Summary of Week 4

Coupled Human Environment Systems

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This summary of the fourth week of the *Sustainability Science: An* Interdisciplinary Introduction covers the discussions on Chapter 3 of the manuscript and key supplemental readings from the Reader. The chapter was introduced by Professor Bill Turner from Arizona State University and the discussant and moderator was Professor Elizabeth King from Princeton University. The student group responding was a Cambridge team comprising students from Harvard University and MIT. This summary document reflects the group discussion on Monday, and also includes some responses from the Cambridge Group's class discussion immediately following the conference call. The focus of the discussion was cross-scale and multi-scale (due to interdisciplinary, temporal and spatial coverage) integration issues involved in coupled human-environment systems (CHES), which form the core framework of sustainability science.

Presentation on the Book Chapter by Billy Turner, Arizona State University

Current conceptualizations of sustainability are built around the concept of coupled human-environment systems (also termed social-ecological systems, coupled human and natural systems, and coupled human-biophysical systems) that recognize that the social, economic, and cultural well-being of people depends not only on their relations with other people, but with the physical and biological environment as well. The chapter emphasizes that the coupling of people and environment ranges across spatial and temporal scales, from the local and short term to the global and long term. It also involves relationships that vary in scope from relatively simple to extremely complex system interactions. The Cambridge student group concluded that the chapter does a thorough job of highlighting this complexity with several examples, and also of describing the sources of complexity within CHES.

In presenting the chapter, Turner highlighted that multiple labels that are used by scholars to describe CHES, including ‘coupled human and natural systems’ (CHANS) and ‘social-ecological systems’ (SES), with subtle differences amongst them. The differences are highlighted in *fig 3.2* of the chapter. However, he clarified that - with the exception of the human-environment system (HES) label - the basic notion behind all of these labels for describing human and environmental sub-systems is that the processes and consequences of the two subsystems are so *tightly* and *dynamically* inter-twined that each affects the structure and operation of the other with *constantly adjusting* outcomes for either subsystem. In addition, there are other coupled systems in similar dynamic interactions with both sub-systems separately as well as with the coupled system as a whole. *Fig. 3.1* seeks to explain this phenomenon of complexity at a meta level. Turner further underlined that any CHES is nested, often hierarchically, with other systems and processes and that there is a constant flow of material, energy and other objects between these systems.

Another facet of complexity is that coupling creates constantly adjusted outcomes and interactions. Turner described this situation as *inter vs. inner-acting systems* - an ontological position of which sustainability science is acutely aware. *Inter* provides analytical convenience, but the book chapter has not settled its position on the ontology of coupled systems. Unpacking the inner-workings of CHES as captured in *fig. 3.2*, he clarified that, A represents the proximate interactions (most closely associated factors), B/C indicates that each subsystem affects and is affected by associated processes, D indicates proximate level dynamics affecting other subsystems and E indicates how external coupled systems interactions change A, B, C and D. Turner argued that while HES of the past focused on D, consideration for dynamic interactions was absent. SES has focused on the bottom half of *fig. 3.2*, up to A, save for governance (which is also treated largely in terms of the E subsystem). According to Turner, sustainability science seeks to better balance both subsystems. Referring to *fig. 3.3* of the book chapter relating to process and flows across scales of systems, he argued that complexity amplified the spatial-temporal scales with processes operating at different scales. Turner argues that the CHANS label focused more on these aspects. Exploring the issue of dimensions, he posited that there are no firm rules to date for binding the CHES. It depends on the problem (event) and is heuristic. However, despite problem-based bounding, one would still have problems of cross-scale interactions no matter how one bounds the problem at hand. In the case of environmental subsystems, there have been some accepted standards of components and linkages crossing the research communities.

Turner identified the following *challenges* for CHES:

- Simplifications and generalizations tend to be at the level of general systems with either too much aggregation or too much abstraction.

- While the *theory of the mid-range* (for specific phenomena & processes) has served the social sciences well, CHES has none yet.

- For practice, complexity, nonlinearities and so on, the outcomes are highly differentiated by case, system and place.

Turner concluded by stating that CHES, being very complex processes, do not have comparative models for analytical purposes and would, therefore, have to rely on a process of *abduction* (not induction or deduction), which may be understood as a theory of mid-range.

