Anderies, J. M., B. H. Walker, and A. P. Kinzig. 2006. Fifteen weddings and a funeral: case studies and resilience-based management. *Ecology and Society* **11**(1): 21. [online] URL: http://www.ecologyandsociety.org/vol11/iss1/art21/

Insight, part of a Special Feature on Exploring Resilience in Social-Ecological Systems

Fifteen Weddings and a Funeral: Case Studies and Resilience-based Management

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ABSTRACT. “Resilience theory” is a systematic methodology for understanding the dynamics of coupled social-ecological systems (SESs). Its ongoing development requires that resilience theory be confronted with case studies to assess its capacity to help understand and develop policy for SESs. This paper synthesizes the findings from several papers in the special feature “Exploring Resilience in Social-Ecological Systems” that do just this. It then highlights key challenges facing resilience as a theory for understanding SESs and provides some avenues for future research.

Key Words: *resilience, social-ecological systems, resource management*

INTRODUCTION

Why 15 weddings and a funeral? A funeral is a time to celebrate past accomplishments, acknowledge the legacies of those past accomplishments, and recognize that their time is past. A wedding is a time to celebrate possibilities, share in the creative energy of new beginnings, and look to the future. In the context of the 15 case studies addressed in this collection of papers, the funeral refers to a management paradigm based on controlling a well understood system to maximize some form of yield from the system or to keep it in some particular state. The weddings refer to the possibilities for new ideas and the emergence a new management paradigm that focuses on resilience in complex social-ecological systems.

THEORY AND SOCIAL-ECOLOGICAL SYSTEMS

The focus of this special issue has been to explore and develop resilience theory as it applies to social-ecological systems (SESs). At their core, SESs are composed of (1) agents ranging from microbes to plants to humans, each with a different degree of information-processing capacity; (2) a set of allowable actions related to their physical or behavioral characteristics; and (3) a physical substrate that includes chemicals, light, and water. The interactions among these agents and their interactions with the substrate generate dynamic social-ecological systems. Any theory devised to understand SESs must thus account for the relationships between information processing, the actions of agents, and the effects of those actions on other agents and on the environment. Such a theory would span cognitive science, psychology, economics, ecology, biogeochemistry, mathematics, physics, etc. Clearly, such a theory does not exist today, and may well never exist.

This presents a major problem for the study of SESs. The problem is not with resilience theory in particular, but with theories about complex social-ecological systems in general. SESs are so complex that the idea of developing a theory to explain their behavior becomes questionable. Because of this extreme level of complexity, there are, of course, many theories that are capable of explaining some aspects of the aggregate behavior of SESs. But how can such theories be validated? With simple physical or ecological systems, experiments can be used to select among competing hypotheses. However, such experiments typically cannot be run on SESs, which makes it impossible to choose from among competing theories.

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Given these problems, it is important to clarify what resilience theory is and what it is not. Resilience ideas do not comprise a theory intended to explain the behavior of SESs, and so might be better termed a resilience framework or resilience approach. Resilience should be thought of as a framework for systematically thinking about the dynamics of SESs. It includes lessons for management and attempts to capture the more general, but not detailed, features of the ways in which many complex systems behave. It sits on top of other theories, e.g. general systems theory, and seeks to use them to view SESs in creative ways to gain new insights. For example, several resilience-based studies combine elements of theory from economics, ecology, and dynamical systems for particular case studies (e.g., Carpenter et al. 1999*a*, *b*, Anderies et al. 2002, Carpenter and Brock 2004, Janssen et al. 2004, Anderies 2005, Anderies et al. 2006) and in more general contexts (e.g., Brock 1998, Scheffer et al. 2000, Brock et al. 2002, Anderies 2003). Resilience has also been used as a guiding principle within disciplines such as political science (Ostrom 1999), political ecology and resource management (Berkes and Folke 1995, 1998, Berkes 1999), and archaeology (Redman and Kinzig 2003).

