Sustainability Leadership

Class 4:

Part 1: Systems

- Systems, System Theory and System of Systems
- Ecosystem Services
- Essential Variables

Part 2: Hazards

Systems and System Theory

The basic ideas of a system whole can be found in both Western and Eastern philosophy.

Many philosophers have considered notions of holism: ideas, people or things must be considered in relation to the things around them to be fully understood (M'Pherson 1974).

System: A cohesive conglomeration of interrelated and interdependent parts.

"**A System is a set of elements in interaction.**" (Bertalanffy 1968)

Every system is:

- delineated by its spatial and temporal boundaries,
- surrounded and influenced by its environment,
- described by its structure and purpose or nature and
- expressed in its functioning.

Bertalanffy, L. von. 1968. *General System Theory: Foundations, Development, Applications*, rev. ed. New York: Braziller.
M'Pherson, P.K. 1974. "A perspective on systems science and systems philosophy". *Futures.* 6(3):219-39.

Systems and System Theory

Systems and System Theory

A system can have emergent behavior and properties.

Systems and System Theory

A system can have emergent behavior and properties.

Changing one part of the system usually affects other parts and the whole system.

Systems and System Theory

A system can have emergent behavior and properties.

Changing one part of the system usually affects other parts and the whole system.

For systems that are self-learning and self-adapting, the positive growth and adaptation depend upon how well the system is adjusted with its environment.

Systems and System Theory

A system can have emergent behavior and properties.

Changing one part of the system usually affects other parts and the whole system.

For systems that are self-learning and self-adapting, the positive growth and adaptation depend upon how well the system is adjusted with its environment.

Some systems function mainly to support other systems by aiding in the maintenance of the other system to prevent failure.

Systems and System Theory

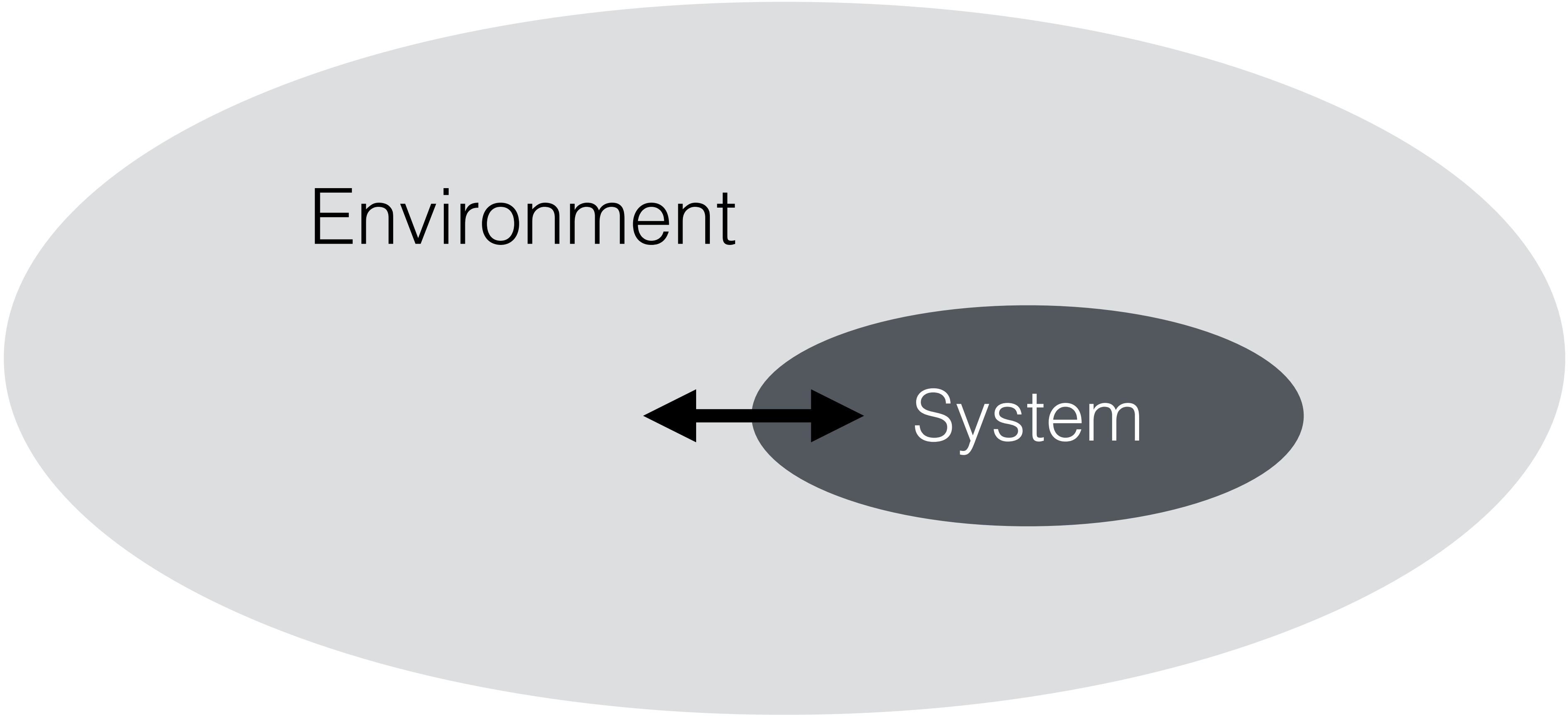
A system can have emergent behavior and properties.

Changing one part of the system usually affects other parts and the whole system.

For systems that are self-learning and self-adapting, the positive growth and adaptation depend upon how well the system is adjusted with its environment.

Some systems function mainly to support other systems by aiding in the maintenance of the other system to prevent failure.

Relation to the environment:
- open systems: interact with the environment;
- closed systems: does not interact and is not impacted by the environment



Systems and System Theory

A system can have emergent behavior and properties.

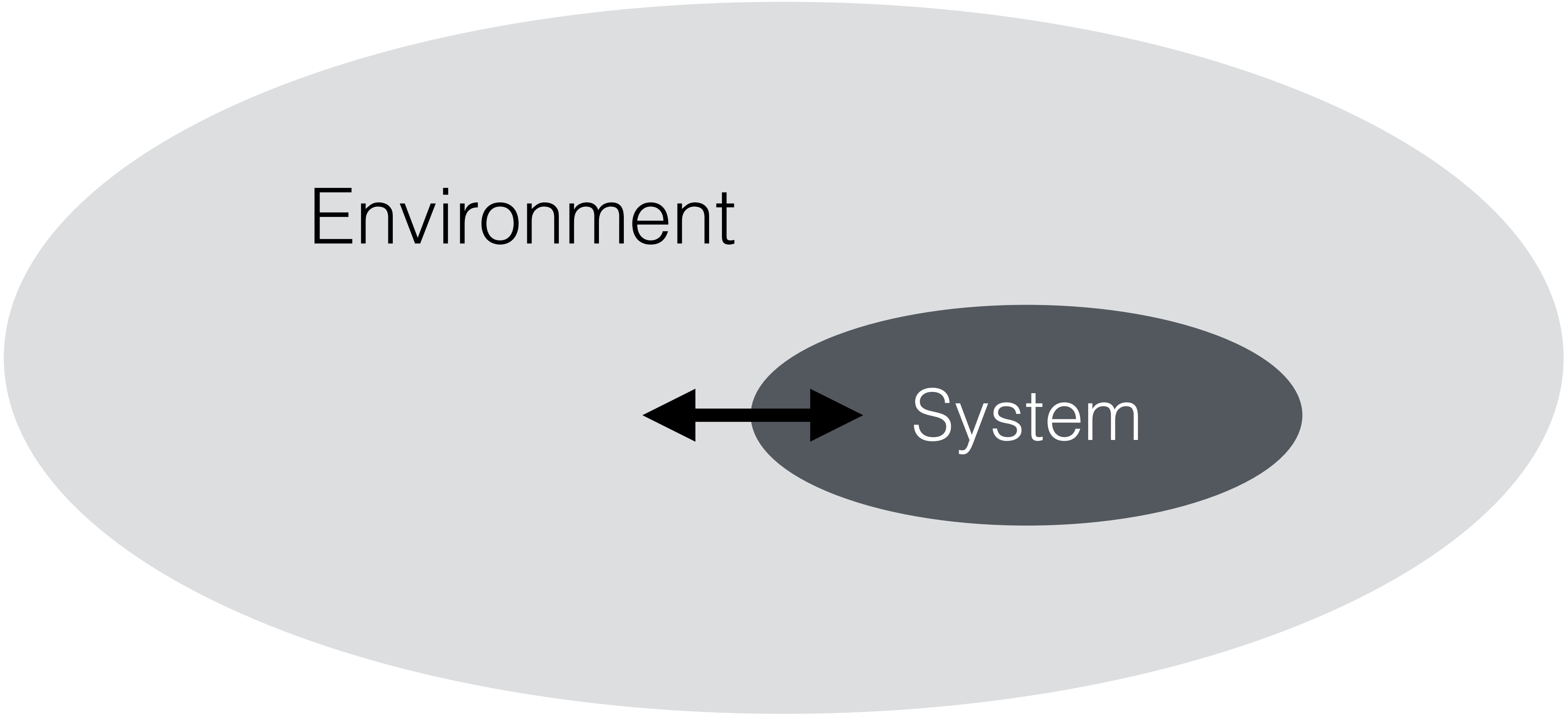
Changing one part of the system usually affects other parts and the whole system.

For systems that are self-learning and self-adapting, the positive growth and adaptation depend upon how well the system is adjusted with its environment.

Some systems function mainly to support other systems by aiding in the maintenance of the other system to prevent failure.

Relation to the environment:

- open systems: interact with the environment;
- closed systems: does not interact and is not impacted by the environment



Almost all systems are open systems.

Systems and System Theory

Bertalanffy, L. von. 1968. *General System Theory: Foundations, Development, Applications*, rev. ed. New York: Braziller.

Systems and System Theory

Systems theory: transdisciplinary approach to understand the behavior of a complex entity.

Bertalanffy, L. von. 1968. *General System Theory: Foundations, Development, Applications*, rev. ed. New York: Braziller.

Systems and System Theory

Systems theory: transdisciplinary approach to understand the behavior of a complex entity.

The goal of systems theory is systematically discovering a system's dynamics, constraints, conditions and elucidating principles (purpose, measure, methods, tools, etc.) that can be discerned and applied to systems at every level of nesting.

Bertalanffy, L. von. 1968. *General System Theory: Foundations, Development, Applications*, rev. ed. New York: Braziller.

System classifications:

There are many classification of open systems. E.g., Bertalanffy (1968) gives nine real world types ranging from static structures and control mechanisms to socio-cultural systems.

A simple classification of system elements:

- **Natural system elements**, objects or concepts which exist outside of any practical human control. Examples: the real number system, the solar system, planetary atmosphere circulation systems.
- **Social system elements**, either abstract human types or social constructs, or concrete individuals or social groups.
- **Technological System elements**, man-made artifacts or constructs; including physical hardware, software and information.

Bertalanffy, L. von. 1968. *General System Theory: Foundations, Development, Applications*, rev. ed. New York: Braziller.

System classifications:

The distinctions can be made as an abstract classification. However, in reality, there are no hard boundaries between these types of systems: e.g., social systems are operated by, developed by, and also contain natural systems and social systems depend on technical systems to fully realize their purpose.

Important mixed types:

- Socio-technological systems
- Socio-ecological systems

Bertalanffy, L. von. 1968. *General System Theory: Foundations, Development, Applications*, rev. ed. New York: Braziller.

Systems

Social Systems:

The concept of social systems is central to the study of sociology. They exist throughout human society by their very definition.

Social systems, also called human systems, begin in simple form and can become progressively more complex. The family is a basic unit that extends to the community, municipality, region and nation. Social systems can exist to serve a specific purpose, such as a corporation or industry or educational institution. A college campus is its own social system. Any individual can belong to a number of social systems simultaneously.

Social systems are characterized by a shared sense of purpose however that may be expressed. The result is a unique and shared set of features, behaviors, norms and standards. For example, the form of government of a particular country produces a social system with its own set of standards. The Soviet social system of the first half of the 20th century, for example, was quite different culturally and socially from its United States counterpart.

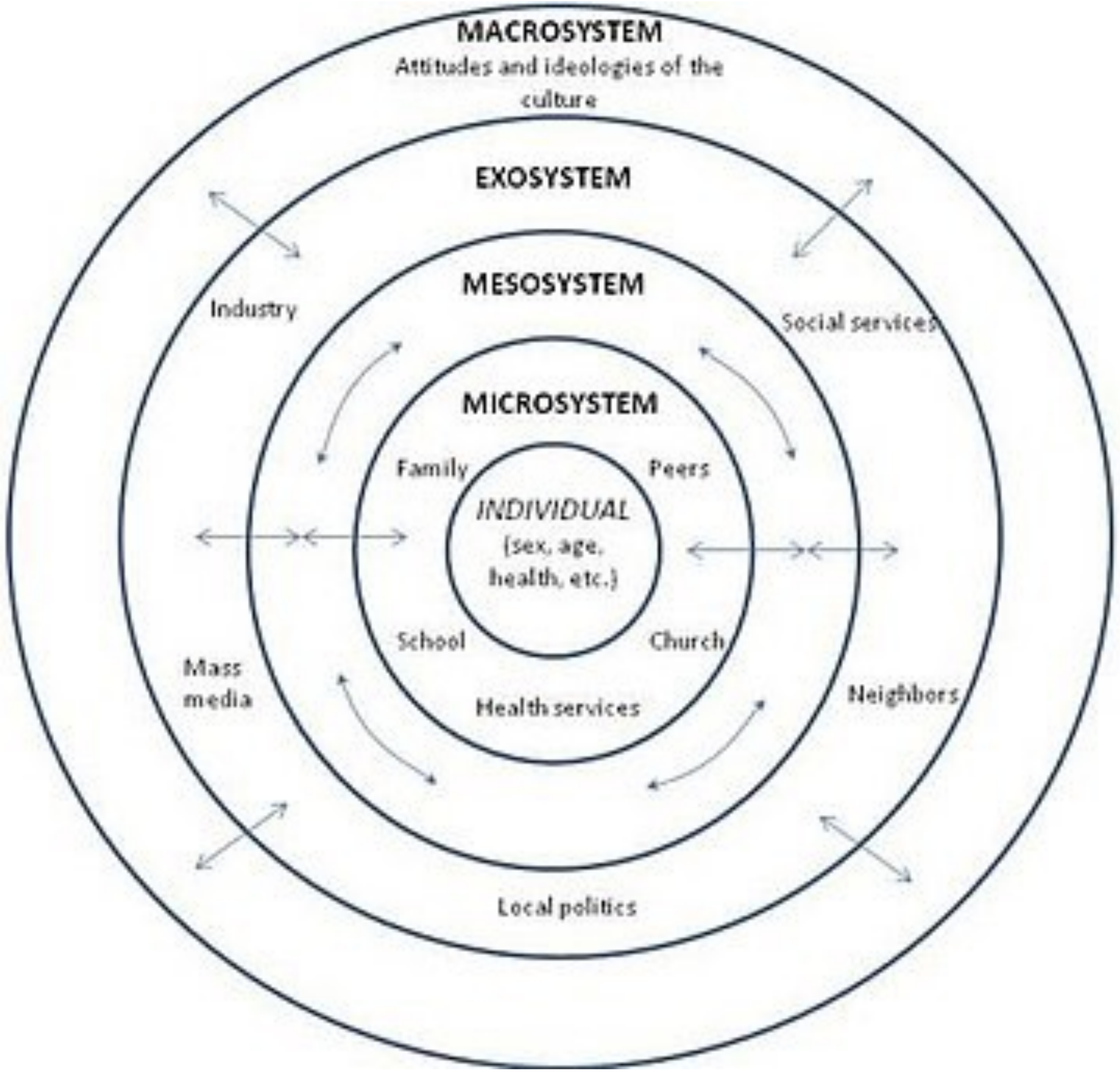
Systems

Ecosystem:

- a system formed by the interaction of a community of organisms with their physical environment
- a community made up of living organisms and nonliving components such as air, water, and mineral soil.

Ecological system theory (development in context, human ecology theory):

- identifies five environmental systems with which an individual interacts,
- offers a framework through which community psychologists examine individuals' relationships within communities and the wider society,
- was developed by Urie Bronfenbrenner.

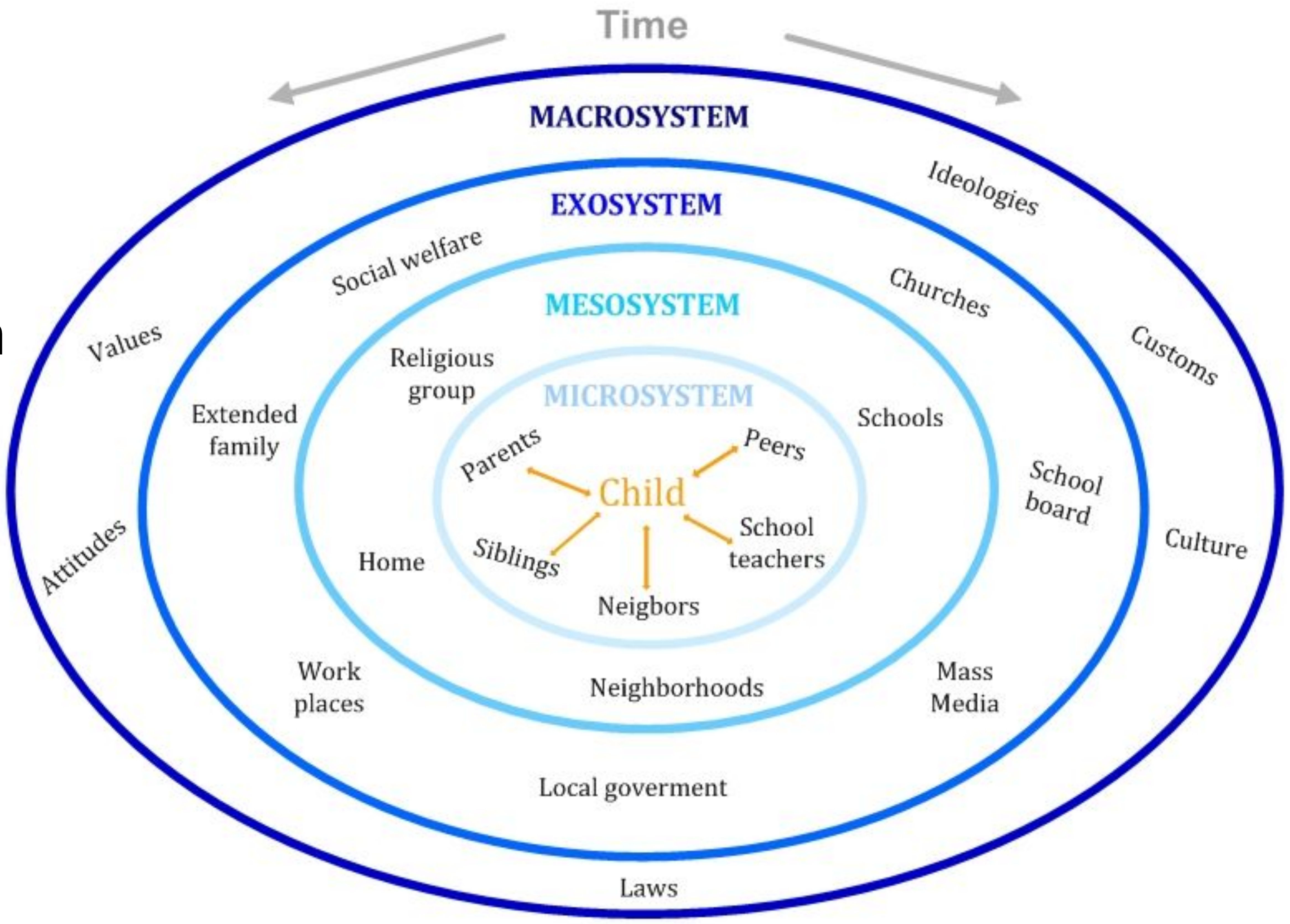


Bronfenbrenner, U. (1979). *The Ecology of Human Development: Experiments by Nature and Design.* Cambridge, Massachusetts: Harvard University Press.

