Mitigation and Adaptation Studies

Class 6: Systems Thinking, Adaptation and Sustainability Science

Contents:

- *(Systems Science)*
- *(Systems Thinking)*
- *Systems Science: Basic Concepts*
- *Systems Thinking and Modern Global Change*
- *The Earth's Life-Support System*

Systems Science: Basic Concepts

Structure
Feedback loops
Complexity
Complex Systems
Dynamical systems
Thresholds - Tipping points
Emerging Properties
Resilience and Panarchy
Antifragility

Systems Science: Basic Concepts

A threshold is a point in a condition or process that once passed triggers some kind of change.

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The threshold is not where the boat goes over the edge, it is far up the river, when the people in the boat lose the option to get to the shore.

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Emerging/Emergent Property:
A property which a (complex) system has, but which the individual members do not have.

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The knowledge of the different types of emergence is essential for understanding complex systems

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Examples

Neurons and brains: the properties of emotions and reasoning
Ants: changing in behavior of colonies
Cities: have many properties that individuals don't have

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Resilience is the capacity of a social-ecological system to absorb or withstand perturbations and other stressors such that the system remains within the same regime, essentially maintaining its structure and functions. It describes the degree to which the system is capable of self-organization, learning and adaptation.

(Holling 1973, Gunderson & Holling 2002, Walker et al. 2004).

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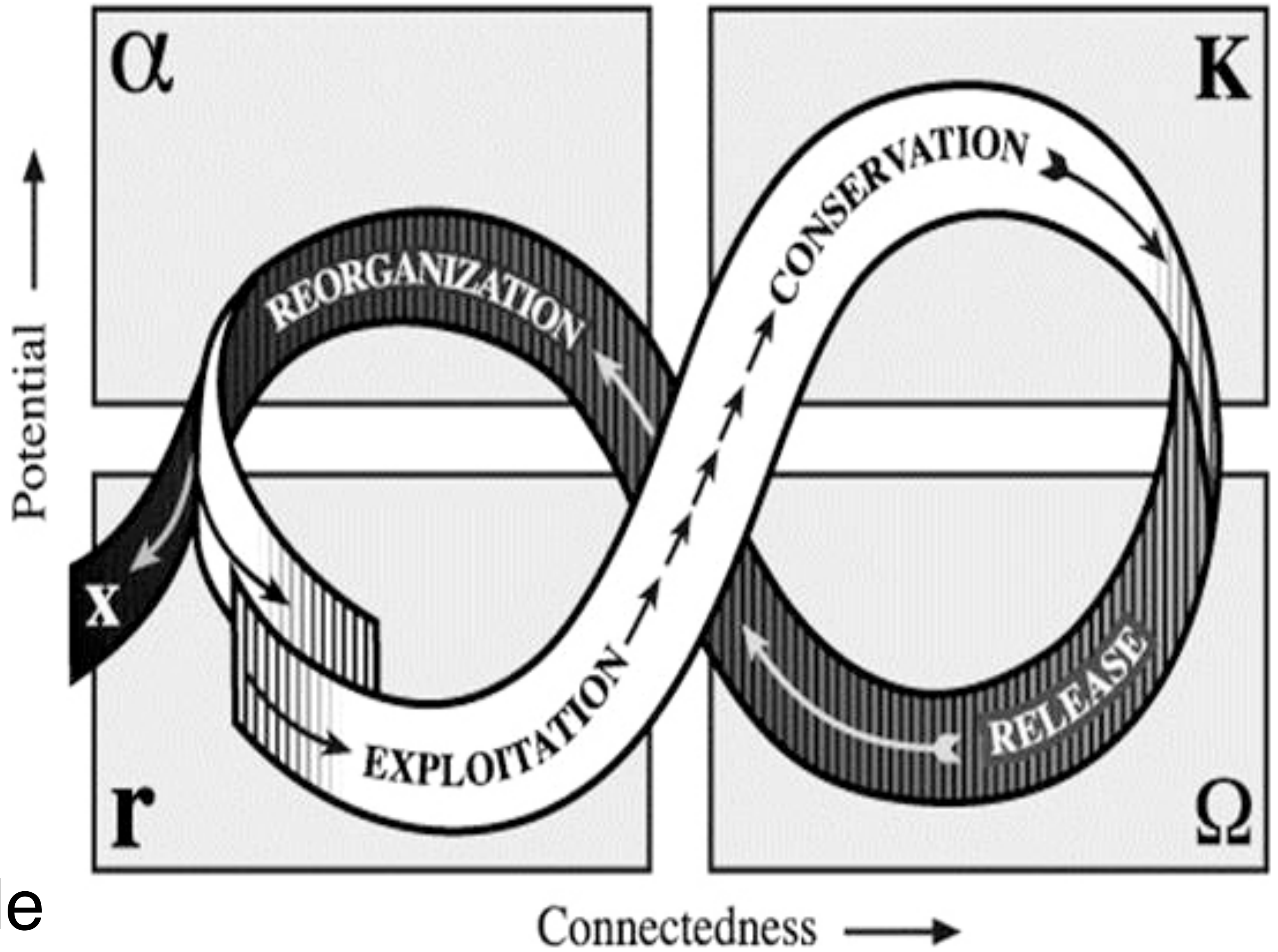

Adaptive cycle

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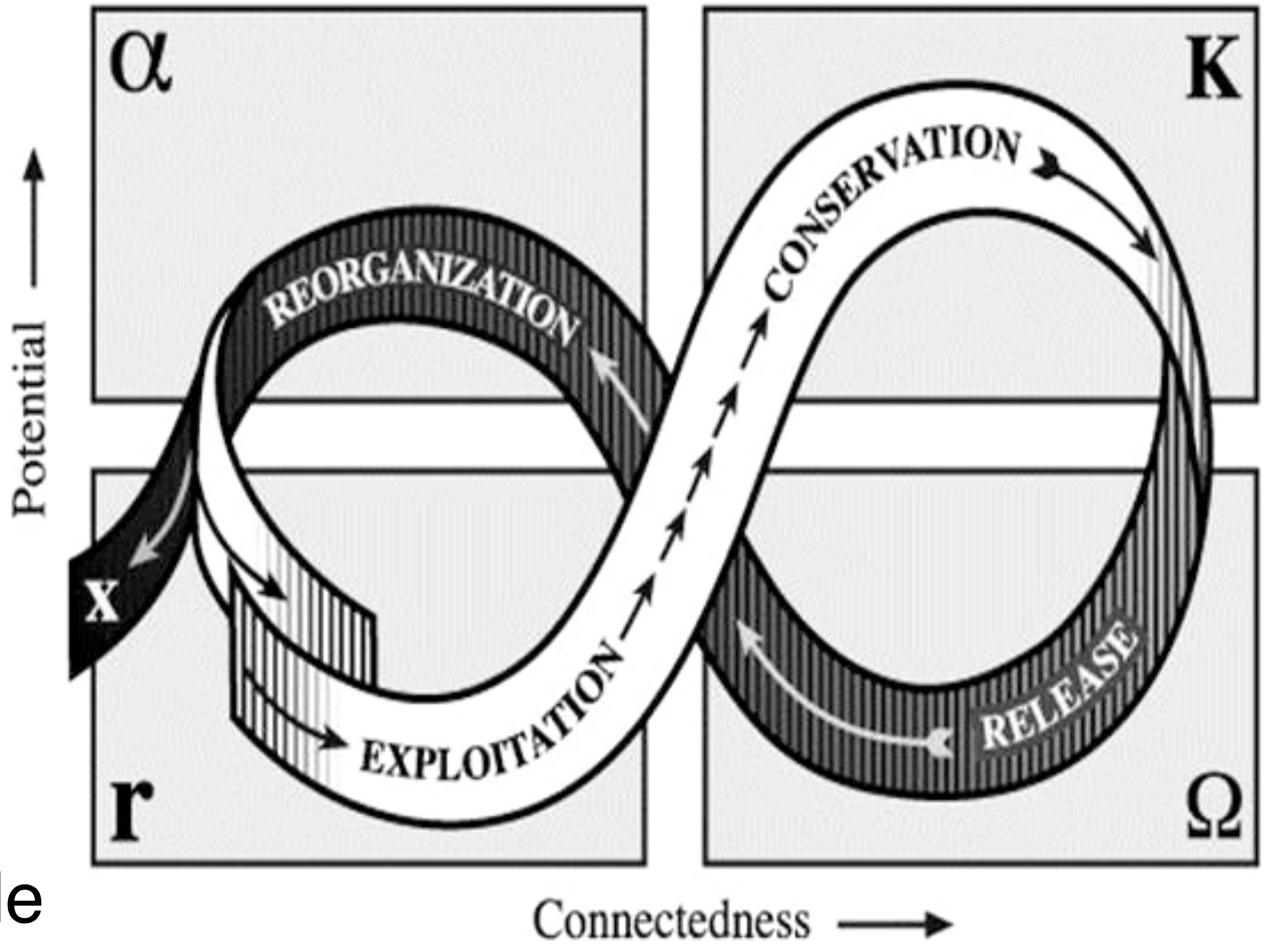
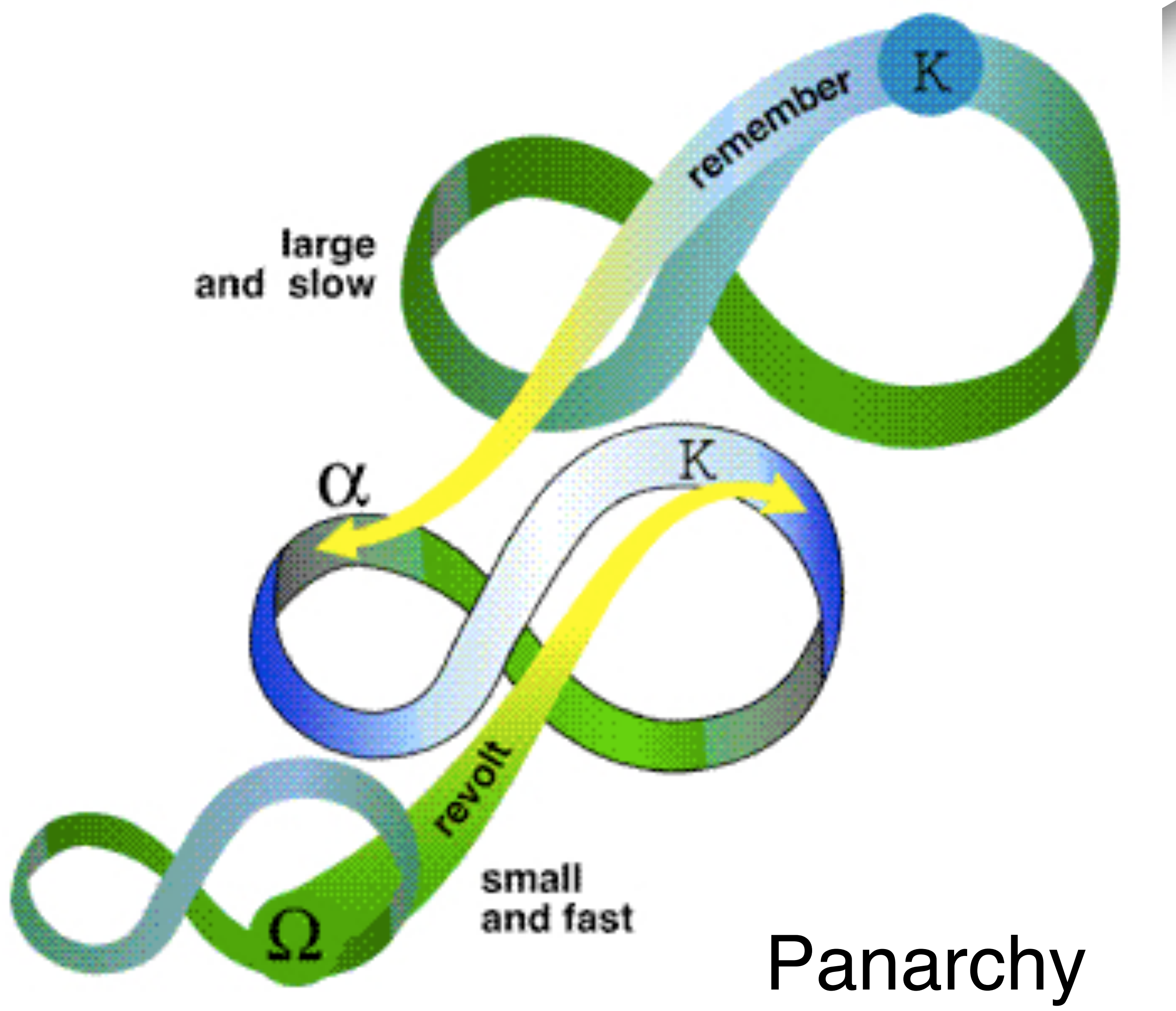


Adaptive cycle



Panarchy

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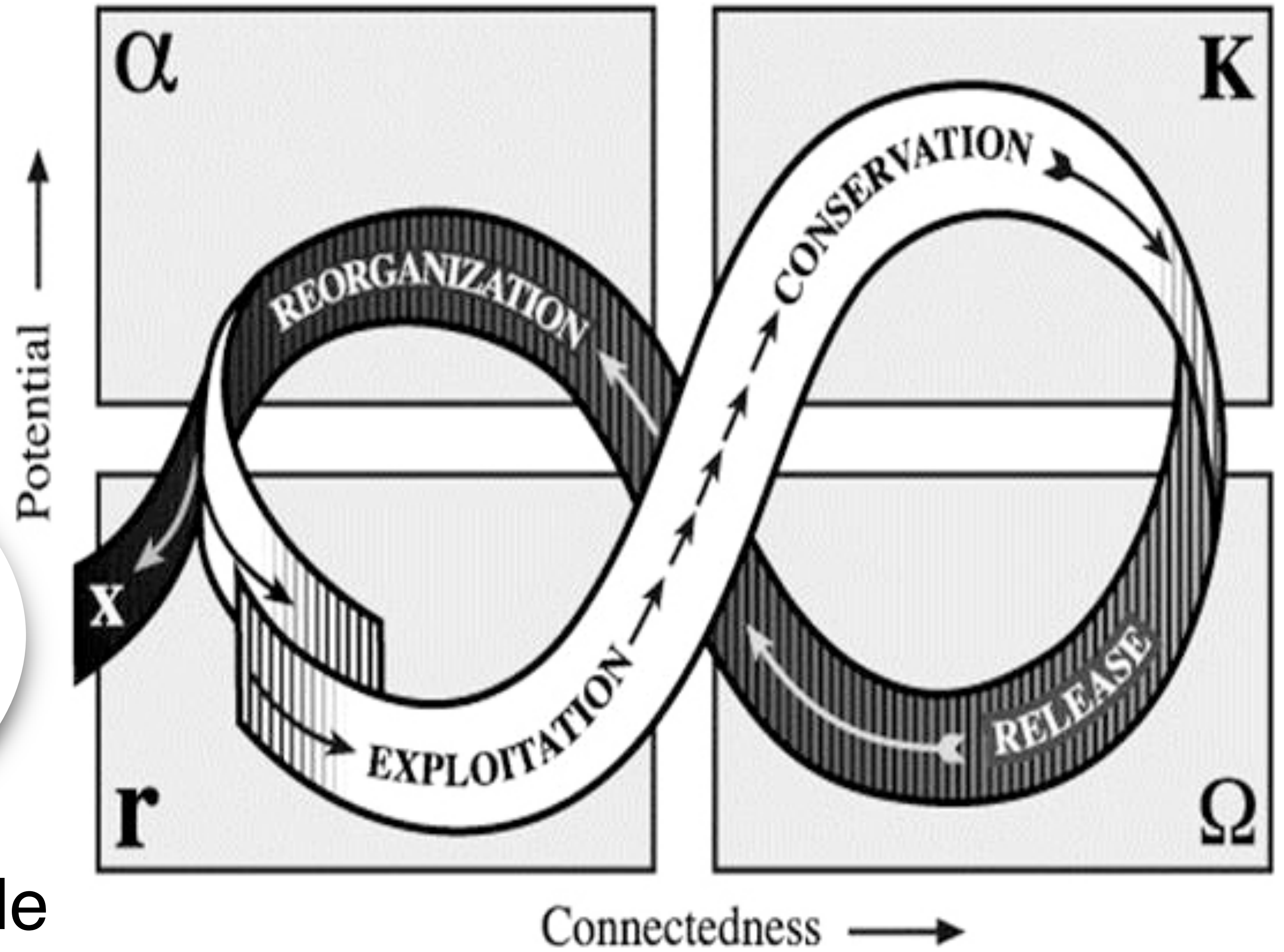
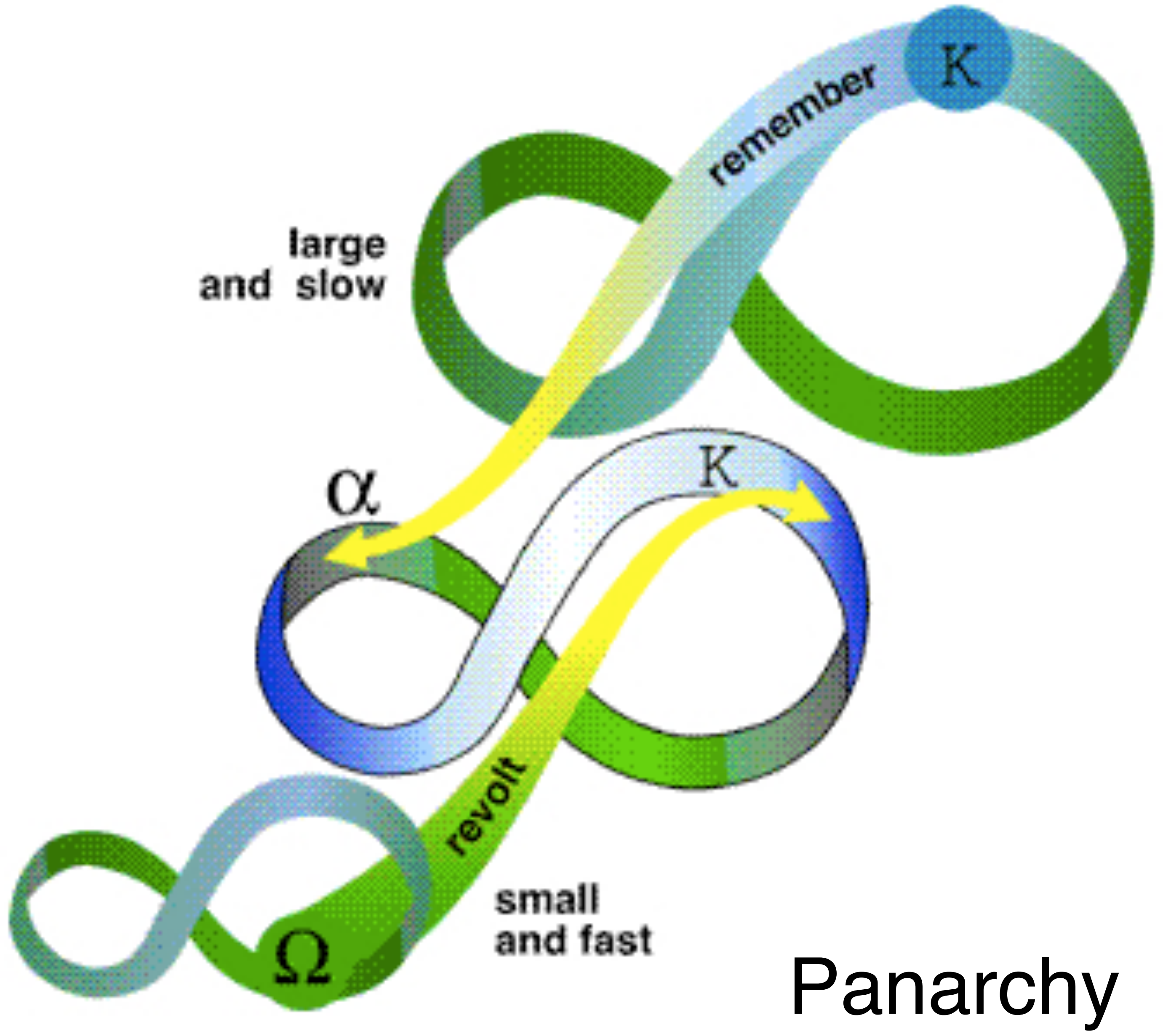
The panarchy framework connects adaptive cycles in a nested hierarchy across spatial and temporal scales.



aptive cycle



Panarchy

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A property of systems that increase in capability, resilience, or robustness as a result of stressors, shocks, volatility, noise, mistakes, faults, attacks, or failures.

Taleb (2012): *Antifragile: Things that gain from Disorder*

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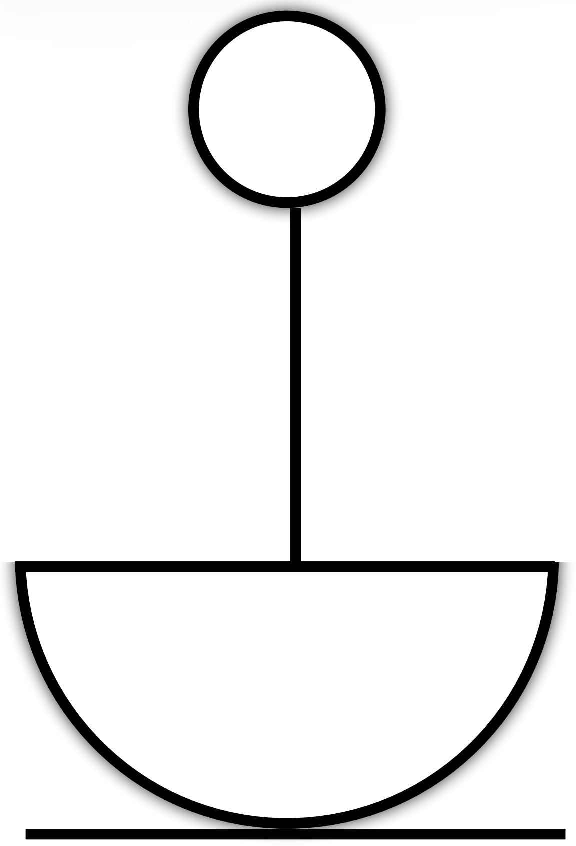

Resilient

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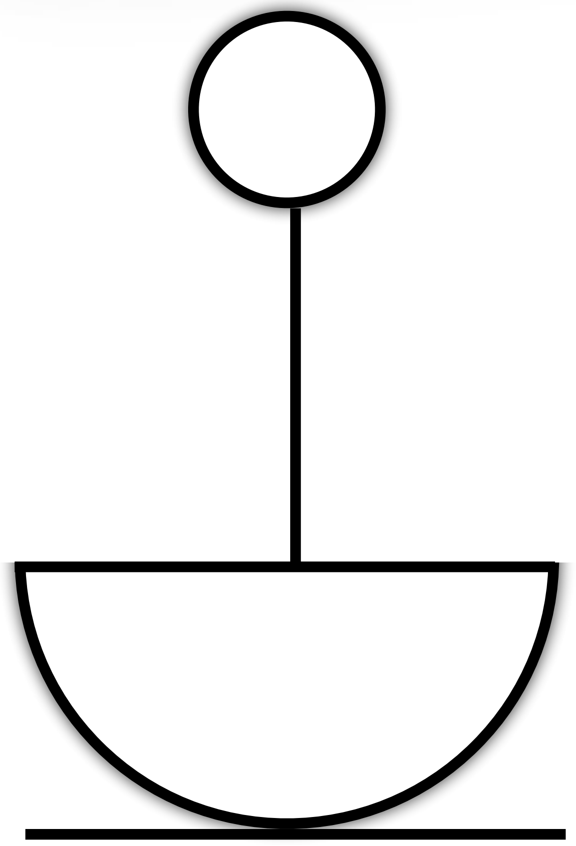

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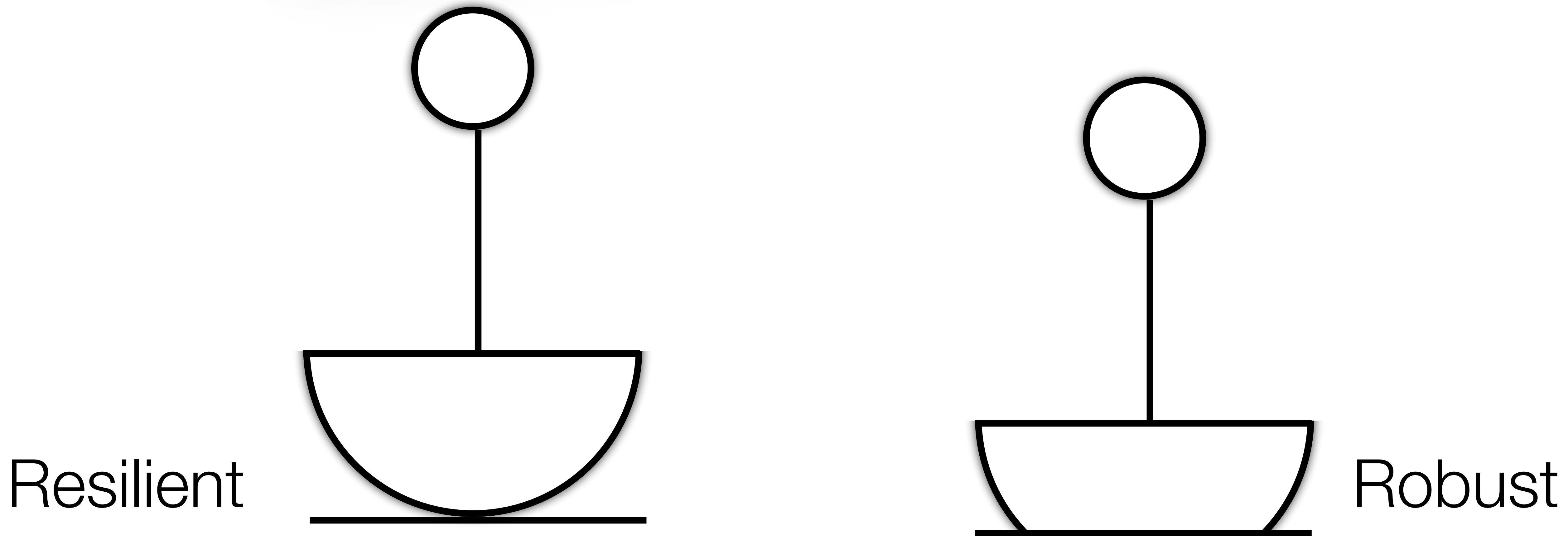