Remarks by Discussant, Elizabeth King, Princeton University

Professor King preferred to look at CHES as 'complex adaptive systems', drawing on the concepts, approaches and tools (components, interactions, selection) of other disciplines such as mathematics, ecology, sociology, economics and geography. These systems have dynamics that are *non-linear, cross-scale and non-deterministic,* as mentioned in the book chapter. King argued that CHES is a *framework* that offers a common foundation amongst these varied disciplines and relates directly to sustainability. It creates a space for multiple approaches to explore and understand the sustainability issue. Elaborating, she explained how earth systems science, agriculture and governance could be seen as approaches based on *disciplines* while *resilience* (based on the concepts of thresholds & surprises) and *social psychology* (based on the concept of how perceptions shape behavior) could be typified as approaches based on *dynamics*. She added that in the Reader, there is another approach: degree of realism. The diversity of approaches provided is beneficial in terms of utility, with each approach using and developing its own tools and the value of approaches varying with context and CHES acting as a common "battery pack" for these different tools. and the diversity is also beneficial in terms of *efficiency*, as a common language facilitates integration between approaches. There are, however, serious challenges associated with widening the gap between vision and reality in so far as CHES and Sustainability Science is concerned. The key challenges are:

1) *Bounding systems for tractability* - How does one choose system boundaries, and how do these choices shape, limit outcomes, and otherwise pose problems?

2) *Integrating disciplinary contributions* - How do we integrate results produced by distinct disciplines? What do you do when research leads to different outcomes? Are we able to integrate disciplines without producing a hierarchy among them?

3) *Tools, models, methods to map CHES* - Are there effective ways to map CHES? What are the methodological alternatives to the kinds of place-based research we have covered thus far?

The Cambridge Student Group explored these issues in greater detail in their presentation.

Cambridge Student Group presentation

Bounding issues

The Cambridge Student Group argued that, considering the problem-solving underpinnings of sustainability science, bounding coupled H-E systems is fundamentally about making a *judgment* on the problem at hand which invariably involves trade-offs and dealing with the uncertainty that they impose. Every discipline and method imposes natural boundaries, which may be accepted or challenged as the problem warrants. But even if the researcher can predict how fluxes into and out of the system may impact our system and subsystems, in most cases, he or she has limited capacity to predict these fluxes/feedback loops due to the *uncertainty* in event or phenomena that is occurring external to the system. Given the difficulties associated with binding, the bounding exercise opens up the opportunity for the conscious or unconscious "gerrymandering" of study boundaries, which the researcher should be aware of. By looking at specific scales, he or she may be missing the phenomena at either the global or the local level. We may also disaggregate our global system into several smaller and more "explorable" subsystems, but that may entail ignoring the true dynamics of interactions. Drawing an analogy from the Heisenberg's Uncertainty Principle, it may be an inherent and intrinsic limitation that by bounding a system along a single dimension (e.g., spatial), the uncertainty regarding the other dimensions (e.g., rate of change) may increase.

There could also be a "matching" problem when the researcher tries to integrate research performed using different boundaries, which sometimes requires combining data that is more granular with data that is less granular, based on the "resolution" and bounds of distinct boundaries. Integrating data that enters the system in different forms (qualitative vs. quantitative; contextual vs. objective) can also be challenging. Given limited resources, there is typically a trade-off between how much is included within the system boundaries and the depth to which any given component is studied. More attention can be paid to the details in a small system, while some of the nuance is inherently lost when one studies a larger system. Effectively studying CHES requires a great deal of resources and capacity to work across traditional disciplinary boundaries, which can be both challenging and expensive. Studying CHES has historically relied on integrated, place-based assessments - an approach that requires spatial bounding, limiting the researchers' ability to scale-up to the global context. Examples of ways in which CHES research delineates and manages the boundary-setting issue are cross-disciplinary collaboration in defining variables, pluralism (triangulating data and information sources), use of "slow" variables as the limiting factors and flexibility to use outcomes to inform new boundaries and "robustness" checks for varying boundaries. The Cambridge Student Group argued that one could follow a research approach that varies the types of boundaries within the same problem itself. This would, however, raise issues of testing the "robustness" of such studies and possibly of *replicating* them across time and space. They argued that, in such cases, it feels not only ethical but also warranted that the boundaries of the research are allowed to be iterated as one understands and explores the outcomes of the study vis-à-vis the observations of reality.

Issues with integrating disciplines

Some of the challenges of integration identified in the session were:

- Integrating across natural and social science research.
- Integrating across formal scholarship, clinical research and local knowledge.
- Integrating scholarly output originating from a methodological individualism and atomistic approach with outputs emanating from a more holistic approach.