Systems

Ecosystem:
- a system formed by the interaction of a community of organisms with their physical environment
- a community made up of living organisms and nonliving components such as air, water, and mineral soil.

Ecological system theory (development in context, human ecology theory):
- identifies five environmental systems with which an individual interacts,
- offers a framework through which community psychologists examine individuals' relationships within communities and the wider society,
- was developed by Urie Bronfenbrenner.



Bronfenbrenner, U. (1979). *The Ecology of Human Development: Experiments by Nature and Design.* Cambridge, Massachusetts: Harvard University Press.

Engineered Systems Classifications

The classification approaches discussed above have either been applied to all possible types of systems or have looked at how human-made systems differ from non-human systems.

The idea of an engineered system is to provide a focus on systems containing technological as well as social and ecological elements, developed for a defined purpose by an engineering life cycle.

Engineered Systems:

- are created, used and sustained to achieve a purpose, goal or mission that is of interest to an enterprise, team, or an individual.
- require a commitment of resources for development and support.
- are driven by stakeholders with multiple views on the use or creation of the system, or with some other stake in the system, its properties or existence.
- contain engineered hardware, software, people, services, or a combination of these.
- exist within an environment that impacts the characteristics, use, sustainment and creation of the system.

Engineered systems typically

- are defined by their purpose, goal or mission.
- have a life cycle and evolution dynamics.
- may include human operators (interacting with the systems via processes) as well as other natural components that must be considered in the design and development of the system.
- are part of a system-of-interest hierarchy.

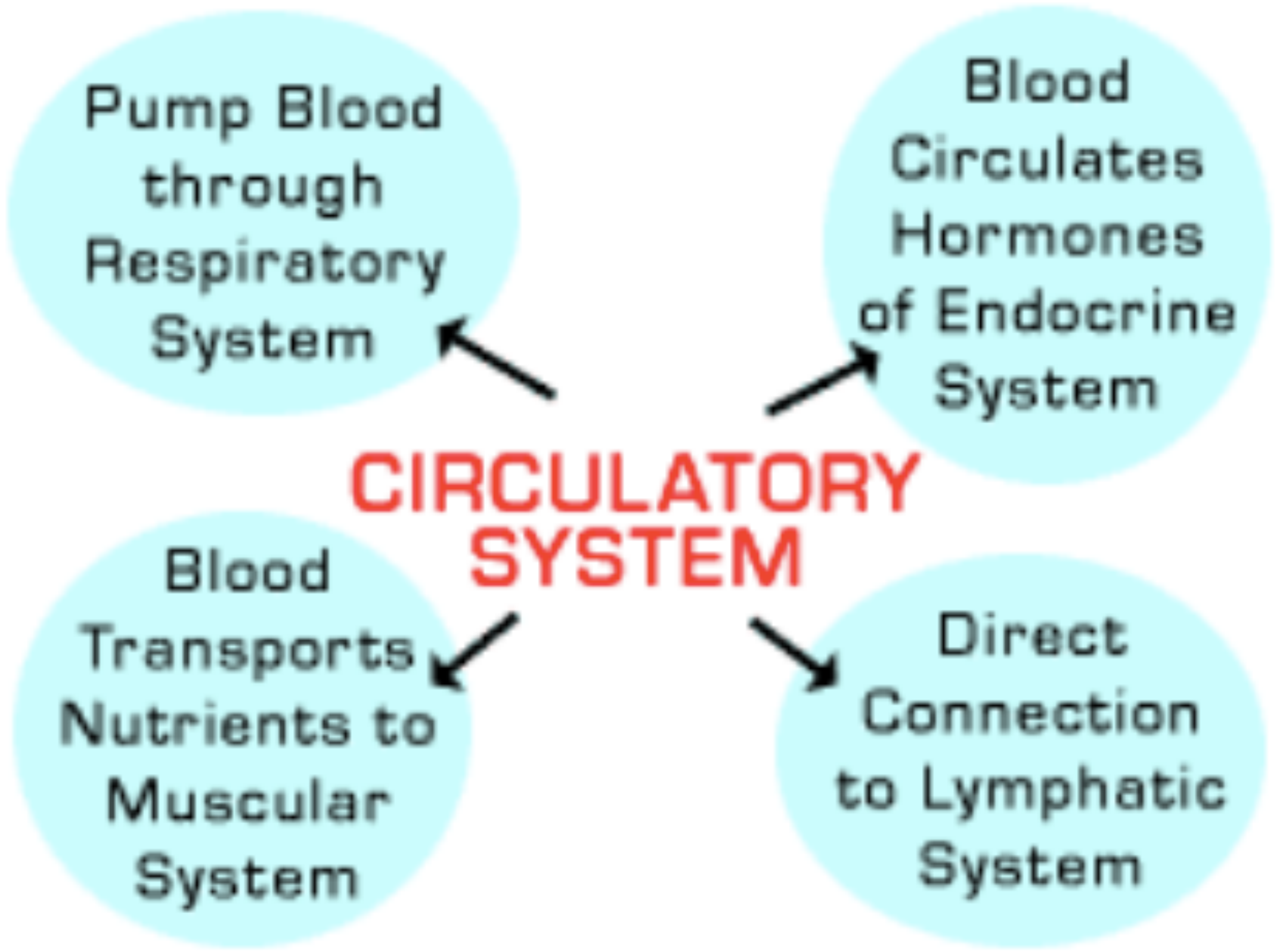
Sustainability Leadership and Systems:

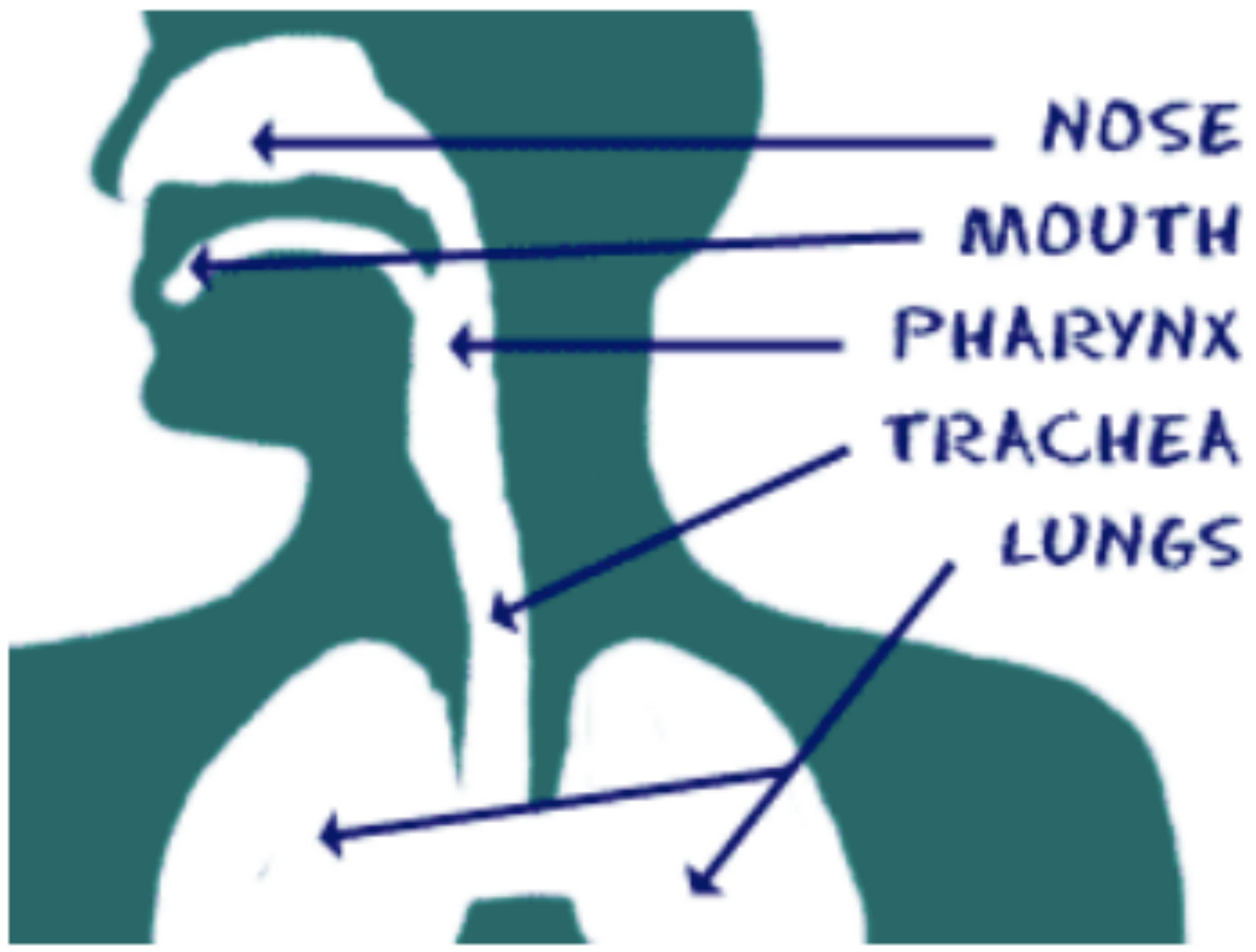
Systems theory provides a basis to visualizes the entity under consideration as a collection of interrelated parts bound together to operate sustainably.

The relationships between the parts are as important as the parts themselves.

The whole of the system (ecosystem, human community, humans and built environment embedded into the non-human environment) interrelates with its external environment (the Earth's life-support system) as well.

Systems as part of an organism





The circular system regulates the transports within the system.

The respiratory system exchanges gases with the environment.

The system of systems aims to maintain a homeostasis.

Systems of Systems

System of systems (SoS): any system which contains elements which in some way can be considered as independent (Maier, 1998):

(1) Two or more systems that are separately defined but operate together to perform a common goal. (Checkland 1999)

(2) an assemblage of components which individually may be regarded as systems, and which possess two additional properties:

(a) Operational Independence of the Components: If the system-of-systems is disassembled into its component systems the component systems must be able to usefully operate independently. That is, the components fulfill customer-operator purposes on their own.

(b) Managerial Independence of the Components: The component systems not only can operate independently, they do operate independently. The component systems are separately acquired and integrated but maintain a continuing operational existence independent of the system-of-systems. (Maier 1998, 267-284)

(3) System-of-systems applies to a system-of-interest whose system elements are themselves systems; typically these entail large scale inter-disciplinary problems with multiple, heterogeneous, distributed systems. (INCOSE 2012)

Maier, M. W. 1998. Architecting Principles for Systems-of-Systems. Systems Engineering, 1(4): 267-84.
Checkland, P. B. 1999. *Systems Thinking, Systems Practice*. Chichester, UK: John Wiley & Sons Ltd.
INCOSE. 2012. *Systems Engineering Handbook: A Guide for System Life Cycle Processes and Activities*, version 3.2.2. San Diego, CA, USA: International Council on Systems Engineering (INCOSE), INCOSE-TP-2003-002-03.2.2

Systems of Systems

Maier (1998) postulated five key characteristics of SoS: Operational independence of component systems, Managerial independence of component systems, geographical distribution, emergent behavior, and evolutionary development processes.

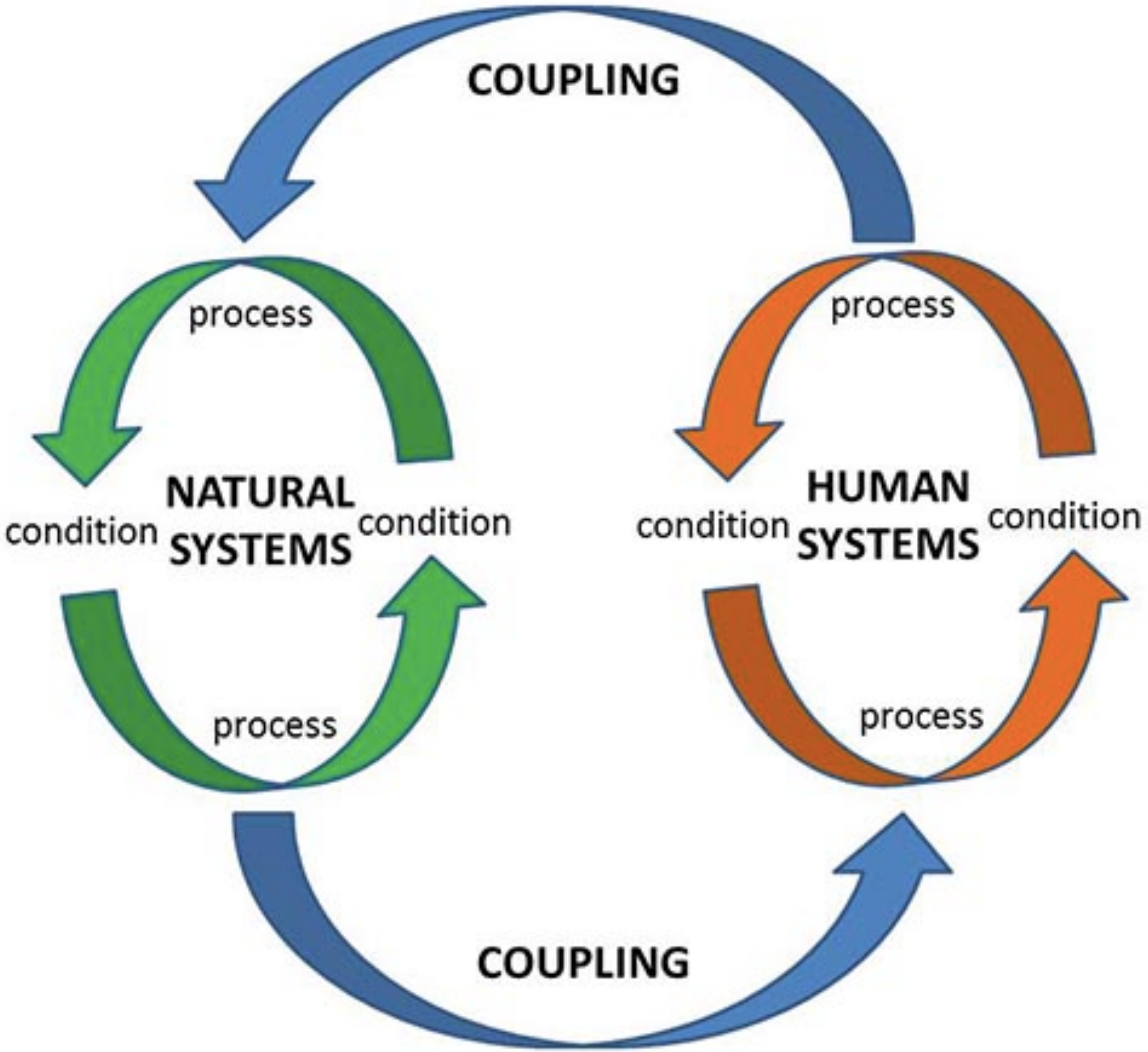
Additional characteristics: A SoS is an integration of a finite number of constituent systems which are independent and operatable, and which are networked together for a period of time to achieve a certain higher goal.

Federation of Systems (FoS)

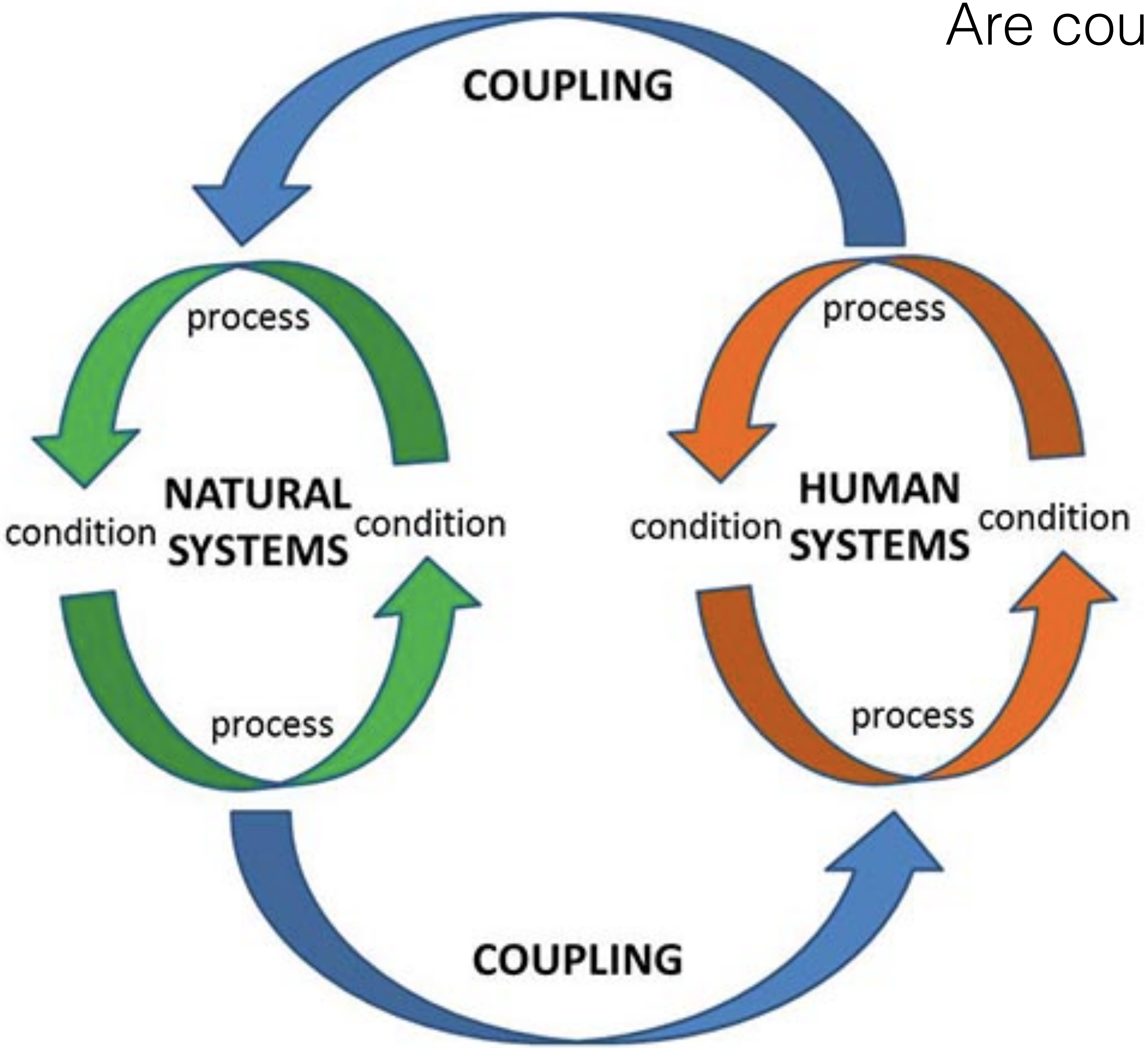
A system of systems that rates high on three dimensions of autonomy, heterogeneity, and dispersion. Each component system chooses of its own accord to participate in the FOS as it sees fit. It is a "coalition of the willing." (Krygiel 1999)

Maier, M. W. 1998. Architecting Principles for Systems-of-Systems. Systems Engineering, 1(4): 267-84.
Checkland, P. B. 1999. *Systems Thinking, Systems Practice*. Chichester, UK: John Wiley & Sons Ltd.
INCOSE. 2012. *Systems Engineering Handbook: A Guide for System Life Cycle Processes and Activities*, version 3.2.2. San Diego, CA, USA: International Council on Systems Engineering (INCOSE), INCOSE-TP-2003-002-03.2.2
Krygiel, A. J. 1999. Behind the Wizard's Curtain: An Integration Environment for a System of Systems. Arlington, VA, USA: C4ISR Cooperative Research Program (CCRP).

