Ecosystem Surprises: Research Needs

background for
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Introduction

Extensive persistent changes in ecosystems (regime shifts) are an emerging concern because of their large impacts on ecosystem services and human well-being (Millennium Ecosystem Assessment, http://www.MAweb.org). The Millennium Ecosystem Assessment (http://www.MAweb.org, *General Synthesis*, p. 11) concluded

> There is established but incomplete evidence that changes being made in ecosystems are increasing the likelihood of nonlinear changes (including accelerating, abrupt, and potentially irreversible changes) with important consequences for human well-being . . . Capabilities for predicting some nonlinear changes are improving, but for most ecosystems and for most potential nonlinear changes, while science can often warn of increased risks of change it cannot predict the thresholds at which the change will be encountered.

Ecological surprises are regime shifts that people did not expect. Examples include rapid harmful changes in boreal forests, dryland ecosystems, rangelands, fisheries and freshwater quality; and novel problems such as emergence of disease or irruptions of nuisance species. These phenomena are closely associated with human activity, and evidently must be understood and managed as behaviors of social-ecological systems (SES). Reports of regime shifts in SES are increasingly common; the more we look the more we find. Yet regime shifts are hard to predict and leading indicators of regime shifts are just beginning to be understood. Therefore it has been difficult to address ecological regime shifts in environmental assessments and decisions.

This short document summarizes the state of knowledge about ecological surprises and suggests research priorities to support policies that address ecological surprise.

Case Studies

Empirical data-based case studies of regime shifts exist for a wide range of ecological systems, such as boreal and temperate forests, rangelands, dryland agriculture, freshwater quality, freshwater and marine fisheries, and coral reefs. Studies of regime shifts in integrated social-ecological systems also exist but are not as numerous as studies of purely ecological systems. The reading list at the end of the document covers a range of ecological and social-ecological case studies.

Considering the examples as a whole, regime shifts have most often been observed at relatively large spatial extents in heterogeneous ecosystems. However, examples are known from biogeochemical systems that might seem well-mixed, such as eutrophication of freshwaters and coastal oceans. Island and lake ecosystems are particularly rich sources of published examples (perhaps because it is easier to see patterns when there are many similar ecosystems to compare).

Among social-ecological systems, the best-represented cases come from fisheries and rangelands, though other situations have been studied including eutrophication of water supplies and salinization in dryland agriculture. From a social perspective, research has addressed the role of interest groups in stabilizing policies that create conditions favorable for regime shifts.

In general, research on ecological surprise requires integrated social-ecological programs employing long-term studies of spatially extensive regions, or comparative studies across broad gradients.

Models

Various kinds of models have been used to represent regime shifts. Regime shifts can be viewed as a kind of structural instability: under certain conditions, a small change in one variable leads to a qualitative change in stability of the entire SES. A number of particular models of structural instabilities have been studied and used to represent different regime shifts. The classic model of alternate stable states is only one simple and specific case.

A general model for regime shifts may not exist. Regime shifts may turn out to be individualistic. It is probably not true that "if you've seen one, you've seen them all". Therefore, models and data will need to be tailored for each particular situation and policy issue.

The chief commonality is thresholds for changes in feedbacks, stability characteristics, or attractors. Thus it makes sense to focus empirical and modeling research on threshold phenomena.

In general, model studies that address structural instabilities are less common than ones that address other kinds of stability, e.g. stable points or stationary distributions.

