Sustainability Science Distributed Graduate Seminar

Summary of Session 8 – Emergent properties of coupled human-environment systems

Cambridge group students: Erin Frey, Tara Grillos, Lilli Margol, Dominic Maxwell, Jess Newman, Leah Stokes, David Bael (Minnesota), Suhyun Jung (Minnesota)

Session eight took place on November 1, 2010 and centered on the discussion of chapter 3.1 "Emergent Properties of Human-Environment Systems" in *Sustainability Science: An Introduction*. Chapter lead author Billie Turner (Arizona State University) presented his remarks followed by a response from Jim Heffernan (Florida International University) and Cambridge group students. This summary will focus on the book chapter as well as the three key topics identified by Jim Heffernan and the Cambridge students.

Chapter 3.1 and Billie Turner's remarks

Chapter 3.1 focuses on two key emergent properties of the coupled human-environment system (CHES): vulnerability and resilience. The authors admit that it is lacking in the other important emergent properties of threshold dynamics and tipping points and also could be enhanced by framing the CHES as a complex adaptive system. Emergence can be seen as the way complex patterns in a system can arise out of many simple interactions. Emergence in a CHES ideally involves the coupling of both systems, even though many examples of emergent properties have tended to focus on either the human or the environment subsystem. Vulnerability and the related concept of resilience are chosen as the focus of the chapter because the vulnerability of a system determines the implications for ecosystem services and human well-being as the result of a disturbance to a CHES. Thus, determining the vulnerability (and resilience) of a CHES is a major goal of sustainability science.

Vulnerability and resilience are complimentary concepts but reflect different framings of a CHES. Vulnerability, or the degree to which a system is likely to experience harm due to exposure to a hazard, is generally determined by the weakest part of the system and historically has mainly been considered from the perspective of social science in the human subsystem. The three components that determine a system's vulnerability are exposure (to disturbances), sensitivity and resilience. Resilience is the coping capacity of the system or the ability to absorb disturbance without changing state. It has generally been examined within ecological sciences to characterize the environmental subsystem. Vulnerability and resilience are inherently interrelated; vulnerability can be viewed as the antonym of resilience.

Tipping points are an emergent property that arise out of resilience. When a disturbance reaches the level of resilience of a system, a threshold (or tipping point) can be crossed such that only a small additional perturbation can qualitatively alter the state of the system (i.e., a regime shift). Tipping elements are the factors that push systems to and across thresholds (e.g., phosphorus can be seen as a tipping element in the eutrophication of shallow lakes). Tipping points and tipping elements have largely emanated from climate sciences, and the global climate system is a primary example of a CHES with tipping elements (e.g., human population density, carbon dioxide loading) and potential tipping points that may be crossed.

Another example of tipping points and elements in the CHES is the Maya case where human alterations of the landscape interacting with climate change through a series of causal linkages and impacts in both the human subsystem and the environment subsystem eventually led to the crossing of a tipping point where the whole system collapsed and the entire region became depopulated. This is an example of collapse (or regime shift) in a CHES where the human and environmental subsystems collapsed in tandem with each other. Other examples of increased vulnerability, decreased resilience and tipping points in a CHES are Angkor Watt and the Aral Sea. In both of these cases, the CHES moved to a new and qualitatively different state. The Aral Sea presents a case where the environmental subsystem recovered in a somewhat modified state. There are fewer examples where after a regime shift in a CHES the human subsystem recovers while the environmental subsystem does not. This may reflect the inherent fact that humans are more dependent on the environment than the environment is dependent on humans.

Jim Heffernan and the Cambridge Group Students

Jim and the Cambridge Students brought forth three main questions or themes that arose from the chapter around which to build their discussions. These are:

1) What are emergent properties of CHES and are there important differences between the way we should characterize emergent properties in the human and environment subsystems?
2) What are resilience and vulnerability? How are they (inter-)related and how are they treated differently in the social and ecological sciences?
3) What are the sustainability implications of tipping points in the context of policy and management of ecosystem services?