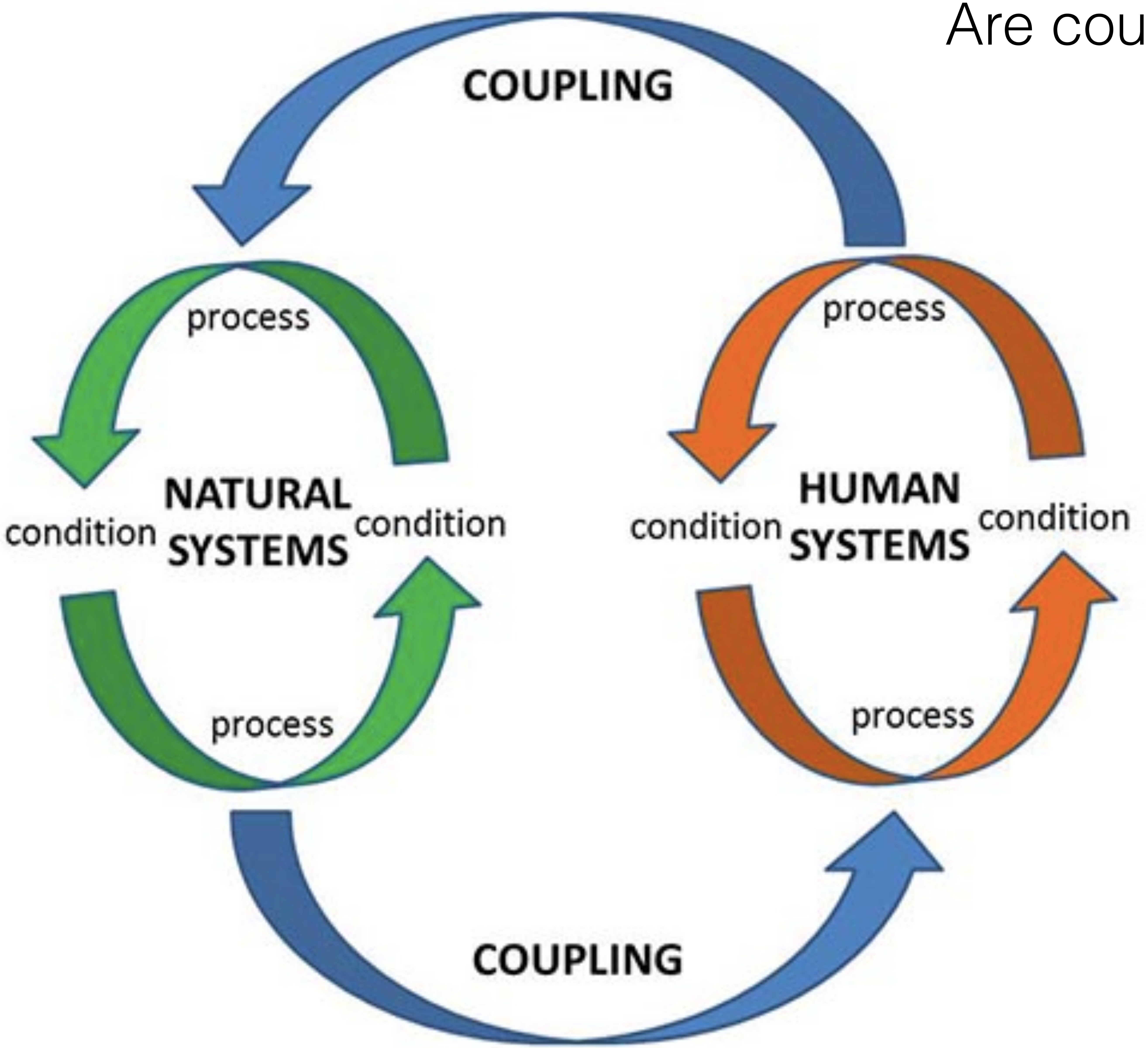
Systems of Systems



Systems of Systems



Are coupled systems a system of systems?

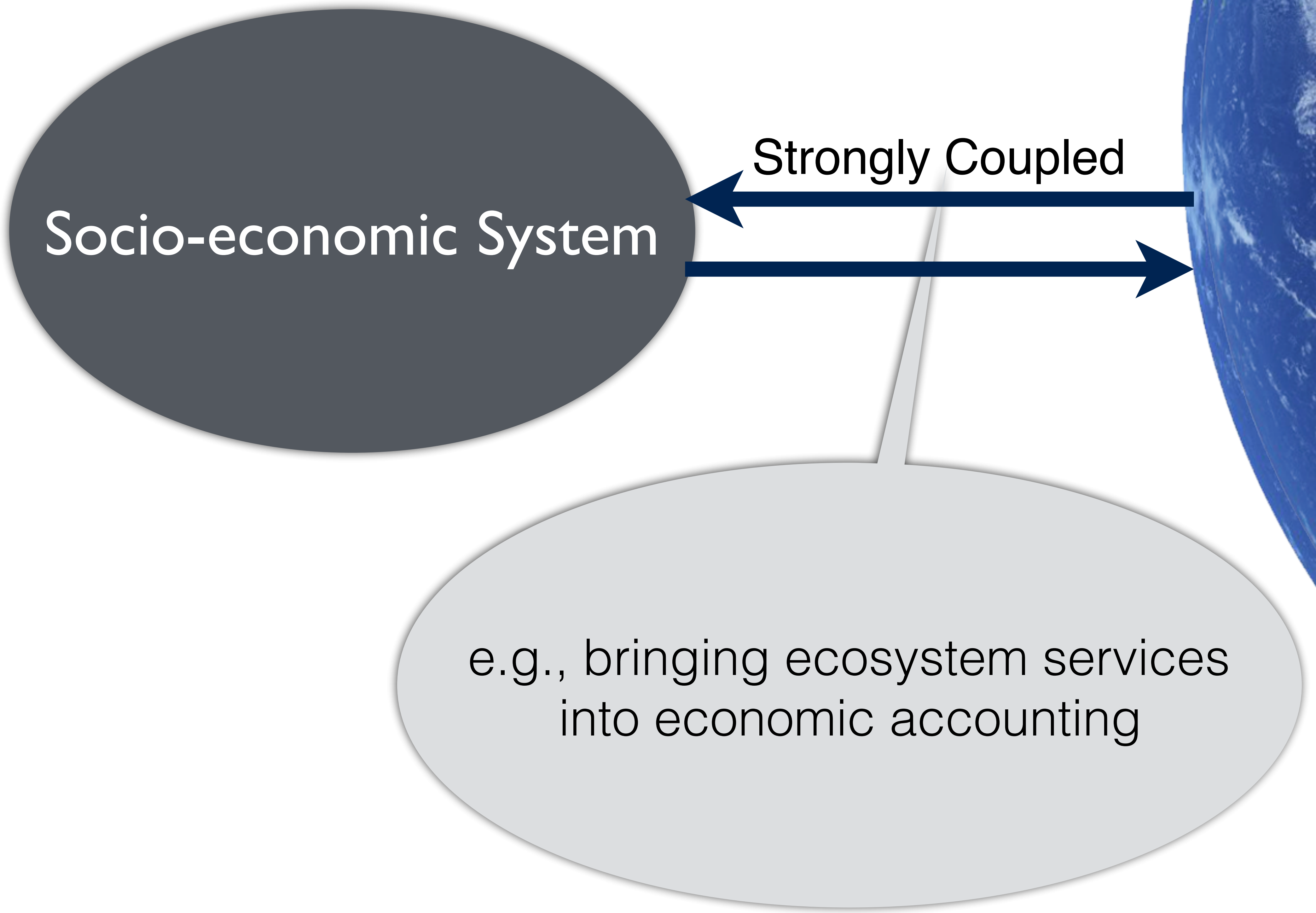


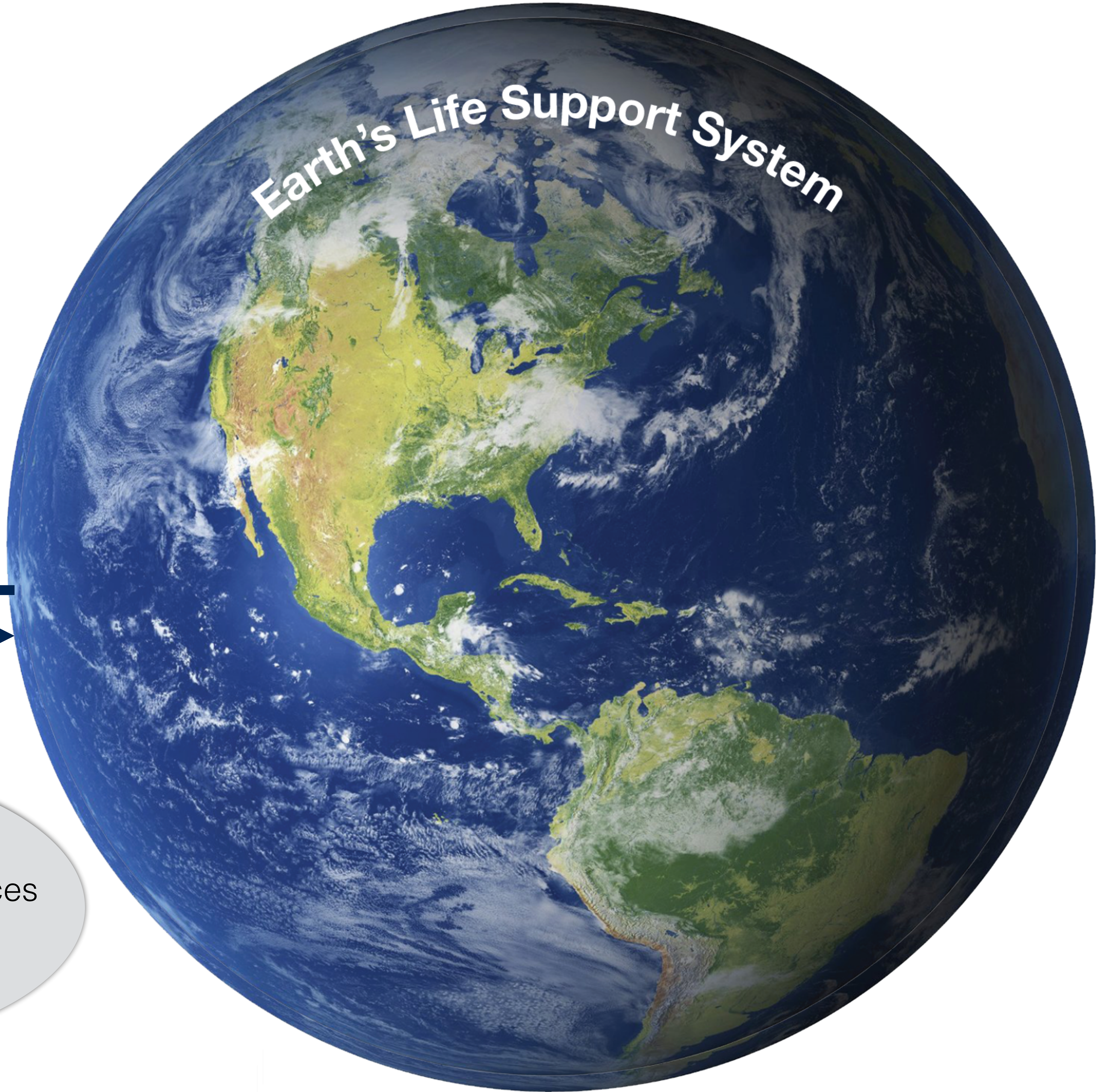
Are coupled systems a system of systems?

Depends on the level of integration.

Systems of Systems

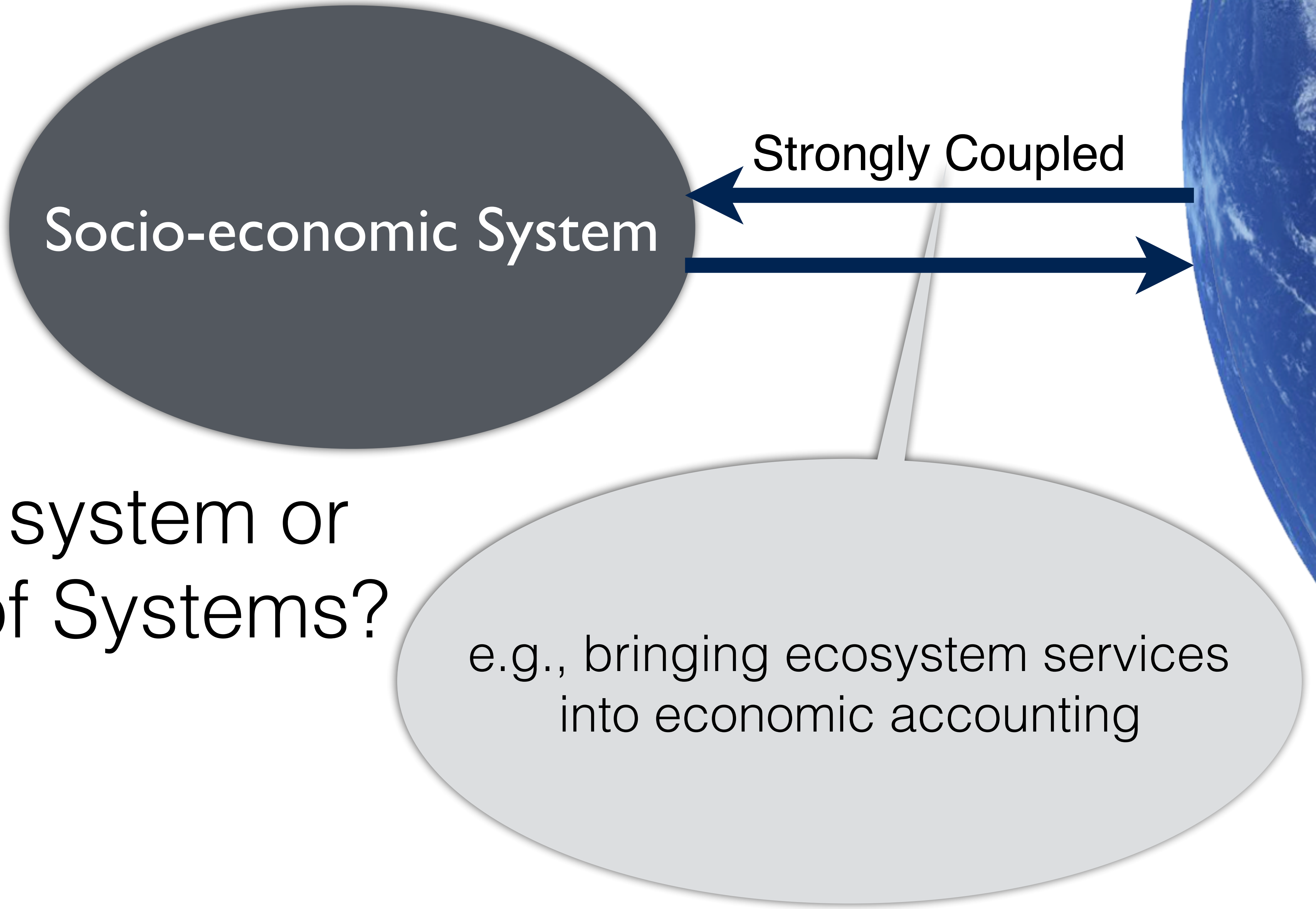
The Earth's life-support system is a system of systems that is in a transition from a homeostasis to a high-energy state, with potential severe changes in meteorological and hydrological hazards. The relationships found in the long-term baseline also indicate that the recent and projected rapid climate change has committed humanity to a large sea level rise during the next centuries unparalleled by all changes experienced by civilization.