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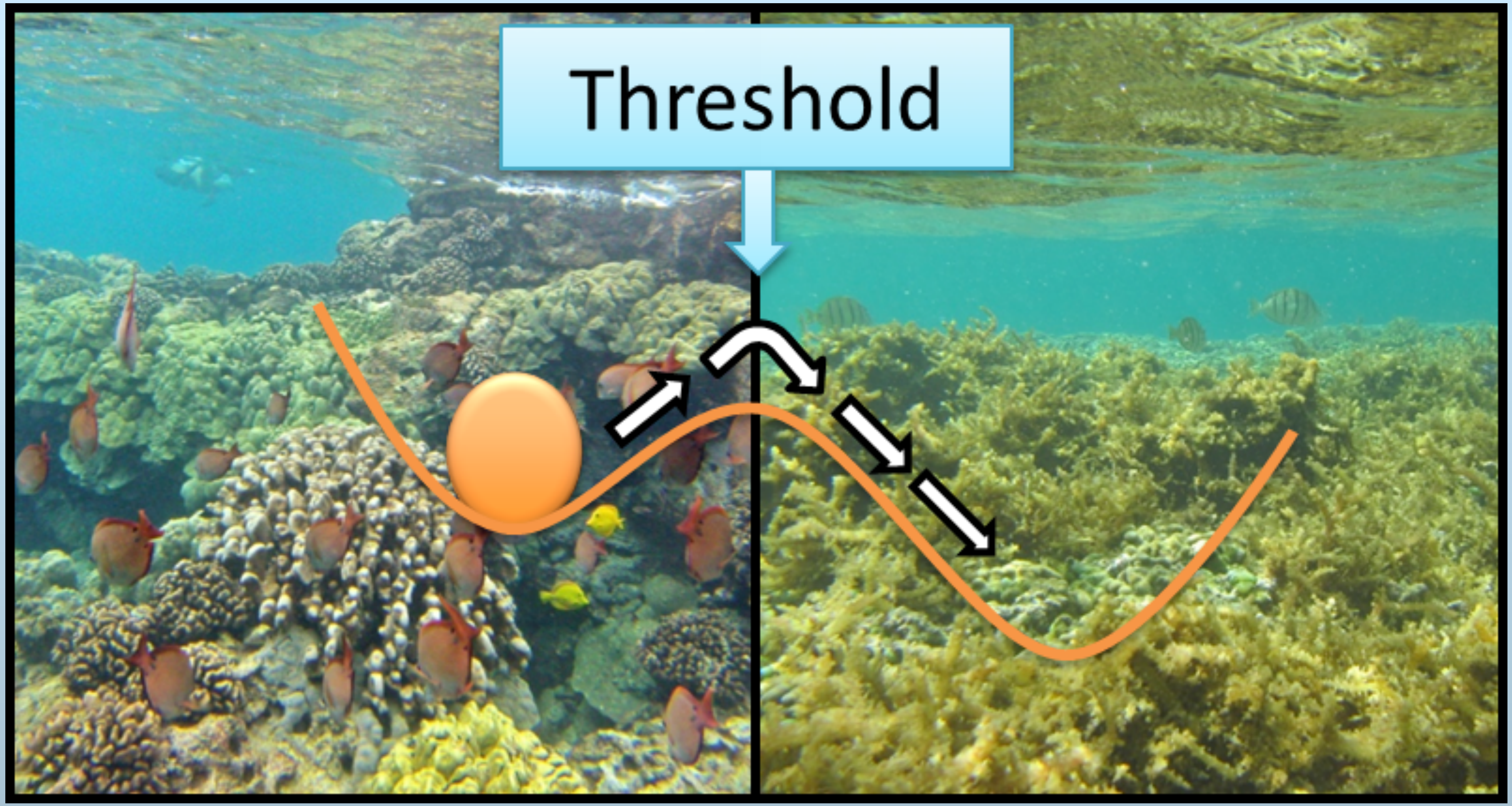
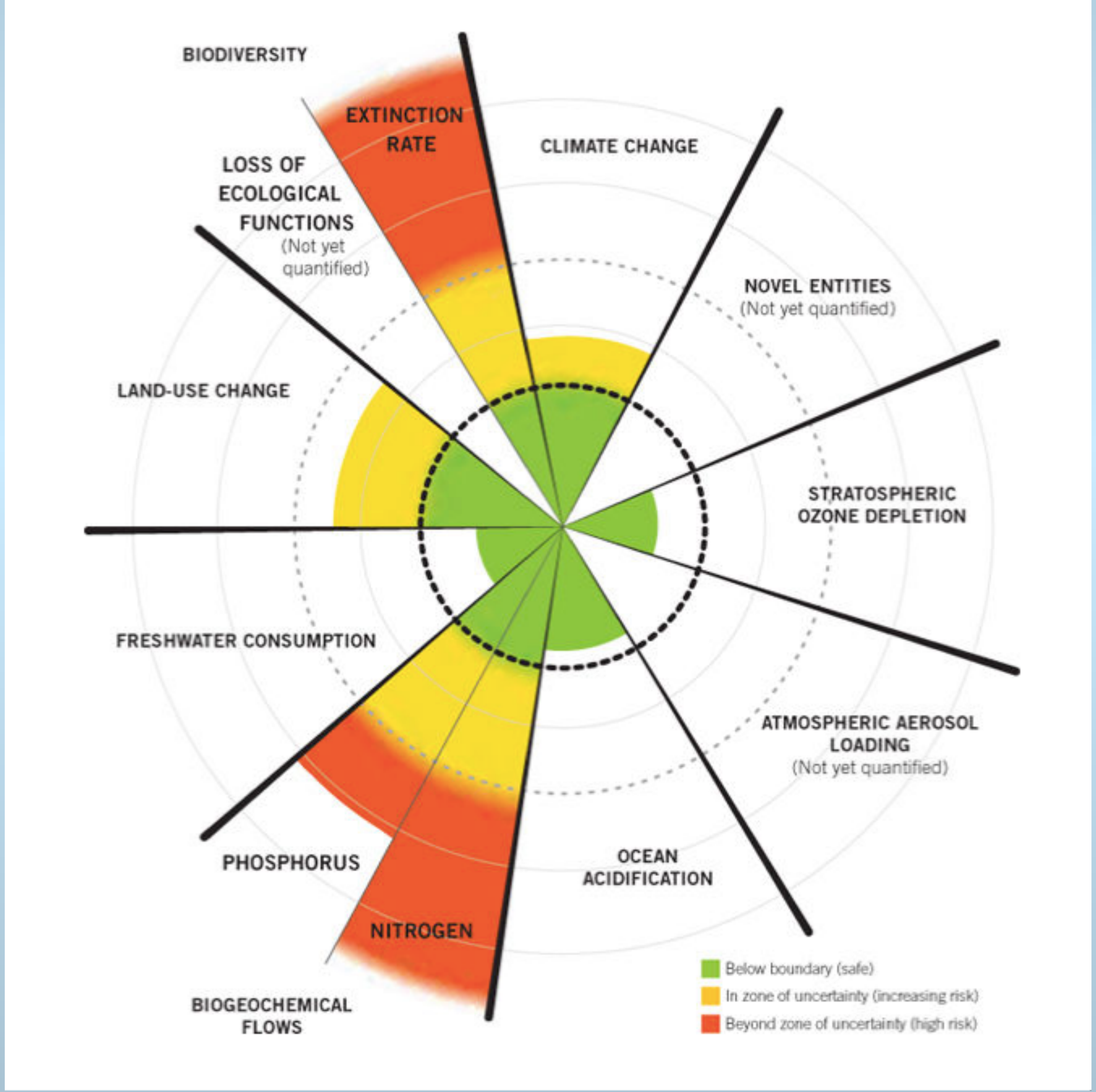
Stability of Systems

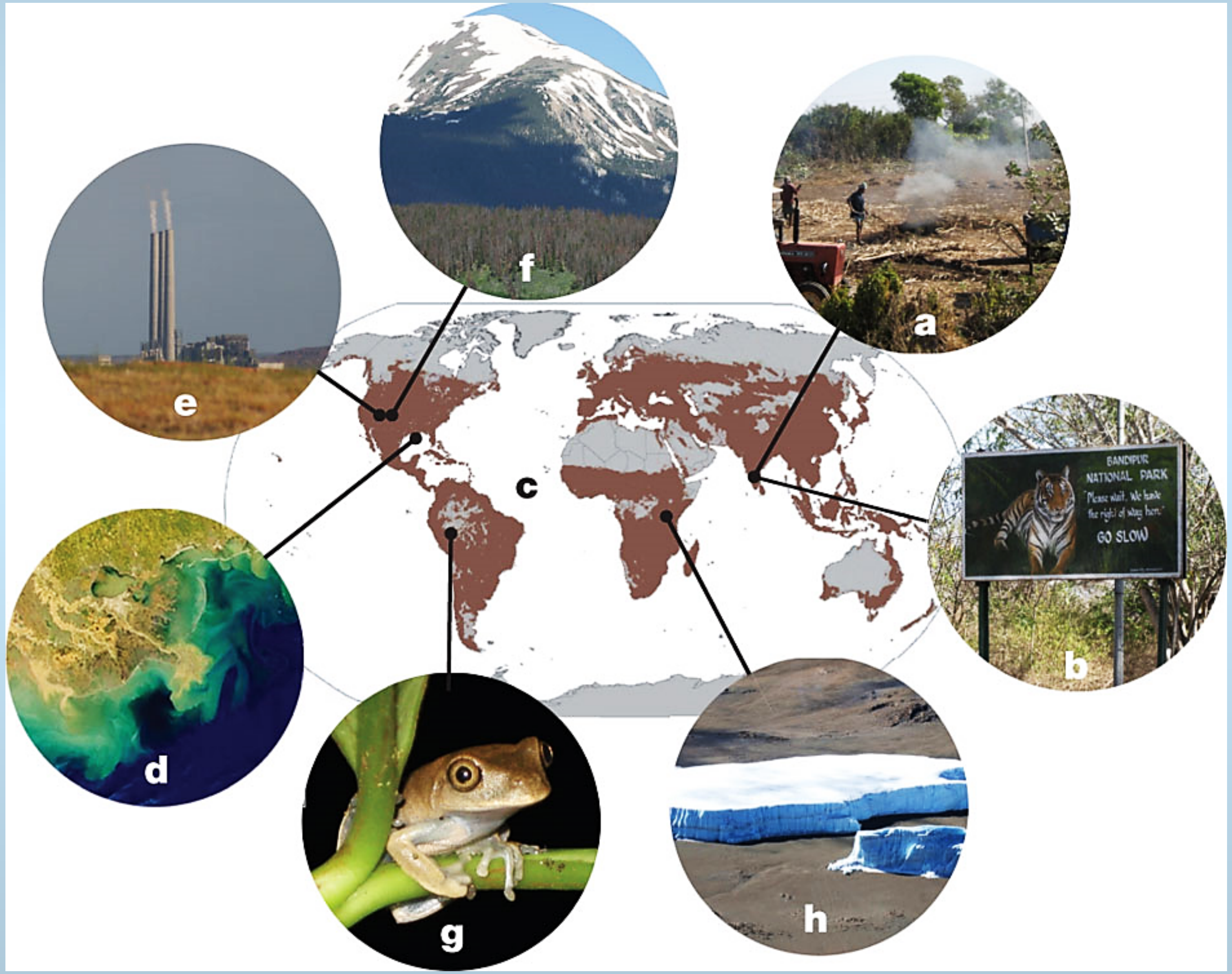
- State Shift –a severe disturbance in which the system does not return to normal but instead results in significant changes in some of its state variables



Leaving the “Safe Operating Space”



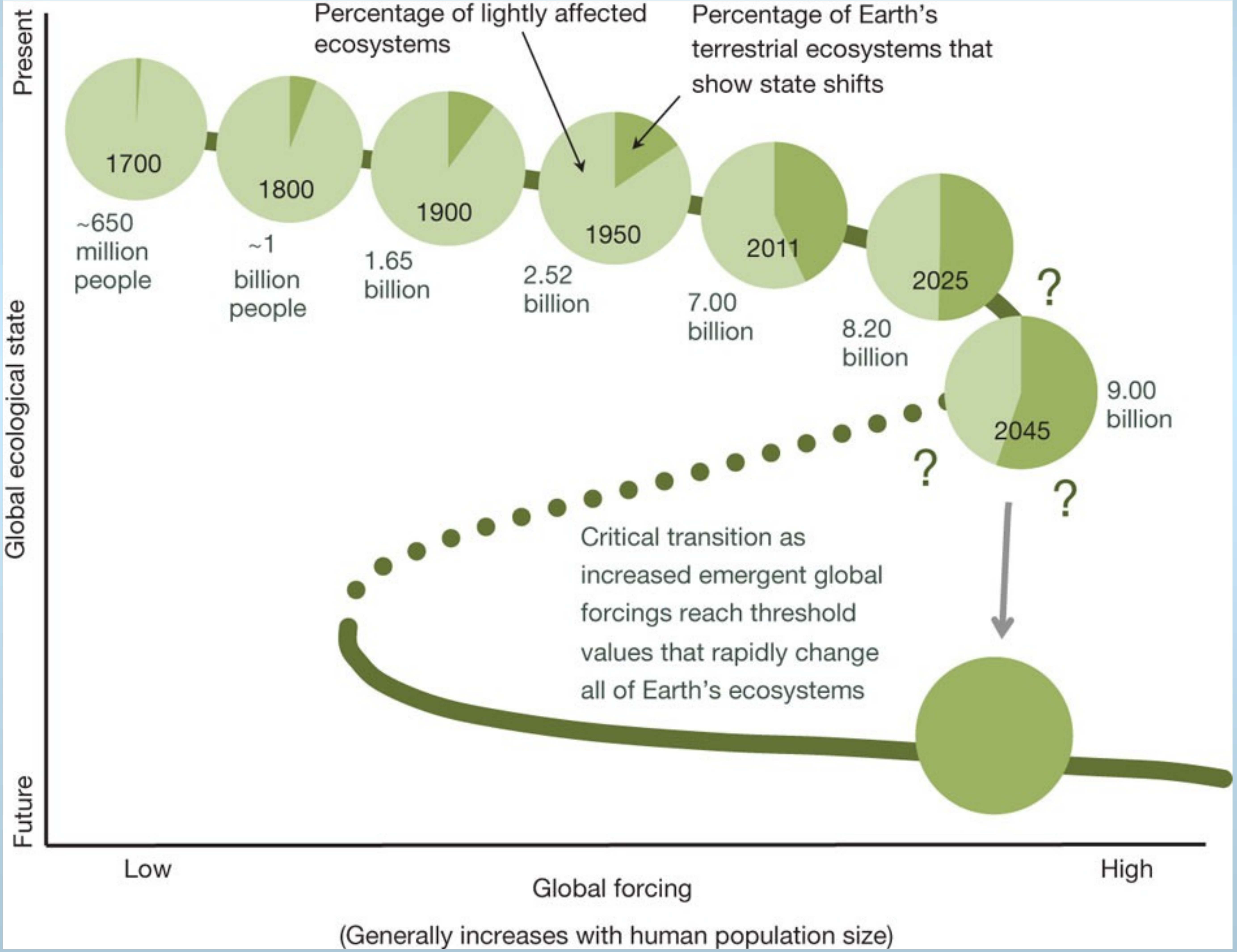
Drivers of a potential planetary-scale critical transition



A D. Barnosky *et al.* *Nature* **486**, 52–58 (2012) doi:10.1038/nature11018

brown color indicates ~ 40% of terrestrial ecosystems that have now been transformed to agricultural landscapes

Quantifying land use as one method of anticipating a planetary state shift



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Threshold of 2ºC might determine the new state of the planet

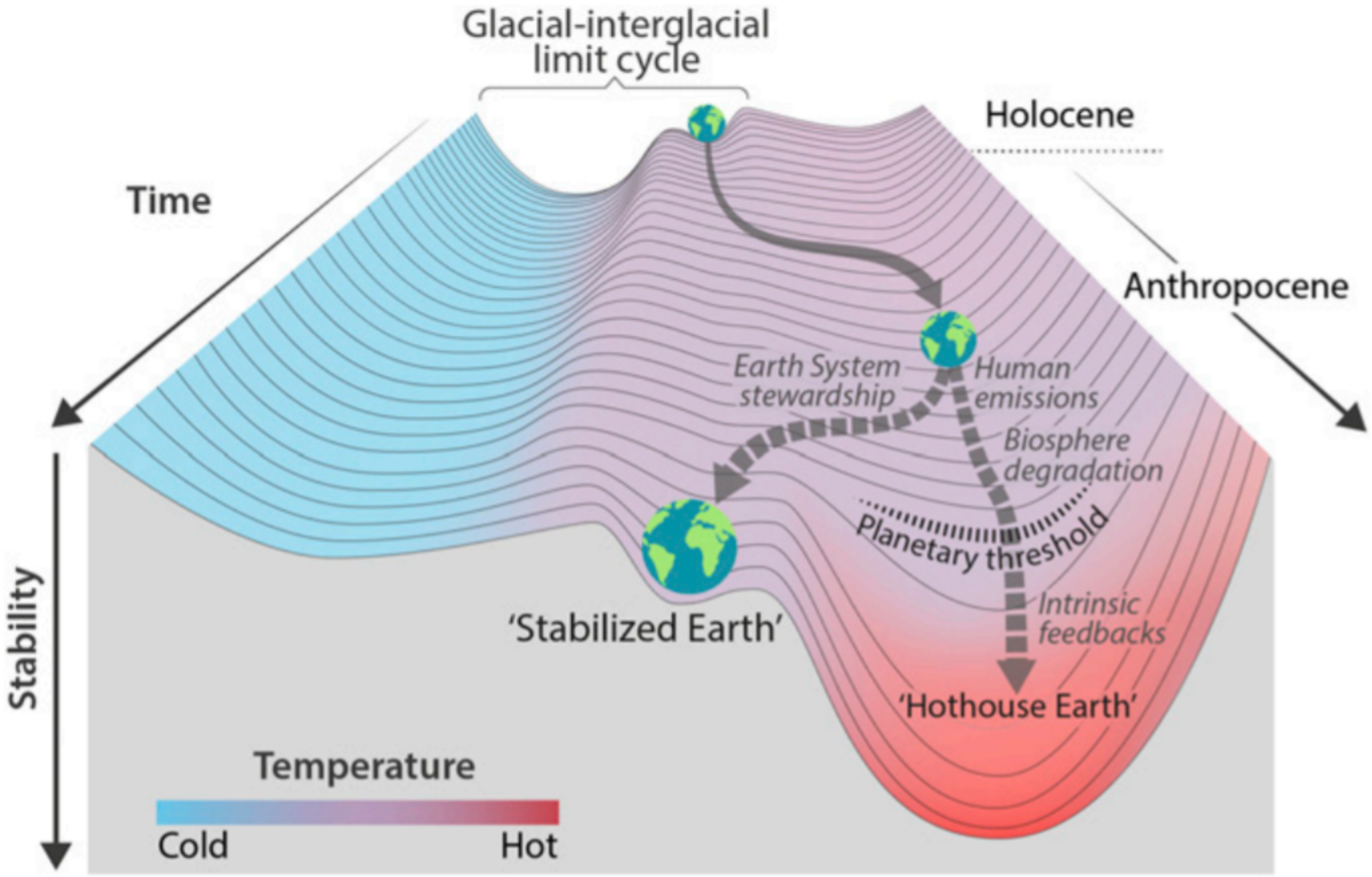
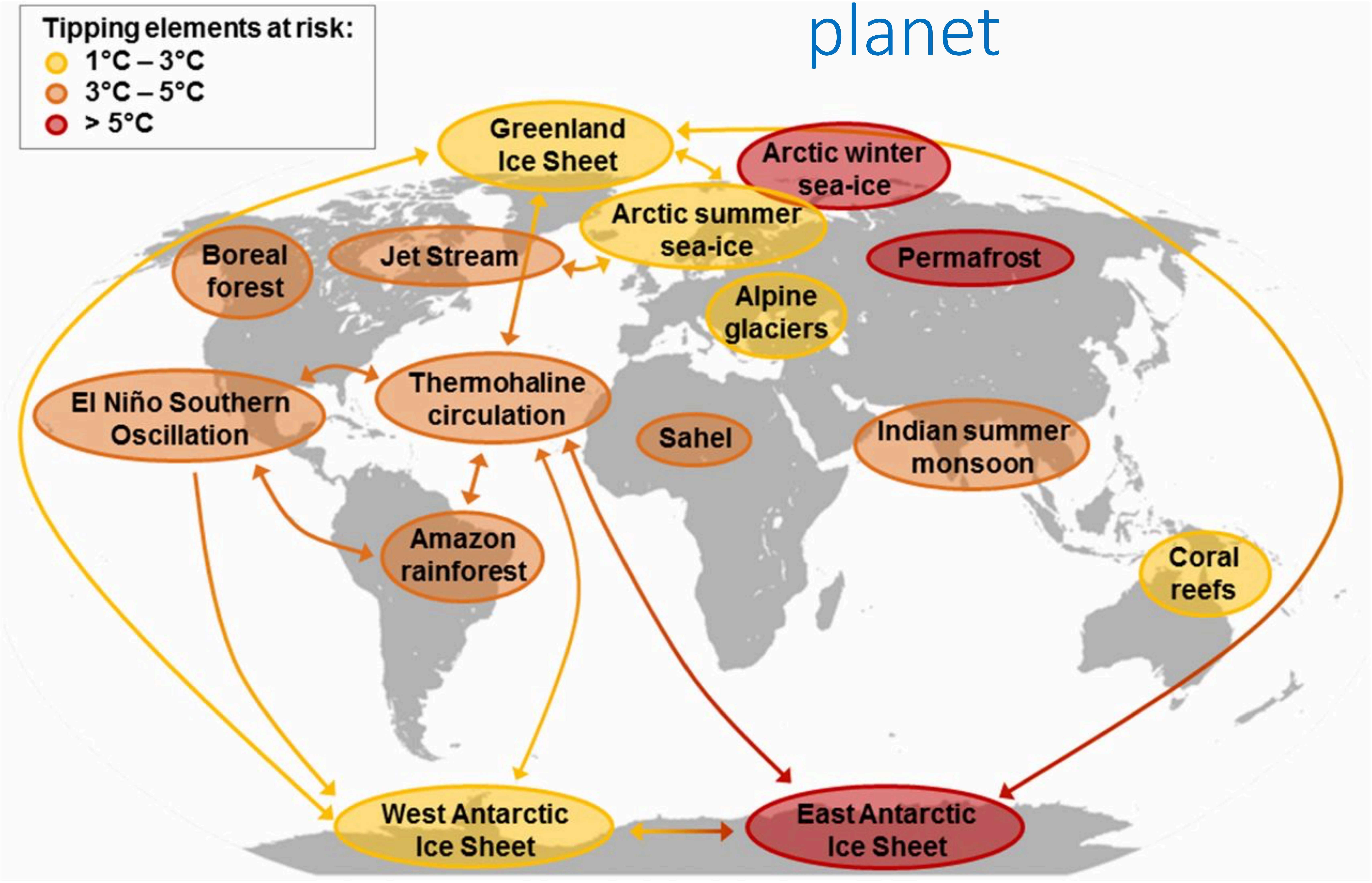


Fig. 2. Stability landscape showing the pathway of the Earth System out of the Holocene and thus, out of the glacial–interglacial limit cycle to its present position in the hotter Anthropocene. The fork in the

Steffen et al., 2018. PNAS, vol. 115, no. 33

Threshold of 2⁰C might determine the new state of the planet



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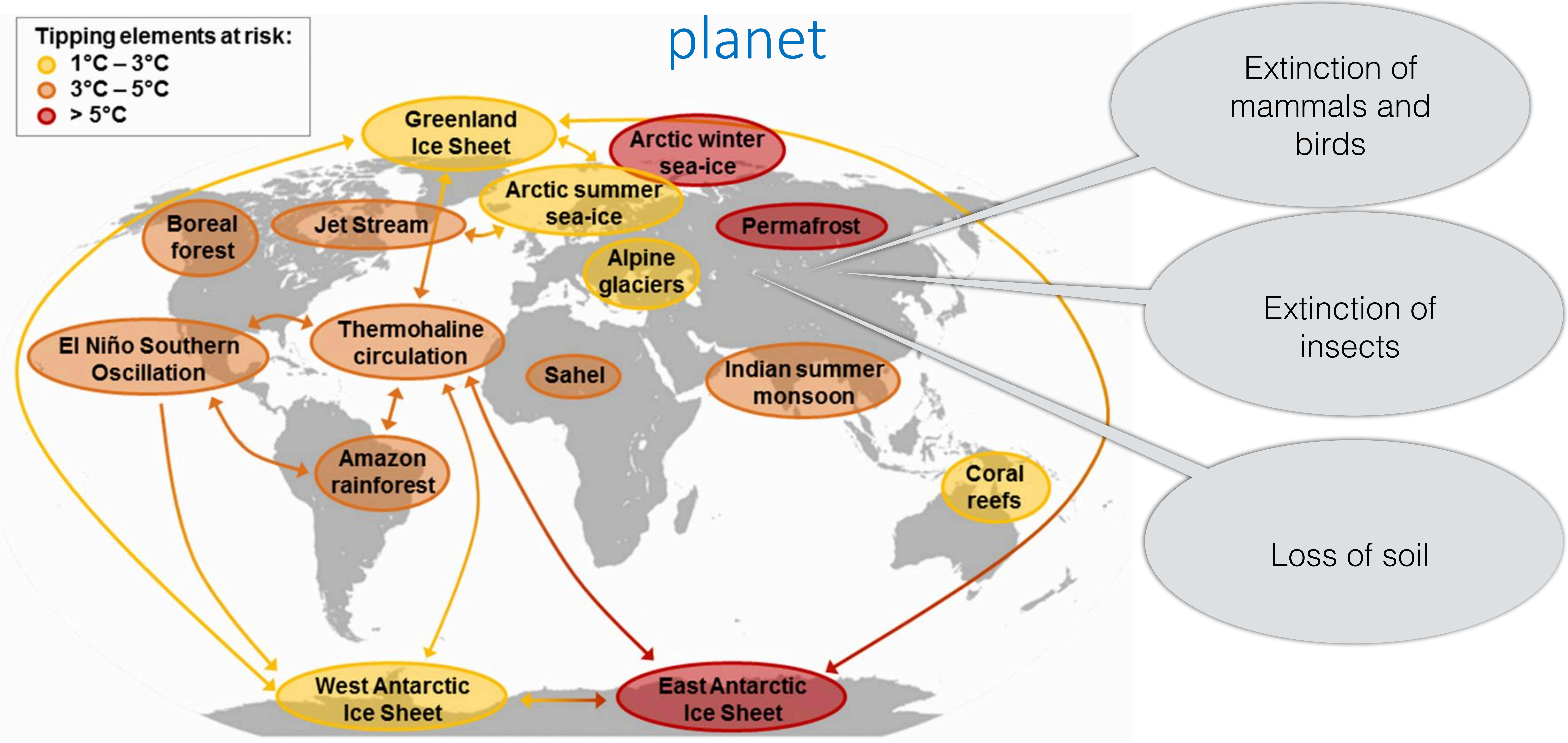