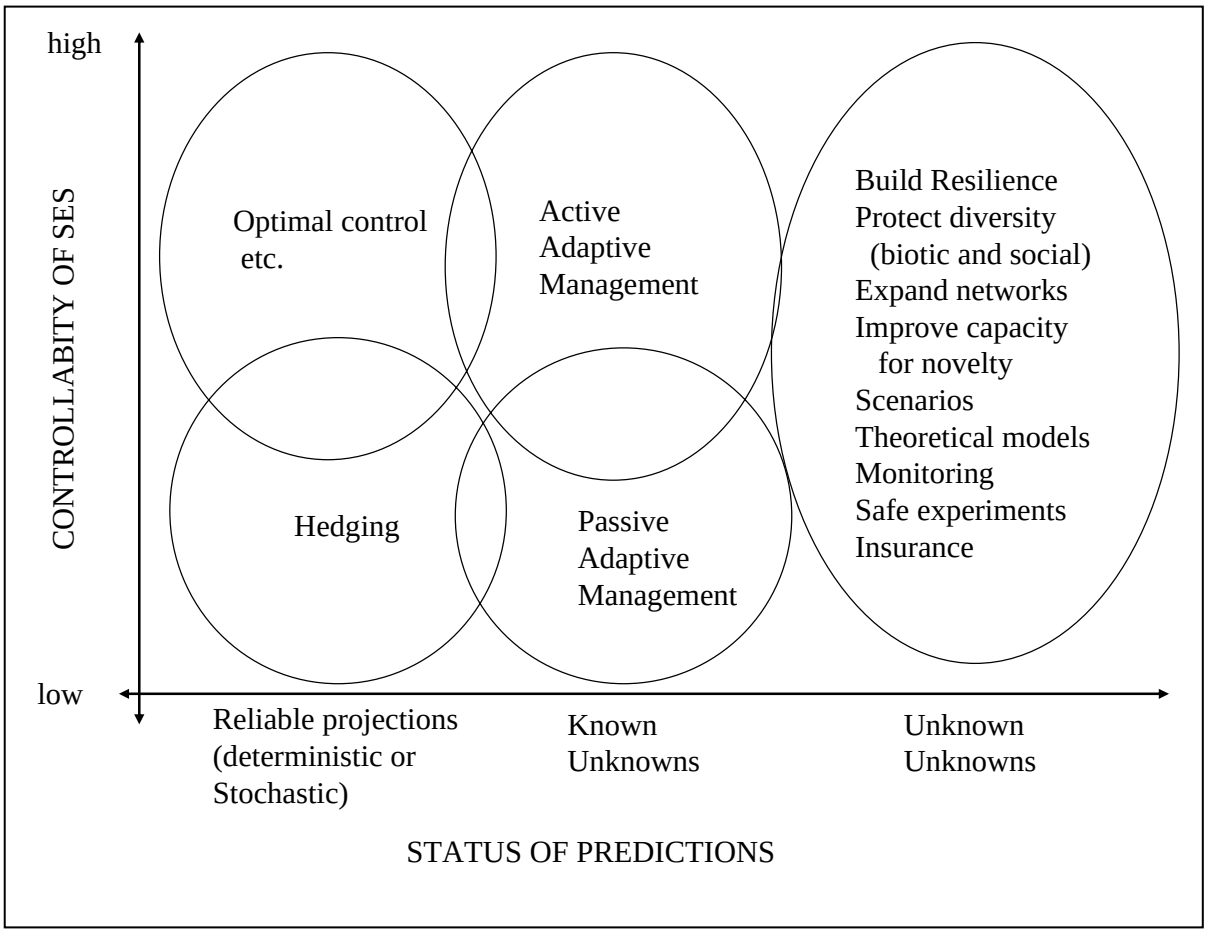
Policy Studies and Decision Analysis

At least three somewhat different approaches have been used to consider policies for systems subject to surprising changes.

Utility projection attempts to project the future returns from alternate institutions, including the possibility of regime shifts in either deterministic or stochastic ways, then implement the "best" institution. This approach is theory-rich but data-poor. Success hinges on knowing the probability distribution for the threshold dynamics, but these distributions are rarely known. Some authors have considered the possibility of learning the threshold location through careful experimental probing. To date this work is largely theoretical.

Indicators and Adaptation employs leading indicators of regime shifts to trigger adaptive changes in practice. There are a number of ecosystem indicators that could be used to provide advance warnings of regime shifts. So far, these indicators have been studied in models or simplified laboratory systems. Also, little work has been done in a social-ecological context to understand how social systems might adapt appropriately to signals from the indicators. SES modeling work suggests that markets for ecosystem services could be designed to respond appropriately to signals of impending regime shift. Nevertheless, much practical work remains to be done to integrate theory and practice.

Resilience-building approaches assume that SES are difficult to control and predictability is limited (Fig. 1). Therefore policy should build the capacity of SES to learn, adapt or transform as the situation evolves. Some key properties of resilient SES are diversity, effective networks, multi-level connections, and capacity to discover or innovate new approaches; each of these has social and ecological aspects. Some tools associated with resilience-building include wide-ranging scenarios of change, multiple theoretical models, sustained monitoring of key indicators over wide gradients, safe experiments, and insurance. This area of science is rich in experience and case studies, but models and theory are sparse, ad hoc, and/or poorly connected to observations.



Research Needs for Ecosystem Surprise

- An overarching international framework that encompasses (1) long-term interdisciplinary studies of SES, spanning periods of important change, and (2) comparative studies of SES, spanning important contrasts in social-ecological development and organization

- Theory and models tailored to the individual properties and policy issues of important SES, based on measurable aspects of SES

- Data-based risk analysis for thresholds that can be quantified (possibilities include freshwater eutrophication, rangeland degradation, drought persistence in drylands, some collapses of living resources, among others)

- Assessment of leading indicators at the scale of ecosystem management and grounded in empirical observation

- Practical, empirically-confirmed guidelines for building resilience in sensible day-to-day decision-making

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Reading List

Berkes, F., J. Colding and C. Folke. 2003. *Navigating Social-Ecological Systems*. Cambridge University Press, Cambridge, England.

Carpenter, S.R. 2003. *Regime Shifts in Lake Ecosystems: Pattern and Variation*. Volume 15 in the Excellence in Ecology Series, Ecology Institute, Oldendorf/Luhe, Germany.

Muradian, R. 2001. Ecological thresholds: a survey. Ecological Economics 38: 7-24.

Repetto, R. (ed) 2006. *Punctuated Equilibrium and the Dynamics of U.S. Environmental Policy*. Yale University Press, New Haven, Connecticut.

Scheffer, M., Carpenter, S.R., Foley, J., Folke, C. & Walker, B. (2001). Catastrophic shifts in ecosystems. *Nature*, 413, 591-596.

Walker B & Meyers JA. (2004). Thresholds in ecological and social-ecological systems: A developing database. *Ecology and Society*, 9(2):3, URL: http://www.ecologyandsociety.org/vol9/iss2/art3

Walker, B. and D. Salt. 2006. *Resilience Thinking*. Island Press, Washington D.C.

Westley, F., B. Zimmerman and M. Patton. 2006. *Getting to Maybe: How the World is Changed*. Random House, Canada.