Systems of Systems

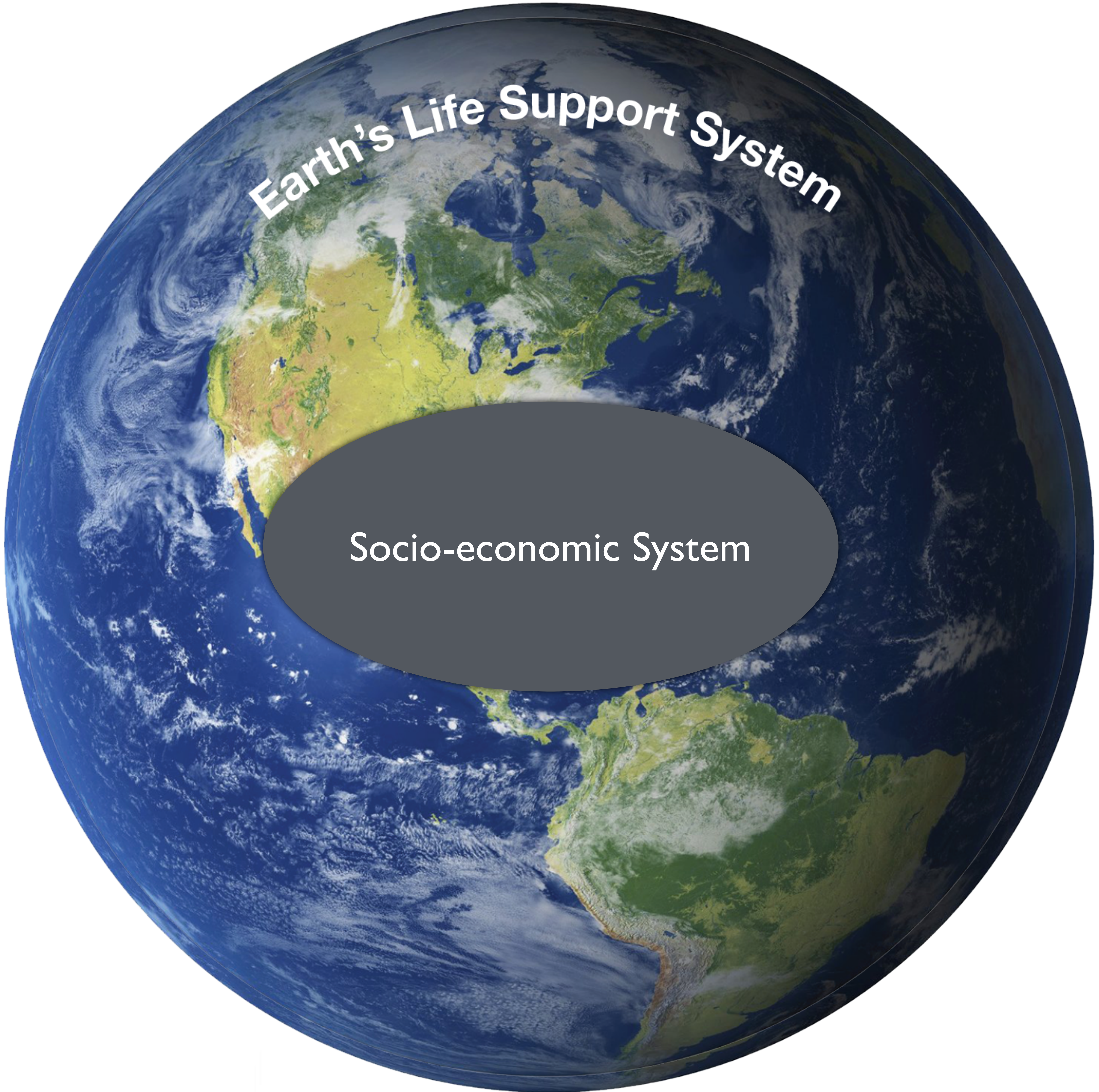
The Earth's life-support system is a system of systems that is in a transition from a homeostasis to a high-energy state, with potential severe changes in meteorological and hydrological hazards. The relationships found in the long-term baseline also indicate that the recent and projected rapid climate change has committed humanity to a large sea level rise during the next centuries unparalleled by all changes experienced by civilization.



Coupled system or System of Systems?

Systems of Systems

The Earth's life-support system is a system of systems that is in a transition from a homeostasis to a high-energy state, with potential severe changes in meteorological and hydrological hazards. The relationships found in the long-term baseline also indicate that the recent and projected rapid climate change has committed humanity to a large sea level rise during the next centuries unparalleled by all changes experienced by civilization.

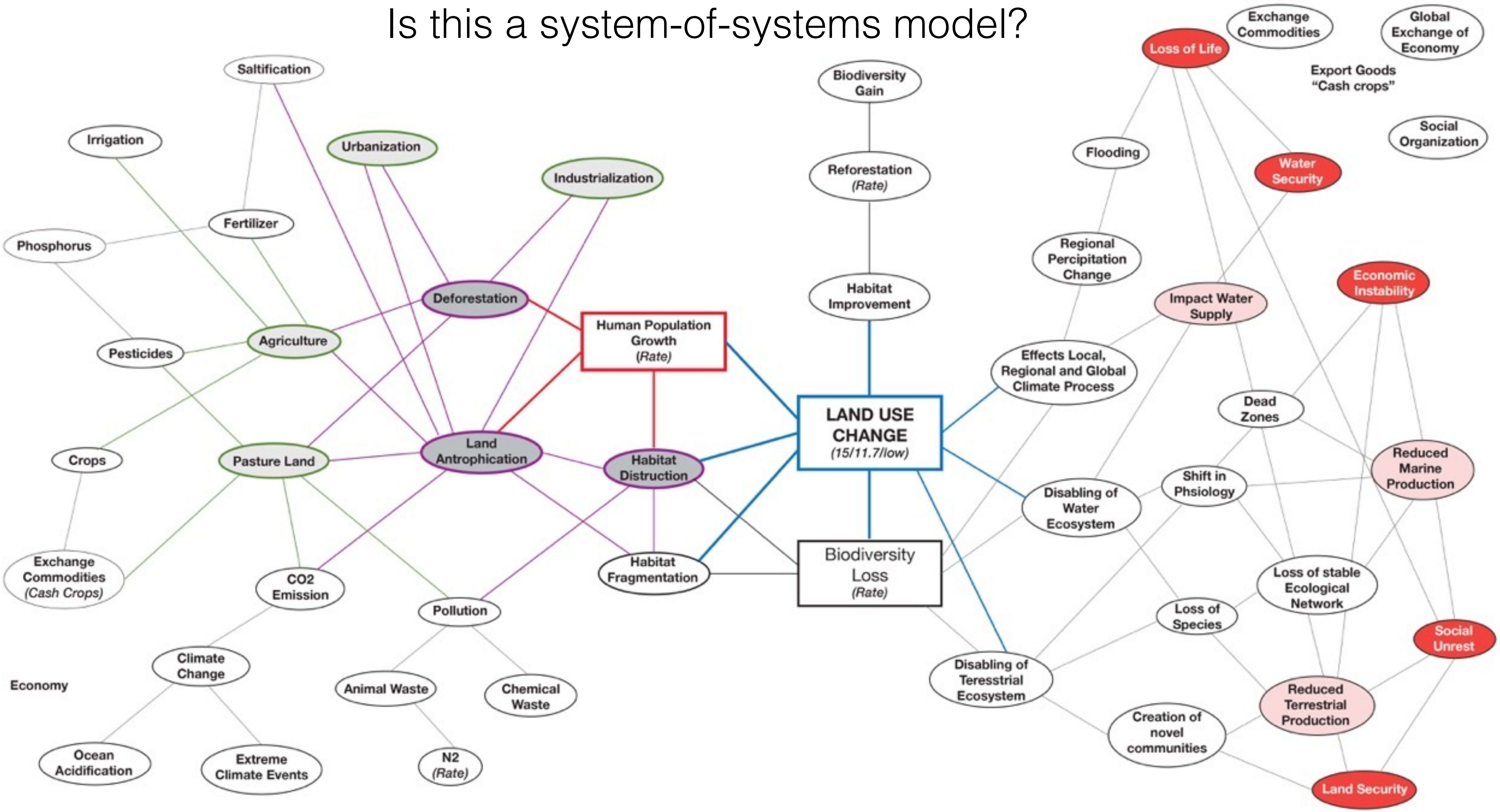


Systems of Systems

The Earth's life-support system is a system of systems that is in a transition from a homeostasis to a high-energy state, with potential severe changes in meteorological and hydrological hazards. The relationships found in the long-term baseline also indicate that the recent and projected rapid climate change has committed humanity to a large sea level rise during the next centuries unparalleled by all changes experienced by civilization.

Is this a system-of-systems model?

Is this a system-of-systems model?



Ecosystem Services

“Ecosystem services are the many and varied benefits that humans freely gain from the natural environment and from properly-functioning ecosystems. Such ecosystems include, for example, agroecosystems, forest ecosystems, grassland ecosystems and aquatic ecosystems. Collectively, these benefits are becoming known as 'ecosystem services', and are often integral to the provisioning of clean drinking water, the decomposition of wastes, and the natural pollination of crops and other plants.”

Wikipedia

“Ecosystem goods and services produce the many life-sustaining benefits we receive from nature—clean air and water, fertile soil for crop production, pollination, and flood control. These ecosystem services are important to environmental and human health and well-being, yet they are limited and often taken for granted.

Ecosystem-focused research develops methods that measure ecosystem goods and services. This research addresses:

- how to estimate current production of ecosystem goods and services, given the type and condition of ecosystems;
- how ecosystem services contribute to human health and well-being; and
- how the production and benefits of these ecosystem services may be reduced or sustained under various decision scenarios and in response to regional conditions.”

EPA

https://www.epa.gov/eco-research/ecosystem-services

Ecosystem Services

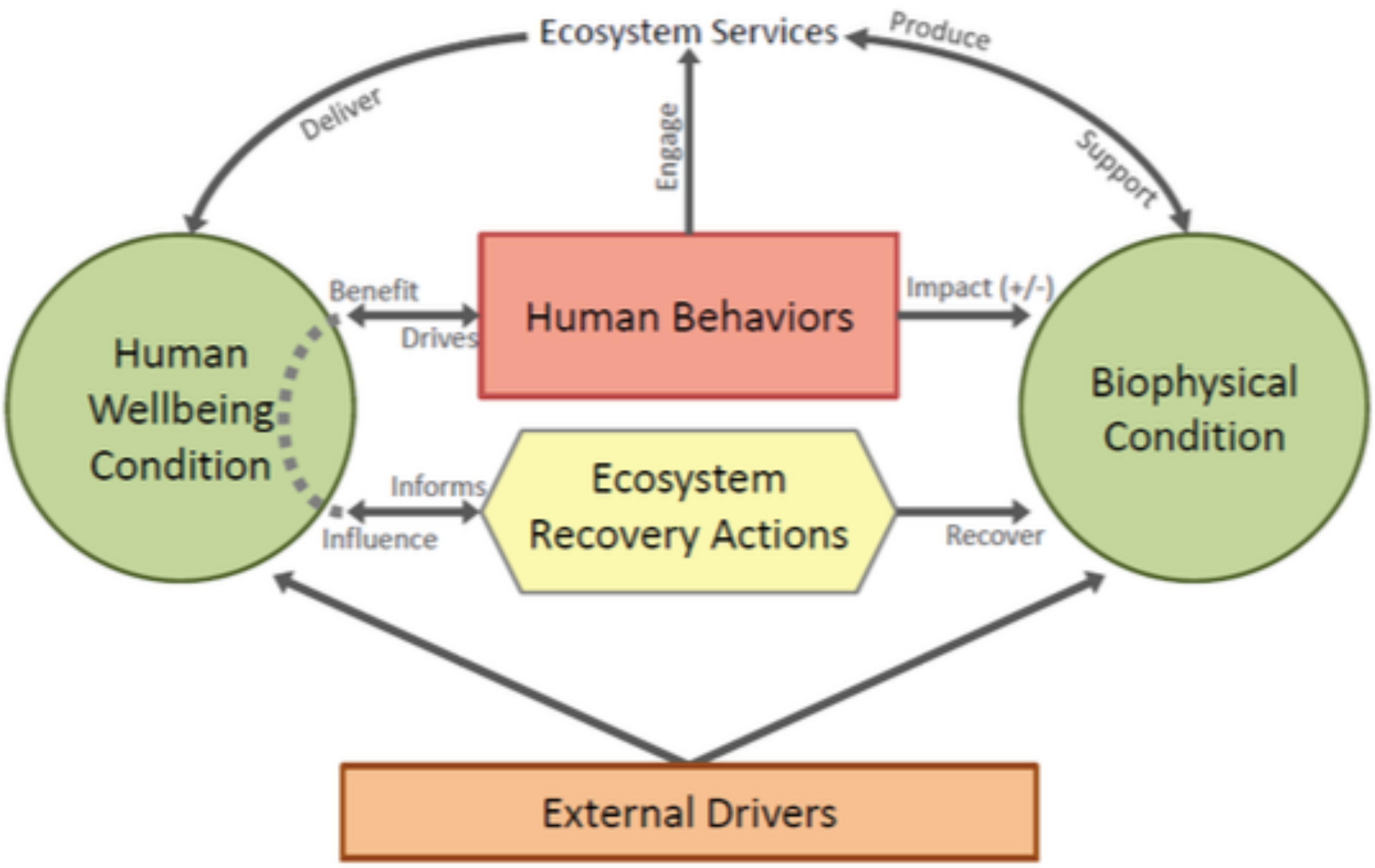


Figure 2: Integrated Conceptual Model for Ecosystem Recovery

https://www.eopugetsound.org/sites/default/files/files/PSP%20Integrated%20Conceptual%20Model%20for%20Ecosystem%20Recovery%20Report_2015-04-03_0.pdf

Ecosystem Services

Is this a system model?

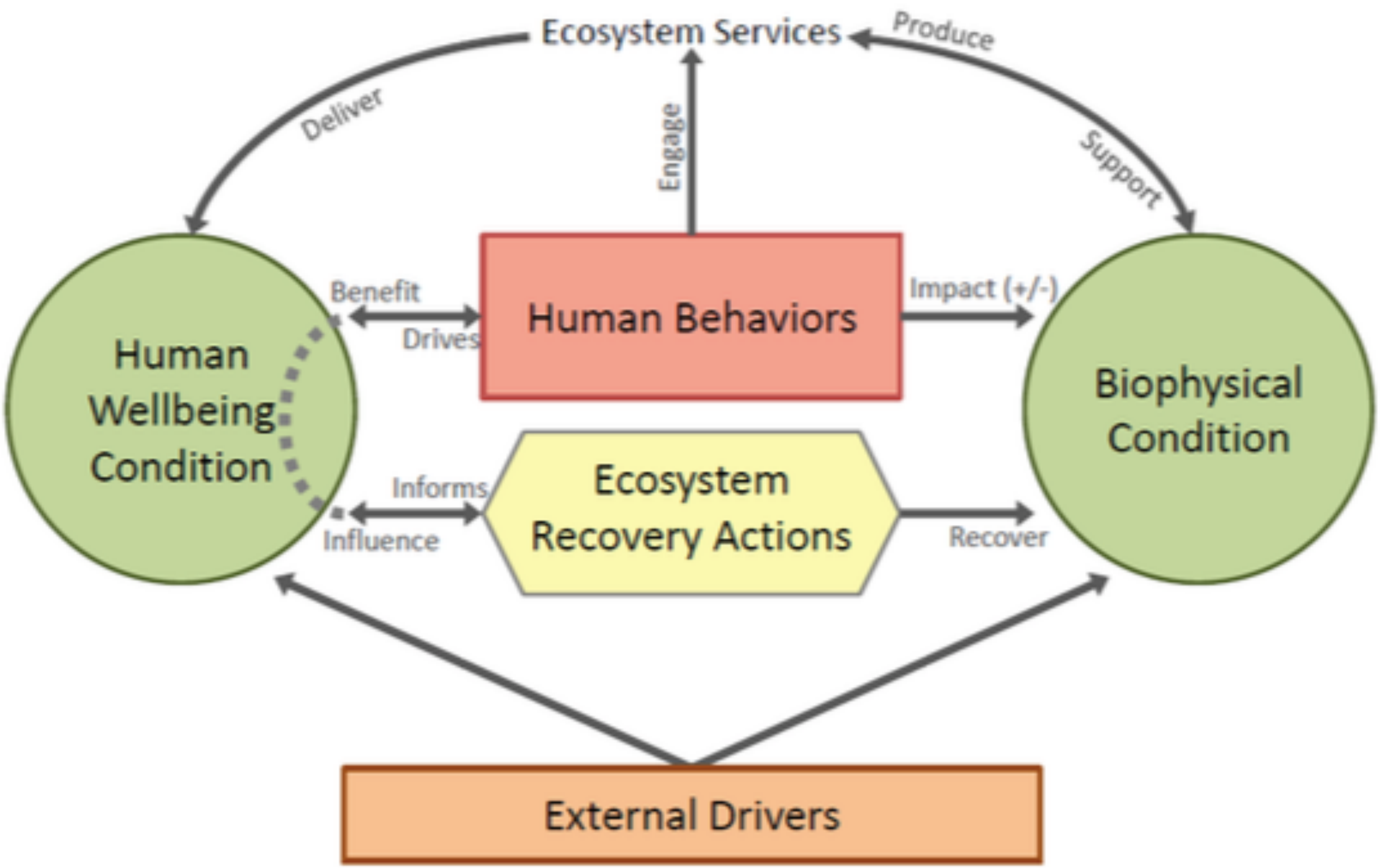


Figure 2: Integrated Conceptual Model for Ecosystem Recovery

https://www.eopugetsound.org/sites/default/files/files/PSP%20Integrated%20Conceptual%20Model%20for%20Ecosystem%20Recovery%20Report_2015-04-03_0.pdf

Ecosystem Services

Is this a system model?