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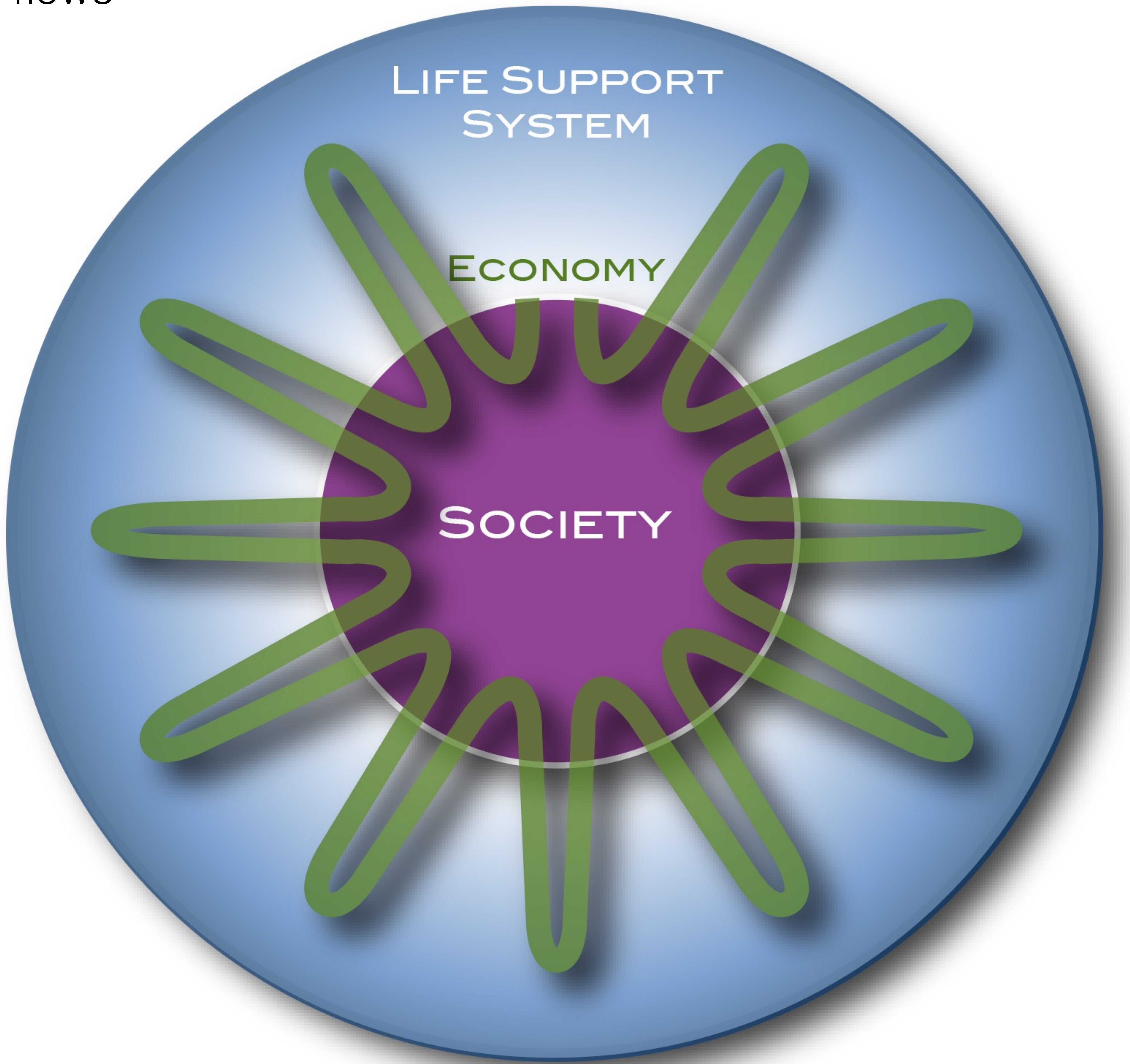
The importance of flows

The Earth's Life-Support System

Everything is about Flow - we have increased many flows



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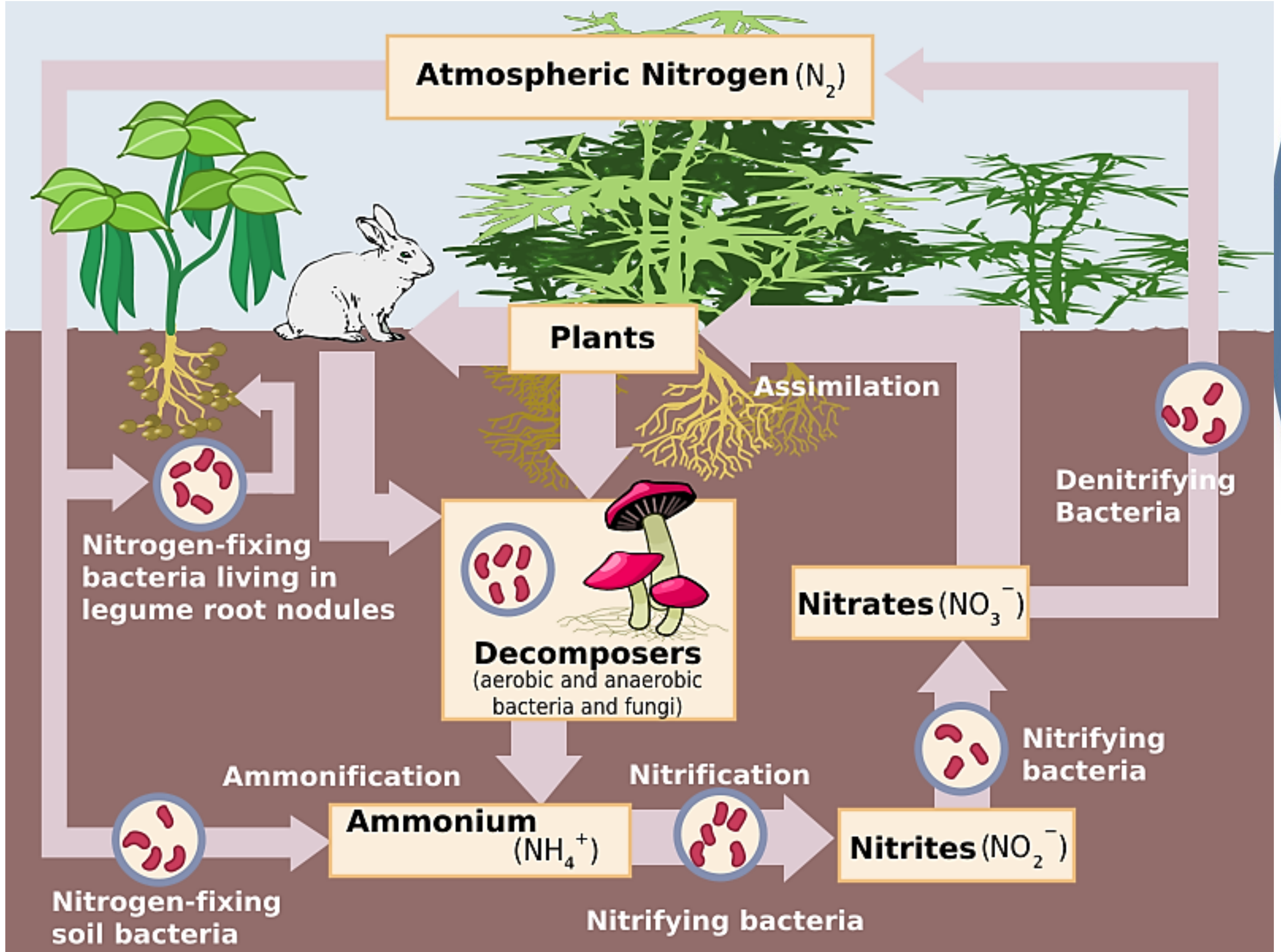

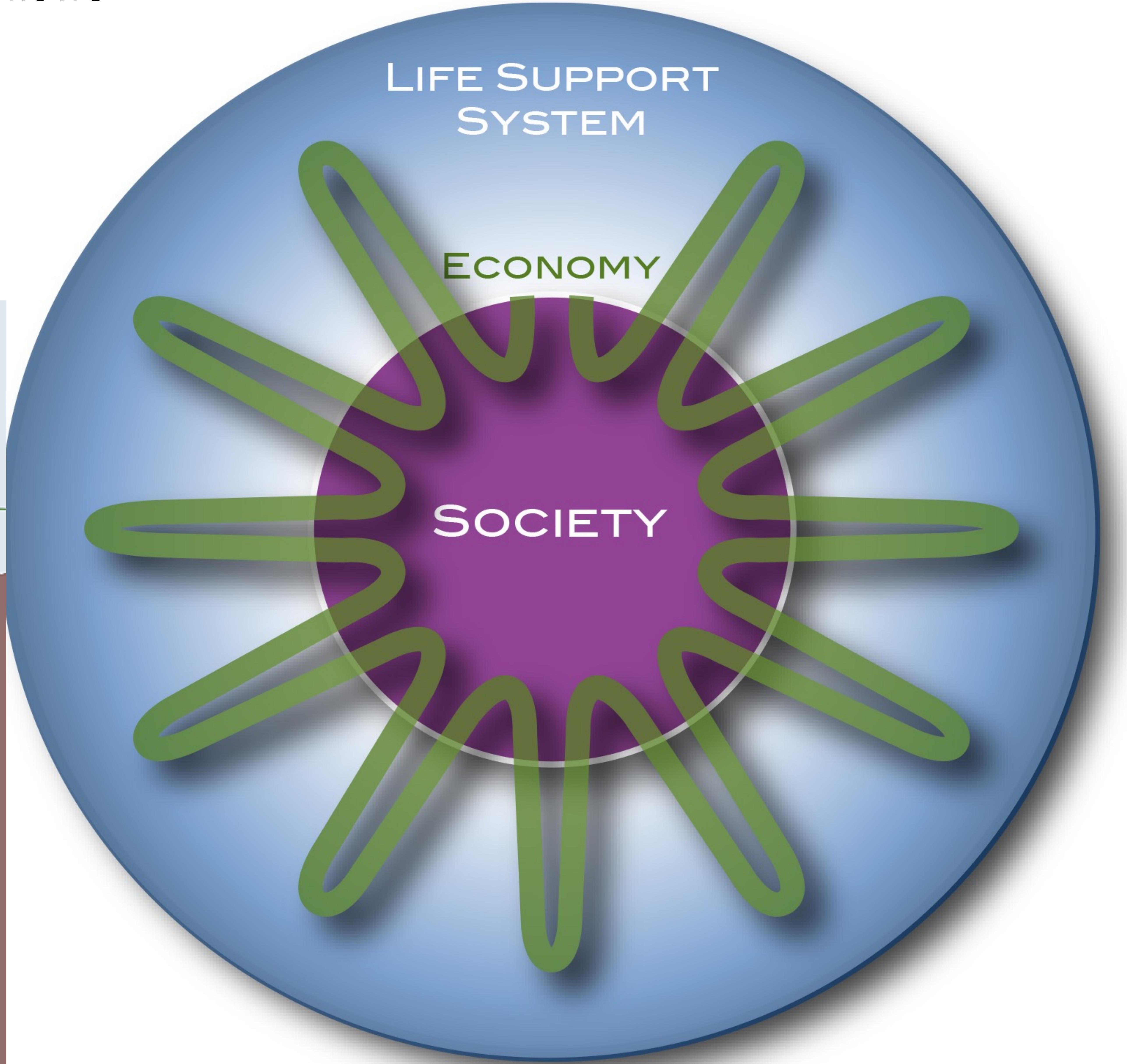

The Earth's Life-Support System

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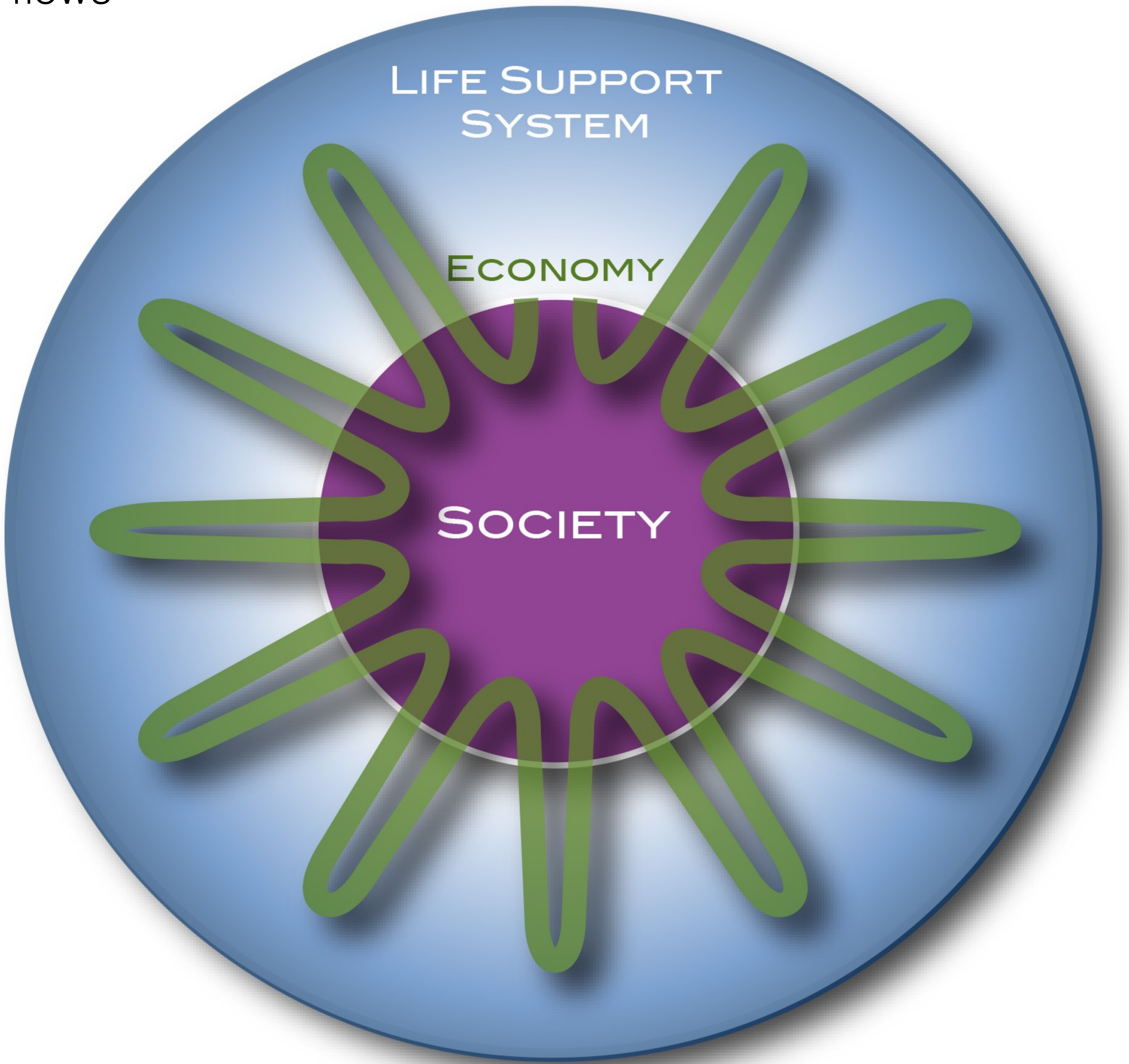
Earth is an "undiagnosed Patient"

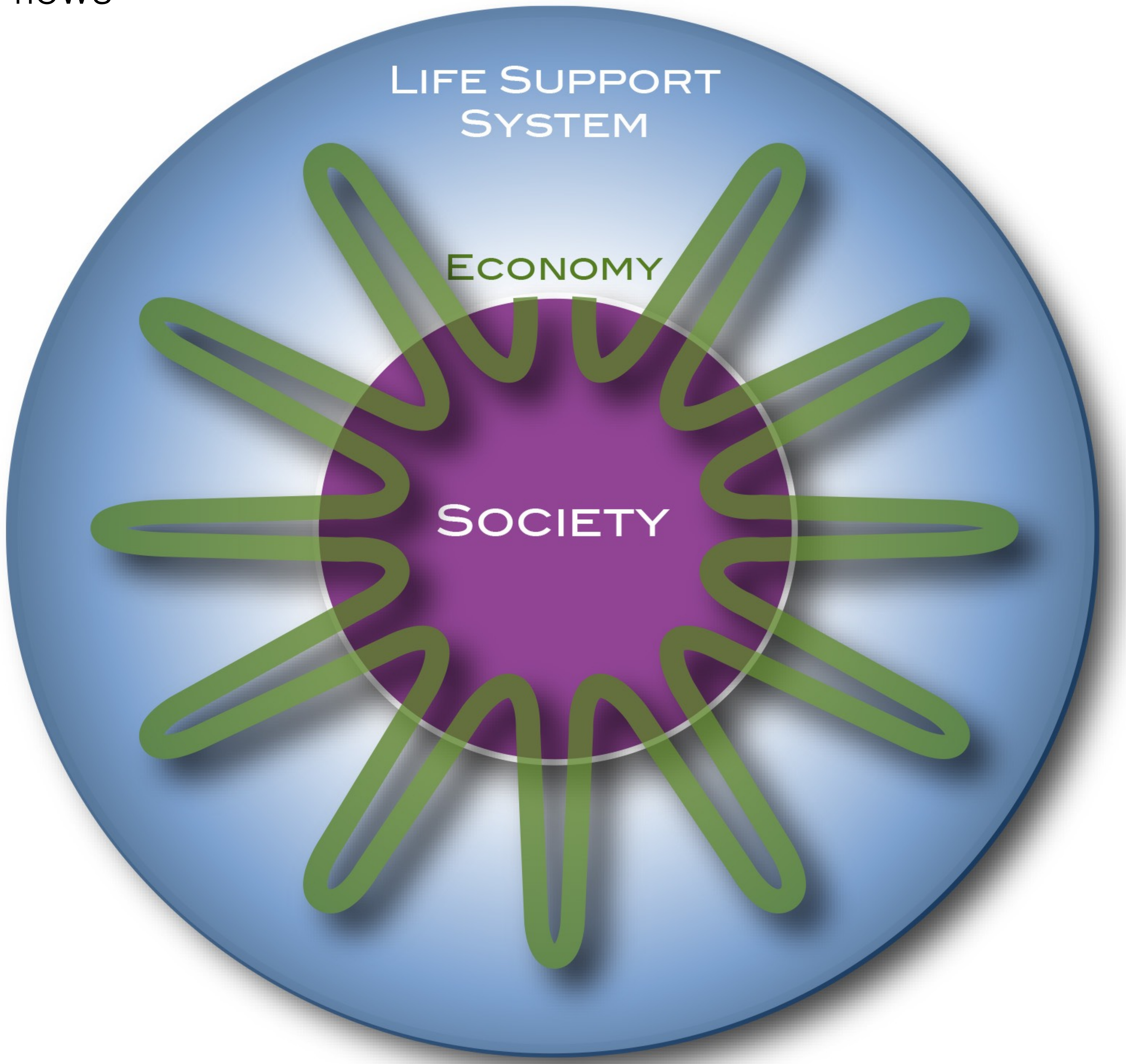


The Earth’s Life-Support System

Everything is about Flow - we have increased many flows

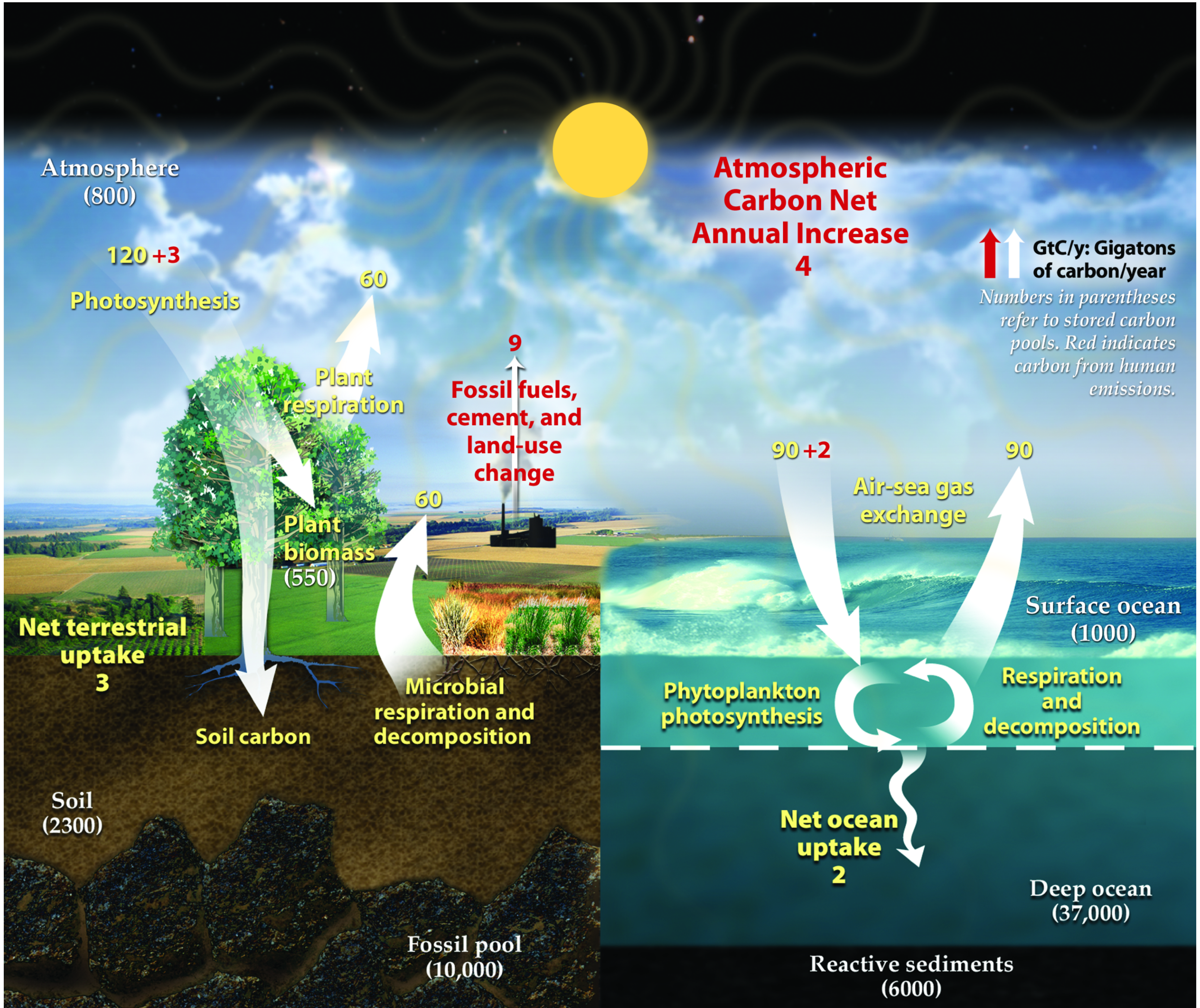
Earth is an “undiagnosed Patient”

Flows in the ELSS allow us to assess the “Health of the Planet” and to diagnose the “patient”

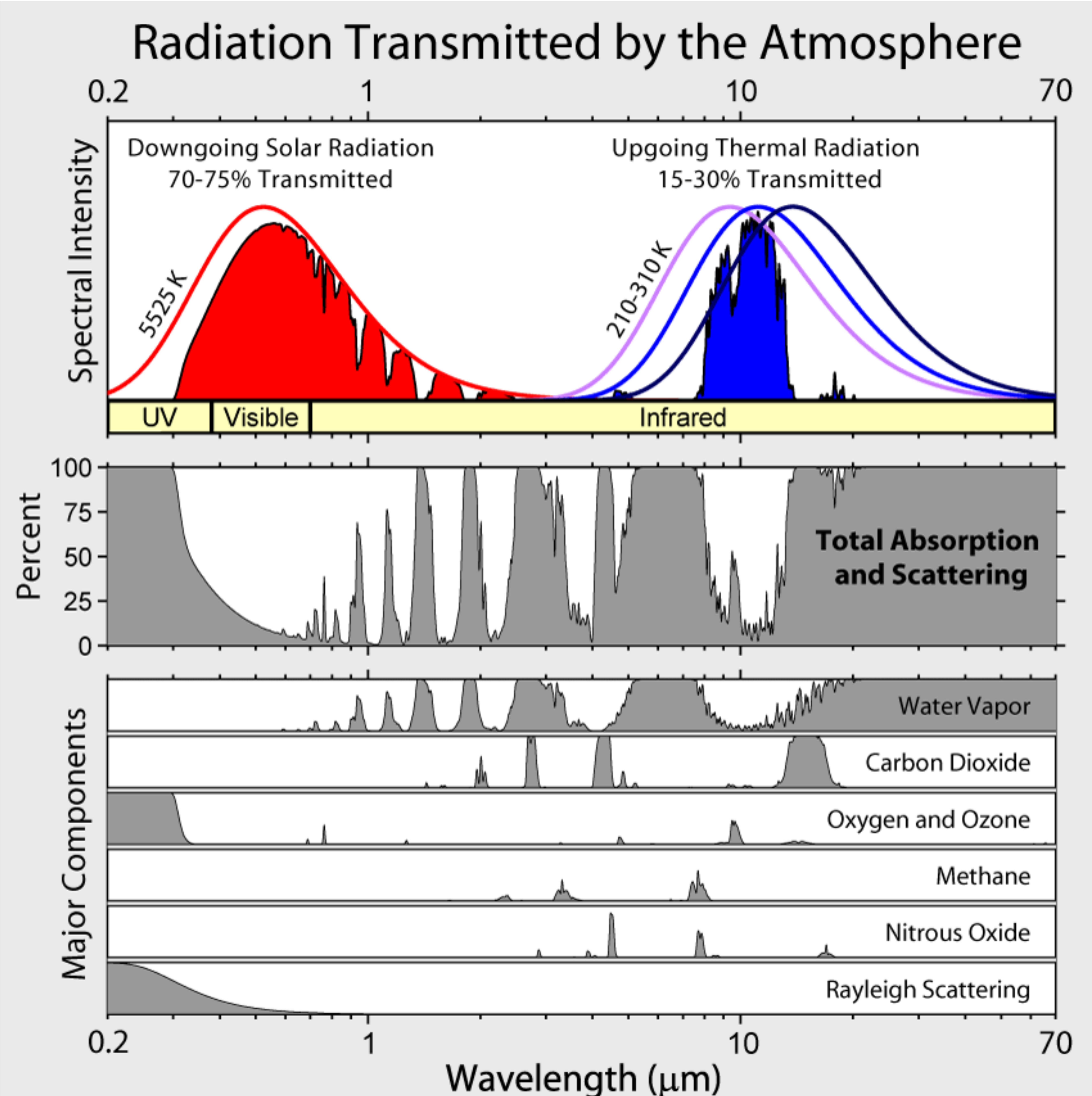


The importance of stocks and flows

The Earth's Life-Support System



The importance of regulating processes



Atmospheric absorption and scattering at different wavelengths of electromagnetic waves. The largest absorption band of carbon dioxide is not far from the maximum in the thermal emission from ground, and it partly closes the window of transparency of water; hence its major effect.

