Tutorial 4: Understanding S-E Systems-Hierarchies and Scale

*Learning Goals:*

- Understand the hierarchical nature of complex systems.
- Define what scale means and describe why it is a critical consideration for understanding systems.
- Identify relevant scale dimensions of an S-E system, including spatial, temporal, and structural dimensions.
- Understand what cross-scale linkages are and why they are important to understanding S-E systems.
- Be able to explain what scale mismatch is and why it is an important consideration in studying S-E systems.

Given that socio-environmental systems are usually extensive and include many subsystems, considering all relevant connections at once can be overwhelming. A more manageable approach involves focusing on defined subsets of the overall system, as we naturally do when using stock and flow diagrams: the cloud icons indicate the arbitrary boundaries for the system one is considering. This allows one to focus on discrete parts of the system while leaving the connections to other system components for later analysis. However, an integrated view of all these parts is required for a full understanding of S-E systems, and to accomplish this, one must consider the hierarchical structure of the system and linkages across different scales.

***The Hierarchical Structure of S-E Systems***

Most complex systems, including socio-environmental systems, have a hierarchical structure (Cumming, 2011). Hierarchies are an inherently useful organizational structure that make a system more stable, resilient, and efficient: the structure inherent in hierarchies (subsystems nested within larger systems) allows subsystems to operate independently and more efficiently on their own while maintaining cohesion through the linkages between the different subsystems. These linkages coordinate the nested subsystems within the broader system.

Examples of hierarchical systems are everywhere:

- Natural system example- The human body is composed of many subsystems such as the lymphatic system, the skeletal system, the nervous system, etc. These subsystems are linked and are coordinated within the larger system of the human body. For example, there are many connections between the neurons that comprise the nervous system, but there are also connections between neurons and the muscular system, although these connections are fewer.

- Social system example- Universities are commonly structured hierarchically with colleges within the university, departments within those colleges, and disciplinary clusters within those departments. Connections are strongest within departments, but connections also exist between departments and colleges and the university. Again, connections are strongest within a subsystem, but linkages between subsystems are essential to the integrity of the system as a whole.

- Socio-environmental system example- In Bali, rice fields are organized in a hierarchical way: Individual rice farmers tend to their own rice paddies; Neighboring farmers belong to collectives called subaks, which meet regularly at subak temples for religious and social functions. Neighboring subaks congregate at regional temples called Masceti, and all Masceti in the Oos-Petanu watershed are governed by the Temple at Crater Lake. In this case, the religious hierarchy is tightly correlated with the spatial hierarchy of rice fields in the watershed, and there are linkages between the different hierarchical scales.

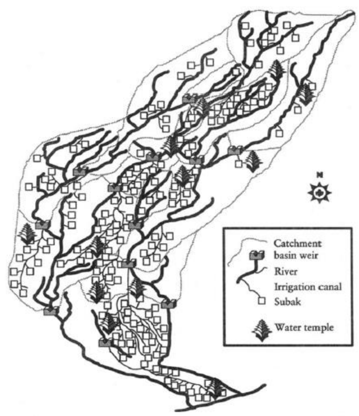


*Figure 1 from Lansing and Kremer 1993: 103. This figure is exempt from the CC license*

Because socio-environmental systems are hierarchically organized, with many of the interactions and dynamics in the system occurring across different hierarchical levels or **scales**, understanding the interactions within a system requires focus at multiple **scales**.

***The Concept of Scale***

When focusing on the natural world, the concept of scale typically refers to the spatial or temporal dimensions of a pattern or process. For example, a forest ecosystem can be considered from many spatial scales from trees to patches to forests to landscapes. The dynamics in a forest ecosystem can also be considered across many time scales from the daily cycles of photosynthesis, to the annual cycles of tree growth, or the decadal processes of forest communities.

When we are talking about social systems, scale often refers to social structures, including individuals, organizations, and social institutions such as policies, cultural norms, laws, etc. For example, the American school system is scaled such that individual schools are nested within local school districts, which are then part of city-wide school systems. Similarly, laws and policies of civil society are nested from local to national and international scales.

An important consideration when studying social systems- and socio-environmental systems- is the extent to which individual humans have the power to influence and processes of both social and natural systems at broad scales, particularly if the individual holds power within an organization or institution. With the rise of modern technologies that connect via the internet and fly us across the world, the reach and influence of humans now extend frequently beyond the local scale (Liu et al. 2007). We are creating an unprecedented degree of linkages across spatial and temporal scales, while the growth of human populations and the development of human society is rapidly increasing the degree of connections between humans and the natural world. The extent of human influence on the natural world, in contrast to other species, has propelled us into the “Anthropocene,” the informally known epoch that alludes to the profound impact of humans on Earth’s ecosystems.