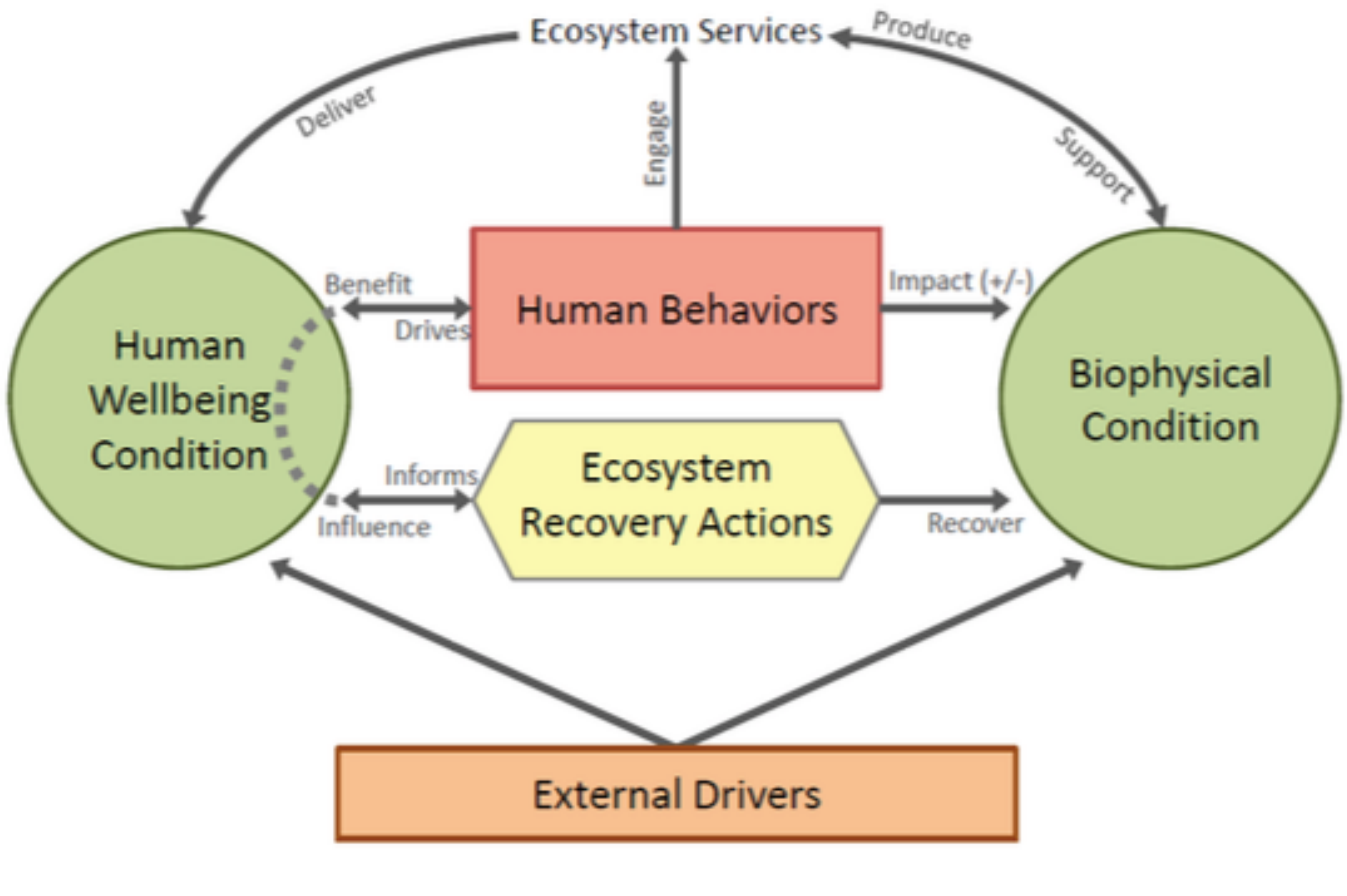
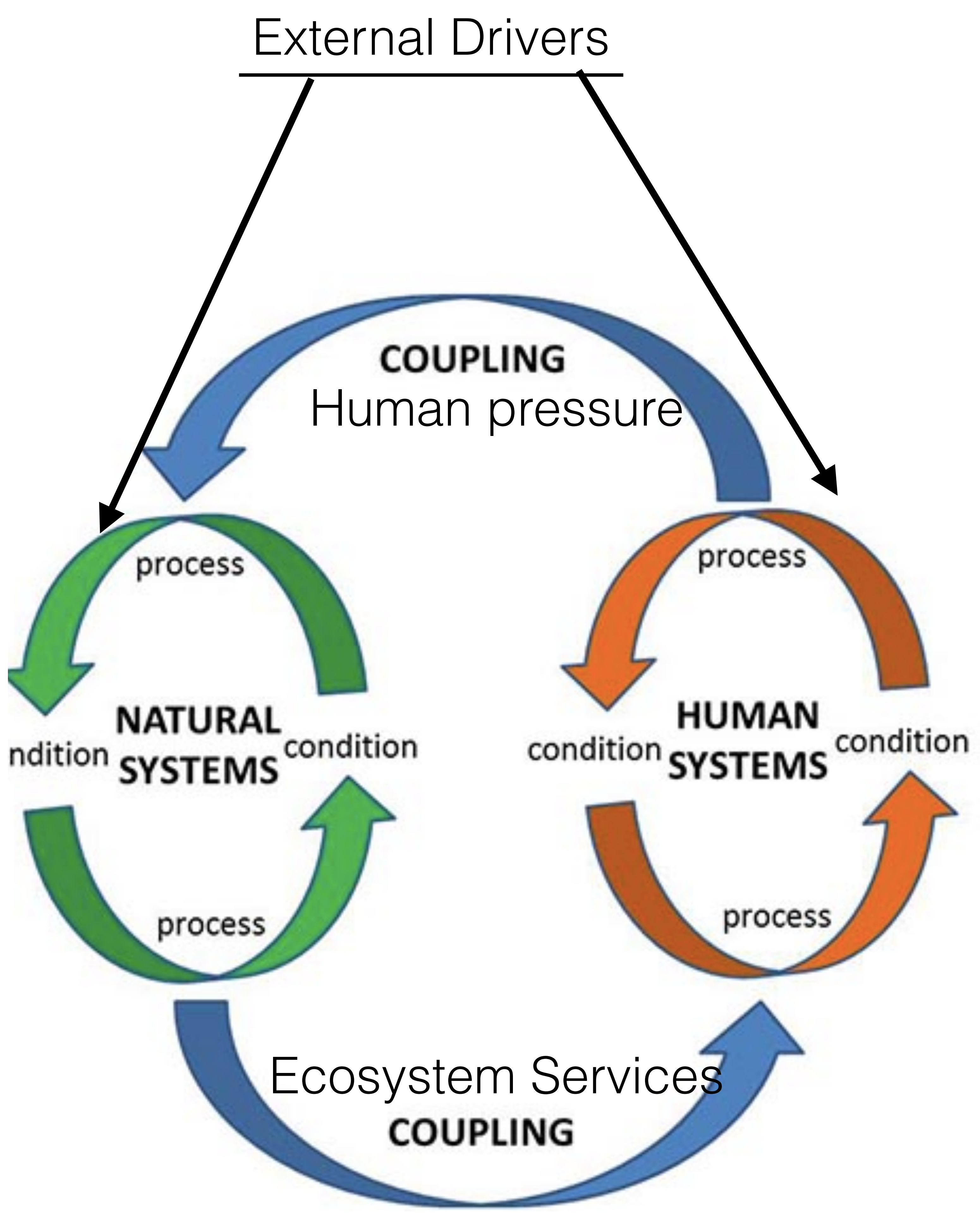


Figure 2: Integrated Conceptual Model for Ecosystem Recovery



https://www.eopugetsound.org/sites/default/files/files/PSP%20Integrated%20Conceptual%20Model%20for%20Ecosystem%20Recovery%20Report_2015-04-03_0.pdf

Ecosystem Services

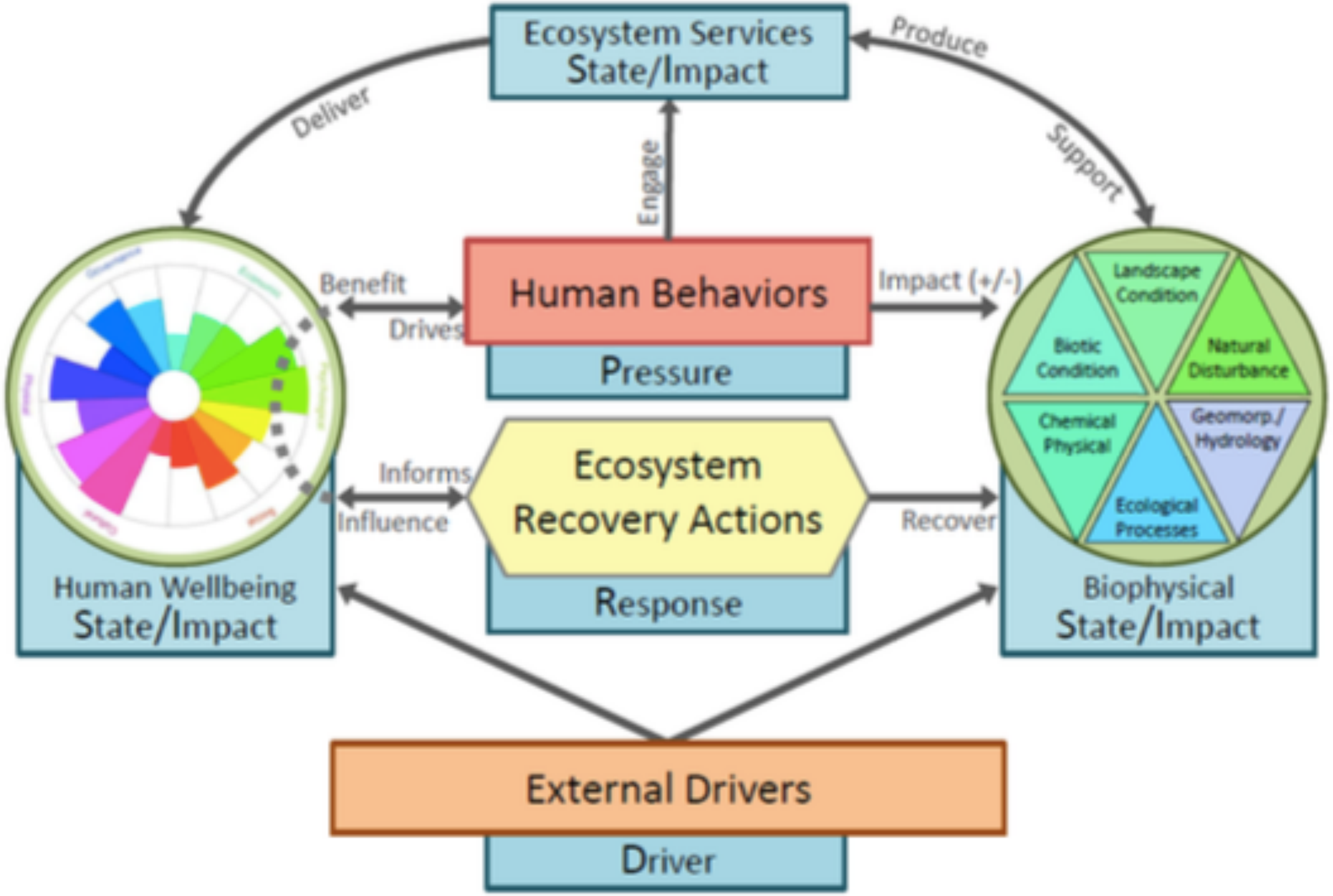


Figure 3: Integrated Conceptual Model for Ecosystem Recovery with DPSIR Framework. The Driver-Pressure-State-Impact-Response (DPSIR) framework is embedded within the new conceptual model (blue boxes). The Essential Ecosystem Attributes (EPA 2002) are shown within the biophysical condition (colored wedges), as well as the domains of human wellbeing (colored wedges; Biedenweg et al. 2014)

https://www.eopugetsound.org/sites/default/files/files/PSP%20Integrated%20Conceptual%20Model%20for%20Ecosystem%20Recovery%20Report_2015-04-03_0.pdf

Ecosystem Services

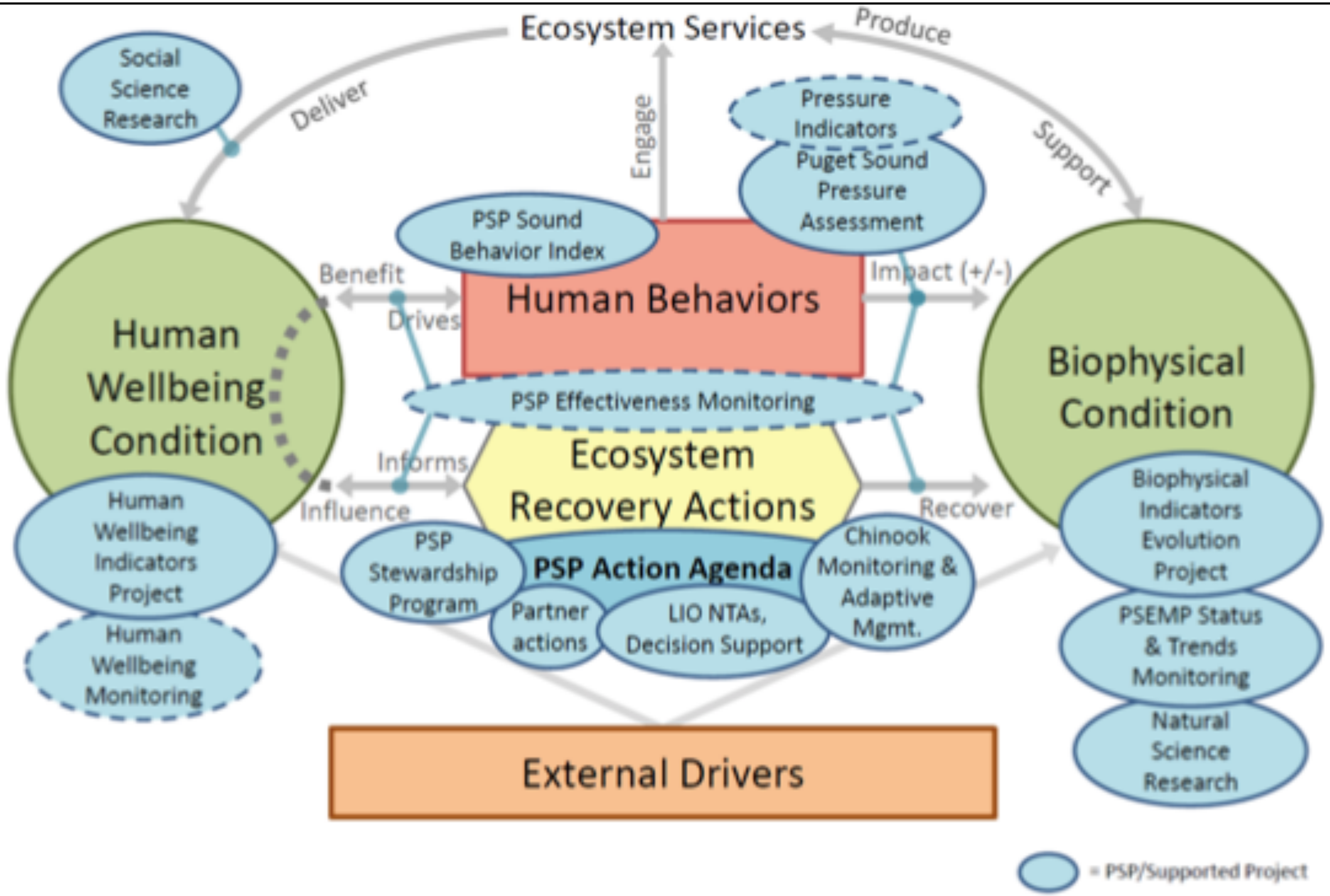


Figure 5: Integrated Conceptual Model for Ecosystem Recovery + PSP Projects and Programs. PSP programs and projects (blue ovals) are mapped to the conceptual model to illustrate where management, research and planning efforts are focused, and which components of the SES require more attention. The blue ovals with dotted outlines indicate projects that are in development.

https://www.eopugetsound.org/sites/default/files/files/PSP%20Integrated%20Conceptual%20Model%20for%20Ecosystem%20Recovery%20Report_2015-04-03_0.pdf

Ecosystem Services

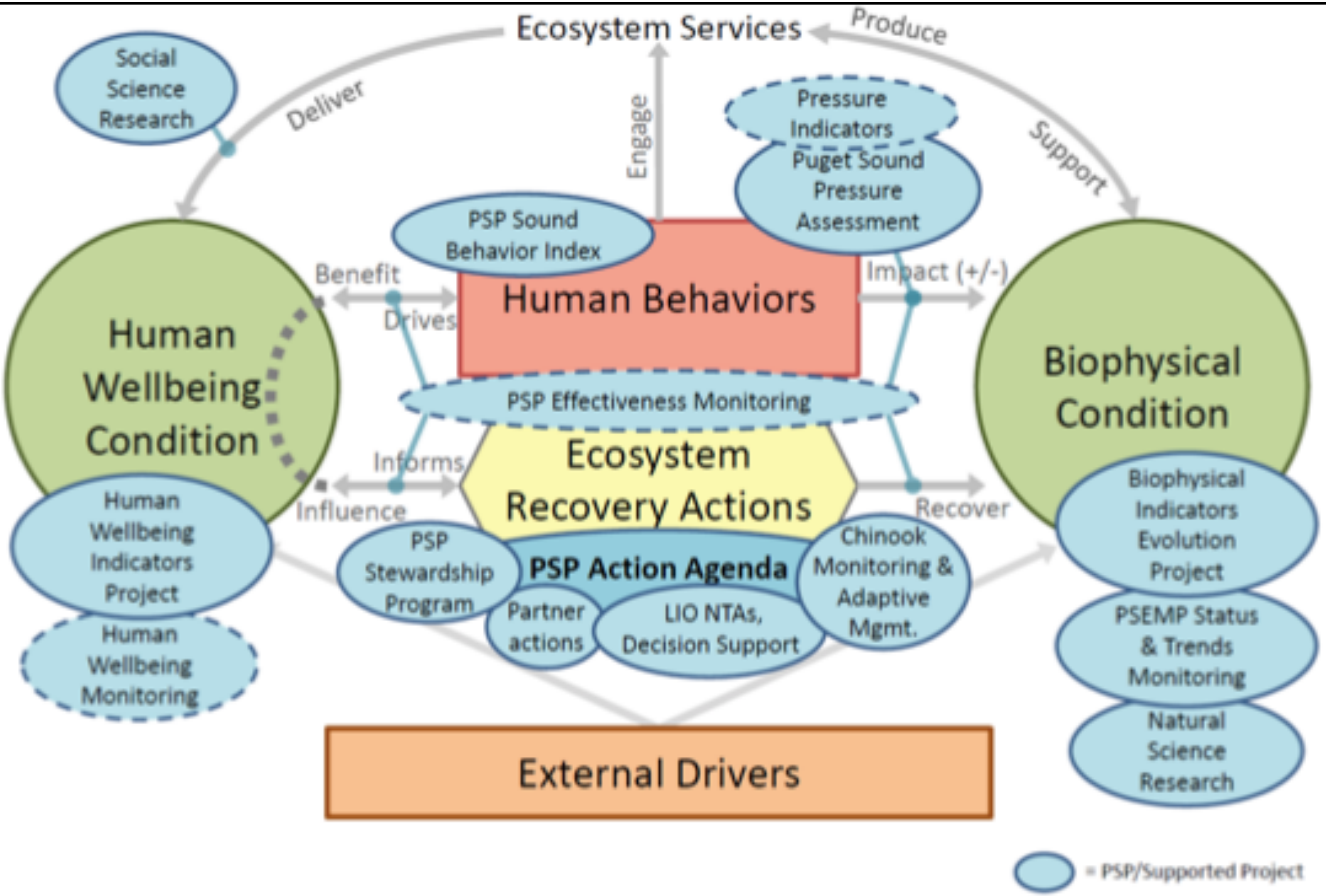


Figure 5: Integrated Conceptual Model for Ecosystem Recovery + PSP Projects and Programs. PSP programs and projects (blue ovals) are mapped to the conceptual model to illustrate where management, research and planning efforts are focused, and which components of the SES require more attention. The blue ovals with dotted outlines indicate projects that are in development.

https://www.eopugetsound.org/sites/default/files/files/PSP%20Integrated%20Conceptual%20Model%20for%20Ecosystem%20Recovery%20Report_2015-04-03_0.pdf