Atmospheric lifetime and GWP relative to CO_2 at different time horizon for various greenhouse gases

Gas name	Chemical formula	Lifetime (years)[22]	Global warming potential (GWP) for given time horizon		
			20-yr[22]	100-yr[22]	500-yr[39]
Carbon dioxide	CO_2	30–95	1	1	1
Methane	CH_4	12	84	28	7.6
Nitrous oxide	N_2O	121	264	265	153
CFC-12	CCl_2F_2	100	10 800	10 200	5 200
HCFC-22	$CHClF_2$	12	5 280	1 760	549
Tetrafluoromethane	CF_4	50 000	4 880	6 630	11 200
Hexafluoroethane	C_2F_6	10 000	8 210	11 100	18 200
Sulfur hexafluoride	SF_6	3 200	17 500	23 500	32 600
Nitrogen trifluoride	NF_3	500	12 800	16 100	20 700

The importance of concepts and language

The Earth's Life-Support System

Greenhouse

The Earth’s Life-Support System

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Greenhouse

Poolhouse

The Earth’s Life-Support System

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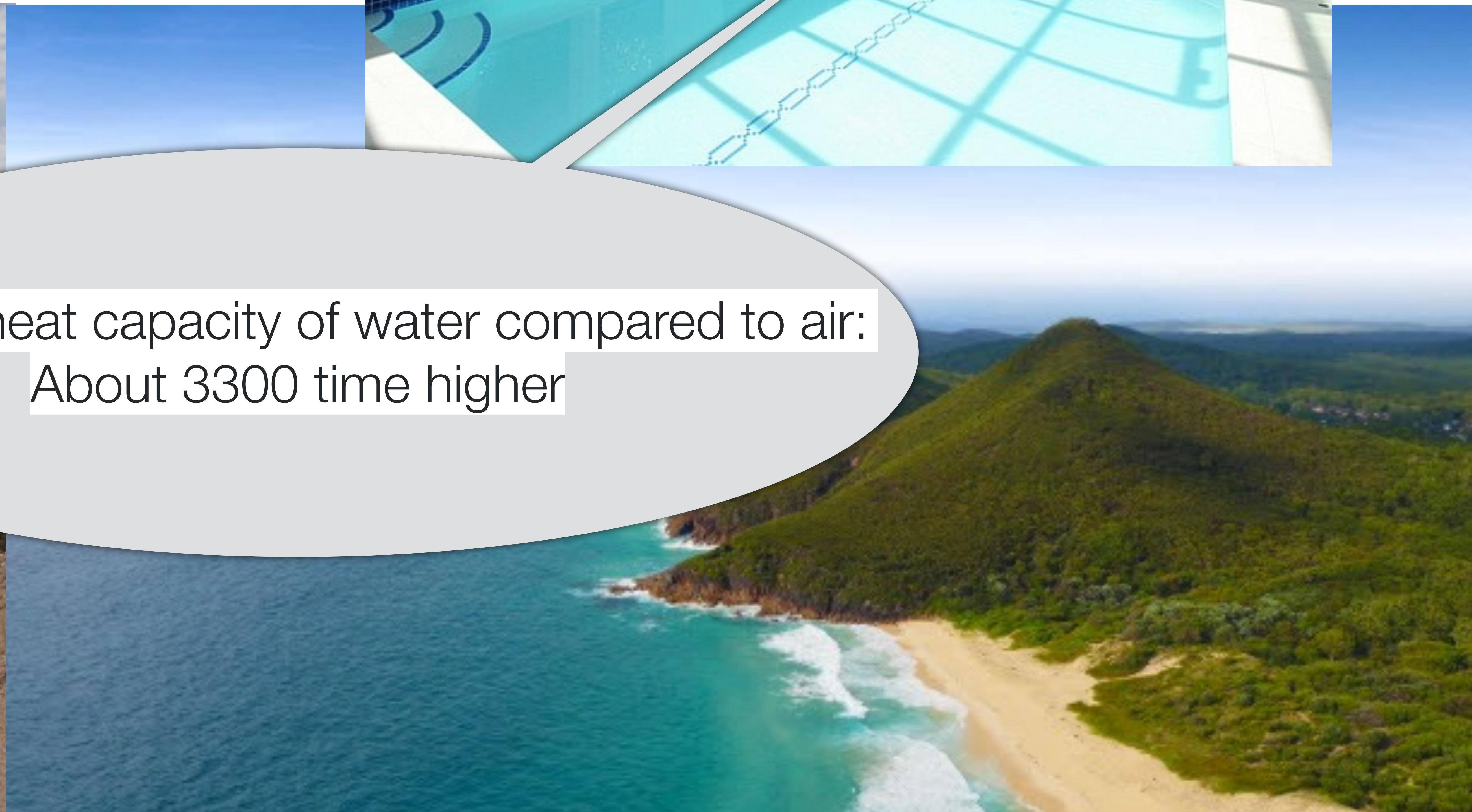
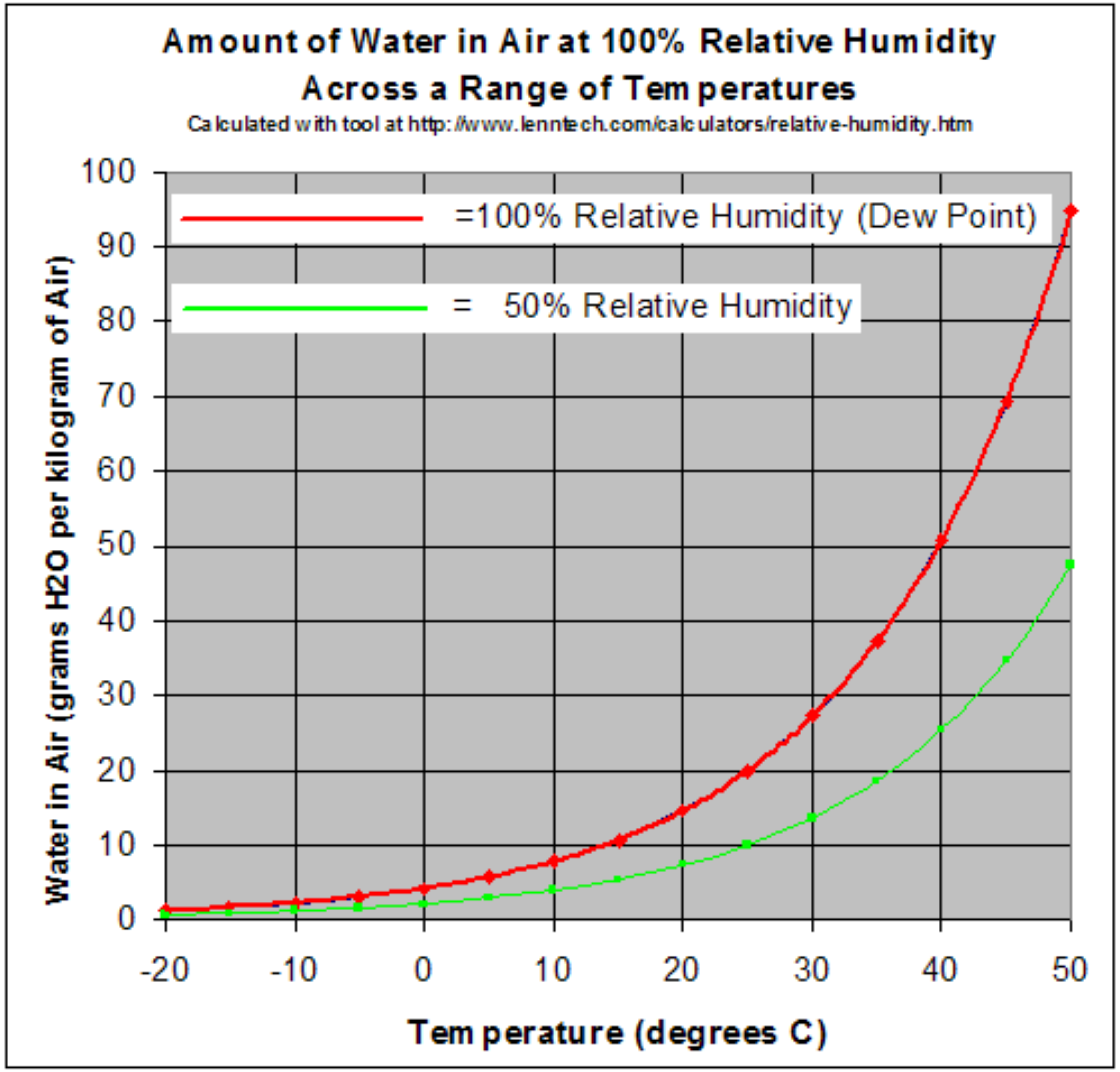


Volumetric heat capacity of water compared to air:
About 3300 time higher

The Earth's Life-Support System



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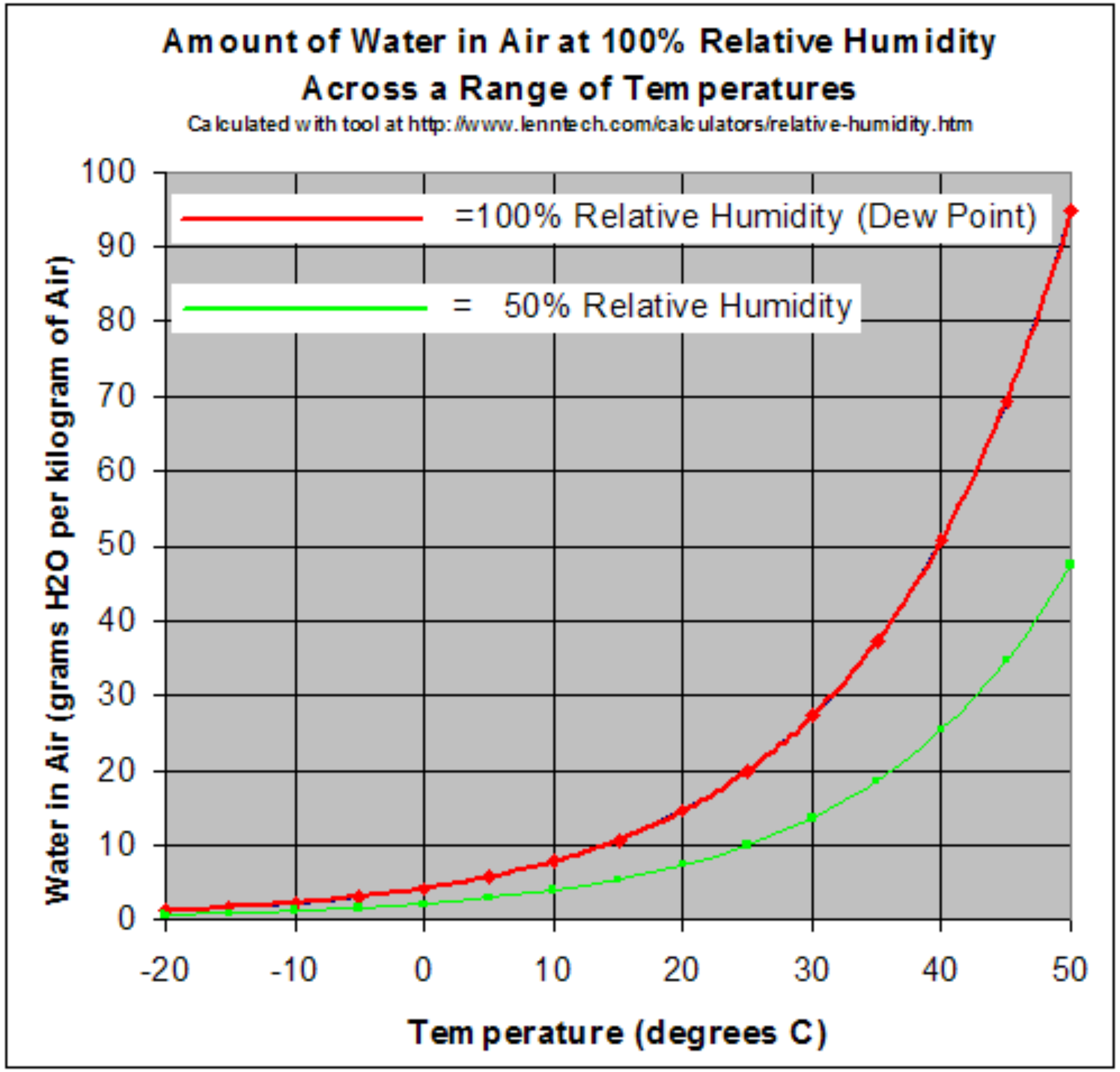
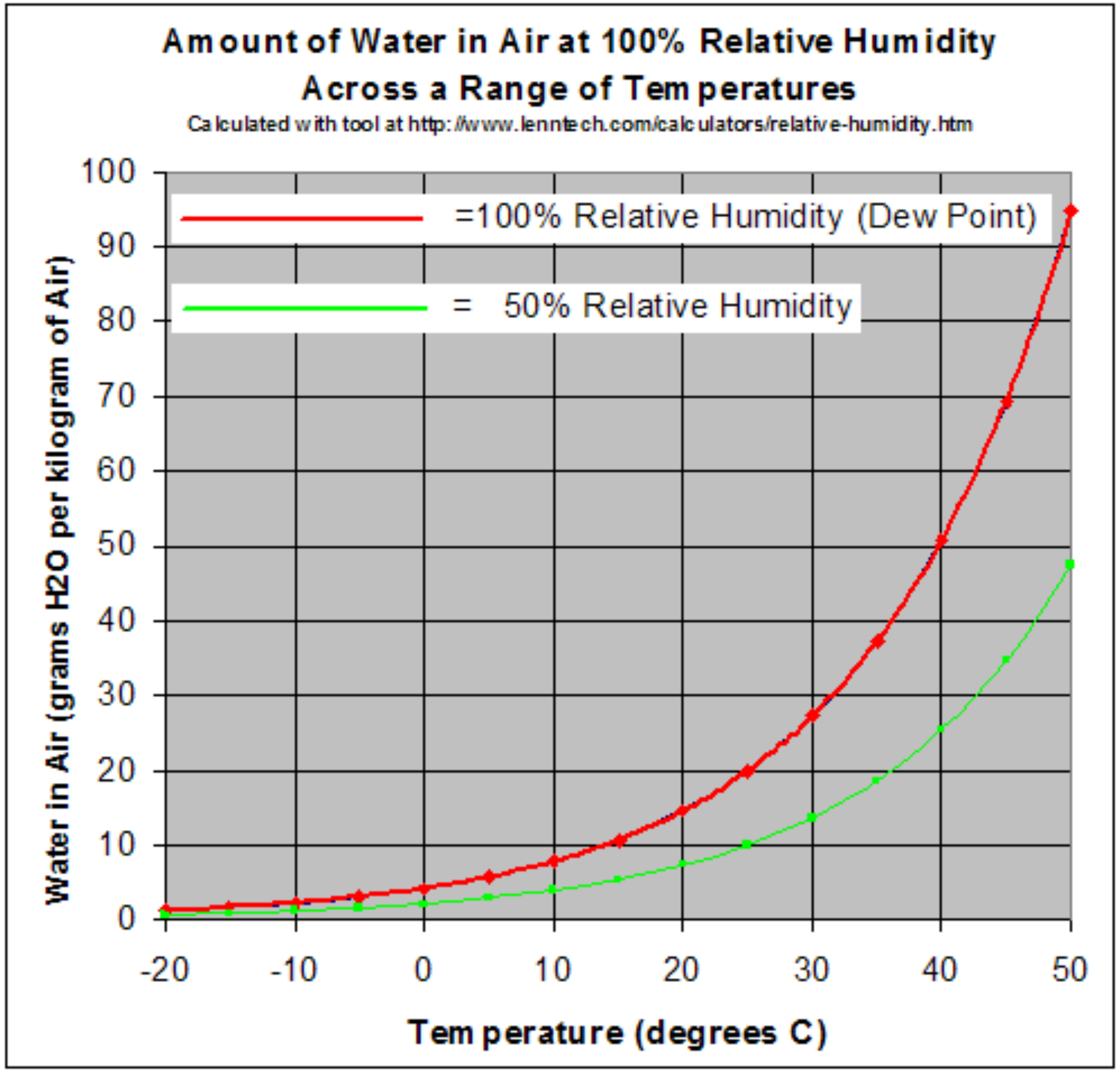


Specific heat capacity:
Water: 4200 $Jkg^{-1}K^{-1}$
Air: 993 $Jkg^{-1}K^{-1}$

Water has 4.23 times higher specific heat capacity.



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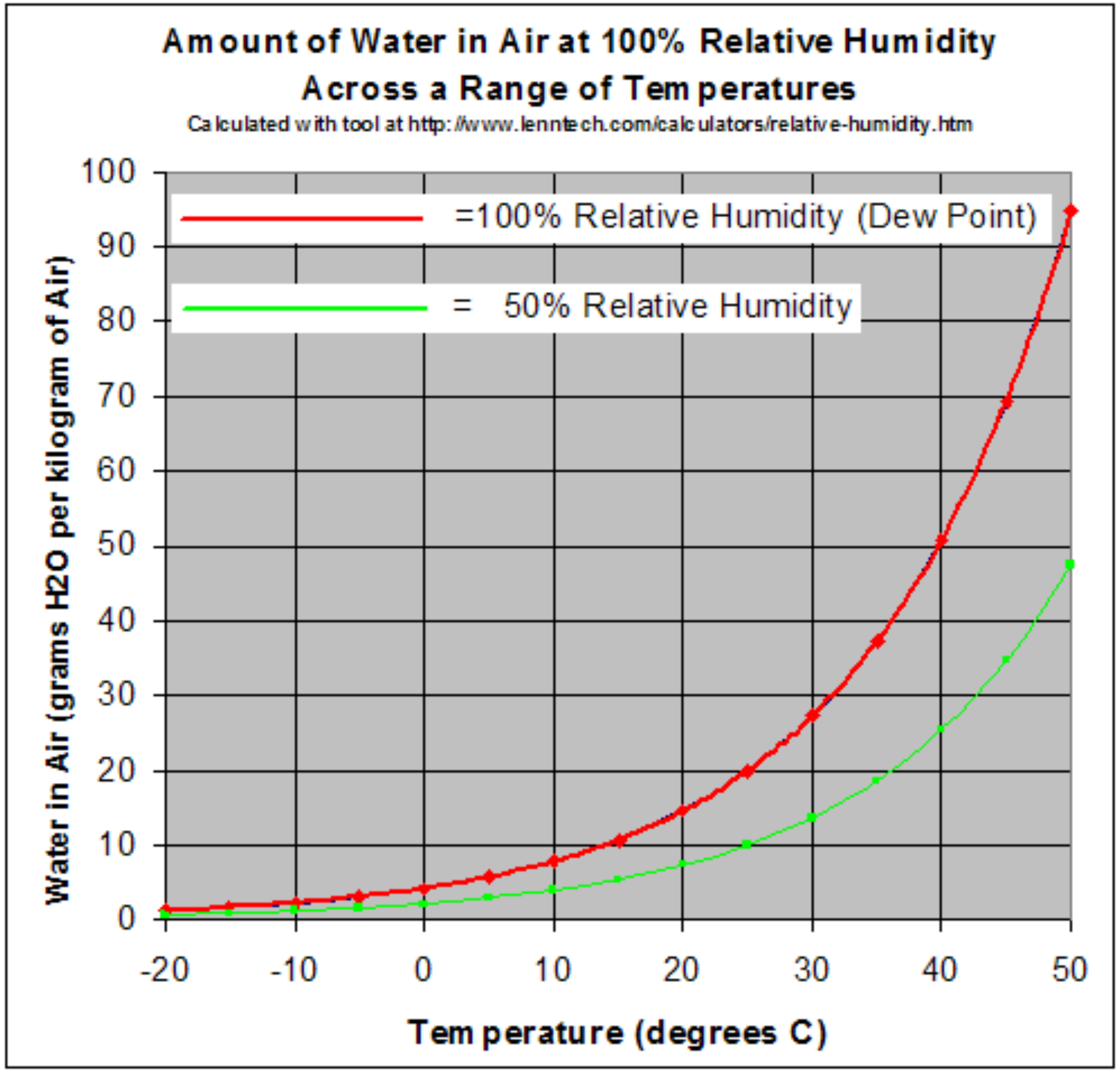
Density:
Water: 1000 kg/m^3
Air: 1.275 kg/m^3

Water is about 785 times denser than air.



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Volumetric heat capacity:
Water compared to air:
About 3300 time higher volumetric heat capacity

The Earth's Life-Support System

What are the Impacts of Climate Change?

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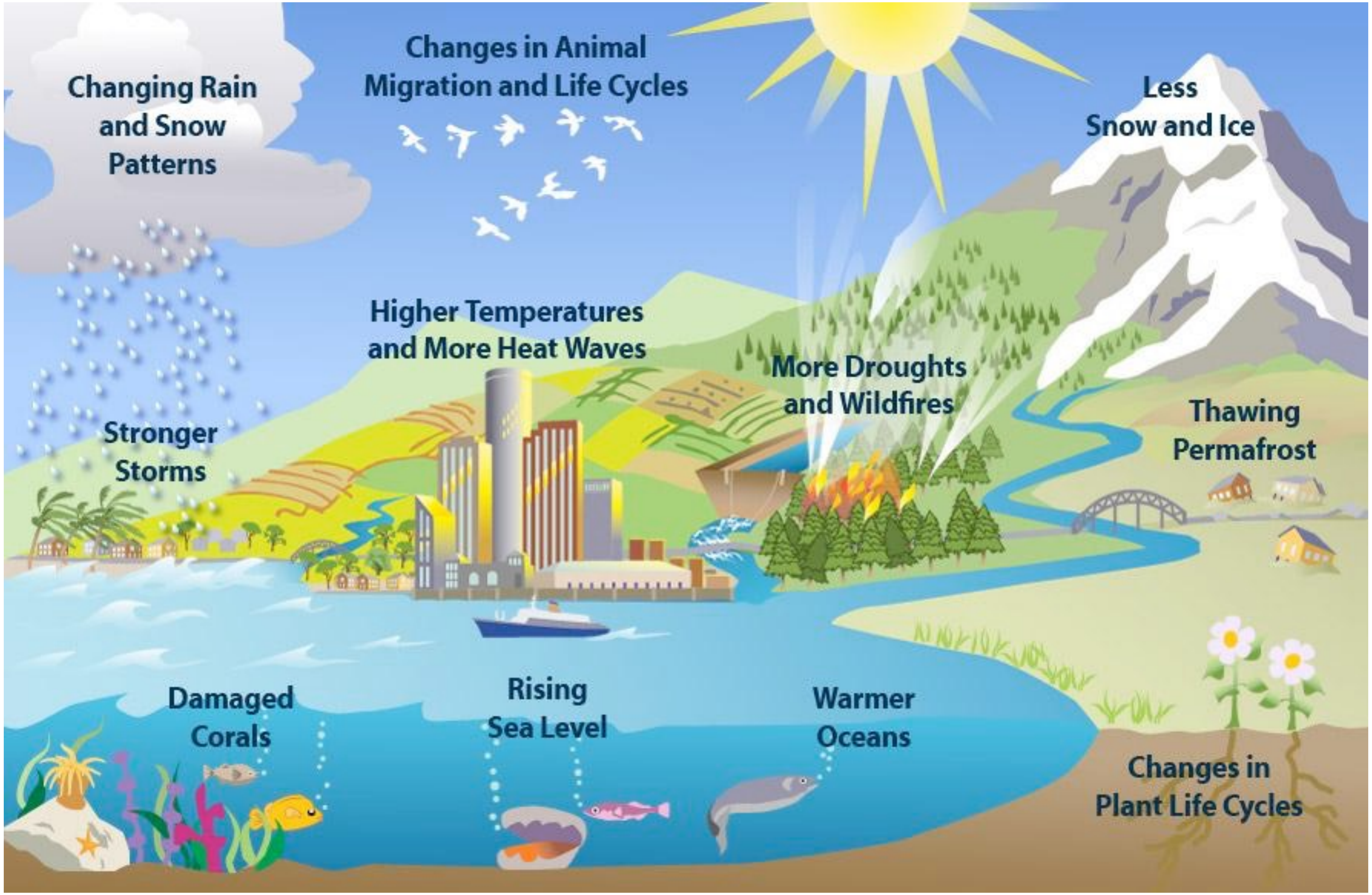
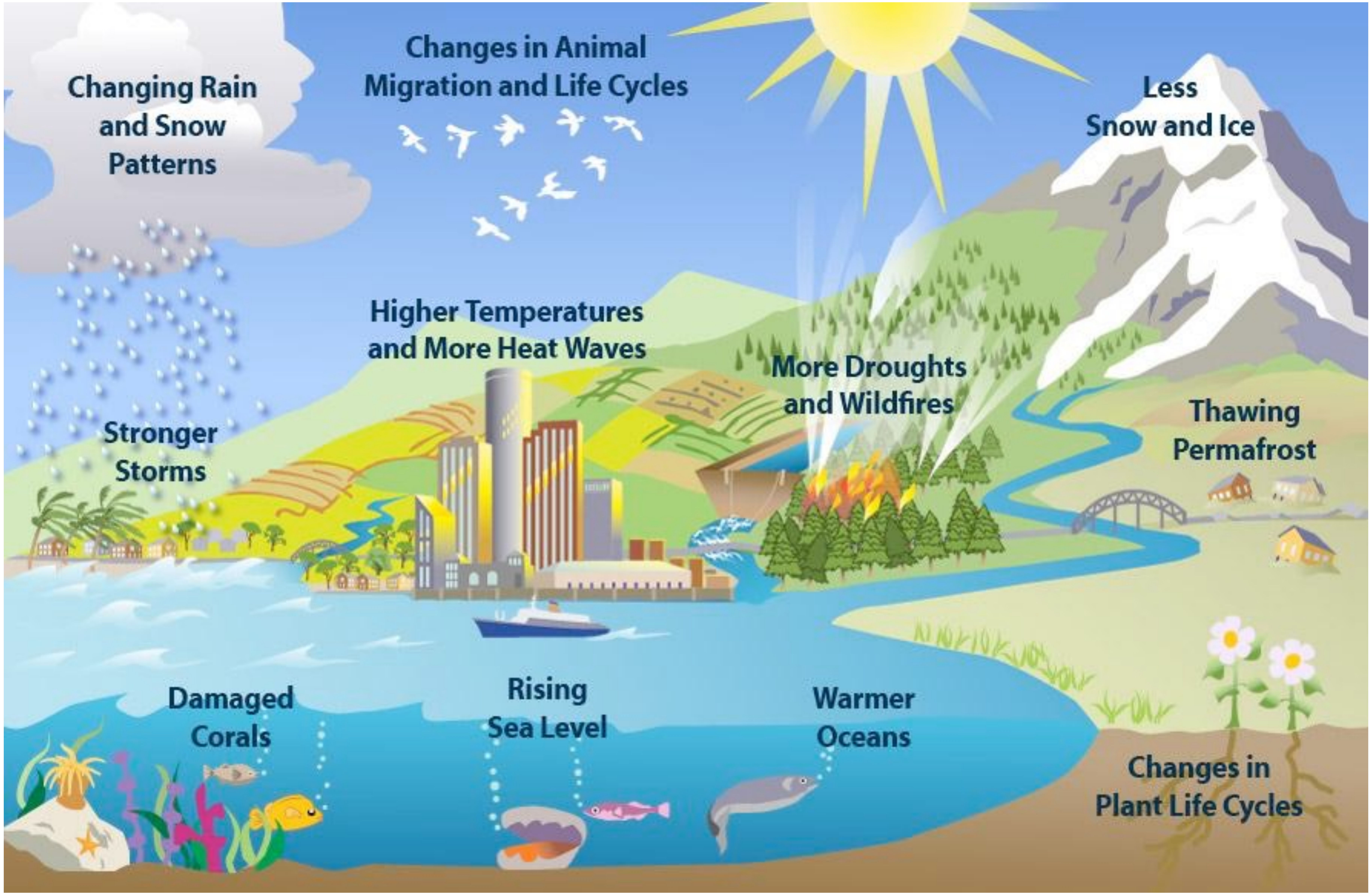
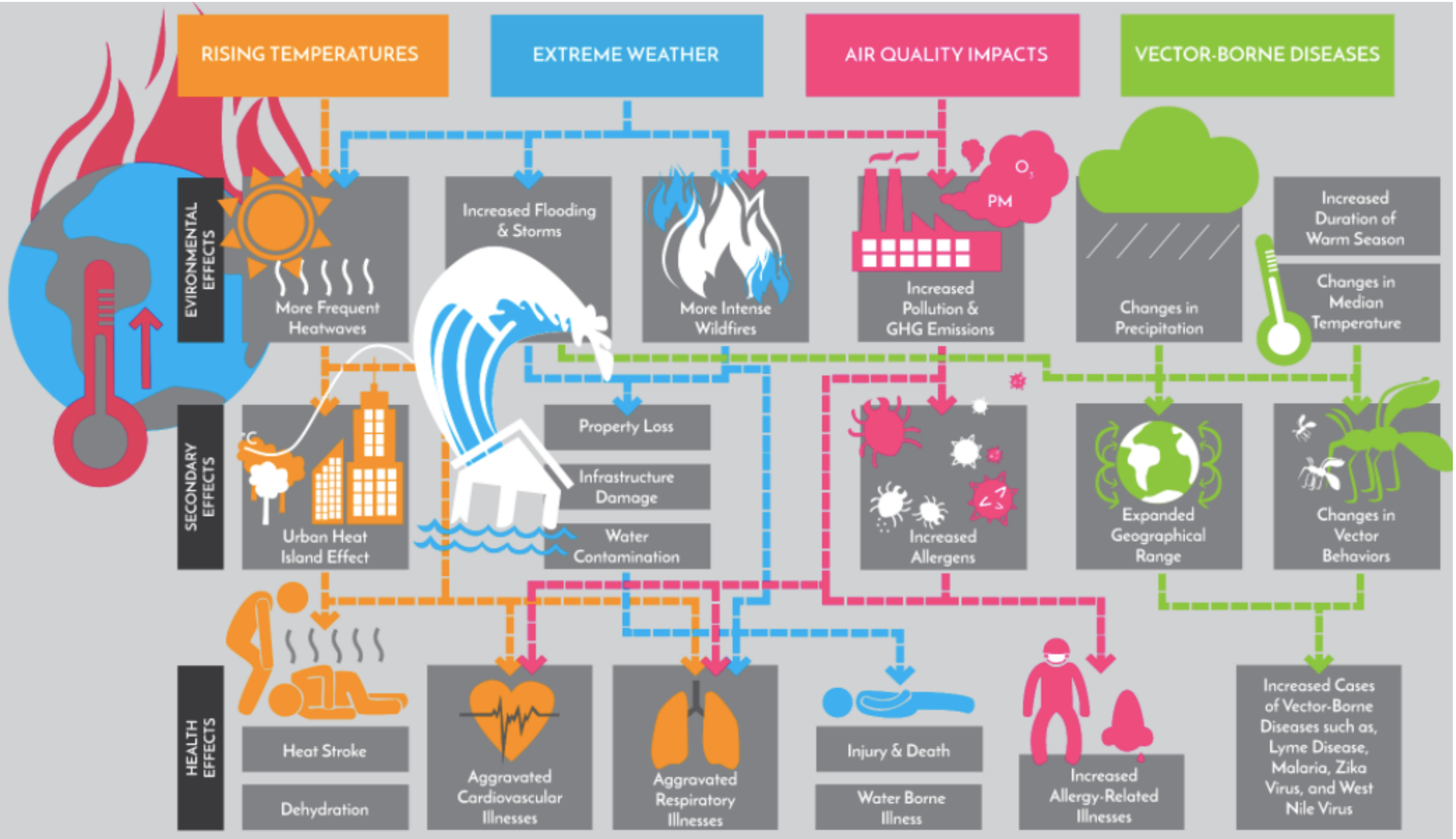


What are the Impacts of Climate Change?

