve a desired property and characteristic.
- Additives to arrive at a set of properties appropriate to the product: plasticizers, colorants, reinforcements, and stabilizers.
    - Plasticizers: change the Tg of a polymer.
    - Colorants: most plastics are coloured: e.g., titanium dioxide and zinc oxide (white), carbon (black), and various other inorganic oxides such as iron and chromium; organic compounds either as pigments (insoluble) or as dyes (soluble).
    - Reinforcements: used to enhance the mechanical properties of a plastic.
    - Stabilizers: added, usually in small quantities, to counter the effects of aging. Other stabilizers are designed specifically to reduce degradation by sunlight, ozone, and biological agents.
- While most plastics are produced from petrochemicals, bioplastics are made substantially from renewable plant materials such: as cellulose and starch
- Today, seven commodity thermoplastics account for ~85% of total plastics demand for use in virtually all market sectors

Types and Use Plastics



Supplemental Figure 1. (a) Percent distribution of U.S. production of plastic resins in 2014. HDPE = High Density Polyethylene; LLDPE = Linear Low Density Polyethylene; LDPE = Low Density Polyethylene; PP = Polypropylene; PS = Polystyrene; PVC = Polyvinyl Chloride; PET = Polyethylene Terephthalate. (b) Percent distribution of U.S. resin sales and captive use of thermoplastics (all materials shown in top panel except thermosets) according to major markets in 2014. Source: American Chemistry Council (2015). From Lavender Law (2017)

Types and Use Plastics



POLYURETHANE (PU)

POLYCARBONATE (PC)

POLYSTYRENE (PS)

POLYETHYLENE (PE)

POLYPROPYLENE (PP)

POLYVINYL CHLORIDE

POLYETHYLENE TEREPHTHALATE (PET)

BIODEGRADABLE PLASTICS

https://www.plasticgarbageproject.org/en/plastic-life

Types and Use Plastics

Production and Use of Plastics

- Global plastics production has increased exponentially since 1950, with 311 million metric tons produced in 2014.
- Substantial fraction of waste results from consumer plastics use (12.8% of municipal solid waste by mass in the United States in 2013; US EPA 2016)
- Straightforward process of mechanical recycling of thermoplastics (grinding followed by remelting into resin pellets; Andrady 2015),
- However, only an estimated 8.8% of postconsumer plastics were recovered for recycling in the United States in 2012 (US EPA 2014).
- Plastics recycling rates are higher in Europe but still reached only 30% in 2014 (Plast. Eur. 2015).
- Even in these highly developed countries with robust infrastructures, obstacles to recycling occur at every step from discard to fabrication of new products:
    - unavailability of collection points,
    - contamination of recycling feedstock,
    - limited marketability of the recycled material

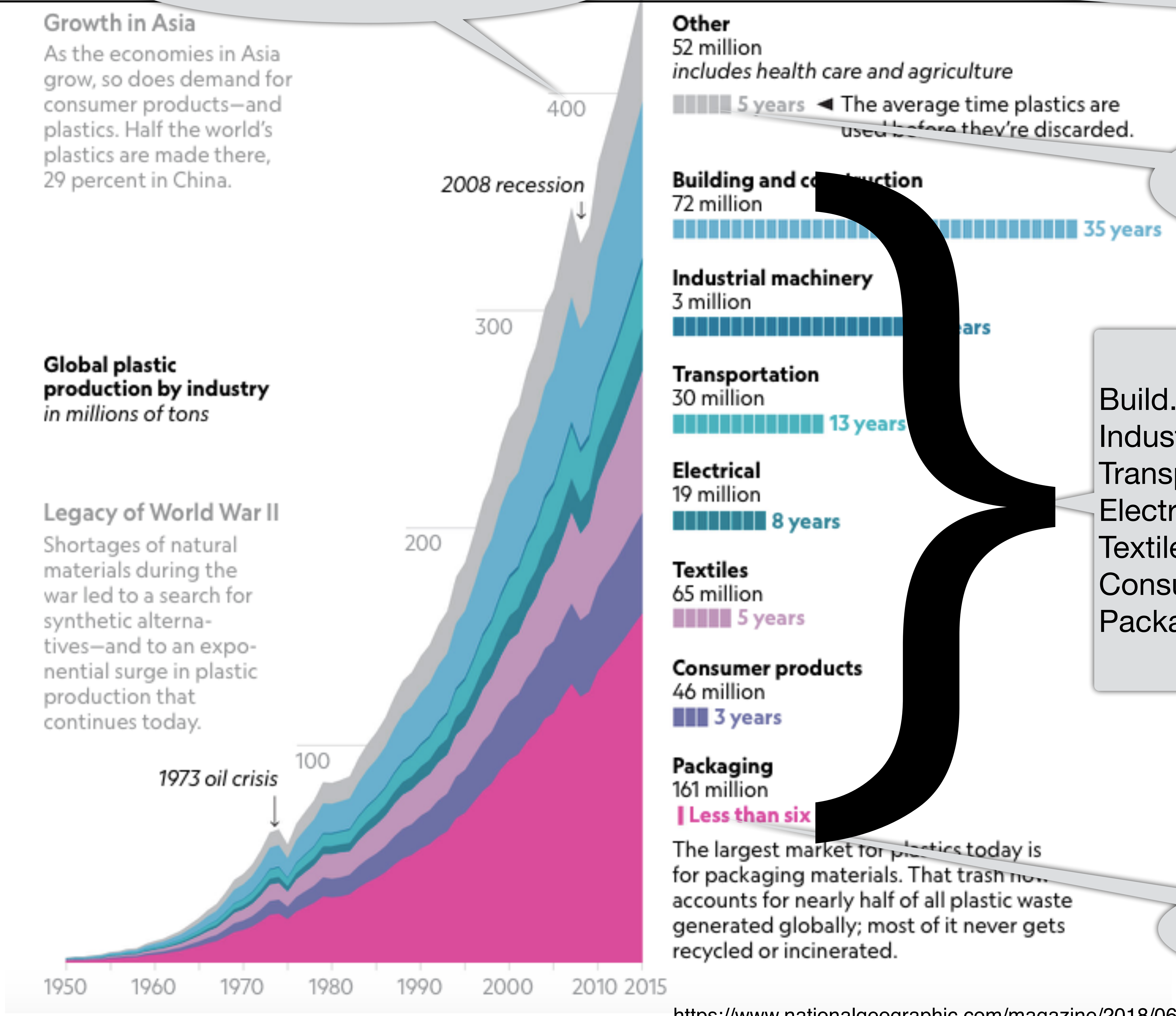
Lavender Law (2017)