*Cross-scale linkages*
Scale is a particularly critical concept when studying complex socio-environmental systems because there are not only linkages within systems, but also across systems and across scales. These linkages are critical to understand because they influence the behavior of the system overall and of the subsystems. *Cross-scale linkages* are of particular interest when studying S-E systems because changes that happen at one scale can impact the dynamics of the system at another scale.

The concept of cross-scale linkages is embodied in the concept of **telecoupling,** “an umbrella concept that refers to socioeconomic and environmental interactions over distances.” (Liu et al. 2013). Increasingly, with modern travel and globalization, systems are connected across great distances, and these connections are important to understand when studying socio-environmental problems. For example, in our coral reef example, there are several factors that influence coral reef decline that are physically distant from coral reefs. These factors include human activity contributing to climate change, which in turn impacts global ocean temperatures and coral reef health (warmer ocean temperatures can lead to coral bleaching), and the world wide aquarium industry and seafood industry creating greater demand for fishing in the coral reefs. While the focus of discussions on telecoupling is primarily on spatial interactions, temporal interactions can also be considered with this framework.

*Spatial scales*
S-E systems have linkages across multiple spatial scales that range from local to regional to global scales. With the increase in globalization and global travel, we are seeing increasing connections between local and global scales such that humans are increasingly influenced by and influencing processes, patterns, and events at multiple scales. In many contexts, consideration of the linkages across different spatial scales is critical for understanding a system, and for finding solutions to systems problems.

For example:

- Rice farmers often face the problem of insect pests that damage the rice plants and reduce rice production. To manage this problem, a rice farmer typically allows their fields to be drained and lie fallow (i.e. no rice is grown for a period of time) to starve the insect population. When the local insect population is gone, then rice can be replanted. However, if rice farmers each considers only the local scale of his own rice field, pest populations will persist and remain a substantial problem for the farmer. This is because rice pests can migrate between fields, and can move from field to field, effectively finding food in other locations while some fields lie fallow. This particular problem needs to consider this socio-environmental system from a broader spatial scale and social scale: management of the rice pests requires that rice farmers coordinate their fallow periods such that neighboring rice fields form a broader area of fallow fields such that pests cannot migrate easily between fallow and planted fields. Instead of relying on each farmer to decide when they will leave their fields fallow, a regional scale social system is needed to coordinate the actions of rice farmers.

- In the Great Barrier Reef in Australia, as we've discussed before, coral bleaching is occurring due to warming ocean temperatures. This local scale effect is caused by global scale processes of climate change: climate change is resulting in warmer ocean temperatures, which in turn causes coral bleaching. However, global climate change is in turn linked to local scale activities, such as the burning of fossil fuels, which cumulatively influence the earth's atmosphere.

*Temporal Linkages*

Linkages across temporal scales can often be difficult to identify because individual humans have a tendency to focus on shorter time scales (hours, days, months, years vs. decades, centuries) because of the way we experience time. Our life spans and individual memory capacities do not function in the scale of centuries; rather we experience time most acutely in the scale of minutes, hours, days or months. Humans also have difficulty recognizing linkages across time scales because we have a natural tendency to associate an effect with a cause when the two events are closely linked in time or space. This is a natural inclination of humans that is the result of experience and the way we learn (e.g. associative learning). Linkages across different time scales, however, often result in **time lags** between the changes in human and natural systems and the resulting impacts. While humans have evolved to understand immediate impacts, the long term consequences of our actions are also vitally important to understand.

Another consideration that is very important for understanding socio-environmental systems is the impact that prior interactions have on later conditions. For example, when humans alter landscapes, such as converting land for farming, such changes can have lasting and continual impacts on conditions such as where people live and how they use the land. These **legacy effects**, the impacts of a past interactions that accumulate and evolve over time, often manifest over long time periods, and are easy to overlook.

Because cross-scale linkages, particularly temporal ones, are often difficult for humans to recognize, it is especially critical that we call attention to them. The importance of such recognizing such linkages is illustrated in the following examples:

- Human activities, particularly the burning of fossil fuels, has contributed to changes in the earth's climate system. However, the impacts of these changes have taken decades to become apparent. This time lag makes it particularly difficult to understand the dynamics of the system, and thus, extremely difficult to develop solutions. Here, human activities that interact with the environment on short time scales (i.e. daily human activities like driving cars and flying) have profound impacts on the system at a longer time scale.