... and there is more:
- health
- supply chains
- mass extinction
- water security
- food security
- migration
- social unrest
...



The Earth's Life-Support System



Accepting knowledge gaps

The Earth's Life-Support System

Energy and Environment

Scientists may have just found an unexpected new threat to the ozone layer

By Chelsea Harvey June 9

Lightning strikes in Denton, Tex., in May 2015. (Al Key/Denton Record-Chronicle via AP)

Severe storms over the central United States may be posing bigger problems beyond bad weather. New research suggests that frequent summertime storms in the Great Plains region could be depleting the

Sahara greening intensify tropical cyclone activity worldwide

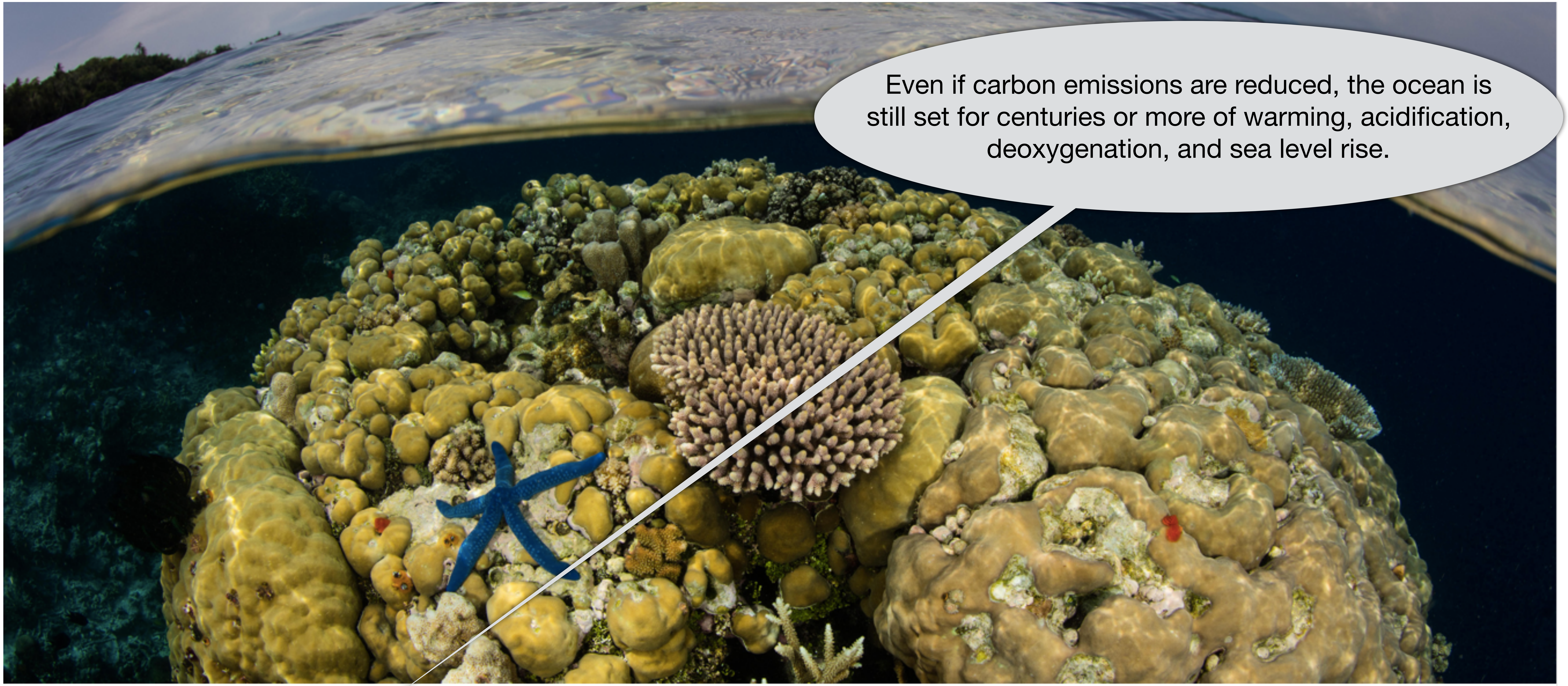
Future climate warming could lead to a re-greening of the southernmost Sahara (Sahel), with decreased dust emissions and changes in land cover. In a recent study, researchers at the Department of Meteorology have found that tropical cyclone activity may have increased during past warm climates in connection with a greening of the Sahara.

Cyclone Catarina seen from ISS. Photo: Earth Observations Laboratory, Johnson Space Center, via

Importance of Time Scales

Even if carbon emissions are reduced, the ocean is still set for centuries or more of warming, acidification, deoxygenation, and sea level rise. Photo by Ethan Daniels/Alamy Stock Photo

When It Comes to Climate Change, the Ocean Never Forgets



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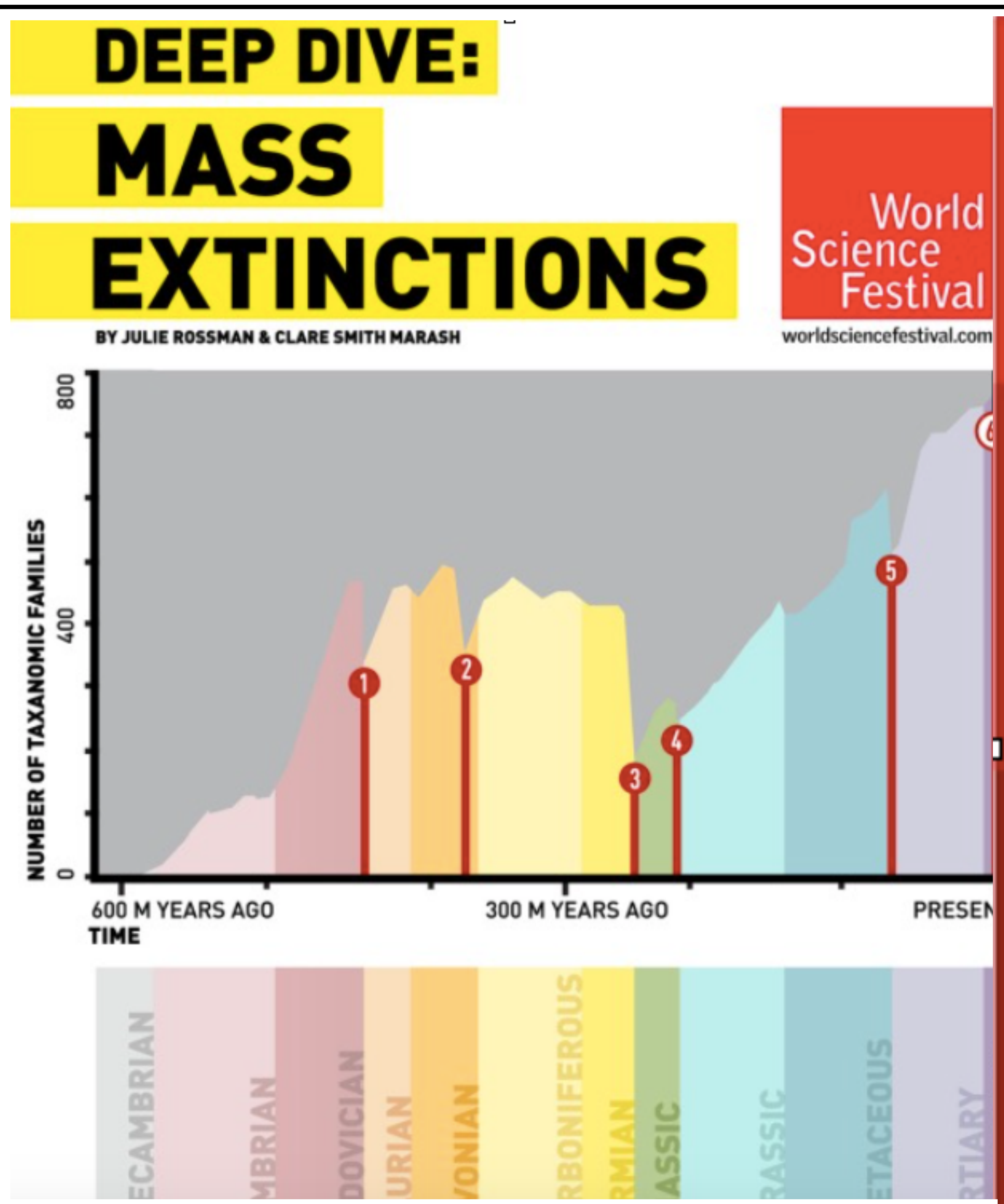
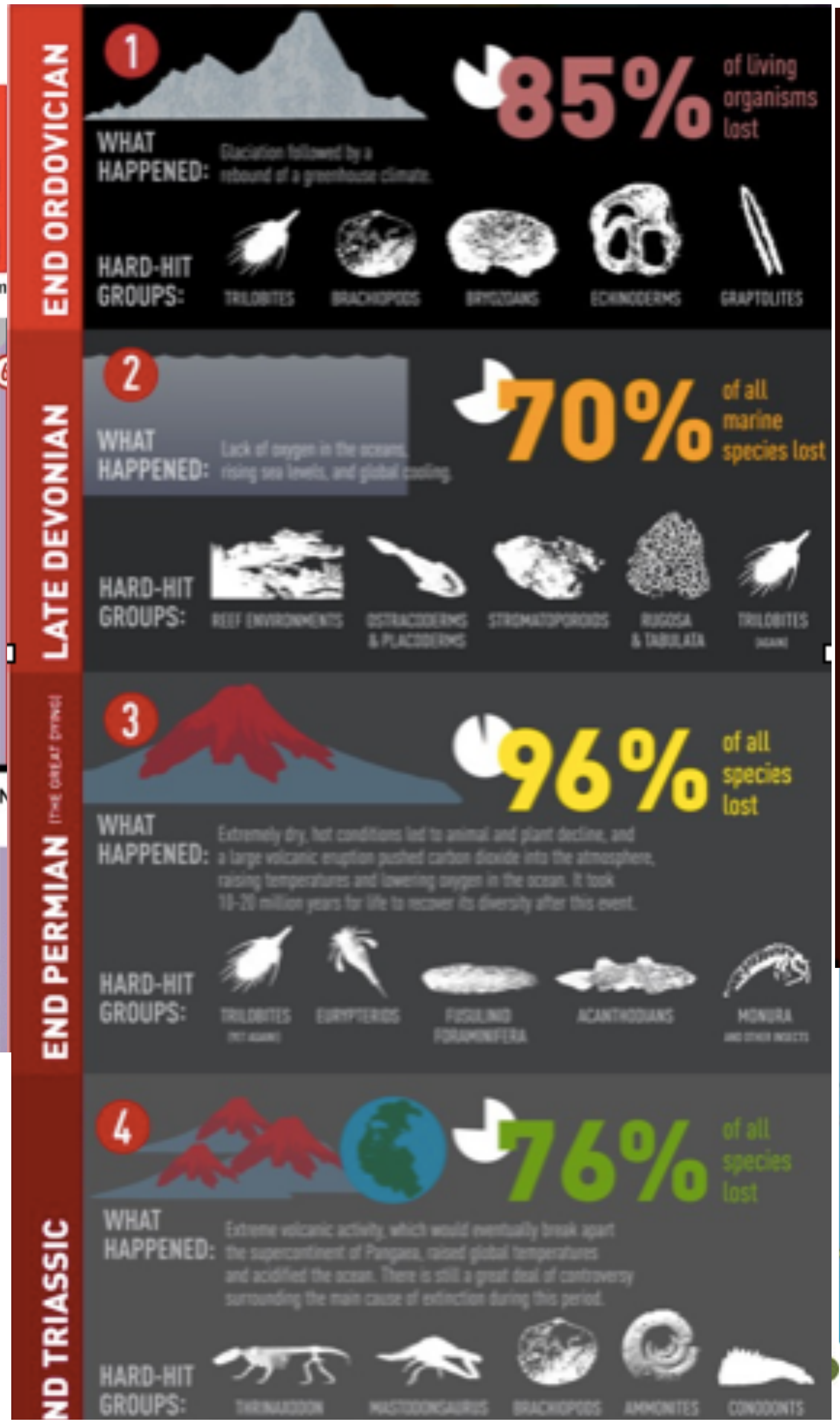


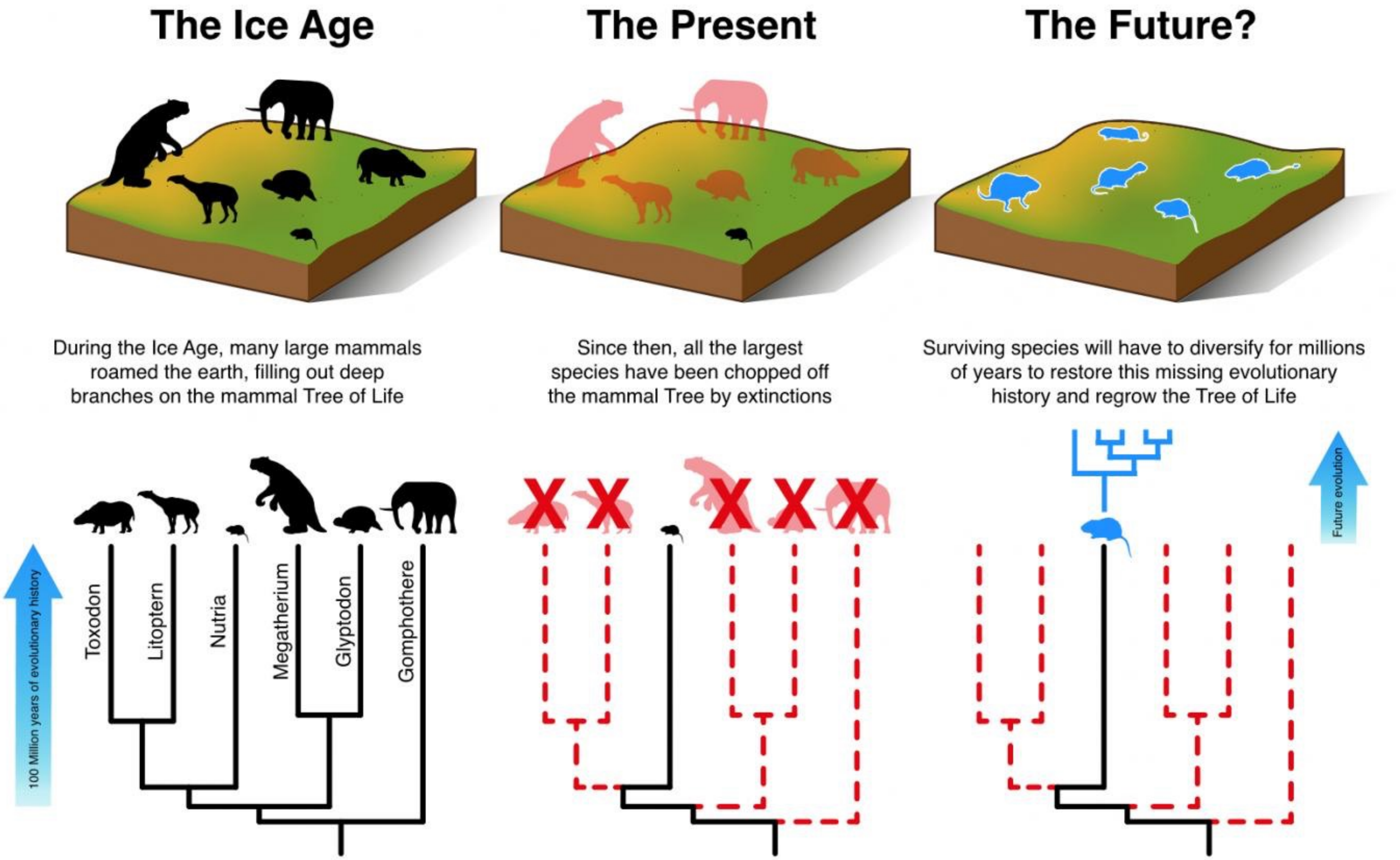


Current extinction rates:

300 times background rate for birds

80,000 times background rate for mammals

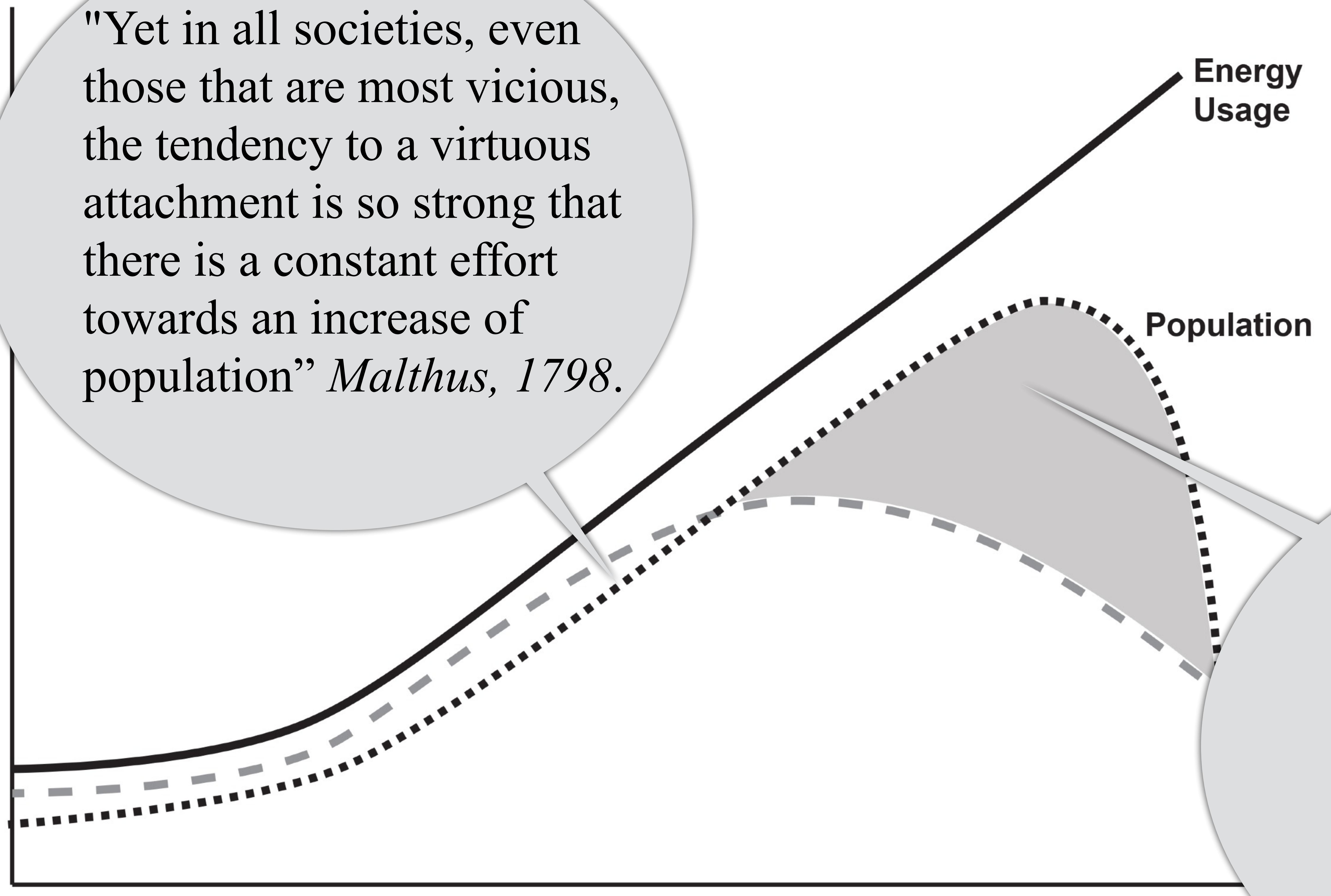
The Earth's Life-Support System



Davis et al., 2018

Importance of Ethics, Morality

The Earth's Life-Support System



"Yet in all societies, even those that are most vicious, the tendency to a virtuous attachment is so strong that there is a constant effort towards an increase of population" *Malthus, 1798.*

"That the increase of population is necessarily limited by the means of subsistence, That population does invariably increase when the means of subsistence increase, and, That the superior power of population is repressed, and the actual population kept equal to the means of subsistence, **by misery and vice**."

Malthus, 1798.

The Earth's Life-Support System

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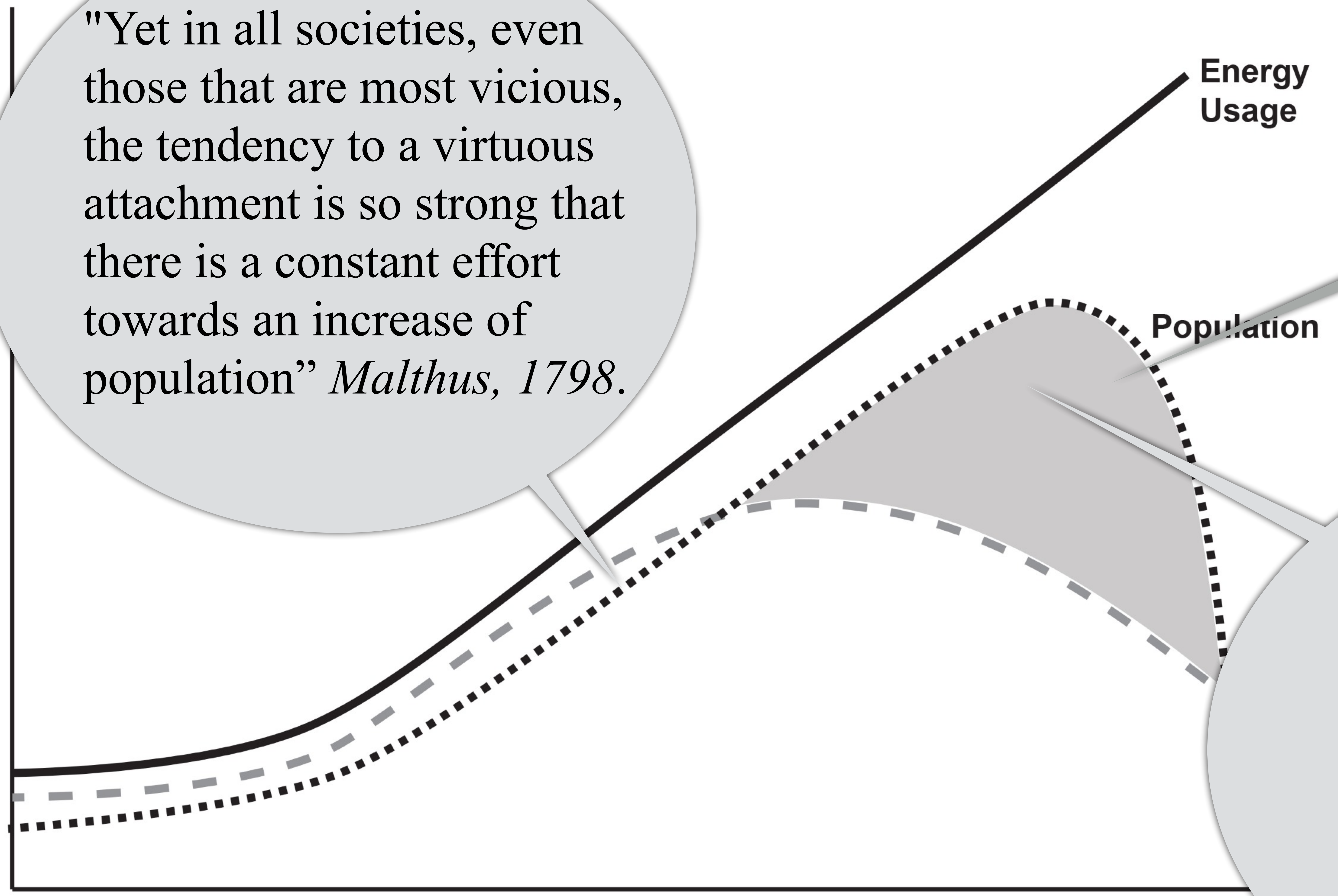

Should be multiplied by the resource usage per person

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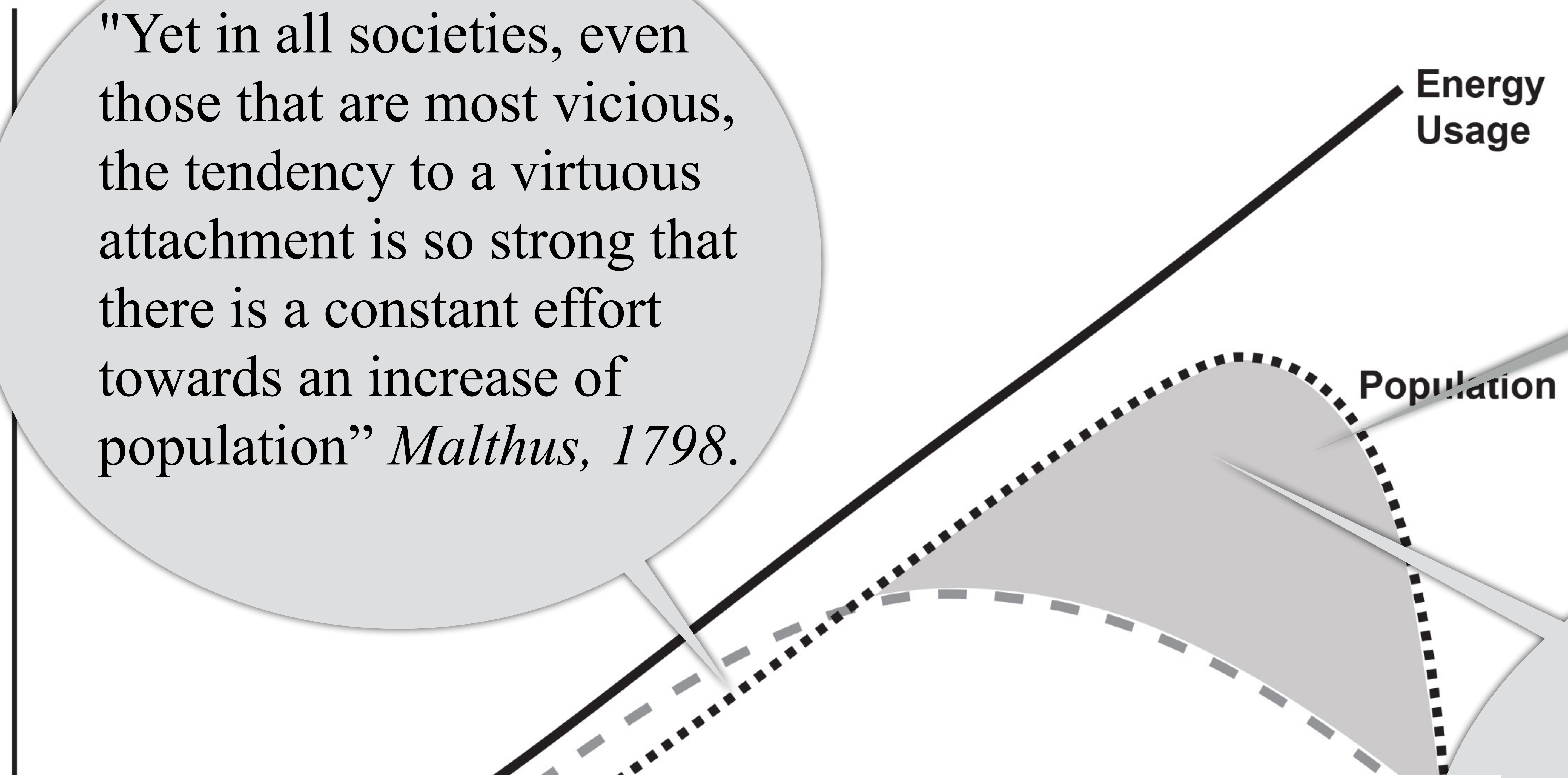
The Earth's Life-Support System



"Yet in all societies, even those that are most vicious, the tendency to a virtuous attachment is so strong that there is a constant effort towards an increase of population" *Malthus, 1798*.