The resilience approach addresses issues about the dynamics of systems at multiple interacting scales that are not addressed by other theories and, in addition, provides a process for integrating other theories and ideas to develop a better understanding than might be possible with these theories in isolation. In terms of ecosystem dynamics, enough experimental and other evidence has accumulated to perhaps warrant the emergence of a body of theory. However, for SESs, it has a long way to go. In this capacity, can resilience-based approaches improve management? Yes, although not by providing a mechanism that can be used to predict the impact of management actions, but rather by focusing attention on particular system attributes that play important roles in the dynamics of SESs and attempting to develop principles to guide interventions in SESs to improve their long-term performance. We have confronted the resilience approach with 15 case studies to test whether, in fact, it adds value to understanding their dynamics and providing better options for their management. The key insights are summarized below.

WHAT WE HAVE LEARNED

In this section we highlight the main insights and themes that emerged from the case studies. These insights and themes then motivate our discussion of the future development of theory and management practice in the sections that follow.

A handful of heuristics

The set of propositions presented in Walker et al. (2006) is an account of ideas about resilience in social-ecological systems (see Table 1 in Walker et al. for a summary). They express our current understanding of how these complex systems change and what determines their ability to absorb disturbances in either the ecological or social domain. The key value of the propositions is that they attempt to make explicit the underlying mental models of change used by resilience scholars. They also provide a starting point for scientists and others to test the concept of how change occurs in complex social-ecological systems (SESs). By comparing and contrasting these statements across a wide range of case studies, we hope to articulate, refine, or discard these concepts. Do they have any predictive value? Can they be used in management? This remains to be seen. They need to continue to be tested, refined, rejected, and altered in an iterative process that will continue to increase their value. One thing that emerges from these propositions is a key message that we need more experiments and observations on how systems do or do not change in response to various external shocks and the system processes and feedbacks that are involved in determining these changes.

Resilience and regime shifts: assessing cascading effects

Most published accounts of regime shifts involve a single dominant shift defined by one, often slowly changing, variable in an ecosystem. A comparison of the changes occurring in four quite different regions (Kinzig et al. 2006) led to the recognition that, when the whole SES is considered at multiple scales, there are multiple interacting regime shifts.

Several case studies were examined to explore the implications of such multiple interacting regime shifts, and several significant features of social-ecological systems emerged:

- Multiple thresholds define multiple possible regime shifts that collectively define a number of theoretically possible alternative regimes in which the SES can exist. In practice, crossing one threshold in a complex SES often either initiates or precludes crossing other thresholds, so that only a few of these regimes are attainable. Understanding how threshold excursions interact with each other can help managers determine the most likely future regimes and how to influence the trajectory of the system as a whole.

- These “cascading” regime shifts tend to lead to highly resilient, and often undesirable, states. Managers need to be aware of the interaction of ecological, social, and economic thresholds across scales, rather than focusing narrowly on any single threshold within their domain and scale of interest.

- Managing a single threshold by moving that threshold to a different position could be dangerous in that it may influence other thresholds in ways that make the system as a whole less resilient. This is akin to the notion of robustness trade-offs in engineered systems (Csete and Doyle 2002) and raises the issue of general resilience in, e.g., systems that are robust to many perturbations and thresholds, vs. specific resilience to a subset of perturbations and a single threshold; this is an important area for further research.

Resilience, adaptability, and transformability in lake and wetland social-ecological systems

The erosion of ecological resilience in aquatic and wetland ecosystems is in part driven by human intervention in the form of land development or direct water management. The key message from Gunderson et al. (2006) is that there are different kinds of learning that take place in SESs: incremental, episodic, and transformational. The last of these pays special attention to cross-scale effects and novelty, and involves the reframing of problem domains. It requires the involvement of several levels in a social-ecological panarchy, not simply one level of a social system responding to ecological surprises. According to Walker et al. (2004), transformational learning is a key ingredient for enhancing transformability, i.e., the capacity of an SES to reinvent itself, to become a different kind of system when the existing one is no longer tenable. Transformations rely on social-ecological memory and understanding and are limited by existing social legacies and key vulnerabilities that determine ecological resilience. To learn and innovate, systems must be open to and tolerant of failure. The key to transformational learning is to know what to keep in terms of memory, experience, and wisdom and what to discard.