It was argued that, even while integrating results from different disciplines, there is a need to allow for a social science approach that is reflexive, context dependent and interpretive rather than a largely deductive and positivistic approach. Natural science approaches and quantitative research have historically dominated the ways in which researchers have thought about ecological systems. There may be a need to present quantitative results, layered with social science analyses of systems of institutions and governance, so that the social mechanism driving change can be fully understood within a CHES.

This is a somewhat constructivist approach. CHES systems are focused on outputs from different sub-systems. Integrating qualitative observations (e.g., case studies, and reflexive and iterative research) with quantitative research may require flexibility and context-dependent processes for doing sustainability science. A critical understanding of the role and contributions of natural and reflexive social science might be a first step for many scholars. The dominant praxis in the latter is the provision of input for public deliberation and decision making, i.e. democratic due diligence (democratic rationality). This democratic rationality flows from the reflexive analysis of values and interests, and how they affect different groups in society. This approach is fundamentally different than the traditional model, which attempts to apply theories and laws to solve social problems. For example, social engineering (instrumental rationality) flows from the theories and laws of society and social action (an epistemic rationality) (Flyvbjerg, 2005).

A case study on how multiple disciplines - including agronomy, biogeochemistry, ecology, economics, geography, hydrology, international policy analysis, remote sensing, and water resources engineering - called *'People, Land Use, and Environment in the Yaqui Valley, Sonora, Mexico'* was presented (Matson et al., 2005). The group argued that the paper did not offer a *single* technique for integrating multiple disciplines. Rather an *iterative* process over 10 years identified relevant directions and scales of inquiry as they became apparent. But even here, attempts to aggregate reflexive social science data with economic and environmental data led to a mismatch in scale of analysis that proved to be particularly challenging.

Tools, models and methods issues

The Cambridge group asserted that the book chapter did not adequately reflect on the *methods* issue. That is, on methods and tools that the researcher can employ to better understand and interact with CHES. What seemed clear is that there is no single best way to do so, making the 'mixed methods' or 'portfolio' approaches used by various scholars, including Young and Ostrom, particularly attractive (Ostrom and Nagendra 2006; Young et al. 2006). Still, it is helpful to layout what the options are, and under which conditions each may be more or less appropriate. Peterson, Cumming and Carpenter (2003) propose *controllability* and *uncertainty* as two axes along which methods for managing complex systems can be placed, and focus on scenario planning as an "appropriate [tool] for systems in which there is a lot of uncertainty that is not controllable. In other cases optimal control, hedging, or adaptive management may be appropriate responses" (Peterson, Cumming and Carpenter 2003: 365). For understanding and interacting with CHES, scenario planning may be a more or less appropriate tool. Even Kates referred to it when talking about phases and predicting the contours of a future phase or transition. There are, of course, several other approaches, including the resilience approach, agent-based spatial modeling, adaptive management, system dynamics and so on. Each may be used - or simply chosen - in different cases for a variety of reasons, including the problem at hand and the researcher's judgment and faculty.

The Cambridge group proposed the addition of a third axis to run orthogonally to Peterson, Cumming and Carpenters' (2003) controllability and uncertainty: scale. The group did this not to make a definitive assertion, but rather to put out a 'straw man' and invite others to iterate on how different approaches to understanding and interacting with CHES might compare and relate to one another.

For illustrative purposes, the Cambridge Group then introduced system dynamics (SD) as a tool. SD uses computer software to construct models, classifying any relevant resources (human and environmental) as stocks, which are connected via flows. Various relationships beyond the flow of resources exist in systems, which are included as *couplings*. Causal loops are then identified among these stocks, flows and couplings, explaining how changes in any individual stock or flow (i.e. an increase or decrease in a stock, or in a rate of flow) will have implications on other stocks and flows across the system. Issues like time lag, external variables, and the presence of more nuanced factors, like the perceptions of different actors, can make these models highly complex. SD models can be more or less quantitatively precise, but the point is typically to identify the relationships themselves, and the subsequent positive and negative feedback loops that emerge. In this case *positive* and *negative* are not normative judgments on the relationship, but statements on whether that particular loop is likely to be reinforcing (that is, supporting change) or stabilizing (pushing the system towards a steady state). Proponents of system dynamics assert that there are a limited number of archetypal patterns that most systems approximate in behavior over time, including: Exponential growth or decline, self-regulation, goal seeking behavior, s-shaped changes, and various forms of oscillation. SD models can help identify which path any given system seems to be on. For a more thorough primer on SD, see the U.S. Department of Energy's Introduction to System Dynamics at: http://www.systemdynamics.org/DL-IntroSysDyn/start.htm.