Should be multiplied by the resource usage per person

"That the increase of population is necessarily limited by the means of subsistence, That population does invariably increase when the means of subsistence increase, and, That the superior power of population is repressed, and the actual population kept equal to the means of subsistence, **by misery and vice**."

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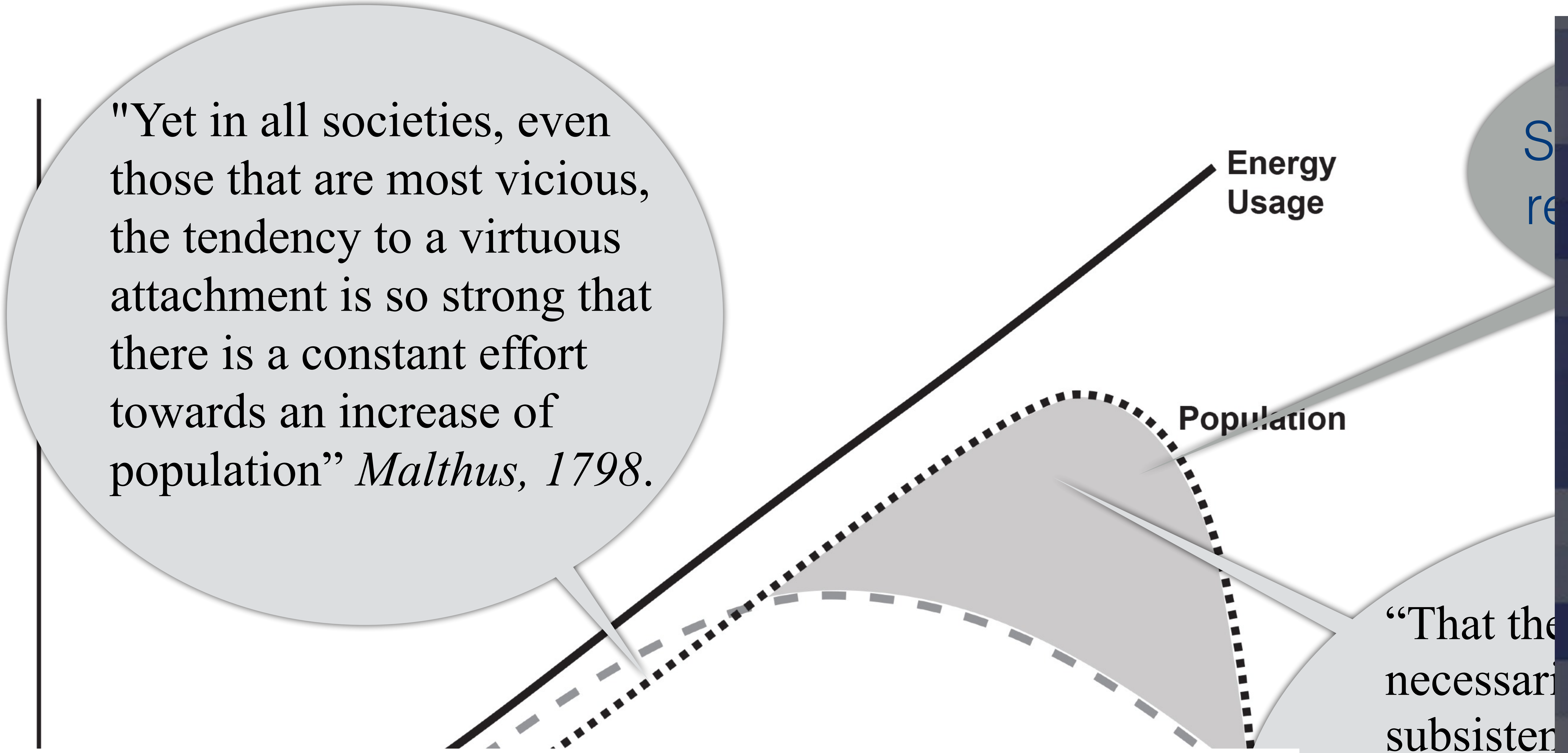
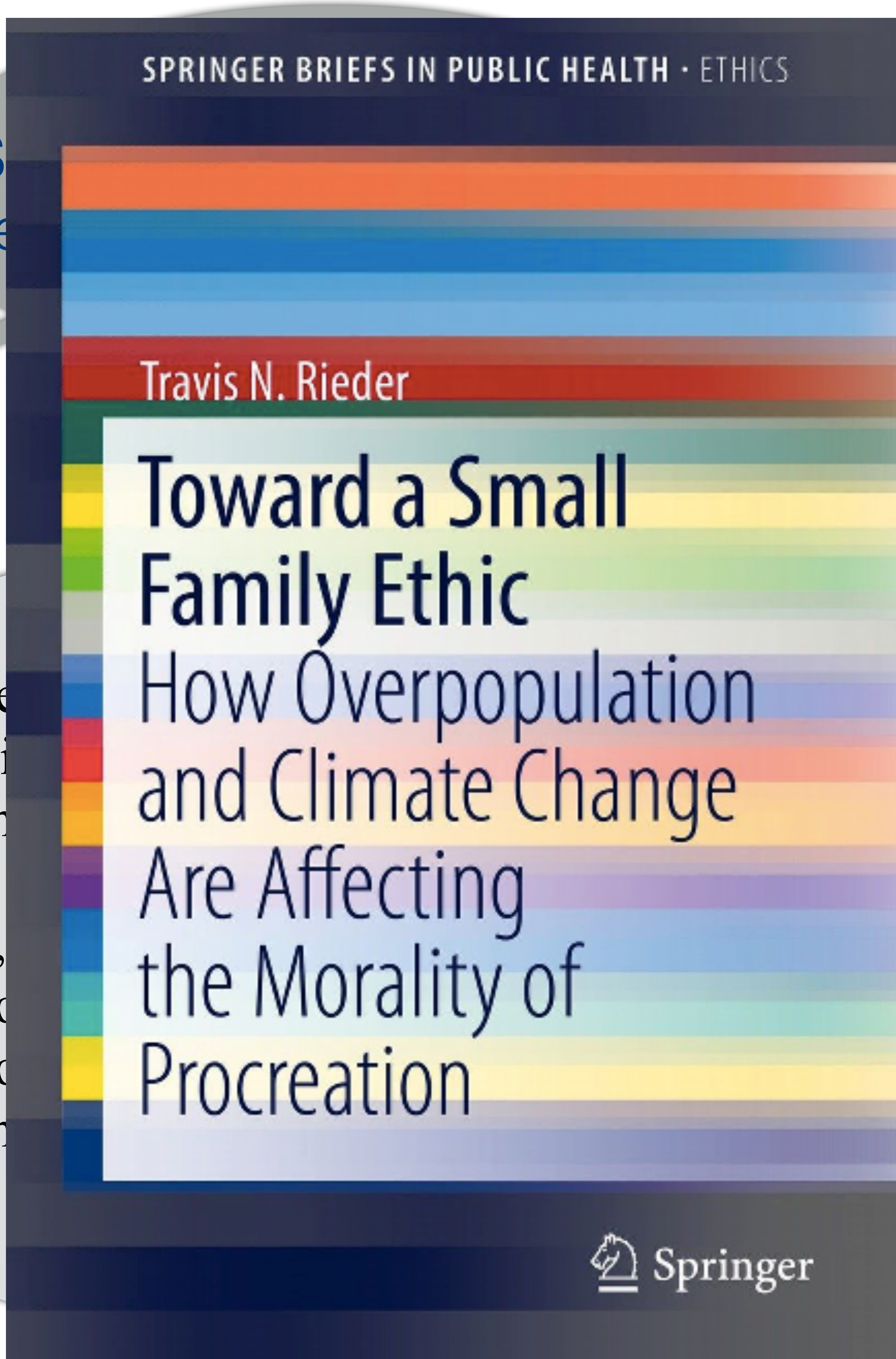
31 October 2011: The day we "celebrated" the 7-billionth baby
I wrote a blog on "Crime against humanity":

$$C(t) = (N(t) - N(t_0))*L$$

C: crime
t: time
t_0: arbitrary time origin
N: number of people in the country under consideration
L: average use of resources per person in the country





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Importance of Risk Perception

Bulletin
of the
Atomic
Scientists

It is two and a half minutes to midnight

2017 Doomsday Clock Statement

Science and Security Board
Bulletin of the Atomic Scientists

Editor, John Mecklin

IT IS TWO AND A HALF MINUTES TO MIDNIGHT©

Reducing risk: Expert advice and citizen action. Technology continues to outpace humanity’s capacity to control it, even as many citizens lose faith in the institutions upon which they must rely to make scientific innovation work for rather than against them. Expert advice is crucial if governments are to effectively deal with complex global threats. The Science and Security Board is extremely concerned about the willingness of governments around the world—including the incoming US administration—to ignore or discount sound science and considered expertise during their decision-making processes.

Bulletin of the Atomic Scientists

Doomsday Clock Announcement, 2018

National Press Club, Washington, D.C.

January 25th, 2018, 10:00a.m. EST

https://clock.thebulletin.org

IT IS TWO AND A HALF MINUTES TO MIDNIGHT®

By KATIE REILLY Updated: January 25, 2018 10:29 AM ET

The Bulletin of the Atomic Scientists moved the doomsday clock closer to midnight on Thursday morning, warning the world that it is as close to catastrophe in 2018 as it has ever been.

Scientists cited growing nuclear threats, climate change and a lack of trust in political institutions as they set the doomsday clock at two minutes to midnight — 30 seconds closer than it was last year.

"The world is not only more dangerous now than it was a year ago; it is as threatening as it has been since World War II," Lawrence Krauss and Robert Rosner of the Bulletin of the Atomic Scientists wrote in a Washington Post column on Thursday, referencing President Trump's repeated threats of war against North Korean leader Kim Jong Un, as well as his reversal of the Obama Administration's efforts to stop climate change.

Time, January 25, 2018

The Earth’s Life-Support System

https://vimeo.com

Mitigation and Adaptation Studies

Class 6: Systems Thinking, Adaptation and Sustainability Science

Contents:

- *(Systems Science)*
- *(Systems Thinking)*
- *Systems Science: Basic Concepts*
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- *Creation of Knowledge*
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Creation of Knowledge

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Epistemology (part of philosophy):

- develops a theory of knowledge
- separate from science

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Knowledge:

- a "justified true belief" (Plato) - abbreviated as JTB
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Knowledge as justified true belief (JTB):
A subject S knows that a proposition P is true if and only if:

1. P is true, and
2. S believes that P is true, and
3. S is justified in believing that P is true

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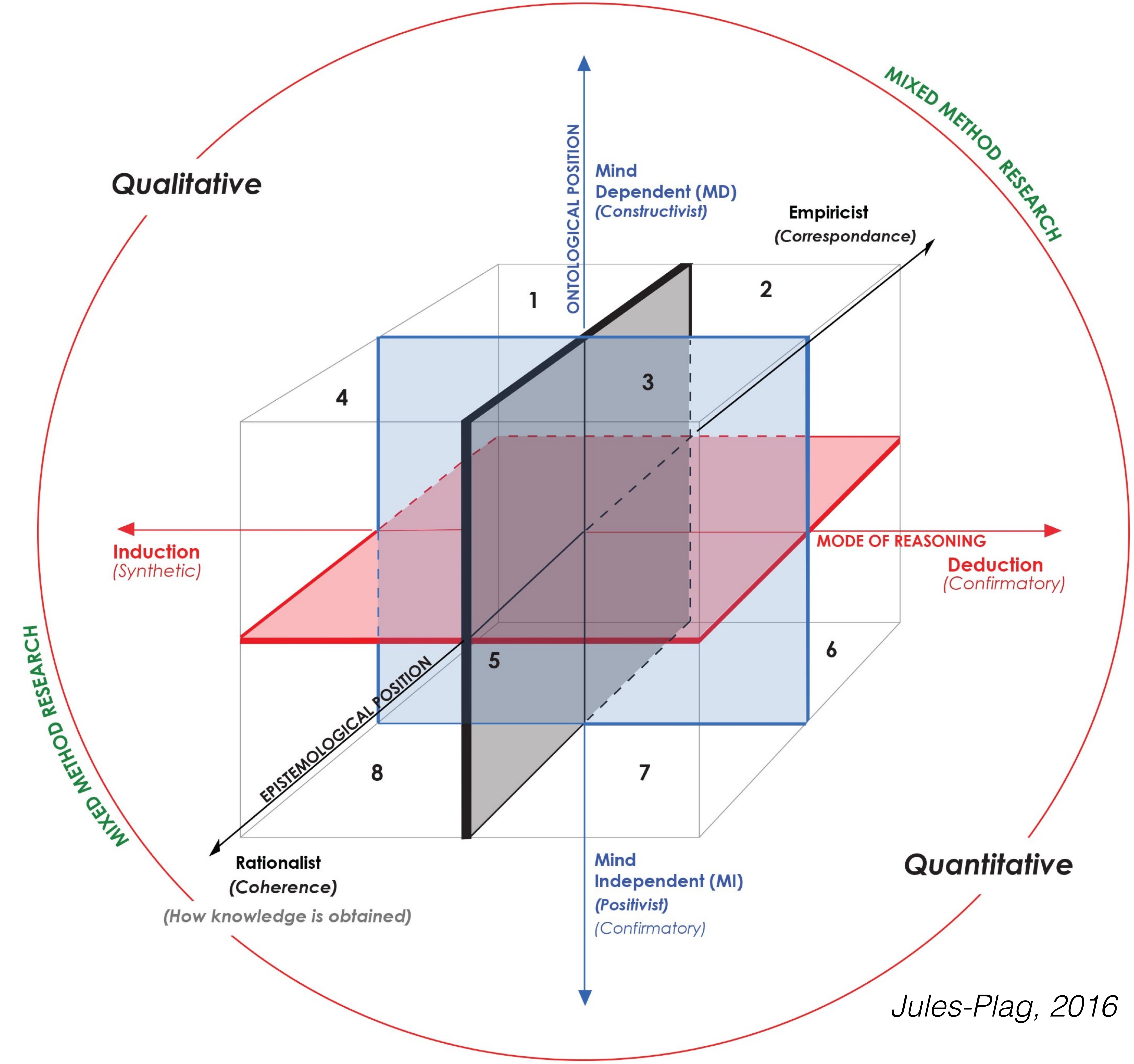
Many think today that JTP is a necessary but not sufficient condition
Need a fourth condition

Creation of Knowledge



Jules-Plag, 2016

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Epistemology (part of philosophy):
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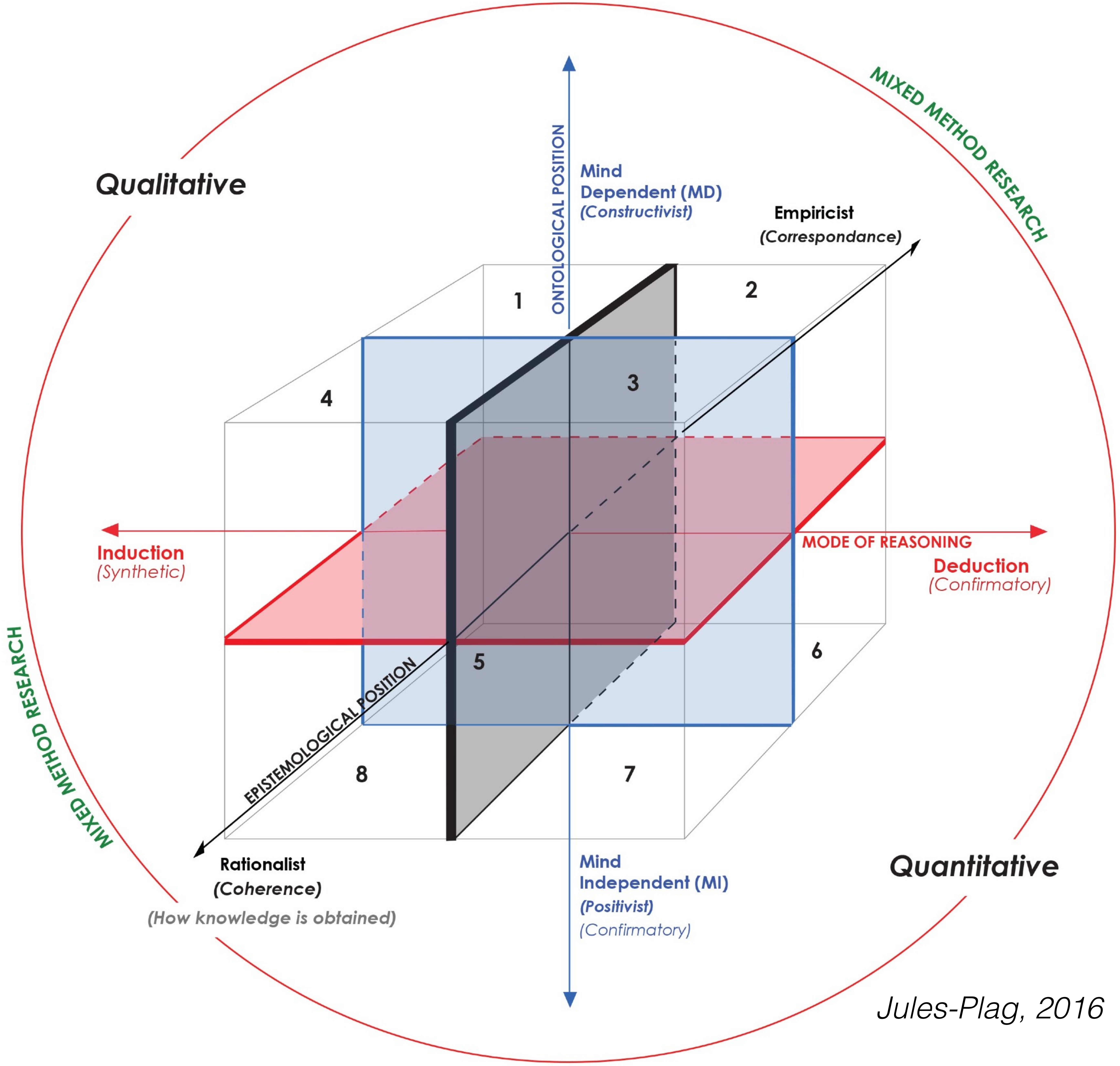

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- studies the nature of things
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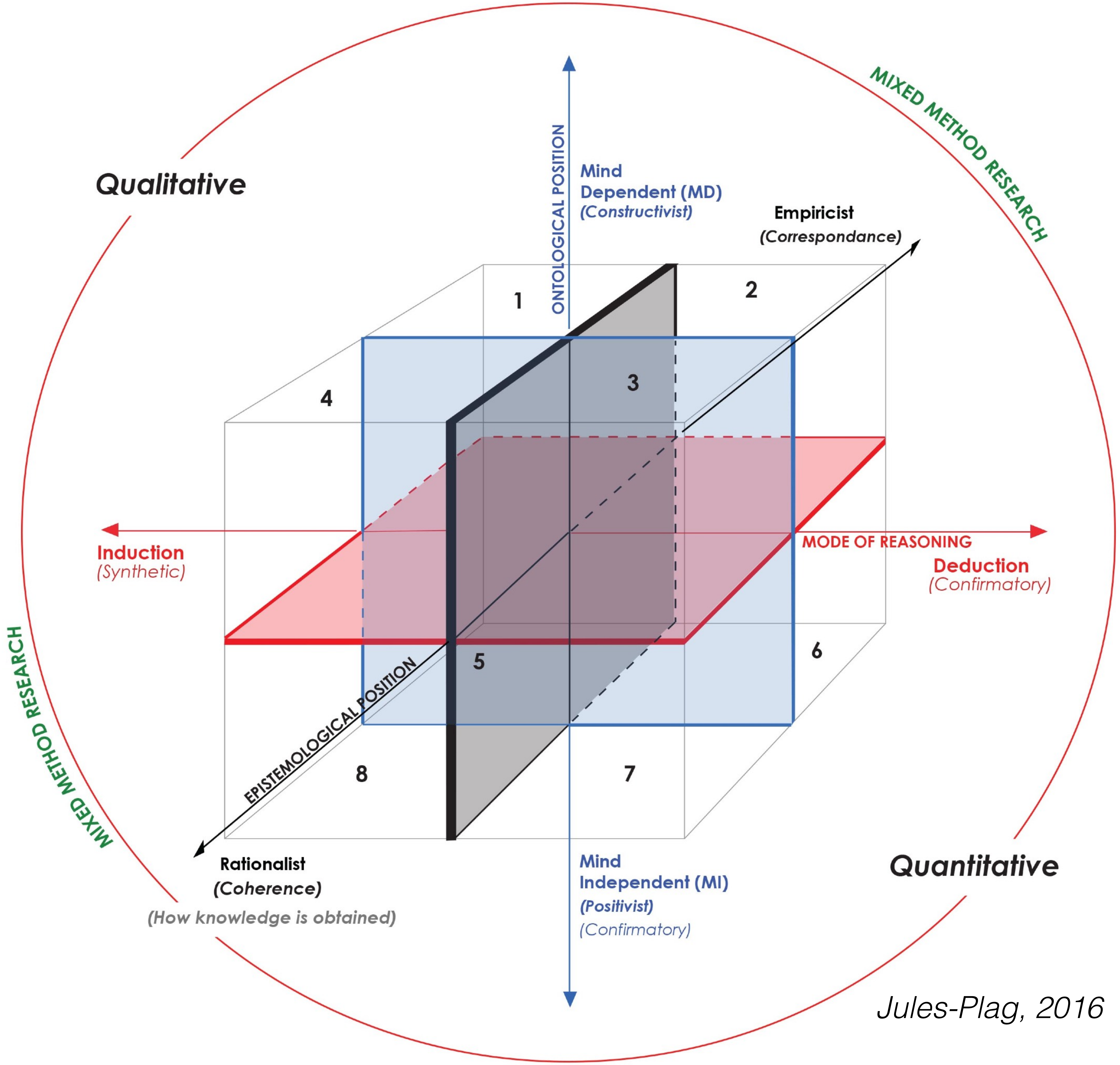

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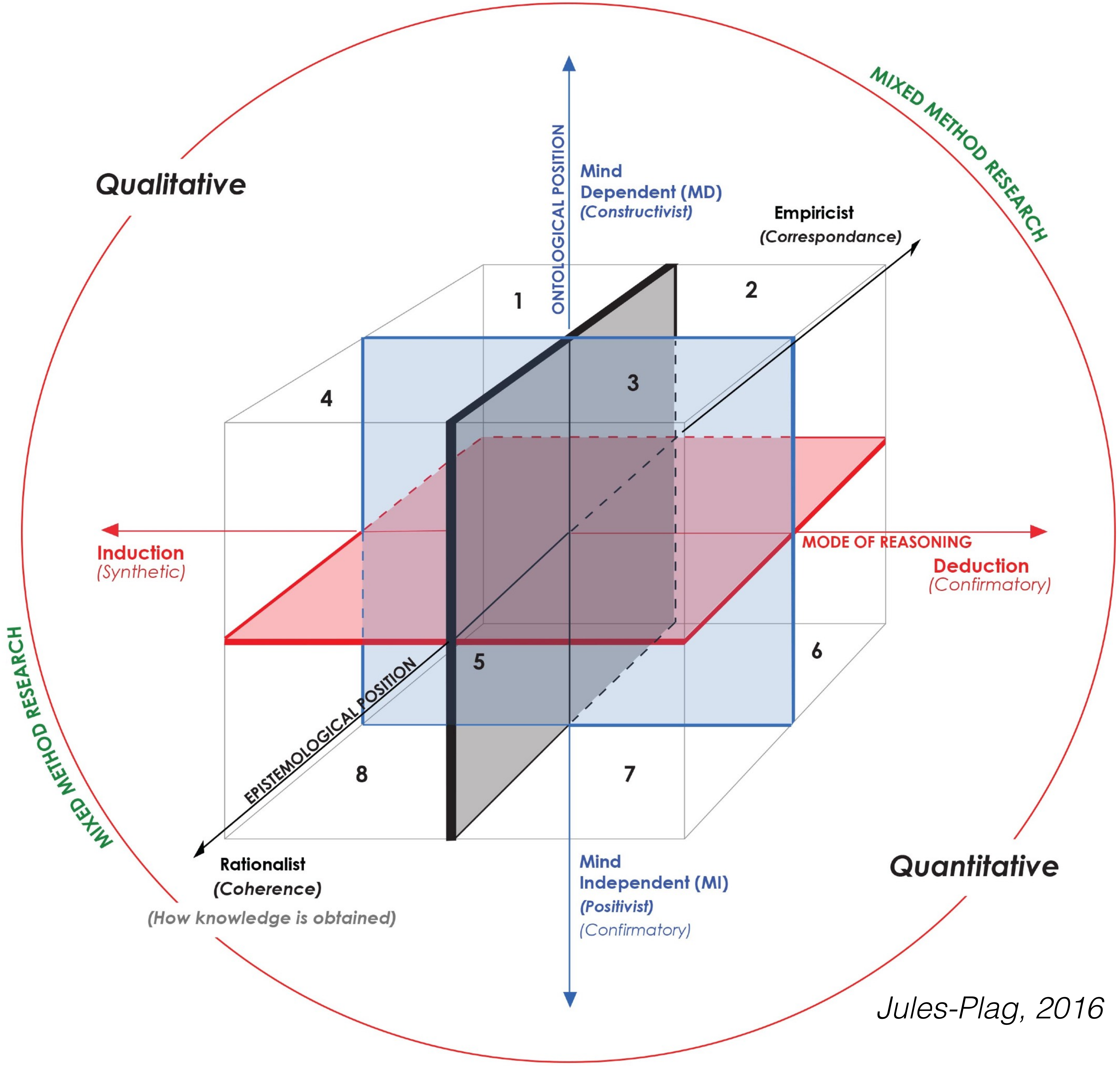