- The use of CFCs, the chemical used in refrigerants and fire retardants, lead to the depletion of the ozone layer in the atmosphere. Depletion of the ozone layer has serious implications for ecosystems because atmospheric ozone plays a critical role in deflecting damaging UV radiation from sensitive organisms and ecosystems. There is a substantial time lag -on the order of years or even decades- between the release of CFCs and the depletion of the ozone layer as the effect accumulates over time.

- In the Florida Everglades, the full impact of draining the Everglades and converting the area into agricultural land took decades to manifest. The legacy effects of draining regions of the Florida Everglades continue to impact the health of the Everglades ecosystem and the patterns of human development in the area. Understanding the legacy effects of draining the swamp is necessary to understand the regime shift in the ecosystem from sawgrass to cattails and to understand the loss of resilience in the Everglades.

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*A Note about Coupled Human-Natural Systems (CHANS):*

One note about terminology. The terms "socio-environmental systems" (S-E systems) and "socio-ecological systems" are similar enough that most people consider them interchangeable. The difference between the terms amount to the term "environment" being a broader term that includes "ecology." Another term that is commonly used to describe S-E systems are **coupled human and natural systems (CHANS)**. CHANS are "systems in which human and natural components interact." (Liu et al. 2007). Usage of the terminology "CHANS" is favored by some because it emphasizes the importance of the linkages within an S-E system, particularly the cross-scale "couplings." Because of the increasing connectivity of our modern world and the relative ease with which humans now travel across the world, connections across systems and between scales are increasing and becoming more crucial to understand. As a result, the field of CHANS research "focuses on patterns and processes that link human and natural systems… emphasizes reciprocal interactions and feedbacks…. and understanding within-scale and cross-scale interactions between human and natural components." (Liu et al., 2007).

*The problem of scale mismatch*
As illustrated in the previous examples, understanding the effects that one scale has on another is critical for solving S-E problems. Mismatches between scales can create problems for managing or solving S-E problems. Mismatches can arise either within the dynamics of the social system or the environmental system or from dynamics between the social and environmental systems.

Differing concepts of scale are particularly important to consider when studying socio-environmental systems because mismatches of scale between the social and the environmental scales of analysis are often difficult to recognize. For example, if an agency is managing fisheries within specific geographical boundaries, how do they know that they are managing the correct spatial scale? Should they manage locally or regionally? In the example of salmon, if the extent of a resource managers' influence does not reach the spawning sites of salmon, then the spatial scales of the organization system may not match that of the ecological system.

In resource management, mismatching scales can lead to loss of adaptive capacity in the social system (e.g. resource managers may not be able to manage effectively), and loss of resilience in the ecosystem (e.g. loss of species, ecosystem function, or other vital system components) (Cumming, Cumming, & Redman, 2006). Mismatches in this context have been hypothesized to occur when: "the scale of environmental variation and the scale of the social organization responsible for management are aligned in such a way that one or more functions of the socio-ecological system are disrupted, inefficiencies occur, and/or important components of the system are lost." (Cumming, Cumming, & Redman, 2006). For example:

- For a particular threatened coral reef, such as the Great Barrier Reef in Australia, a spatial scale mismatch might occur if a local organization is charged with protecting and restoring the reef on its own. The local organization alone will not be able to deal with all the threats to coral reefs, as many of the threats to coral reefs, including ocean acidification and rising ocean temperatures, must be managed on a global scale. Thus, the local spatial scale of the social organization is mismatched with the global spatial scale of the environmental processes impacting the S-E system of the coral reefs.

- An example of a problem with temporal scale mismatch is the management of long-lived organisms, like redwood trees. It's not hard to imagine that temporal scale of the policies and/or organizations focused on preserving redwoods, might not match the temporal scale of redwoods, which have life spans of 500-700 years. If the organization that is protecting them disappears or the law expires, the redwoods can become vulnerable to logging and destruction. The ecological processes that create redwood trees occur over the scale of centuries, but the human processes that can destroy them occur over much shorter scales.

These examples also illustrate key challenges to understanding socio-environmental systems and developing solutions to socio-environmental problems. Considering challenges such as the unexpected ways in which cross-scale linkages influence systems dynamics or the way mismatched scales create difficulties in determining how to manage an S-E system, the need for integration of knowledge and insights across the natural and social sciences becomes clear.

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