SD is one method, which has been employed frequently in this history of sustainability science, from the seminal *'Limits to Growth'* book (Meadows et al. 1972) to the more recent *'Climate Collaboratorium'*, which was prepared by John Sterman and his team for the Copenhagen Climate Change Conference (see: http://climatecolab.org).

Given the work that has been done with SD and the value that it, or a tool like it, can provide when attempting to understand CHES, the Cambridge group found it somewhat surprising that SD and other tools were not touched on more in the chapter. Of course, any attempts to map, let alone quantify, any CHES comes with complications and pitfalls. In fact, one of the advantages of putting a concrete approach to better understanding CHES, like SD, on the table is that it also introduces a surrounding body of literature, including healthy critiques, that may be extrapolated to the broader endeavor. SD has, for example, been heavily criticized for trying to quantitatively understand systems that are inherently so complex that attempts cannot come even close, but trying provides a false sense of confidence that solutions can be derived from modeling. Any attempts to understand CHES may face the same paradox. SD practitioners and scholars have undoubtedly become more humble over the years, recognizing the limits of their methods and the need to directly engage stakeholders in the modeling process.

Lane (2000) introduces criticisms leveled at SD for being 'hard' or 'deterministic', with its assumptions that the future can be predicted, agents are largely subsumed by structural dynamics, and cause and effect exist separately from individual subjectivity, and its coercive nature as it attempts to engineer systems. Similar criticisms might be leveled at other attempts to understand CHES. Lane (2000) responds that some of these critiques are unfair while in other areas, including the subjectivity of causality and the relationship between SD and systems engineering, more thought is required within the field. SD can be used in different ways, but there is no reason why models cannot be considered contingent and highly responsive to ongoing learning and dialogue.

General Discussion and Questions &Answers

John Sheehan raised a question about complex systems, referring to Stephen Carpenter's cautioning that narrow sets of thinking can lead to surprise outcomes: "How do you reconcile the complexity of marrying what are two uncertain and complex systems into one modeling framework with the need for transparency and comprehensibility in engaging a sufficiently broad range of views?" In response, Elizabeth King, stated that "awareness that there is at least some fundamental language that can be used as a tool is a first step that I am interested in ensuring stays a part of the sustainable science discussion rather than narrowing it down."

Bill Clark pointed out that the Cambridge groups' slide on reflexive social science "matched interestingly with the distinction between system analysis approaches and the complex adaptive systems approaches" that Elizabeth King presented. Clark commented that, in his experience performing system analytics, the approach is almost always top-down, “presuming that there are some fixed theories or laws” governing interactions between individual agents such as consumers and producers, and that these laws “are somehow global and sensed by everybody at the same time.” In complex adaptive system approaches, “the key parameters are the behavioral biases of individual agents, which aggregate upwards (bottom up) not as a presumption of any laws, but by encountering one another in a landscape of rules or incentive structures.”

Referring to the reflexive social science discussion, Bill Turner noted that “the distinctions made in the Flyvbjerg article are about reaching towards a policy or decision outcome, but are not predicated on how you get to the base understanding of the operation of the systems.” Turner suggested that the distinction between the natural and social sciences is a “false distinction”. The distinction should not be between these two “broad sciences”, but rather between the “ways of knowing that some social sciences share with the natural sciences and the alternative ways of knowing” that are not shared.

In response to the Cornell student group’s question on the characteristics of a HES that relate to sustainability science, Elizabeth King noted flows of relevance as highly important, the iterative procedure, and “some degree of reflexivity with sustainable development would also be important in how you model your system to make it more applicable to sustainability.” King later made a final remark that “it is beholden unto the field to create utility”, given the importance of the interface of sustainability science and sustainable development. One of the important aspects of the “battery pack”, is its cross applicability. “We need a common language in order to glean the utility to the field.”

On the question of incorporating values into the CHES model or the SD model, Bill Clark clarified that the approach would probably have to be one based on explanatory epistemology and not necessarily one based on integration. Elizabeth Barron and Amar Patnaik, however, raised concerns relating to generalizability when multiple epistemologies are followed. Bill Clark clarified that sustainability science may be construed as offering a “battery pack” of tools from which the researcher could choose the appropriate tool depending on the problem he wanted to solve; though such decisions could be influenced by political and other considerations depending on who wanted to use it. This was admittedly problematic.

Works cited

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