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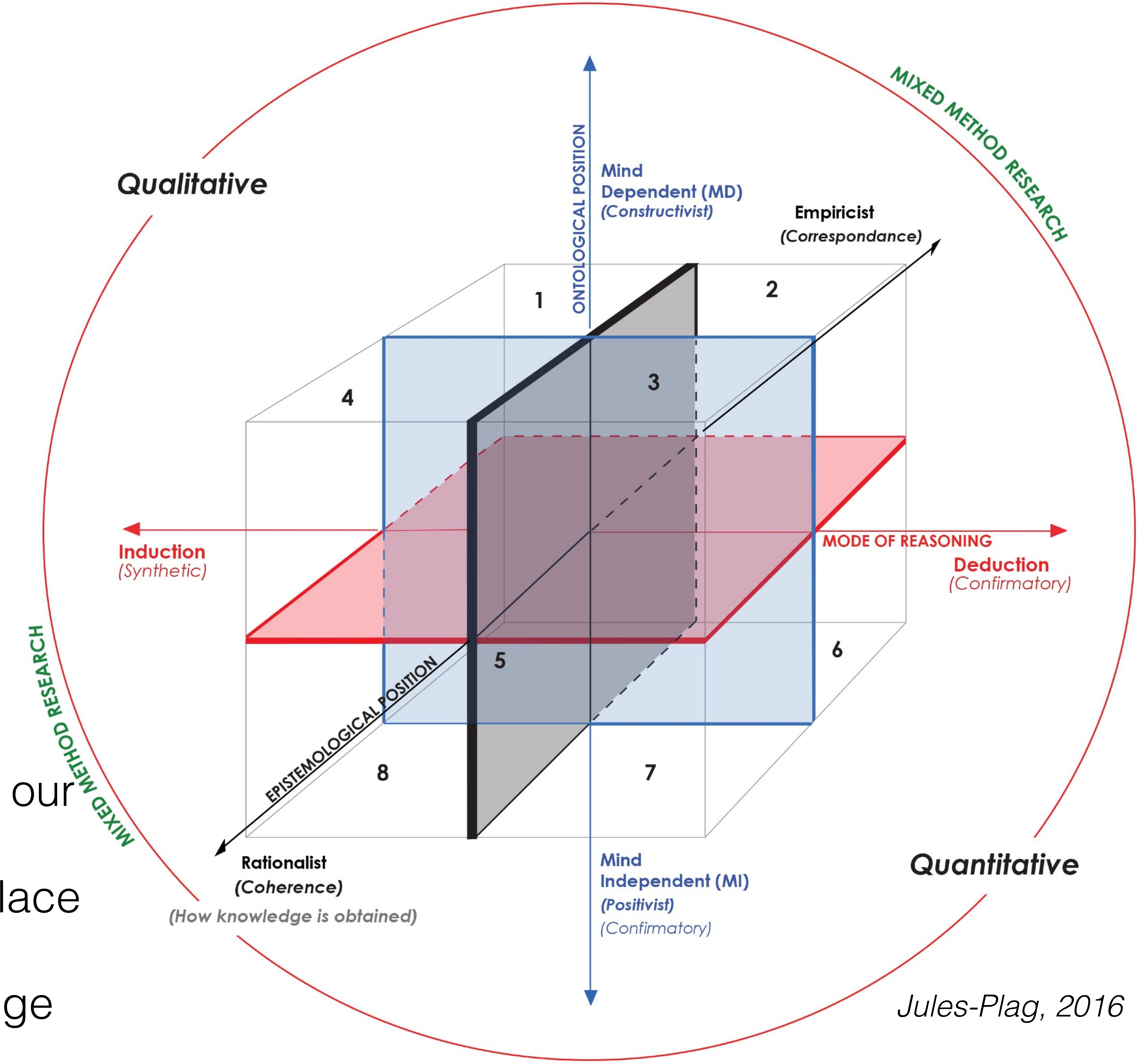

- Knowledge and truth are core concepts of our civilization
- In a knowledge-based world, there is no place for “alternative facts”
- In a “post-truth” world, there is no knowledge

Jules-Plag, 2016

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Sustainability Science

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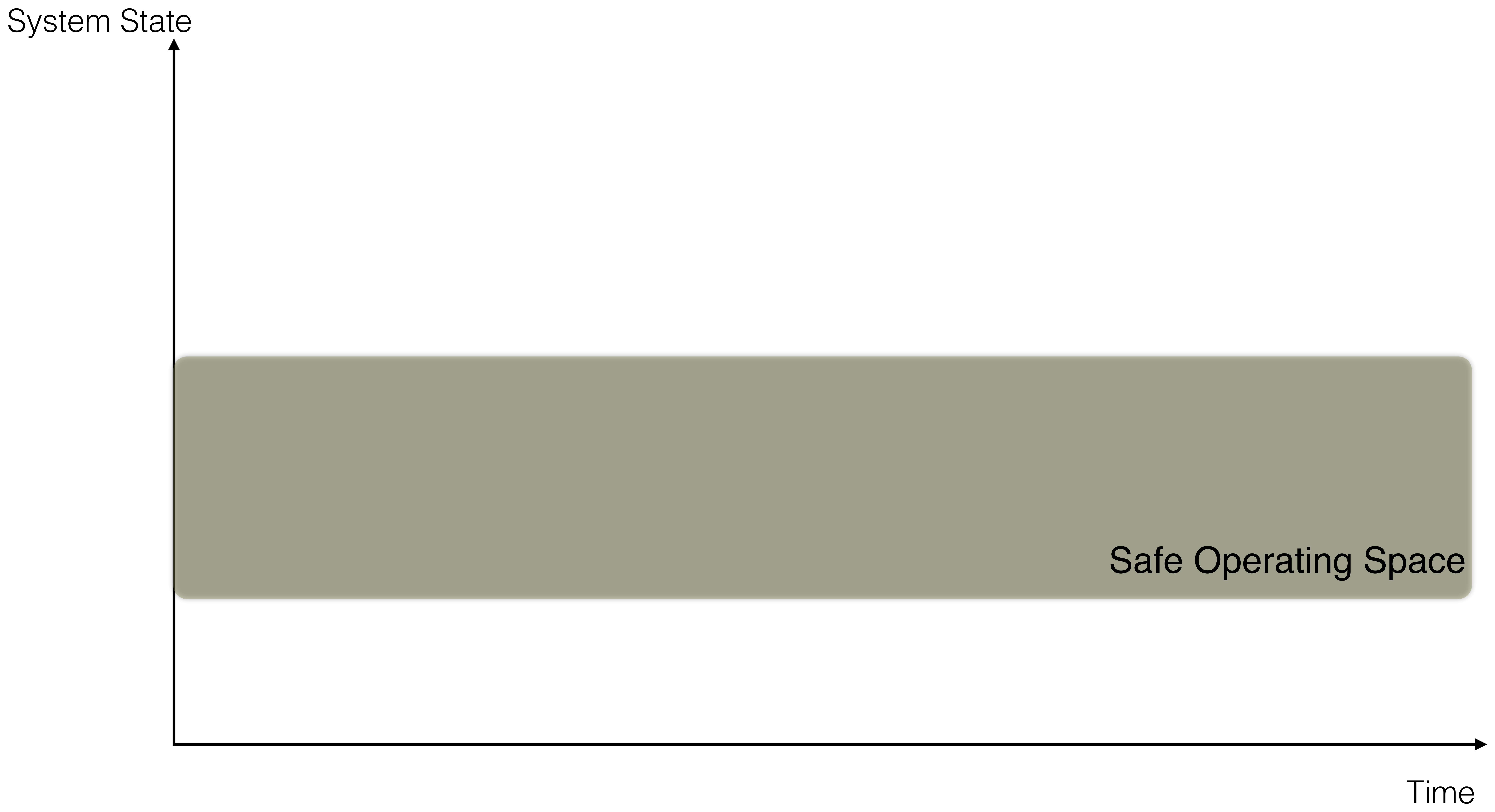

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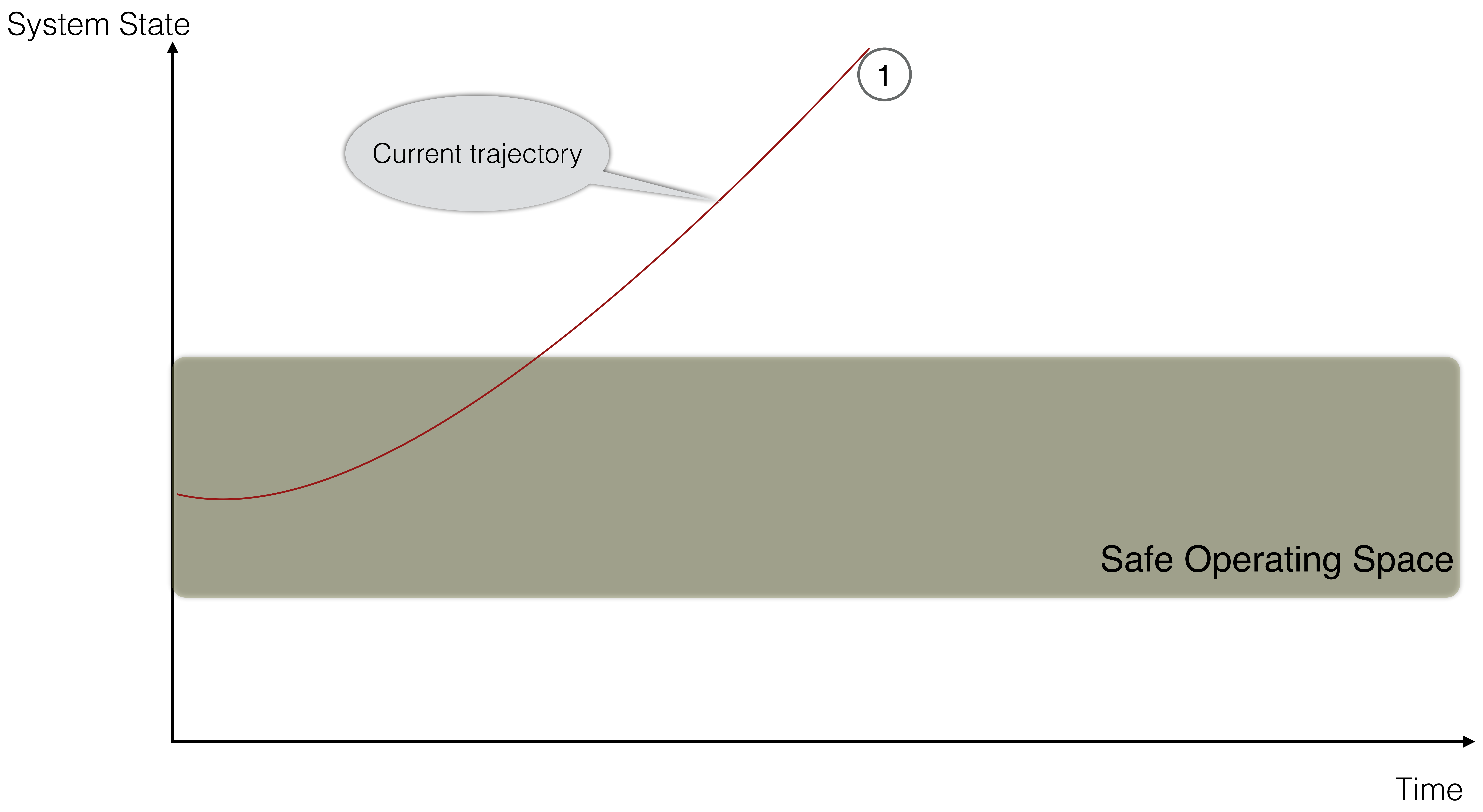

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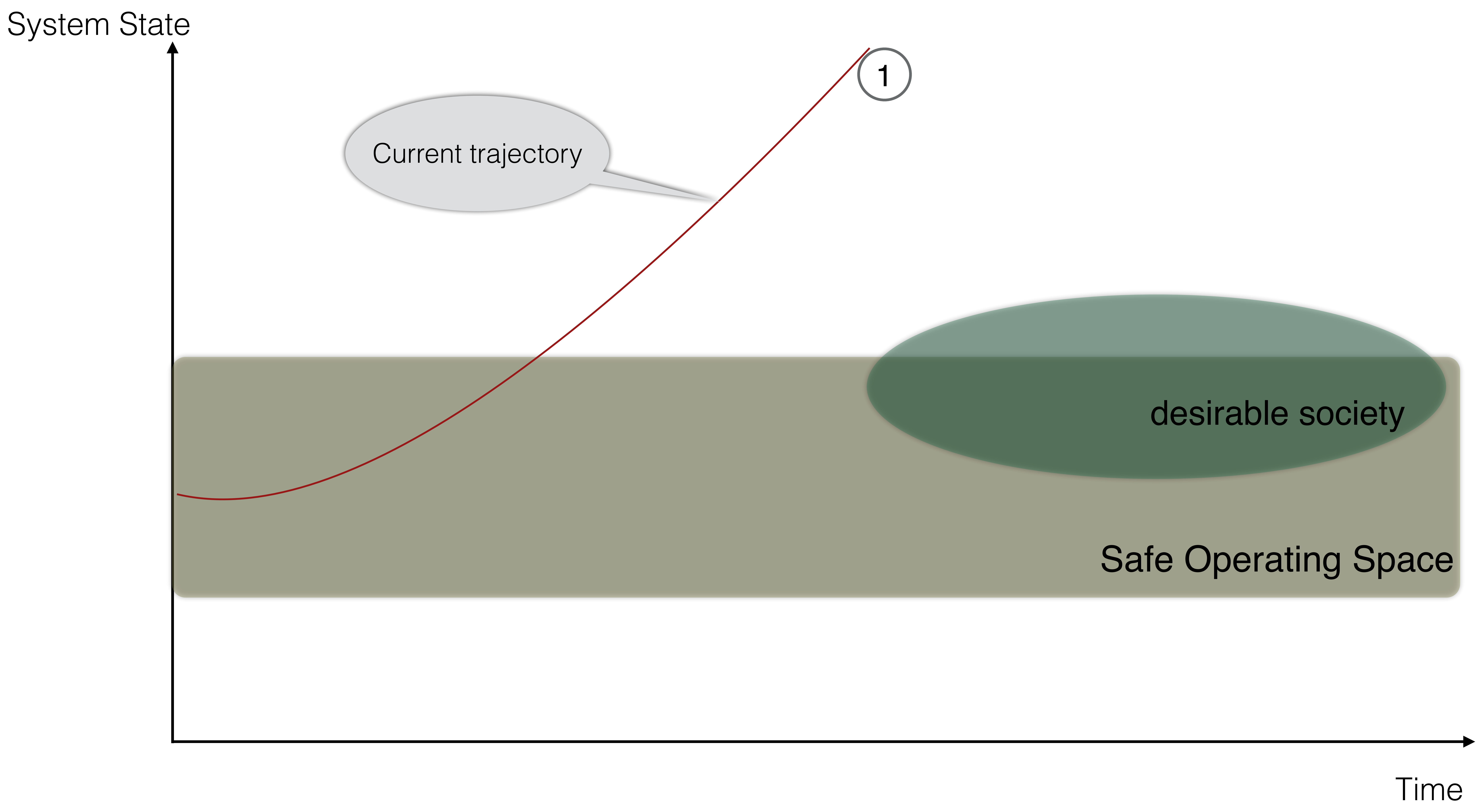

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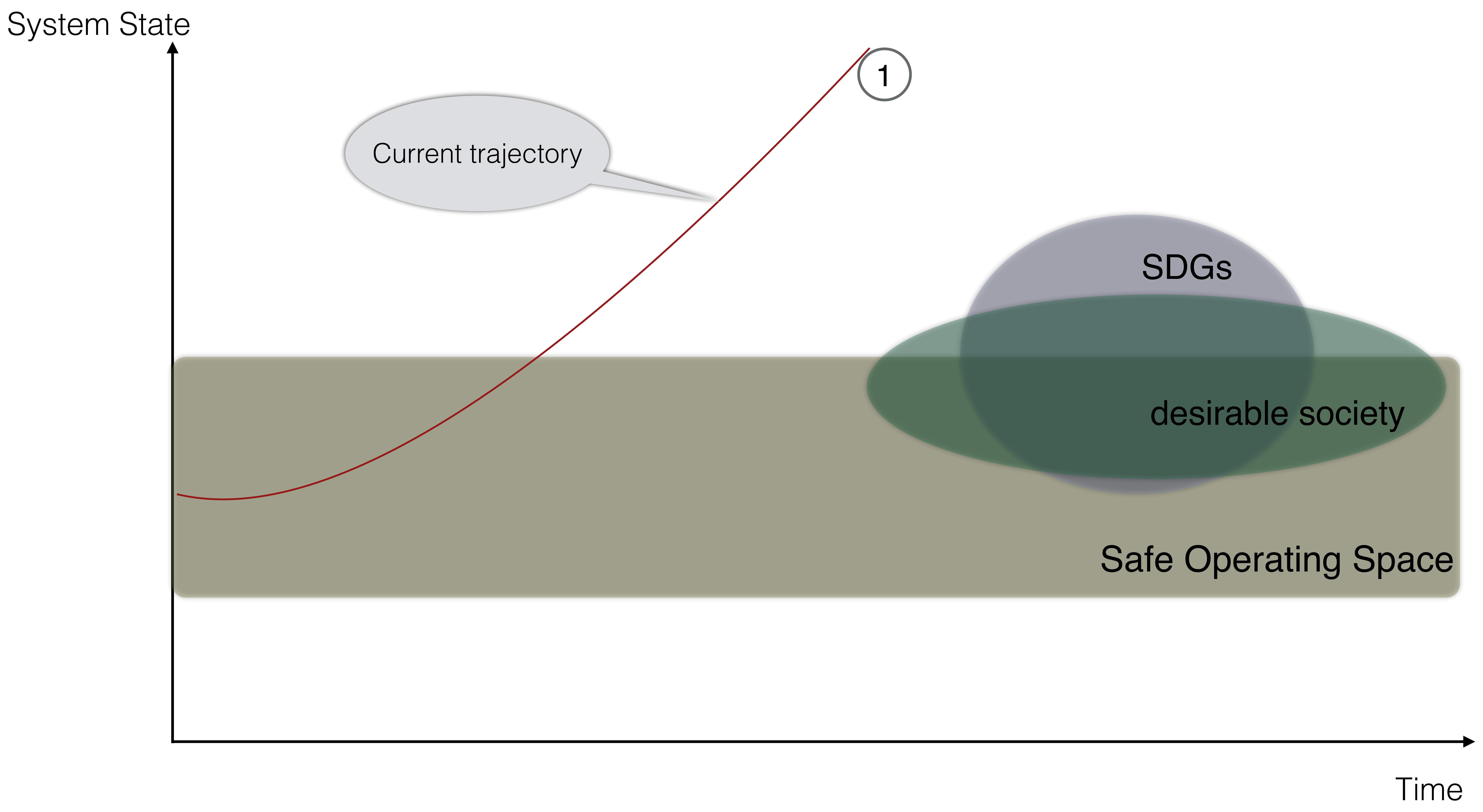
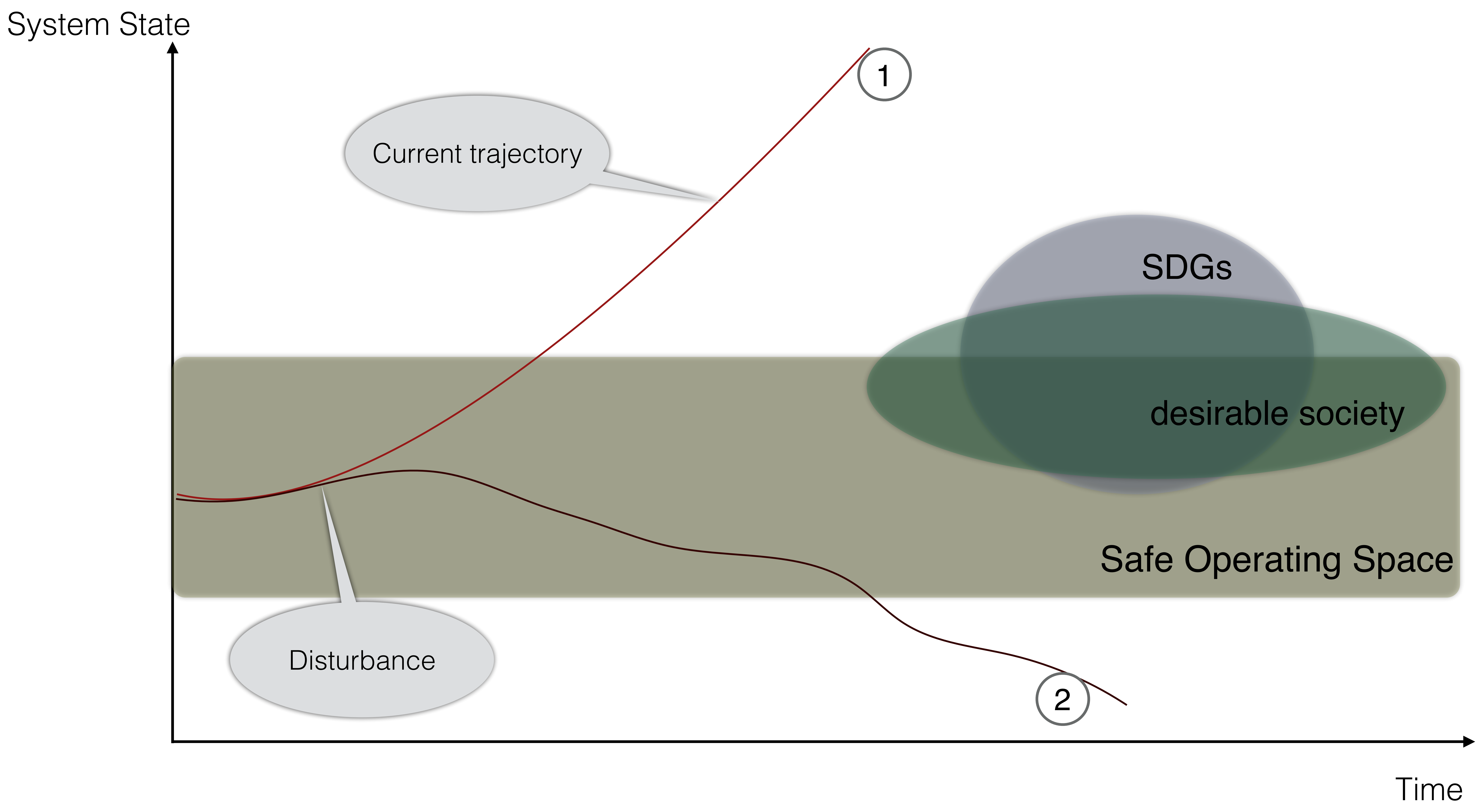
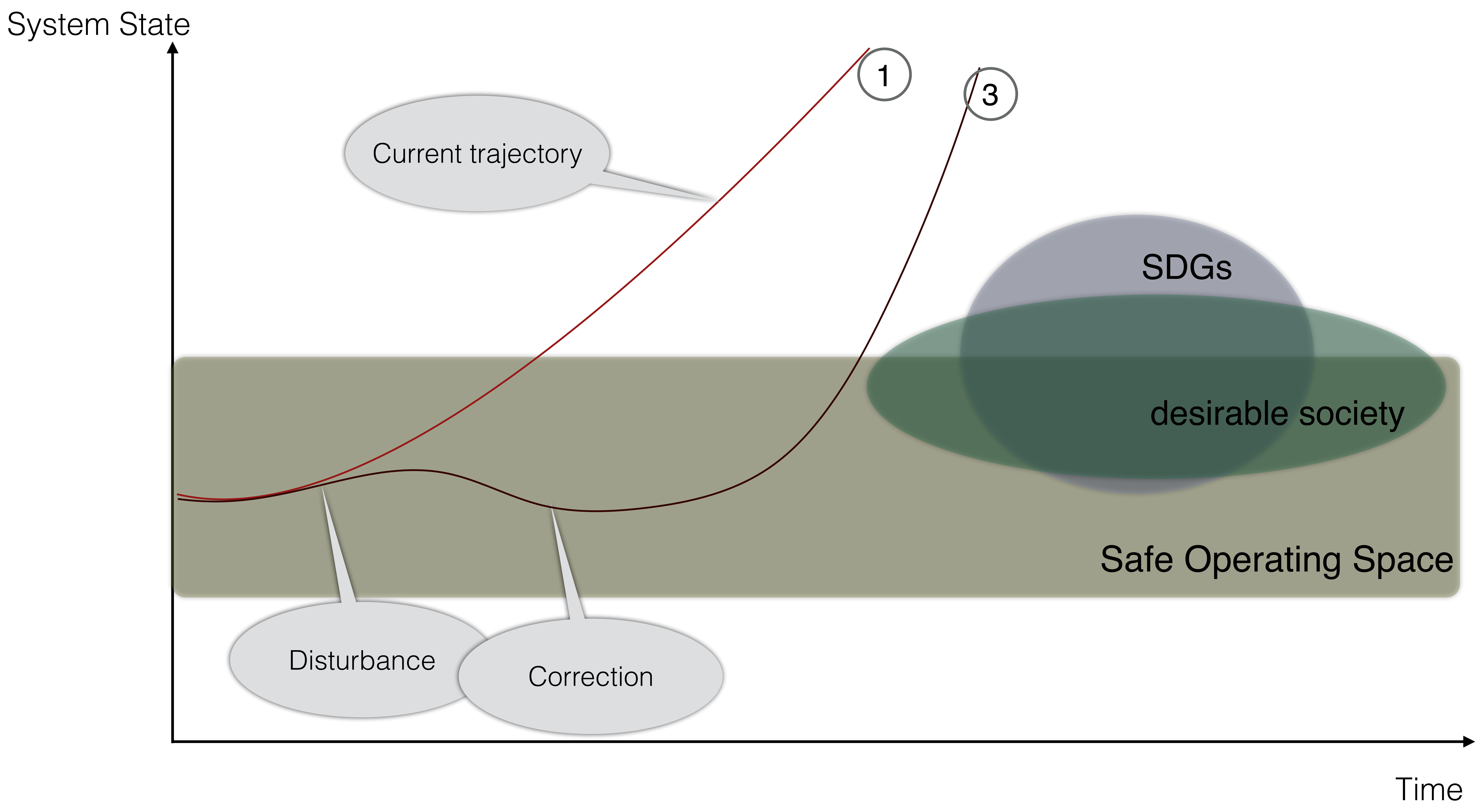



System State
1
Current trajectory
SDGs
desirable society
Safe Operating Space
Disturbance
2
Time

