Sustainability Leadership

Class 4:
Part 1: Systems
• Systems, System Theory and System of Systems
• Ecosystem Services
• Essential Variables
Part 2: Hazards
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.


Systems and System Theory
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- open systems: interact with the environment;
- closed systems: does not interact and is not impacted by the environment
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Almost all systems are open systems.
Systems and System Theory

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

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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.

Systems and System Theory

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.
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
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.

Systems

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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 visualize 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.
The respiratory system exchanges gases with the environment.

The system of systems aims to maintain a homeostasis.
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 (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)
Systems of Systems

![Diagram of Systems of Systems](image)
Systems of Systems

Are coupled systems a system of systems?
Are coupled systems a system of systems? Depends on the level of integration.
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.

**System of Systems**

- **Socio-economic System**: e.g., bringing ecosystem services into economic accounting

**Earth's Life Support System**
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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

Is this a system model?
Ecosystem Services

Is this a system model?

Figure 2: Integrated Conceptual Model for Ecosystem Recovery

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).

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.
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.
Ecosystem Services

Application of Cascade Framework following Systemic Approach: Indian Case study

Governance: Public and community

- Policy
  Public Governance
  Rules
  Regulatory and implementation framework

- Community Institutions for social regulation
  Collective action
  Control mechanism

Biophysical/NC structure and function

Ecosystem Services

Mangrove forest

Agri field

Fish pond

Estuary

Provisioning – Fish, crab, fuel, fodder, paddy

Regulatory – shelterbelt, carbon sequestration

Supporting - Nutrient recycling

Cultural - ecotourism

Benefits for Well Being

Food security

Nutrition

Health

Food and

Livelihood security

Education Collective Action

Values – voluntary conservation

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

Ecosystem Services

Understanding the role of conceptual frameworks: Reading the ecosystem service cascade
M. Padoch-Young, R. R. Harrew-Young, C. Gómez, U. Heink, K. Jan, C. Schleyer


Ecosystem state

- Water table level
- Species diversity
- Landscape diversity
- Soil fertility
- Invasive alien species

Ecosystem function

- Woody biomass annual growth
- Herbaceous biomass annual growth
- Maintenance of agrobiodiversity
- Abundance of natural pollinators
- Landscape nectar provisioning capacity for apiculturists
- Soil fertility

Ecosystem service

- Timber & firewood yield
- Hay yield
- CO2 uptake
- Abundance of natural pollinators
- Landscape nectar provisioning capacity for apiculturists

Benefits / Well-being

- Local subsistence
- Prosperity of non-local owners
- Health
- Local identity
- Recreation, tourism
- Honey yield
- Arable crop yields
- (Safety &) resilience
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 for weather (EVs, WMO)
- Essential Climate Variables (ECVs, GCOS)
- Essential Ocean Variables (EOVs, GOOS)
- Essential Biodiversity Variables (EBVs)
## Essential Variables

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

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

W. Daniel Kissling1,*, Jorge A. Ahumada2, Anne Bowser3, Miguel Fernandez1,3,5, Néstor Fernández2,4, Enrique Alonso García8, Robert P. Guralnick9, Nick J. B. Isaac10, Steve Kelling11, Wouter Lou1, Louise McRae12, Jean-Baptiste Milhoub13,14, Matthias Obst15,16, Monica Santamaria17, Andrew Kristen J. Williams19, Donat Agosti20, Daniel Amar21, Lucy Bastin22,23, Francesca De Leo17, Willi Egeöff20, David Martin19, Henrique M. Pereira3,5, Graziano Hannu Saarenmaa24, Dmitry Schigel21, Dirk S. Sch Eren Turak25,31, Paul F. Uhlir25, Brian Wec26,32 and

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

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

W. Daniel Kissling1,4, Jorge A. Ahumada2, Anne Bowser3, Nestor Fernandez3,1, Enrique Alonso Garcia8, Robert P. Steve Kelling11, Wouter Leo4, Louise McRae12, Jean-Ita Matthias Obst15,16, Monica Santamarino17, Andrew K. S. Kristen J. Williams19, Donat Agosti20, Daniel Amariles21, Lucy Bastin24,25, Francesca De Leo17, Willi Egloff30, Jan David Martin19, Henrique M. Pereira4,5, Graziano Pesol Hannu Saarenmaa30, Dmitry Schigel17, Dirk S. Schmell31, Eren Turak33,34, Paul F. Uhlir35, Brian Wec36 and Ale
Building essential biodiversity variables (EBVs) of species distribution and at a global scale

W. Daniel Kissling1,*, Jorge A. Ahumada2, Anne Bowser3, Miguél Néstor Fernández-Camacho4, Enrique Alonso García5, Robert P. Guraln6 Steve Kelling7, Wouter Lo4, Louise McRae12, Jean-Baptiste M. Matthias Obst15,16, Monica Santamaria17, Andrew K. Skidmore18, Kristen J. Williams19, Donat Agosti20, Daniel Amarile21,22, Chr. Lucy Bastin24,25, Francesca De Loro17, Willi Egloff18, Jane Elith28 David Martin19, Henrique M. Pereira3,4, Graziano Pesole17,28,29 Hannu Saarenmaa10, Dmitry Schigef27, Dirk S. Schnelle4,13,14,17 Eren Turak23,31, Paul F. Uhlir33, Brian Wex35 and Alex R. Ha
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 sessions focused 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

Evolution Variables (EVs) are the minimum set of variables required to characterise change in a system. 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 help to focus Sustainable Development Goals monitoring.

Figure 2. An integrated social–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 help to focus Sustainable Development Goals monitoring

Belinda Reyes 
Mark Stafford-Smith 
Karl-Heinz Erb 
Robert J Scholes 
Odikwe Selomane

Essential Variables

1. Develop/draw on social-ecological model(s) of SDG system

2. Identify first order EV categories, through sensitivity analysis or expert judgement
   (a) Identify key flows between system components
   (b) Highlight/filter for transformation facilitators
   (c) Add variables exposing interactions between policy domains
   (d) Filter set on basis of redundancy/indispensability

3. Identify ESDGVs in each category through expert workshops, on-line consultation and filter criteria

4. Identify ESDGVs not curated in other communities, and prioritise collecting these

5. Refine/revise to check whether all key system interactions and flows and policy coordinations (criteria A & C) are covered
# Essential Variables

Essential Variables help to focus Sustainable Development Goals monitoring.

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