Ecosystem Services

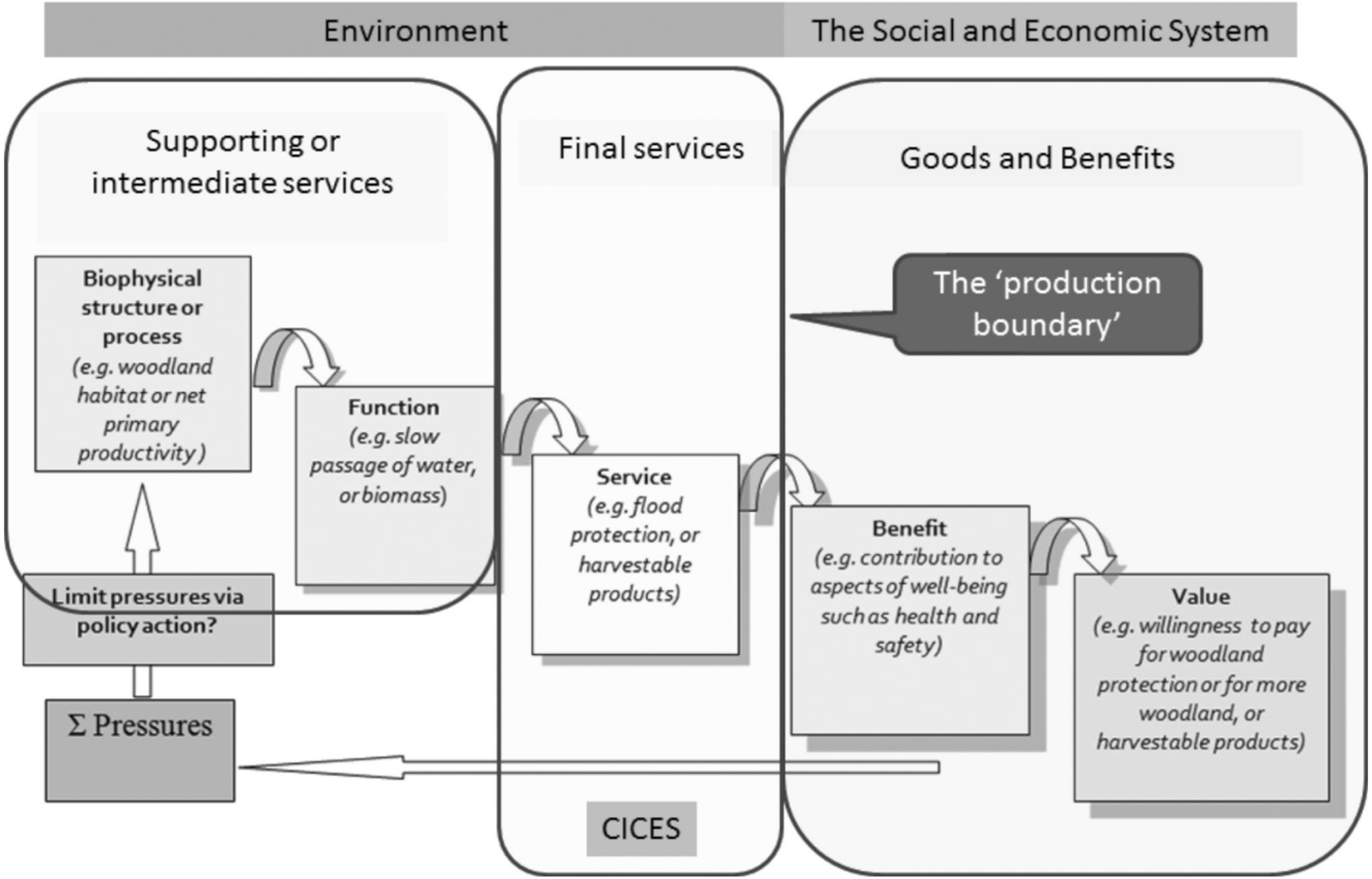
Ecosystem Services
Volume 29, Part C, February 2018, Pages 428-440

Understanding the role of conceptual frameworks: Reading the ecosystem service cascade

M. Potschin-Young [a], R. Haines-Young [a], C. Görg [b], U. Heink [c], K. Jax [c, d], C. Schleyer [b, e]
Show more

https://doi.org/10.1016/j.ecoser.2017.05.015 Get rights and content
Open Access funded by European Research Council

https://www.sciencedirect.com/science/article/pii/S221204161630523X



Ecosystem Services

Ecosystem Services
Volume 29, Part C, February 2018, Pages 428-440

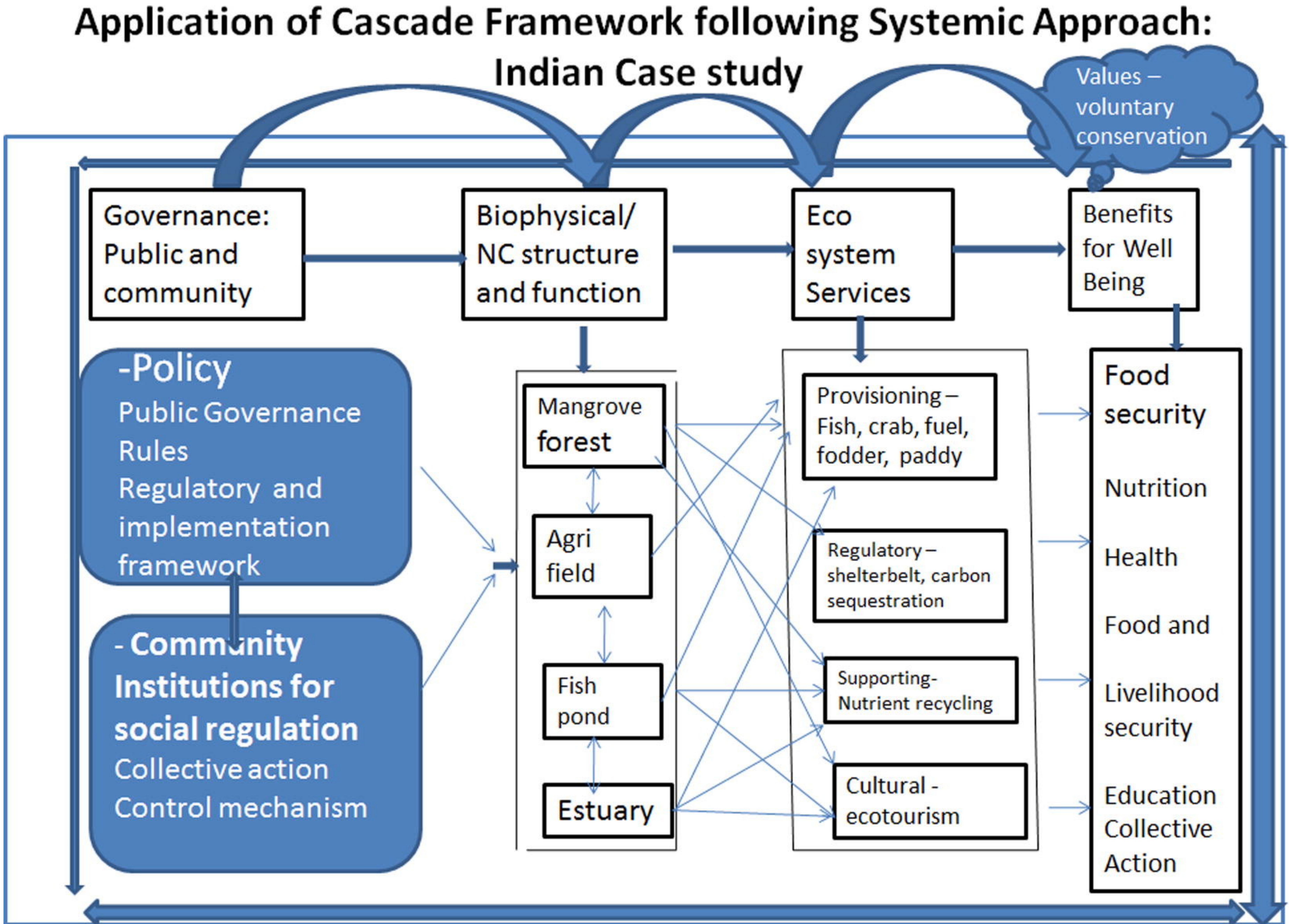
Understanding the role of conceptual frameworks: Reading the ecosystem service cascade

M. Potschin-Young [a], R. Haines-Young [a], C. Görg [b], U. Heink [c], K. Jax [c, d], C. Schleyer [b, e]

Show more

https://doi.org/10.1016/j.ecoser.2017.05.015 Get rights and content

Open Access funded by European Research Council



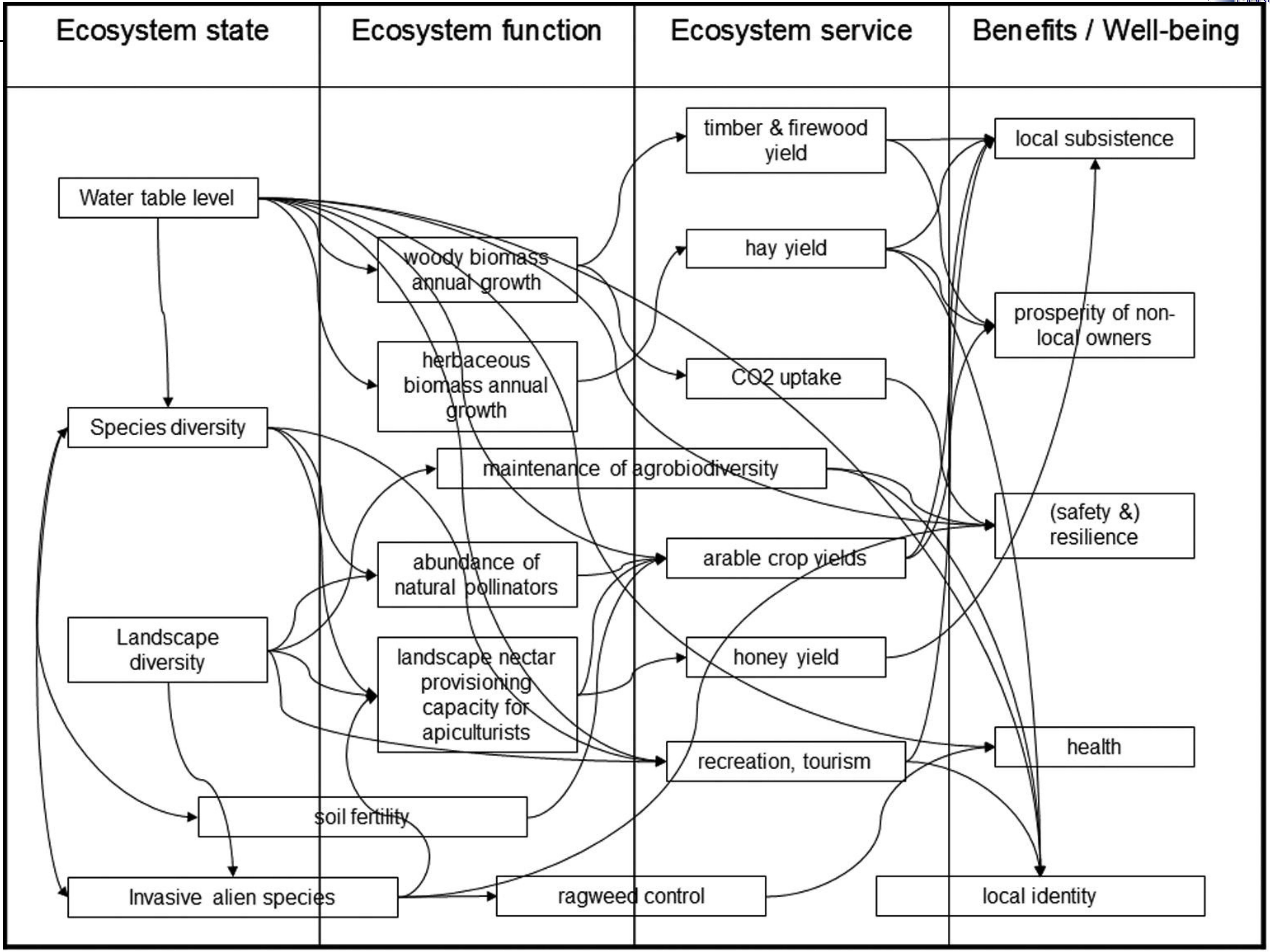
Ecosystem Services

Ecosystem Services
Volume 29, Part C, February 2018, Pages 428-440

Understanding the role of conceptual frameworks: Reading the ecosystem service cascade

M. Potschin-Young [a], R. Haines-Young [a], C. Görg [b], U. Heink [c], K. Jax [c, d], C. Schleyer [b, e]
Show more

https://doi.org/10.1016/j.ecoser.2017.05.015 Get rights and content
Open Access funded by European Research Council



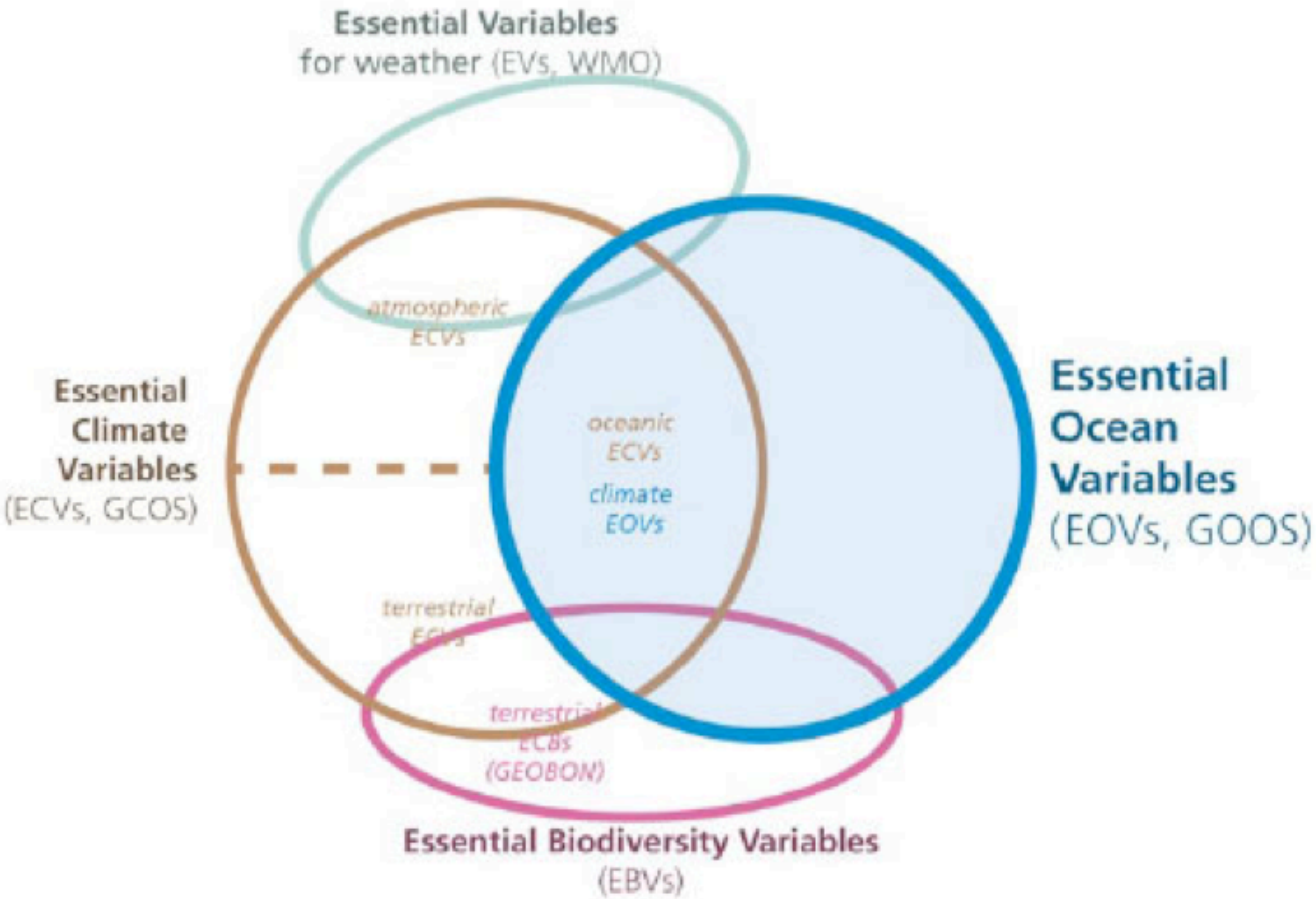
Essential Variables

An important concept for system assessment and observations is that of "Essential Variables."

Different communities have different definitions of what an Essential Variable (EV) is.

Here: EVs are "a minimal set of variables that determine the system's state and developments, are crucial for predicting system developments, and allow us to define metrics that measure the trajectory of the system."

Essential Variables



Essential Variables

Table 4 List of Essential Biodiversity Variables

EBV class	EBV candidate
Genetic composition	Co-ancestry
	Allelic diversity
	Population genetic differentiation
	Breed and variety diversity
Species populations	Species distribution
	Population abundance
	Population structure by age/size class
Species traits	Phenology
	Body mass
	Natal dispersion distance
	Migratory behavior
	Demographic traits
	Physiological traits
Community composition	Taxonomic diversity
	Species interactions
Ecosystem function	Net primary productivity
	Secondary productivity
	Nutrient retention
	Disturbance regime
Ecosystem structure	Habitat structure
	Ecosystem extent and fragmentation
	Ecosystem composition by functional type

Essential Variables

BIOLOGICAL REVIEWS
Cambridge Philosophical Society
Biol. Rev. (2018), **93**, pp. 600–625. 600
doi: 10.1111/brv.12359

Building essential biodiversity variables (EBVs) of species distribution and abundance at a global scale

W. Daniel Kissling[1,*], Jorge A. Ahumada[2], Anne Bowser[3], Miguel Fernandez[4,5,6], Néstor Fernández[4,7], Enrique Alonso García[8], Robert P. Guralnick[9], Nick J. B. Isaac[10], Steve Kelling[11], Wouter Los[1], Louise McRae[12], Jean-Baptiste Mihoub[13,14], Matthias Obst[15,16], Monica Santamaria[17], Andrew K. Skidmore[18], Kristen J. Williams[19], Donat Agosti[20], Daniel Amariles[21,22], Christos Arvanitidis[23], Lucy Bastin[24,25], Francesca De Leo[17], Willi Egloff[20], Jane Elith[26], Donald Hobern[27], David Martin[19], Henrique M. Pereira[4,5], Graziano Pesole[17,28], Johannes Peterseil[29], Hannu Saarenmaa[30], Dmitry Schigel[27], Dirk S. Schmeller[13,31], Nicola Segata[32], Eren Turak[33,34], Paul F. Uhlir[35], Brian Wee[36] and Alex R. Hardisty[37]

EBVs can be considered to be biological state variables with three key dimensions (time, space, and biological organization) that are critical to document biodiversity change accurately.