Sustainability Science



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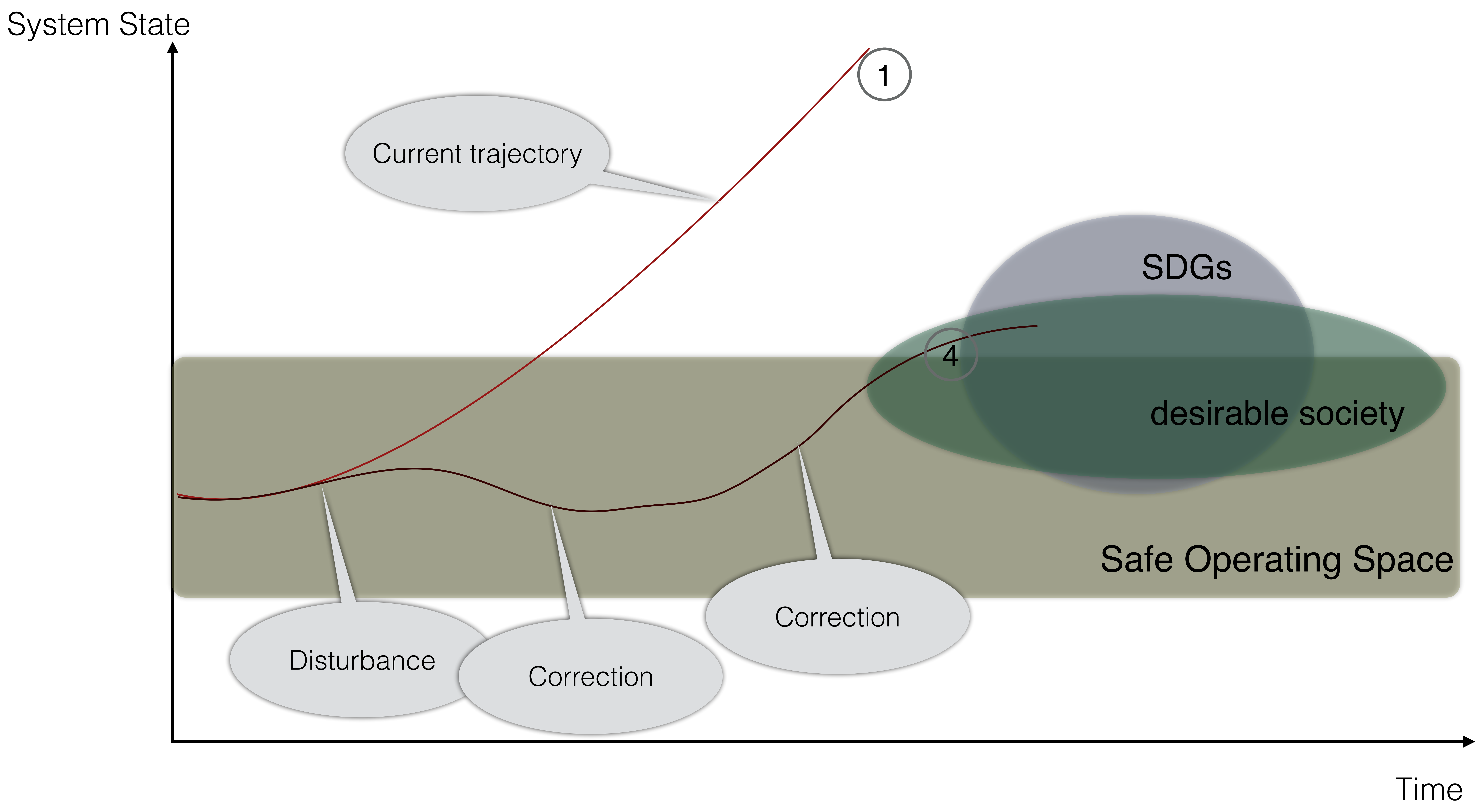

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Foreseeability and Foresight:

- What might happen?
- Possible threats and hazards
- Knowing the system trajectory

} System Knowledge

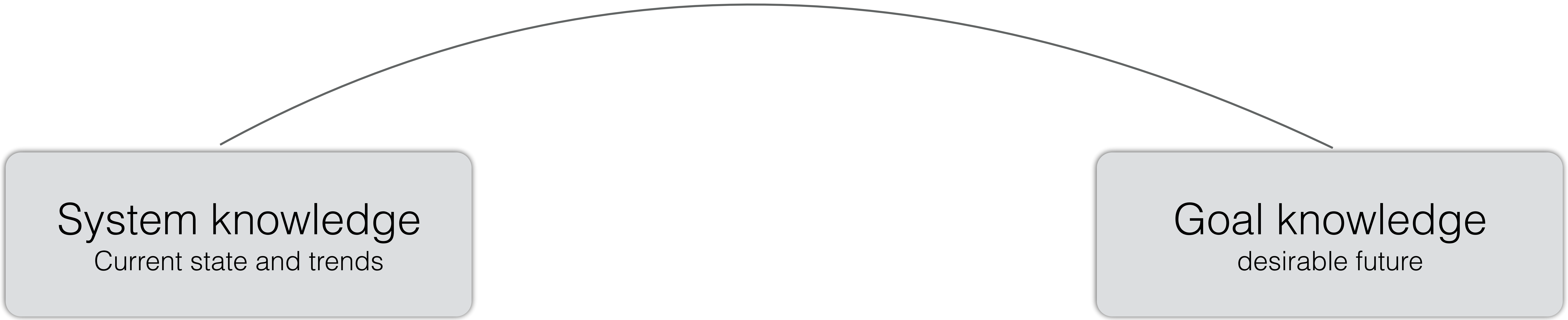
System knowledge
Current state and trends

Foreseeability and Foresight:

- What might happen?
- Possible threats and hazards
- Knowing the system trajectory
- What do we want to happen?

} System Knowledge (first three points)

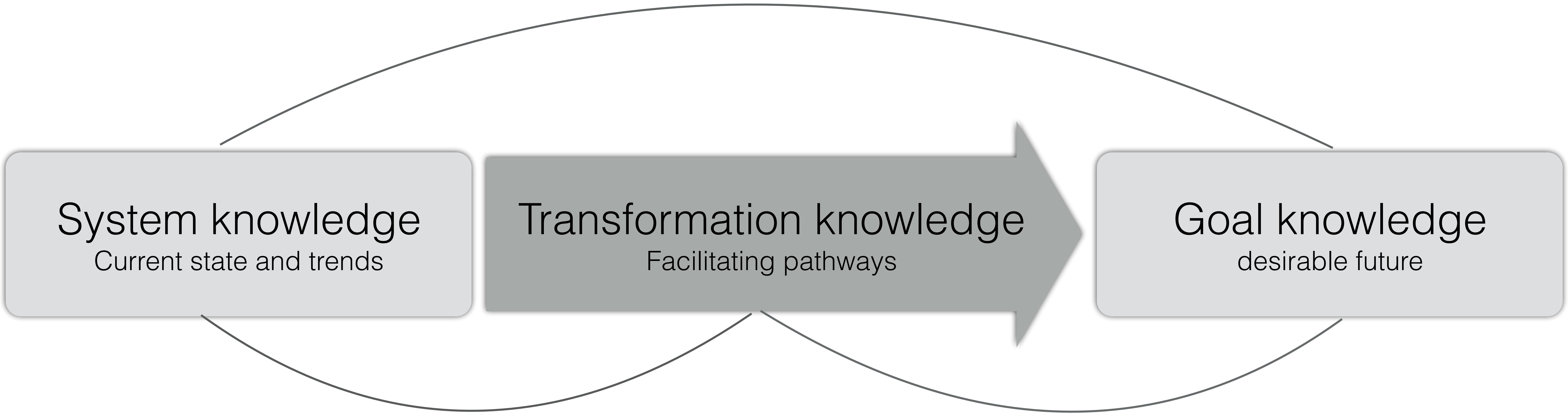
} Goal Knowledge (last point)



Foreseeability and Foresight:

- What might happen?
- Possible threats and hazards
- Knowing the system trajectory
- What do we want to happen?
- How can we impact the system trajectory?

} System Knowledge (first three items)
} Goal Knowledge
} Transformational Knowledge



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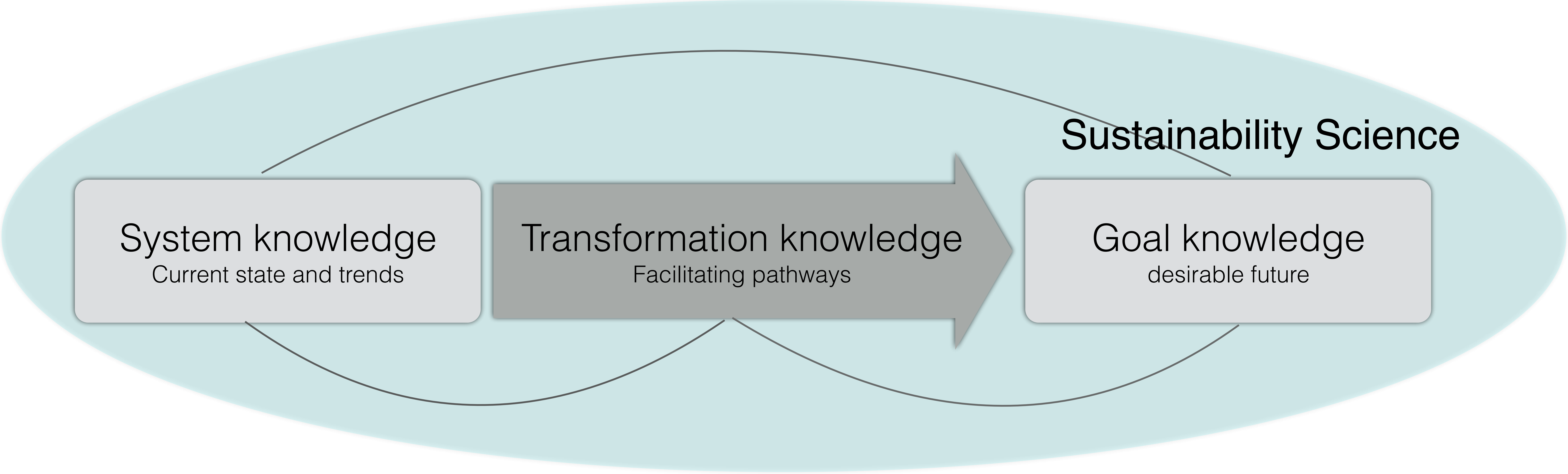

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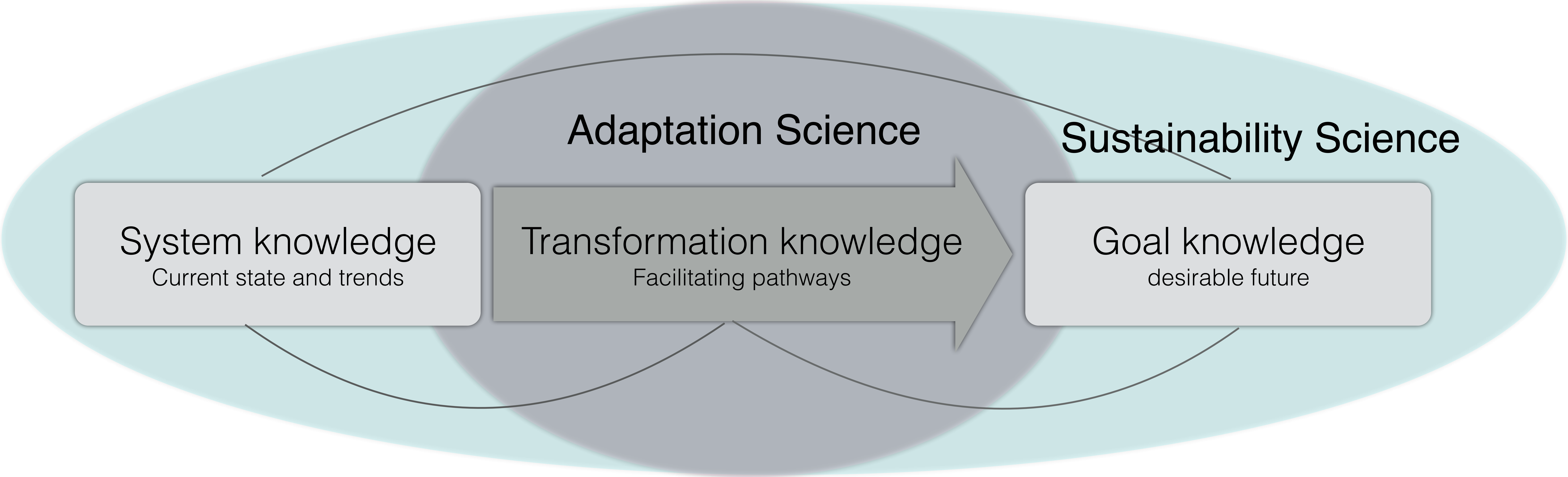

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1. **Mitigation of Change**: actions that limit and reduce changes/degradations in the Earth's life-support system.
2. **Mitigation of Impacts**: actions that aim to protect against certain levels of impacts resulting from degradation of the Earth’s life-support system, including climate change and/or SLR.
3. **Adaptation**: systemic transformations that increase our preparedness for a wide range of plausible futures and allow us to cope with changes if and when they happen.

POLICYFORUM

CLIMATE CHANGE

Hell and High Water: Practice-Relevant Adaptation Science

Adaptation requires science that analyzes decisions, identifies vulnerabilities, improves foresight, and develops options.

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Informing the extensive preparations needed to manage climate risks, avoid damages, and realize emerging opportunities is a grand challenge for climate change science. U.S. President Obama underscored the need for this research when he made climate preparedness a pillar of his climate policy. Adaptation improves preparedness and is one of two broad and increasingly important strategies (along with mitigation) for climate risk management. Adaptation is required in virtually all sectors of the economy and regions of the globe, for both built and natural systems (*1*).

However, without the appropriate science delivered in a decision-relevant context, it will become increasingly difficult—if not impossible—to prepare adequately (*2*). We suggest a number of measures to hasten the development of science to correct maladaptations to current climate variability and support society's increasing need to adapt to a changing climate, drawing on lessons from experience, insights from related endeavors such as sustainability science (*3*), and input from scientific and stakeholder communities.

The entrance to a garage in Lower Manhattan on 31 October, 2012, as New York City began clean-up after Hurricane Sandy.

CREDIT: STAN HONDA/AFP/GETTY IMAGES/NEWSCOM

Adaptation Planning, Information Gaps, and the Need for Adaptation Science

Initial adaptation planning is occurring in some sectors, such as water resource management, forestry, insurance, and coastal zone management. A limited but growing number of states and cities are developing adaptation plans. U.S. federal agencies have implemented sustainability plans that include mitigation and adaptation (*4*).

There are serious science gaps, however (*5*, *6*). In many communities, decision-makers lack climate information or the means to apply it. In others, knowledge of current or potential future impacts exists, but not in a form or context that decision-makers can assimilate or act on in advance. In still others, engineering innovations are needed, as well as social science knowledge, to guide technology deployment and adjustments to management, investments, and public policy.

A key characteristic of emerging adaptation science is that it is both basic—in that it contributes to understanding fundamental physical, environmental, and socioeconomic research questions—and applied, because it is problem focused. Scientists and practitioners "coproduce" relevant research by jointly defining questions and maintaining frequent interactions (*7*). Coproduction is challenging to implement and sustain because participants often have different roles, vocabularies, interests, methods, and incentives. The effectiveness of communications and deliberative processes among scientists and practitioners requires empirical evaluation (*8*).

To support the wide range of necessary adjustments, we outline a comprehensive, integrated approach to research in social, physical, environmental, engineering, and other sciences. We describe adaptation science research needed to understand decision processes and information requirements, identify vulnerabilities, improve foresight about climate risks and other stressors, and understand barriers and options for adaptation.

Understand Decision Processes and Knowledge Requirements

Adaptation science research must clarify what types of scientific information are required for improved decision-making. Decision-makers are concerned with cost, feasibility, social acceptance, tradition, and other factors. To close a "usability gap," scientific information must fit into existing contexts (*9*). Organizational, cognitive, political, ethnographic, and decision sciences research is needed to clarify the problem, the values of participants, and the context in which the information will be applied. Understanding perception and apprehension of climate change risks is also a priority.

Identify Vulnerabilities

Research to characterize vulnerability and adaptive capacity focuses on pinpointing infrastructure, economic sectors, geo-

*Full affiliations for all authors are provided in the supplementary materials. †Corresponding author. E-mail: rhm@pnnl.gov

Moss et al., 2013
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There are serious science gaps, however (5, 6). In many communities, decision-makers lack climate information or the means to apply it. In others, knowledge of current or potential future impacts exists, but not in a form or context that decision-makers can assimilate or act on in advance. In still others, engineering innovations are needed, as well as social science knowledge, to guide technology deployment and adjustments to management, investments, and public policy.

A key characteristic of emerging adaptation science is that it is both basic—in that it contributes to understanding fundamental physical, environmental, and socioeconomic research questions—and applied, because it is problem focused. Scientists and practitioners "coproduce" relevant research by jointly defining questions and maintaining frequent interactions (7). Coproduction is challenging to implement and sustain because participants often have different roles, vocabularies, interests, methods, and incentives. The effectiveness of communications and deliberative processes among scientists and practitioners requires empirical evaluation (8).

To support the wide range of necessary adjustments, we outline a comprehensive, integrated approach to research in social, physical, environmental, engineering, and other sciences. We describe adaptation science research needed to understand decision processes and information requirements, identify vulnerabilities, improve foresight about climate risks and other stressors, and understand barriers and options for adaptation.

Understand Decision Processes and Knowledge Requir[illegible]

Adaptation s[illegible] research must clarify what [illegible] of scientific information are [illegible] for improved decision-making. Decision-makers are concerned with cost, feasibility, social acceptance, tradition, and other factors. To close a "usability gap," scientific information must fit into existing contexts (9). Organizational, cognitive, political, ethnographic, and decision sciences research is needed to clarify the problem, the values of participants, and the context in which the information will be applied. Understanding perception and apprehension of climate change risks is also a priority.

Identify Vulnerabilities

Research to characterize vulnerability and adaptive capacity focuses on pinpointing infrastructure, economic sectors, geo-

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There is an urgent need for "practice-relevant adaptation science"

Key characteristics:

- both fundamental and applied science
- scientists & practitioners co-produce knowledge
- coproduction is challenging
- requires empirical evaluation

Moss et al., 2013
Published on November 8, 2013 in *Science*

Sustainability and Adaptation Science

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CLIMATE CHANGE

Hell and High Water: Practice-Relevant Adaptation Science

Adaptation requires science that analyzes decisions, identifies vulnerabilities, improves foresight, and develops options.

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graphic areas, population groups, and ecosystems at greatest risk of harm (*10*). Two challenges are to:

Improve data, methods, and scenarios for research on vulnerability and resilience of human and natural systems. A georeferenced data system for factors such as population, economic status, preparedness, natural capital, and location of sensitive infrastructure needs to be established and maintained to identify vulnerable human communities and environments. Effective response will be aided by understanding the extent to which vulnerability arises from poverty, under-investment, environmental factors, and their interactions with climate variability and change.

Identify climate thresholds in vulnerable systems. Knowledge of climate and related thresholds, points at which fundamental transformations occur in natural or human systems as climate changes, will improve resource management and inform debates about future atmospheric greenhouse gas stabilization. Coupled with time-dependent climate scenarios, improved knowledge of climate thresholds may help in estimating when effects could occur and thus facilitate setting adaptation priorities.

Adaptation Science in Action

Scientists and practitioners are collaborating on research and applications to support climate change preparedness and address other nonclimate issues. Case examples document research and actions, such as plans and projects, but do not yet provide evidence of improved outcomes. Improved methods and data are needed for evaluating results (*29*).

- Well before Hurricane Sandy, New York City established a task force of city officials, utilities, commercial firms, and researchers to support formulation of adaptation options for vital infrastructure.
- Major urban water utilities, university-based research centers, and private-sector firms in the United States are collaborating to pilot applications of climate science and water utility modeling applications to quantify impacts of climate change on their water systems and evaluate adaptation strategies.
- Researchers in Australia developed a plant functional trait database and modeled habitat suitability under climate scenarios for naturalized and invasive plants to enable land managers to make better-informed decisions about land management at a national and regional level.

- Researchers and local practitioners in the Vietnamese city of Hue and the Bangladeshi city of Satkhira collaborated to assess climate-related risks, identify adaptation strategies, and strengthen local capacity to manage the interaction of rapid development and climate impacts.
- Researchers worked with small-scale farmers and agricultural extension officials in sub-Saharan Africa to provide a bridge between scientific and indigenous knowledge of drought onset and coping strategies to improve delivery of drought prediction information for vulnerable, rain-fed farming operations.

PHOTO CREDIT: HCONGTHANH/ISTOCKPHOTO

Improve Foresight About Climate Hazards and Other Stressors

Physical and biological scientists must study climate processes and develop models to deliver insights about climate features, including temperature and precipitation extremes, and related processes such as evolution of ecosystems, sea level rise, and other first-order effects. Social sciences can characterize human contributions to climate change through emissions and land use and inform mechanisms for improving interactions between climate scientists and potential users (*11*). Research challenges include:

Understand recent and potential future changes in extreme climate events. Extremes occur on many spatial and time scales. They include heat waves, droughts, floods, storms, and other events that have major effects on human and natural systems. There is evidence that many of these extremes are intensifying (*1*, *12*). A concerted focus on detecting changes in extremes and improving predictive products can provide important inputs to adaptation planning and preparedness.

Improve integration of weather and climate information. Common elements of initializing predictions with observations and providing probabilistic weather and climate information across time scales can constitute a unified approach for weather forecasts and climate predictions (*13*, *14*). Decadal climate predictions with next-generation, high-resolution global climate models [e.g., (*15*)] have the potential to produce probabilistic near-term climate information over the next decade and improve insight into future conditions to which human societies will have to adapt (*16*). Research is needed to formulate methods for presenting global climate model information in probabilistic form and applying that information to risk assessment and management (*17*).

Tailor climate information to facilitate its application in decision-making. Sustained interactions among researchers and decision-makers are needed not only to understand how climate affects assets or resources but also to identify how climate information can be used in decisions (*18*). In addition to global climate models, other tools can produce relevant information, such as less computationally intensive intermediate-complexity models [e.g., to assess uncertainty (*19*)], qualitative scenario planning approaches (*20*), and decision-analytic approaches to use climate model information in ways that supplement conventional scenario-led studies [e.g., (*17*)]. Climate and decision scientists can tailor information for application through downscaling of climate model data [e.g., (*21*)] or running fully dynamical nested numerical models at regional or finer grid spacings [e.g., the North American Regional Climate Change Assessment Program (*22*)].

Establish climate information services at the national and international level to translate and communicate adaptation science to public and private sector decision-makers. The Global Framework for Climate Services (*23*) provides a foundation for climate services being developed in many countries. Development of climate services should engage decision-makers, researchers, and others to ensure that products are relevant, uncertainties are explicit, and a portfolio of products that combine monitoring and projections are useable to decision-makers. The U.S. National Academy of Sciences has emphasized the need for climate services (*24*), and the U.S. Global Change Research Program (USGCRP) has made climate adaptation science that would use climate information a focus of its 10-year plan (*25*). Current funding levels are inadequate and declining, and incentives and means to engage with stakeholders are lacking, inhibiting service development and delivery (*5*, *26*).

Identify Barriers, Broaden the Range of Adaptation Options, and Promote Learning

Options need to be studied to guide adjustments in technology, management practices, public policy, standards, institutions, gover-

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Identify Barriers, Broaden the Range of Adaptation Options, and Promote Learning

Options need to be studied to guide adjustments in technology, management practices, public policy, standards, institutions, gover-

PHOTO CREDIT: KCONGTHANH/ISTOCKPHOTO

Improve Forsight About Climate Hazards and Other Stressors

Moss et al., 2013
Published on November 8, 2013 in *Science*

graphic areas, population groups, and ecosystems at greatest risk of harm (*10*). Two challenges are to:

Improve data, methods, and scenarios for research on vulnerability and resilience of human and natural systems. A geo-referenced data system for factors such as population, economic status, preparedness, natural capital, and location of sensitive infrastructure needs to be established and maintained to identify vulnerable human communities and environments. Effective response will be aided by understanding the extent to which vulnerability arises from poverty, under-investment, environmental factors, and their interactions with climate variability and change.

Identify climate thresholds in vulnerable systems. Knowledge of climate and related thresholds, points at which fundamental transformations occur in natural or human systems as climate changes, will improve resource management and inform debates about future atmospheric greenhouse gas stabilization. Coupled with time-dependent climate scenarios, improved knowledge of climate thresholds may help in estimating when effects could occur and thus facilitate setting adaptation priorities.

Improve Foresight About Climate Hazards and Other Stressors

Physical and biological scientists must study climate processes and develop models to deliver insights about climate features, including temperature and precipitation extremes, and related processes such as evolution of ecosystems, sea level rise, and other first-order effects. Social sciences can characterize human contributions to climate change through emissions and land use and inform mechanisms for improving interactions between climate scientists and potential users (*11*). Research challenges include:

Understand recent and potential future changes in extreme climate events. Extremes occur on many spatial and time scales. They include heat waves, droughts, floods, storms, and other events that have major effects on human and natural systems. There is evidence that many of these extremes are intensifying (*1*, *12*). A concerted focus on detecting changes in extremes and improving predictive products can provide important inputs to adaptation planning and preparedness.

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Adaptation Science in Action

Scientists and practitioners are collaborating on research and applications to support climate change preparedness and address other nonclimate issues. Case examples document research and actions, such as plans and projects, but do not yet provide evidence of improved outcomes. Improved methods and data are needed for evaluating results (*29*).

- Well before Hurricane Sandy, New York City established a task force of city officials, utilities, commercial firms, and researchers to support formulation of adaptation options for vital infrastructure.
- Major urban water utilities, university-based research centers, and private-sector firms in the United States are collaborating to pilot applications of climate science and water utility modeling applications to quantify impacts of climate change on their water systems and evaluate adaptation strategies.
- Researchers in Australia developed a plant functional trait database and modeled habitat suitability under climate scenarios for naturalized and invasive plants to enable land managers to make better-informed decisions about land management at a national and regional level.
- Researchers and local practitioners in the Vietnamese city of Hue and the Bangladeshi city of Satkhira collaborated to assess climate-related risks, identify adaptation strategies, and strengthen local capacity to manage the interaction of rapid development and climate impacts.

- Researchers worked with small-scale farmers and agricultural extension officials in sub-Saharan Africa to provide a bridge between scientific and indigenous knowledge of drought onset and coping strategies to improve delivery of drought prediction information for vulnerable, rain-fed farming operations.

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Five Fields:

- Assessing the hazards
- Knowing the vulnerabilities
- Having foresight
- Understanding decision making
- Developing options

POLICYFORUM

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Sustainability and Adaptation Science

Five Fields of
Adaptation Science:

- Hazards
- Vulnerabilities
- Foresight
- Decision making
- Options

Important:
Identify the system and the challenge/ wicked problem

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- Hazards
- Vulnerabilities
- Foresight
- Decision making
- Options

Important:
Identify the system and the challenge/ wicked problem

Questions to asked:

- What **system** (ecosystem, species, community) are we looking at? Why is there a need for the system to adapt? What is the **(wicked) problem**?
- What **conceptual model** represents the stocks, flows, and feedback loops of the system?
- What are the **hazards** the system is exposed to?
- What are the (intrinsic) **vulnerabilities** of the system?
- **Foresight and Goals**: What are possible futures of the system? What are the desired futures?
- How are **decisions** made that impact the system and who is making/can make these decisions? Who is impacted by the decisions?
- What **options** are there for interventions and how do these interventions impact the system's future?
- **Recommendations** for actions

Mitigation and Adaptation Studies

Case Study

Mitigation and Adaptation Studies

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Process:

February 8, 2019:	Selection of case study
February 20, 2019:	Class is reserved for work on case study
March 1, 2019:	Draft outline and bibliography of the case study paper is due.
March 29, 2019:	Draft case study paper is due
April 12:	Final case study paper is due
April 12, 15, 19, 23, 2019:	Presentations are due
April 15, 17, 22, 24, 2019:	Case study presentations (12+3 minutes)

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Do not hesitate to ask if you are uncertain about

- the process,
- the wicked problem you are addressing in your case study,
- the research you need to do,
- or the paper you are writing.