Jim Heffernan

Building from the definitions of vulnerability and resilience in the chapter and in Billie Turner's presentation, Jim sought to establish a framework that relates resilience and vulnerability to each other as well as to the larger concept of sustainability. Resilience and vulnerability are clearly interdependent, but are they inverses or converses of each other? Vulnerability can be characterized as the product of exposure and sensitivity divided as resilience, thus framing vulnerability and resilience as each other's inverses. Within this framework, however, the relationship to sustainability remains unclear. Framing vulnerability as the level of harm done by a disturbance does not preclude sustainability. Furthermore, framing resilience as the inverse or mitigator of vulnerability glosses over two important facets of resilience. First of all, resilience tends to be nonlinear. Secondly, this portrays resilience as inherently good, when it is more appropriate to place no normative value on resilience; a system that has crossed a threshold into a changed (degraded) state can also be highly resilient, and in fact the resilience to change of the system in its undesirable state can be the crux of the problem.

The characterization of the resilience of ecosystems by Carpenter et al. (2001) exemplifies this problematic view of resilience: seeing resilience as the size of the disturbance that the ecosystem can withstand without changing to a new state does not account for the fact that the undesirable state is also highly resilient. An alternative characterization put forth by Carpenter et al. (2001) of the relationship between vulnerability and resilience that does incorporate sustainability posits vulnerability as the product of exposure and sensitivity while sustainability is resilience divided by vulnerability. The authors argue that operationalizing resilience requires specification of the property of the system of interest and the agent or force against which resilience will be measured.

Hollling (2001) introduced the adaptive cycle, a concept related to resilience but that integrates resilience with change, and thus allows for not all change to be bad. The adaptive cycle's focus on change as a mechanism for persistence is more appropriate and useful in the context of a CHES. Furthermore, the adaptive cycle concept along with acknowledgement that resilience does not preclude change highlights an important difference between vulnerability and resilience: vulnerability is defined in terms of harm, and is therefore undesirable and unequivocally recognized as such. Resilience, however, is used in ways that are both value neutral (e.g., degraded ecosystem states are often highly resilient, which is a problem) and ways that are strictly positive.

Peterson et al. (2003) present a theoretical example of emergent behavior in a CHES: a lake with multi-state dynamics that is linked to the management regime which seeks to maximize the value of services from the lake. In this theoretical example they show that apparently rational management decisions lead to a crossing of a tipping point and collapse of the system. The presence of the tipping point is an ecological phenomenon, but the crossing of it emerges from the interaction between the social and ecological systems.

Regarding the final theme of the management implications of tipping points, new research that has shown that systems tend to exhibit changes in statistical behaviors – autocorrelation and variance – but it nonetheless remains a formidable technical challenge to use this information to detect (and avoid crossing) tipping thresholds and an implementation challenge to develop management institutions with the capacity to respond to these indicators.

Cambridge Students

Building on and complementing Jim's presentation, one student from the Cambridge group presented each of the three themes.

1) *Leah Stokes – Conceptual framework: Definitions of emergence, resilience and vulnerability*

Before we can really explore the implications of emergence, vulnerability and resilience in CHES, particularly for policy and management for sustainability, we need to establish a conceptual framework that defines these properties and their relation to one another. Specifically, are vulnerability and resilience sub-components of each other? Are they inverses? Or do they have another relationship? Building on the definitions already presented by Billie and Jim, Leah presented a few illustrative examples of emergent properties (vulnerability, resilience and tipping points) in a CHES. The tipping of the Sahel from a wet and fertile region into drought (see Foley et al. 2003) exemplifies how the interaction between the climate system and human land-use changes can provoke a regime shift. A second example of human and environment systems interacting to incite a regime shift can be seen in fisheries economics. In this CHES, human system dynamics and the resulting human actions can spur changes in the underlying genetics of the fish population, and drive both the species and the fishing industry to tipping points. In both the Sahel and fisheries examples, the questions remain whether these systems exhibit low resilience or high vulnerability and whether the vulnerability resides in the ecological system, social system, or both.