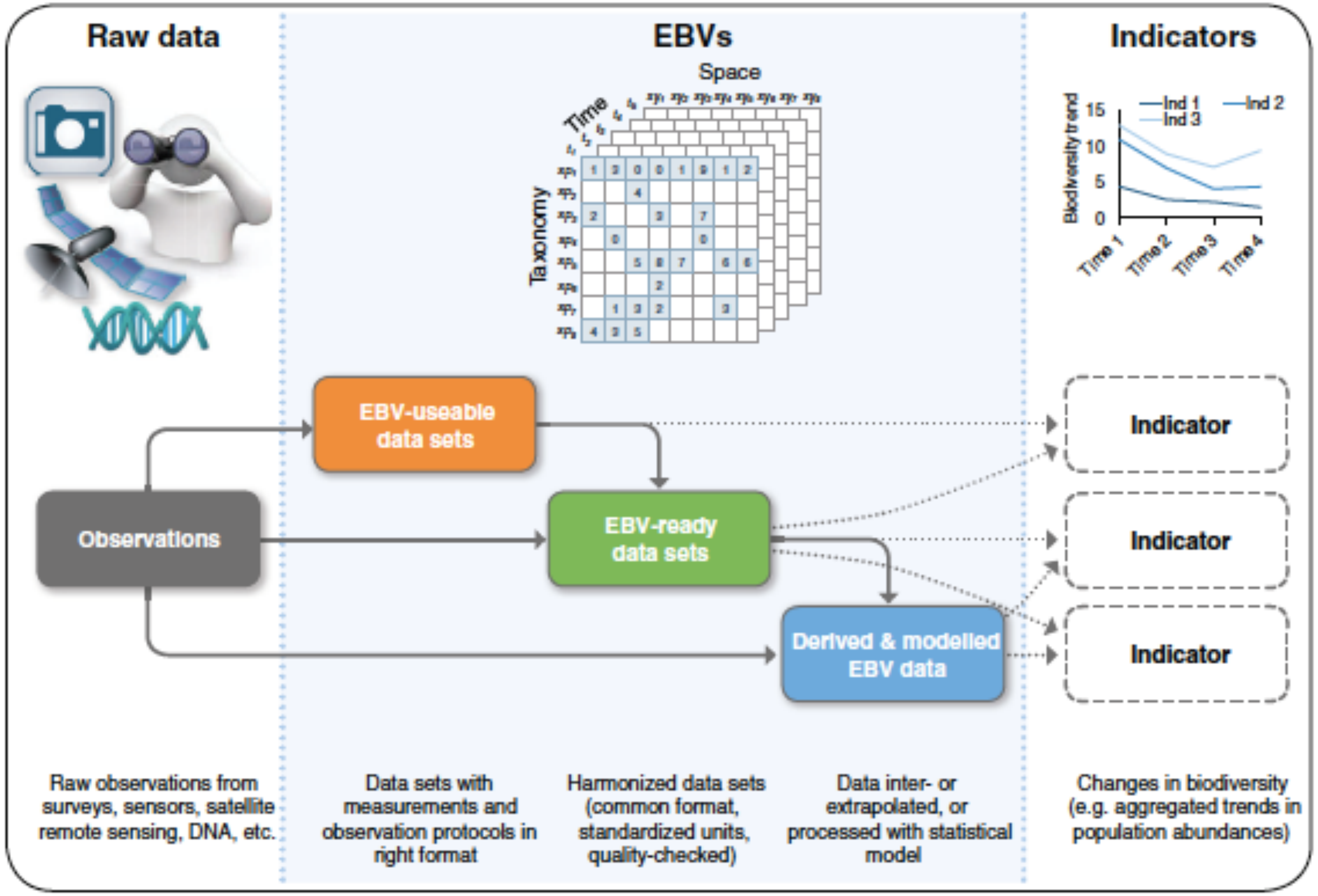


Fig. 1. Essential Biodiversity Variables (EBVs) are part of an information supply chain, conceptually positioned between raw data (i.e. primary data observations) and indicators (i.e. synthetic indices for reporting biodiversity change to policy and management). They can be illustrated as a data cube with three basic dimensions (taxonomy, time and space), covering different species (sp_1, sp_2, ...) at different points in time (t_1, t_2, ...) and different locations (xy_1, xy_2, ...). From the observations (i.e. sampling of raw data), different EBV data products can be obtained with different steps of data processing. We here distinguish EBV-useable data sets, EBV-ready data sets and derived and modelled EBV data. They represent measurements with comparable measurement units or similar observation protocols (EBV-useable data sets), harmonized data sets (EBV-ready data sets) and data products derived from processing data with statistical models (derived and modelled EBV data). These EBV data products can be used in various ways to derive indicators (Ind 1, Ind 2, ...) that quantify spatiotemporal changes in species distributions and population abundances or other aspects of biodiversity. The four images under raw data are freely available at http://www.clipartpanda.com

Essential Variables

BIOLOGICAL REVIEWS
Cambridge Philosophical Society
Biol. Rev. (2018), **93**, pp. 600–625.
doi: 10.1111/brv.12359
600

Building essential biodiversity variables (EBVs) of species distribution and abundance at a global scale

W. Daniel Kissling[1,*], Jorge A. Ahumada[2], Anne Bowser[3], Miguel Fernandez[4,5,6], Néstor Fernández[4,7], Enrique Alonso García[8], Robert P. Guralnick[9], Nick J. B. Isaac[10], Steve Kelling[11], Wouter Los[1], Louise McRae[12], Jean-Baptiste Mihoub[13,14], Matthias Obst[15,16], Monica Santamaria[17], Andrew I
Kristen J. Williams[19], Donat Agosti[20], Daniel Amari
Lucy Bastin[24,25], Francesca De Leo[17], Willi Egloff[20],
David Martin[19], Henrique M. Pereira[4,5], Graziano I
Hannu Saarenmaa[30], Dmitry Schigel[27], Dirk S. Sch
Eren Turak[33,34], Paul F. Uhlir[35], Brian Wee[36] and

Table 1. Examples of key dimensions, attributes and uncertainties related to Essential Biodiversity Variables (EBVs) of species distribution and population abundance

	EBV attributes			
Dimension	Extent	Resolution	Measurement units	Uncertainties
Space	Geographical coverage (e.g. of grid cells, sampling locations, satellites, etc.)	Spatial resolution (e.g. grid cell size, polygons, resolution of satellite sensors, volume, etc.)	Meters, cubic meters, kilometers, degrees, etc.	Precision and accuracy of coordinates and volumes, wrongly recorded coordinates, imprecise sampling locations
Time	Temporal coverage (e.g. length of time series, continuous recording, time period of collection of records, etc.)	Temporal grain (e.g. date or time window of sampling, sampling frequency)	Hours, days, weeks, months, years, decades, etc.	Variation in length of time series, precision of time of collection, etc.
Taxonomy	Taxonomic coverage (e.g. how many and which species are documented)	Species, genus, higher taxonomic level, etc.	Taxonomic entity for which species distribution and abundance data are sampled	Identification and observation uncertainty, ambiguous scientific names, synonyms, differences in taxon concepts, etc.

Essential Variables

BIOLOGICAL
REVIEWS

Biol. Rev. (2018), **93**, pp. 600–625.
doi: 10.1111/brv.12359

Building essential biodiversity (EBVs) of species distribution at a global scale

W. Daniel Kissling[1,*], Jorge A. Ahumada[2], Anne Bowser
Néstor Fernández[4,7], Enrique Alonso García[8], Robert P.
Steve Kelling[11], Wouter Los[1], Louise McRae[12], Jean-Ba
Matthias Obst[15,16], Monica Santamaria[17], Andrew K. Sk
Kristen J. Williams[19], Donat Agosti[20], Daniel Amariles[21
Lucy Bastin[24,25], Francesca De Leo[17], Willi Egloff[20], Jane
David Martin[19], Henrique M. Pereira[4,5], Graziano Pesol
Hannu Saarenmaa[30], Dmitry Schigel[27], Dirk S. Schmelle
Eren Turak[33,34], Paul F. Uhlir[35], Brian Wee[36] and Ale

Table 2. Ideal *versus* minimum requirements of Essential Biodiversity Variables (EBVs) data in relation to species distribution and abundance measurements and their spatial, temporal and taxonomic extent and resolution

EBV dimensions and attributes	Ideal requirements	Minimum requirements
Species distribution and abundance measurements	Presence–absence and density of individuals derived from widely accepted, standardized or explicit sampling protocols, including quantification of uncertainty and recording sampling covariates	Presence-only or (relative, qualitative or ordinal) density estimates across space and time based on raw observations or modelling but only if derived from widely accepted protocols with consistency across space/time
Spatial extent	Global coverage, with the capacity to provide high-quality information for global assessments (e.g. Aichi targets, Sustainable Development Goals)	Adequate spatial coverage to provide reliable information on biodiversity trends for policy decision making (e.g. at regional or national level)
Spatial resolution	Fine-scale estimates of population abundance across subnational (e.g. a protected area), national, regional/continental and global extent	Statistically driven design that allows combining scattered, high-quality information at the scale of policy or management interest (e.g. national extent)
Temporal extent	Continuous long-term time series of abundance or occupancy over several decades suitable to assess potential biodiversity change	Repeated measurements at policy-relevant time intervals to differentiate between fluctuations and trends, including a baseline
Temporal resolution	Temporal resolution (hours, days, weeks, months, years) that is adequate to detect population dynamics for a specific taxon	Reliable species distribution and abundance estimates for at least two time slices at the same spatio-temporal resolution, with relevance to policy and/or management
Taxonomic extent	Maximum possible number of species covering a wide variety of taxa and life forms, and providing information on various dimensions of global change and different ecosystem functions and services	Selected species representing particular taxonomic or functional groups, representative of overall diversity and environments within spatial extent
Taxonomic resolution	Updating compilations of taxonomic names and associated concepts of all species and their synonyms	Clearly defined taxonomic units following known taxonomic authorities

Essential Variables

BIOLOGICAL REVIEWS
Cambridge Philosophical Society
Biol. Rev. (2018), **93**, pp. 600–625.
doi: 10.1111/brv.12359

Building essential biodiversity var
(EBVs) of species distribution and
at a global scale

W. Daniel Kissling[1,*], Jorge A. Ahumada[2], Anne Bowser[3], Migu
Néstor Fernández[4,7], Enrique Alonso García[8], Robert P. Guraln
Steve Kelling[11], Wouter Los[1], Louise McRae[12], Jean-Baptiste M
Matthias Obst[15,16], Monica Santamaria[17], Andrew K. Skidmore
Kristen J. Williams[19], Donat Agosti[20], Daniel Amariles[21,22], Chri
Lucy Bastin[24,25], Francesca De Leo[17], Willi Egloff[20], Jane Elith[26]
David Martin[19], Henrique M. Pereira[4,5], Graziano Pesole[17,28], J
Hannu Saarenmaa[30], Dmitry Schigel[27], Dirk S. Schmeller[13,31],
Eren Turak[33,34], Paul F. Uhlir[35], Brian Wee[36] and Alex R. Ha

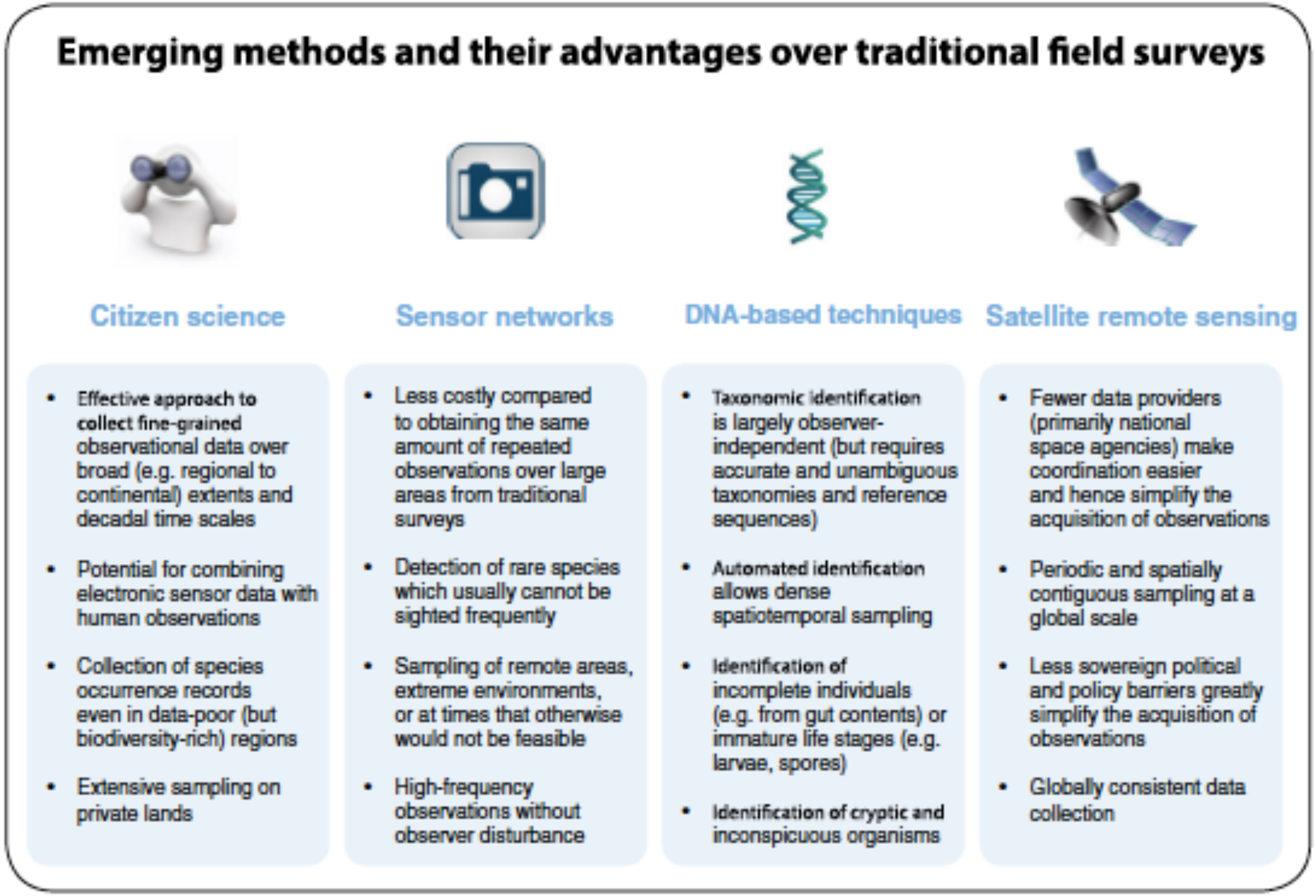
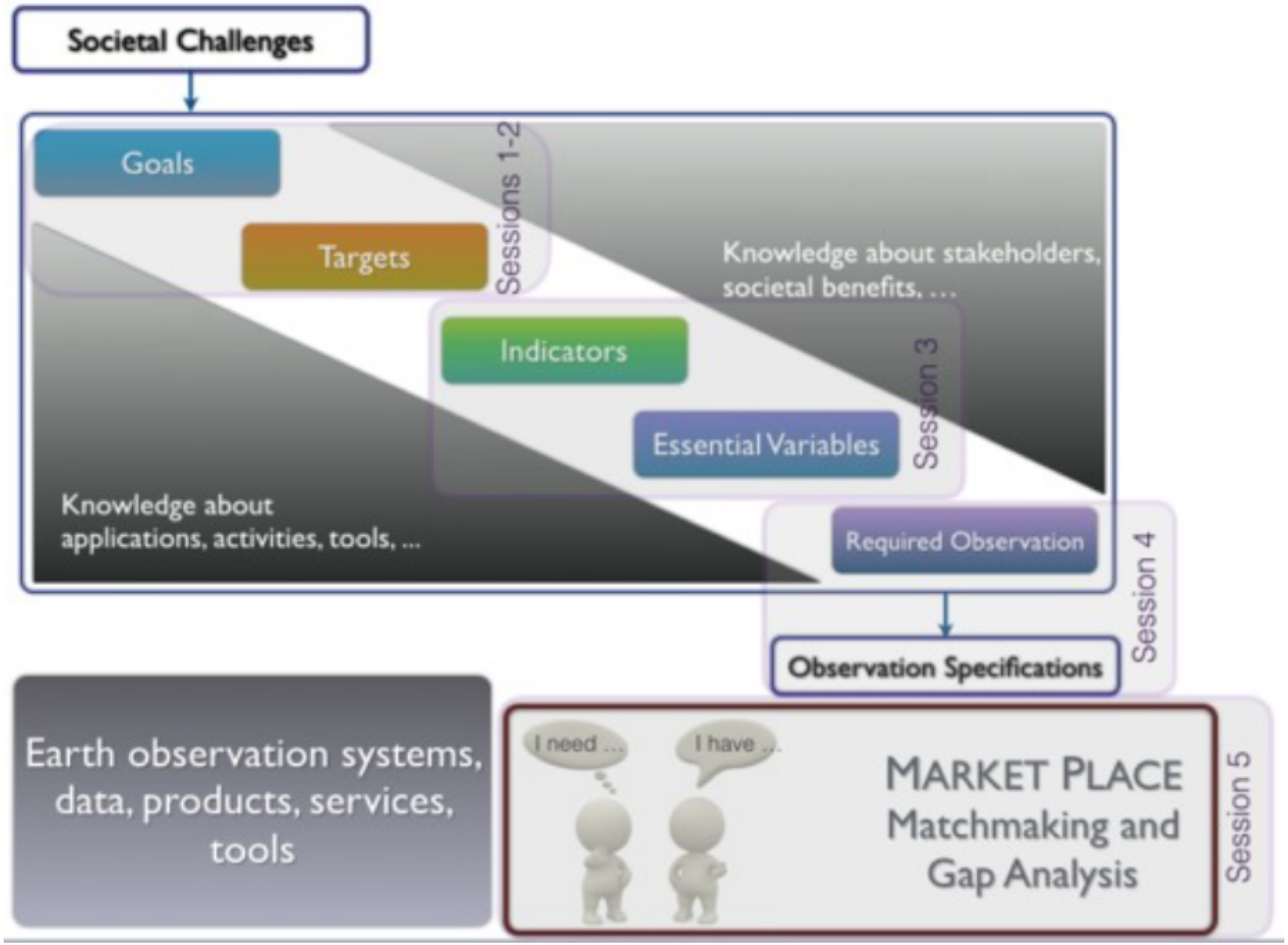


Fig. 2. Emerging methods and technologies for data collection include citizen science, sensor networks, DNA-based techniques and satellite remote sensing. They have several advantages over traditional *in situ* field surveys for collecting species distribution and abundance data. The images are freely available at http://www.clipartpanda.com



The workshop program was informed by a design-based approach to **participatory modeling** developed by Plag et al. (2016). The opening session and the first two subsequent session focussed on creating a **joint understanding of the challenges** as well as the goals, targets and indicators. Session 3 was intended to identify a subset of **essential variables** for both the development of policies to achieve the targets and to quantify the indicators. The intended outcome of Session 4 was a set of **observational requirements** that could either be **matched** in Session 5 to existing products or identified as gaps. Modified from Plag et al. (2016).

Essential Variables

Current Opinion in Environmental Sustainability
Volumes 26–27, June 2017, Pages 97-105

Essential Variables help to focus Sustainable Development Goals monitoring

Belinda Reyers [1, 2, 3], Mark Stafford-Smith [4, 2], Karl-Heinz Erb [5], Robert J Scholes [6], Odirilwe Selomane [3, 7]

⊞ Show more

https://doi.org/10.1016/j.cosust.2017.05.003

Get rights and content

EVs are the minimum set of variables required to characterise change in a system.