Production and Use of

400 million tons (Mt)

A LIFETIME OF PLASTIC

The first plastics made from fossil fuels are just over a century old. They came into widespread use after World War II and are found today in everything from cars to medical devices to food packaging. Their useful lifetime varies. Once disposed of, they break down into smaller fragments that linger for centuries.



JASON TREAT AND RYAN WILLIAMS, NGM STAFF
SOURCE: ROLAND GEYER, UNIVERSITY OF CALIFORNIA, SANTA BARBARA

448 Mt in 2015

Average lifetime:
5 years

Build.+Const.:	72 Mt, 35 yrs
Industrial mach.:	3 Mt, 20 yrs
Transportation:	30 Mt, 13 yrs
Electrical:	19 Mt, 8 yrs
Textiles:	65 Mt, 5 yrs
Consum. prod.:	46 Mt, 3 yrs
Packaging:	161 Mt, <0.5 yrs

161Mt < 6 months

https://www.nationalgeographic.com/magazine/2018/06/plastic-planet-waste-pollution-trash-crisis/

Production and Use of Plastics

Plastics consumption:

- In Western Europe, approximately 92 kilograms of plastic per capita are consumed annually, and this quantity is increasing.
- Worldwide use per capita stands at about 35 kilograms.
- The largest amount of plastic waste comes from the packaging industry: two-thirds generated by households and one-third by industry and commerce.






The “**design of mobile food culture**” is a visible expression of present-day society that always seems to be on the way to somewhere, one characterized by “efficiency and convenience.”

Lifetime much longer than use time:

- Plastic Water Bottle - 450 years
- Disposable Diapers - 500 years
- Plastic 6-Pack Collar - 450 Years
- Extruded Polystyrene Foam - over 5,000 years

https://www.plasticgarbageproject.org/en/plastic-life

Microplastics

Microplastic

https://www.plasticgarbageproject.org/en/plastic-life

Microplastics:

- significant part of the plastic garbage problem
- smaller than 5 mm;
- the smallest particles found to date measure 10^{-6} m;
- enter the sea in various ways.

Can result from:

- plastic debris that disintegrates from the effects of friction and UV radiation,
- Plastic pellets: raw material in the manufacture of plastic products;
- Due to careless handling, for example during transport, considerable quantities enter the environment.
- Textiles made of synthetic fibers such as polyester and especially fleece lose up to 1,900 synthetic fibers with each washing.
- Exfoliating products, many of which often contain small plastic beads made of polyethylene, pose a similar problem.

These microparticles escape the filters in sewage treatment plants and, suspended in wastewater, reach the seas through rivers, pollute beaches.

Accumulate as pollutants and enter the food chain.

"Solutions" that create new problems:

- In 1993, Patagonia became the first outdoor gear company to use recycled PET bottles to make some of its fleece garments.
- This environmentally conscious firm proudly states that this was "a positive step towards a more sustainable system—one that uses fewer resources, discards less and better protects people's health."
- Since then, some 92 million PET bottles have been transformed into articles of clothing.
- However, for many firms that produce fleece pullovers and jackets, recent discoveries about microfibers in wastewater present a challenge to take a further innovative step to protect the environment.

https://www.plasticgarbageproject.org/en/plastic-life

Impacts of Plastics

Dead whale found with 115 plastic cups, 2 flip-flops in its stomach

Detritus also included more than 1,000 other plastic pieces, including plastic bags, bottles

The Associated Press · Posted: Nov 20, 2018 9:03 AM ET | Last Updated: November 20

ROBBIE GONZALEZ SCIENCE 10.22.18 06:00 PM

YOUR POOP IS PROBABLY FULL OF PLASTIC

Plastics: A rapidly growing global challenge for Earth's life-support system and humanity

- Plastics have many many advantages - can replace many other materials
- Current mainstream economic model allows for production-costs only, without considering impact-costs
- Production is rapidly increasing
- Single/one-time use is a major fraction
- There is no recycling, only down-cycling
- Plastics are everywhere
- Plastics are in everything
- Plastics impact ecosystems and accelerate extinction
- Microplastics are in all food chains
- There are many time-lagged impacts: land fills, built environment, coastal infrastructure
- Sea-level rise, climate change impacts (including storms, wildfires) can disperse plastics
- …..
- The threat is increasingly better understood …

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- Plastics impact ecosystems and accelerate extinction
- Microplastics are in all food chains
- There are many time-lagged impacts: land fills, built environment, coastal infrastructure
- Sea-level rise, climate change impacts (including storms, wildfires) can disperse plastics
- …..
- The threat is increasingly better understood …