2) *Jess Newman – The "human/social side" of coupled human-environment systems*

More attention needs to be given to the "social side" to better understand the unique emergent properties that arise from coupled systems. "Social resilience" and "human adaptive capacity" are often used interchangeably, but are they actually the same thing, or is adaptive capacity a subset of resilience? Adger (2000) examined social resilience (largely embedded in social institutions) and its relation to ecological resilience and came to the general conclusion that the two cannot be separated. In a CHES, the buffer capacity of the social system to absorb shocks (i.e., social resilience) cannot be separated from the characteristics of the environment system (i.e., ecological resilience). An example illustrating the interdependence of social and ecological resilience is mangrove conversion and institutional resilience in Vietnam (Adger 2000). In what can be seen as co-evolution of social and ecological resilience, social institutions and norms have a buffer capacity to absorb shocks and avoid crossing tipping points as long as the environmental system is not provoked beyond a tipping threshold. When the ecological resilience is overwhelmed, however, the social resilience also collapses. This example illustrates the tension between social and ecological systems and that we can look at emergent properties (resilience, tipping points) in each subsystem of a CHES, but we are still a long way from understanding how we can look at these emergent properties in a way to better understand the coupled human-environment system.

3) *Dominic Maxwell – Implications for policy*

Scheffer et al. (2009) identify and describe three early warning signs of an impending tipping point: slowness of recovery, increased variance and autocorrelation. But, how plausible are these indicators as tools that can drive management and policy? The good news is that as long as we can recognize these indicators then we do not need an understanding of the underlying mechanisms of the system. However, we are still faced with daunting challenges: these warning signals can only be useful if there is a gradual approach to a threshold; long time series data are required to recognize them; and confounding trends in the perturbations can lead to false positives. Expanding upon the previous seminar session on how to assess human well-being, how can tipping points be integrated into welfare analysis? Examining the value of ecosystem services in a system while there is uncertainty whether that system is approaching a tipping point and uncertainty in the scale of impacts from crossing it presents great challenges in welfare analysis (and thus in management and policy decisions). Particularly in low-probability, high-impact catastrophes such as climate change, this uncertainty produces a "tail-fattening" of expected impacts (see Weitzman 2009), which can have management implications of higher magnitude than the choice of a discount rate.

Question & Answer Session:

Tipping Points: The University of Minnesota, as well as some other participants, requested clarification of the Scheffer et al. (2009) article. The Cambridge students and Jim both reiterated that the methodology presented by Scheffer et al. (2009) requires no knowledge of the causal mechanism of the tipping point, though the paper was based on modeled systems. Jim pointed out that while this is beneficial for scientists, it may prevent the political system from taking action. In particular, current management institutions do not have the capacity to respond to these tipping point indicators yet, so even though the Scheffer et al. article may present a useful concept, it cannot be operationalized as is.

The Relationship between Vulnerability and Sustainability: The Cornell students inquired about the specific relationship between vulnerability--particularly vulnerability over time--and sustainability. Billie Turner and Bill Clark both remarked that time-dependence is an inherent part of sustainability. Of particular interest is the fact that slow changes are often decoupled from fast dynamics, and changes in the slow variables can increase or decrease vulnerability over time. Jim, Billie Turner and Bill Clark also advocated for considering the spatial distribution of resilience and vulnerability, in addition to the temporal component.

Emergent Properties and Well-Being: Jim first pointed out that previous discussions of well-being did not discuss catastrophic risks, and therefore our conception of "wealth" needs to be amended to account for these tipping points.

Tools for Understanding Emergent Properties: The Cambridge group pointed out that resilience has been treated differently in human and ecological subsystems, and questioned whether the tools from one subsystem can simply be applied to the other. While Jim indicated that he thought it was an open question, Billie Turner declared that different tool sets are needed. The Cambridge group suggested that perhaps the methodologies from psychology and anthropology have promise in addressing resilience and vulnerability in human subsystems.