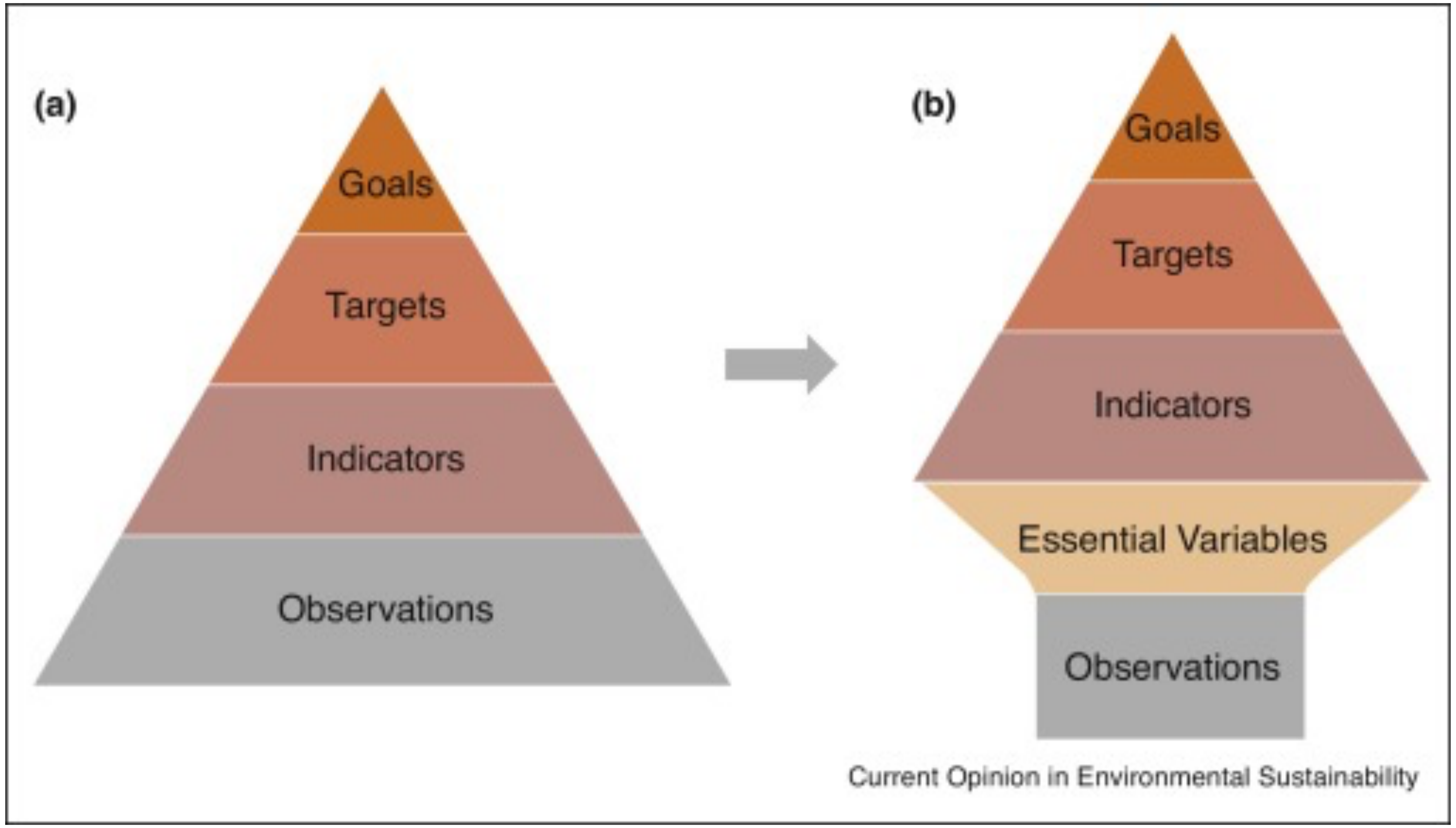


Figure 1. The introduction of Essential Variables (EV) as a layer between primary observations and indicators can transform the shape of monitoring systems from (a) an ever-broadening pyramid to (b) a more streamlined form. In (b) a limited number of EVs, directing a targeted set of repeatable and universal observations, underpin a changing superstructure of policy-relevant indicators, targets and goals. The EV layer insulates the observation levels from the changing policy priorities, and makes the policy indicators independent of the observational platform. It further harnesses systems understanding so that a single EV capturing a key process or structure can potentially contribute to multiple indicators, while similarly 2 or more EVs can direct and use the same primary observations, thus potentially enabling a reduction in the numbers of observations needed to deliver those indicators.

Essential Variables

Current Opinion in Environmental Sustainability
Volumes 26–27, June 2017, Pages 97-105

Essential Variables help to focus Sustainable Development Goals monitoring

Belinda Reyers [1, 2, 3], Mark Stafford-Smith [4, 2], Karl-Heinz Erb [5], Robert J Scholes [6], Odirilwe Selomane [3, 7]

Show more

https://doi.org/10.1016/j.cosust.2017.05.003
Get rights and content

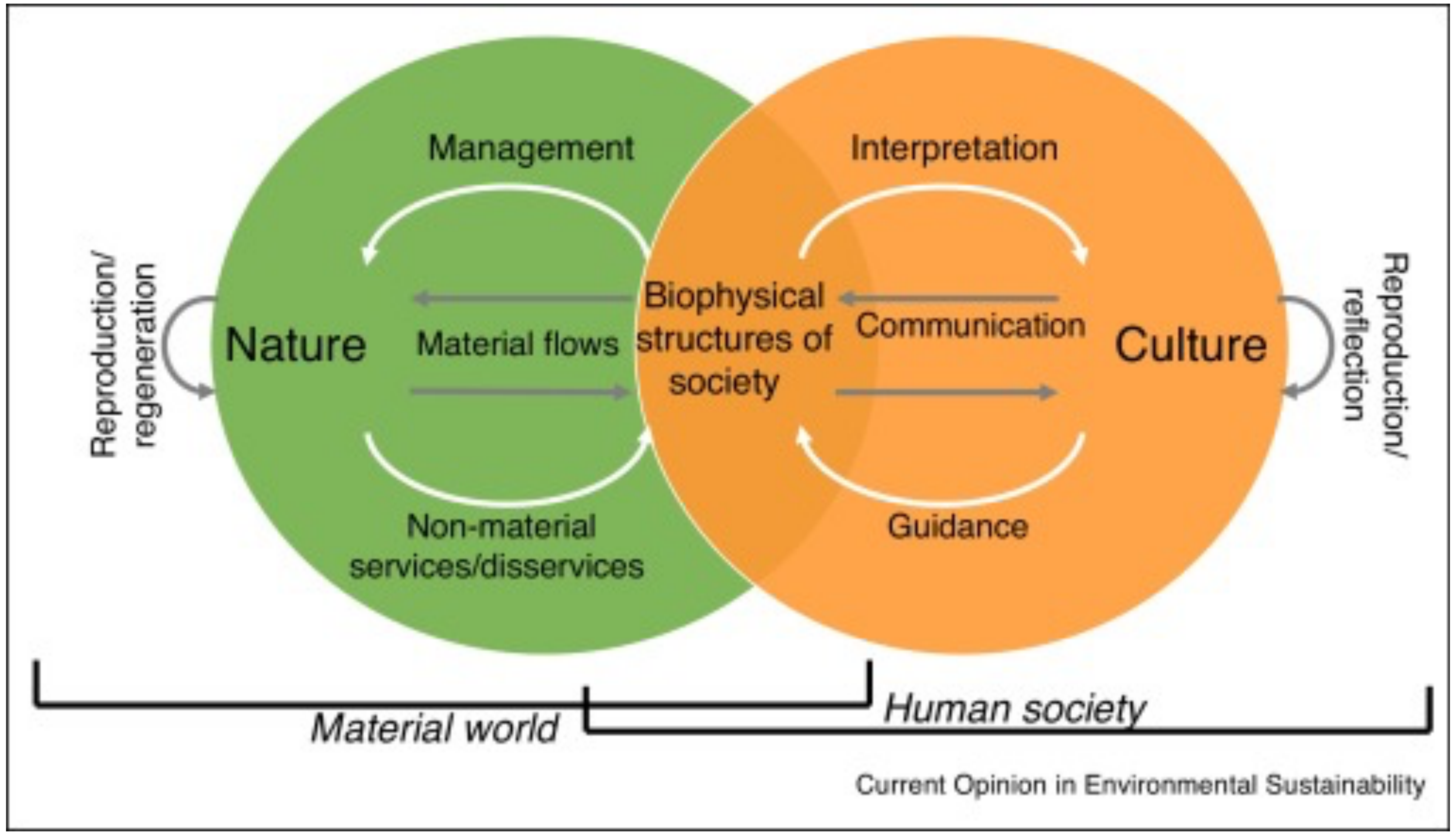


Figure 2. An integrated socialsocial--ecological systems model [53,56] based on an explicit theory of social–ecological coevolution of nature and culture. Nature and culture are linked through the flow of material and non-material effects (and feedbacks) that occurs between nature and biophysical structures of society. The biophysical structures of society include the human population, the built environment, as well as other material assets (*e.g.* livestock) that determine access to services and distribution of benefits and wellbeing. These flows are co-determined by natural and social processes, and are shaped by the cultural system of laws, norms, values, knowledge and beliefs. The links between the biophysical and cultural systems of society are mediated by ‘communication’, that is the reflexive processes of information exchange, interpretation, and understanding which can include legal, economic and monetary processes. Communication allows for the development of practices and institutions, reflection and adaptive learning that guides decisions and actions in the biophysical realm, with resultant impacts on natural processes. Agreeing on a useful (though not necessarily prescriptive) conceptual model of this nature is a key step in developing ESDGVs.

Essential Variables

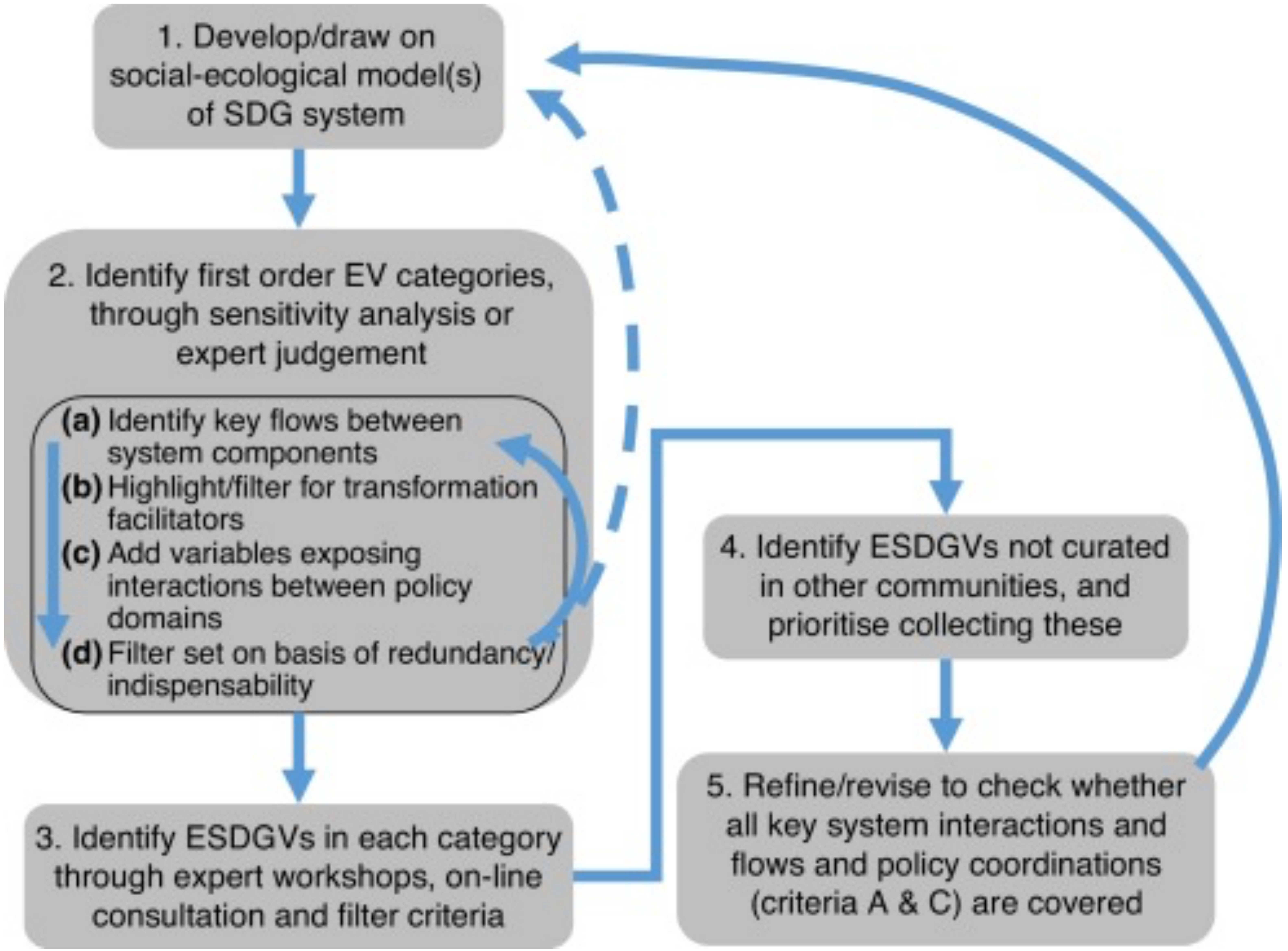
Current Opinion in Environmental Sustainability
Volumes 26–27, June 2017, Pages 97-105

Essential Variables help to focus Sustainable Development Goals monitoring

Belinda Reyers [1, 2, 3], Mark Stafford-Smith [4, 2], Karl-Heinz Erb [5], Robert J Scholes [6], Odirilwe Selomane [3, 7]

⊞ Show more

https://doi.org/10.1016/j.cosust.2017.05.003 Get rights and content



Essential Variables

Current Opinion in Environmental Sustainability
Volumes 26–27, June 2017, Pages 97-105

Essential Variables help to focus Sustainable Development Goals monitoring

Belinda Reyers [1, 2, 3], Mark Stafford-Smith [4, 2], Karl-Heinz Erb [5], Robert J Scholes [6], Odirilwe Selomane [3, 7]

Show more

https://doi.org/10.1016/j.cosust.2017.05.003 Get rights and content

Table 1. List of acronyms describing Essential Variable types including their status of development

Acronym	Description	Status
EV	Essential Variables	
ECV	Essential Climate Variables	Existing
EBV	Essential Biodiversity Variables	Existing
EOV	Essential Ocean Variables	Existing
ESocV	Essential Social Variables	Some existing, but not described as such
ExxV	Essential Variables for missing domains	Proposed for domains not yet thinking in this way that may need collecting under SDGs
ESDGV	Essential Sustainable Development Goal Variables	Proposed entire set of EVs for the SDGs
core ESDGV	Core Essential Sustainable Development Goal Variables	Proposed core set of EVs not collected within sectors, focused on sectoral interactions, transformations and in the social-ecological interface.

Essential Variables

Current Opinion in Environmental Sustainability
Volumes 26–27, June 2017, Pages 97-105

Essential Variables help to focus Sustainable Development Goals monitoring

Belinda Reyers [1, 2, 3], Mark Stafford-Smith [4, 2], Karl-Heinz Erb [5], Robert J Scholes [6], Odirilwe Selomane [3, 7]

Show more

https://doi.org/10.1016/j.cosust.2017.05.003

Get rights and content

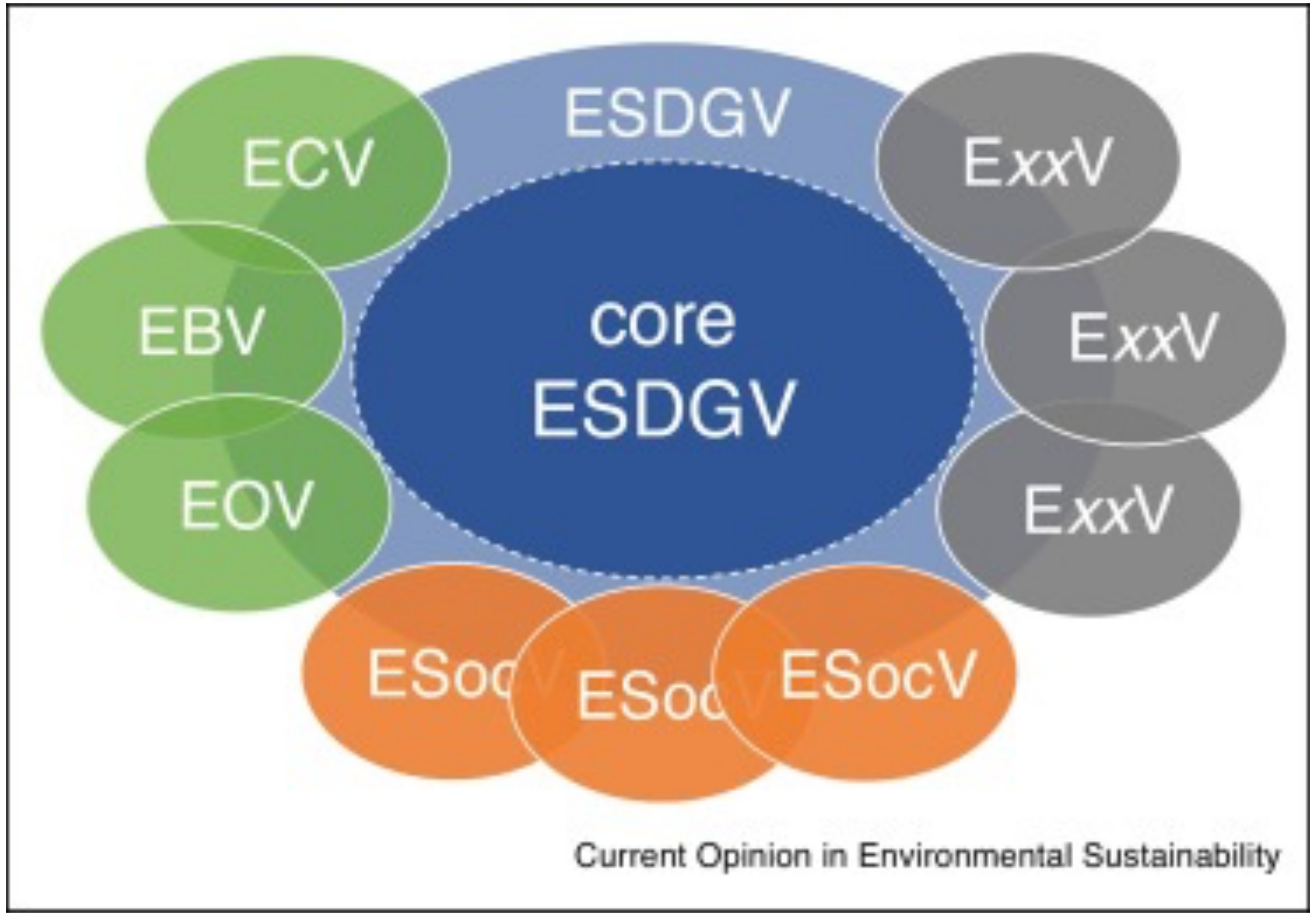


Figure 3. Various areas of global policy development are defining their own Essential Variables (in green), including some social variables (ESocV—in orange) that do not use this terminology (*e.g.* for poverty, inequality and economic performance). Additional Essential Variables for sectors not yet thinking this way may need collecting under the SDGs (ExxV—in grey). The total set of Essential Sustainable Development Goal Variables (ESDGV—in blue) would draw on and initiate some of these domain-specific Essential Variables (outside dashed circle), while the core set of ESDGV (inside dashed circle) would focus on Essential Variables not collected elsewhere by specific sectors, that support transformations, interactions and coordination among the domains that might otherwise be missed.

Sustainability Leadership

Class 4:

Part 1: Systems

- Systems, System Theory and System of Systems
- Ecosystem Services
- Essential Variables

Part 2: Hazards