One interesting supposition is that the people involved in SESs that are rich in resources and monetary capital, such as the Everglades, continue to make mistakes but fail to learn from them because they assume that these resources will buy solutions over time, mistakes can always be remedied with an infusion of resources, and learning can be replaced with organizational infrastructure. In contrast, open, flexible systems such as the Northern Highlands Lake District in Wisconsin and the Kristanstad Vattenrike in Sweden show tremendous capacity for learning despite, or perhaps because of, much more limited resources. The people in such systems appear to be willing to take risks and to tolerate and learn from mistakes, and they know that they must focus on activities that lead to learning so that they can maximize the impact of meager resources. A general hypothesis is beginning to emerge from this comparison and related studies, namely, that most capital inputs from outside the SES, i.e., from higher in the panarchy, amount to subsidies intended to prevent these systems from changing, as opposed to subsidies designed to encourage change.

Collapse and reorganization in social-ecological systems

Are there specific, identifiable dynamics that occur during periods of collapse that fundamentally drive subsequent periods of reorganization? From a comparison of two kinds of SESs in each of two regions, the South East Lowveld in Zimbabwe and the rangelands of New South Wales in Australia, it seems that cross-scale interactions dominate the pattern of backloop dynamics.

In the case of Zimbabwe, the demand for hunting coupled with declining terms of trade in the livestock industry and rangelands degraded by years of overgrazing allowed the system to reorganize from agriculture to a new means for generating livelihoods. However, the wealth brought by hunters into the system was generated elsewhere around the world, and individuals in Zimbabwe could reach out to the entire globe to bring resources into their system. In the case of the Aboriginal people in Australia, their ability to reorganize has been enabled by both a national sentiment in favor of human rights and international concern for human rights generated by the international media. Again, the Aborigines reached out on national and global scales to take advantage of available social capital. It is not clear from these cases that backloop dynamics were particularly important forces for the nature of reorganization in these systems.

One lesson that emerges from these studies of collapse and reorganization is that, although the capacity to self-organize is essential, maintaining this capacity can be costly. It must be generated and maintained at the cost of foregone higher short-term returns by careful investment in human, natural, human-made, and social capital either within the system or at larger scales. If this investment comes from a larger scale, as in these two cases, a balance between this cross-scale subsidization and self-organization is critical. Excessive subsidization can reduce the capacity of a system to self-organize by generating perverse incentives. Further, cross-scale subsidization can increase the vulnerability of the broader system. This is because vulnerability can never be entirely eliminated, i.e., enhancing the robustness of one part of a system or at a particular scale may reduce the robustness of other parts of the system (Csete and Doyle 2002). Thus, the cost of maintaining robustness at smaller scales must be traded off against the potential resulting loss of robustness at larger scales, or vice versa. Cross-scale relationships should, in the long term, be mutually sustaining, not exploitative from above or parasitic from below. The political difficulty associated with maintaining this balance may be a main reason why SESs so often remain maladapted to current conditions and opportunities, even to the point of collapse. It is a reflection of failure in the system of governance, a point that is again emphasized in the paper on governance (Lebel et al. 2006).

Toward a network perspective of the study of resilience in social-ecological systems

This paper addresses the fact that the formal models used to study the resilience of SESs generally do not explicitly include the internal structural characteristics of the system. Given the complexity of SESs, an understanding of the structure of the interactions between their identifiable components beyond that provided by simplified aggregate models is a logical development. A general consideration of several SESs suggests that, in terms of their influence on resilience, there are three important kinds of social-ecological network effects: (1) people connect ecosystems by information or material flows; (2) ecosystem networks can be disconnected and fragmented, or be increasingly connected, by the actions of people; and (3) people create new ecological networks such as irrigation systems. Each of these three characteristic kinds of social-ecological networks faces different problems that influence their resilience. Obviously, the addition or removal of connections can affect resilience. It may increase or decrease coordination problems or the diffusion of desirable and undesirable attributes, e.g., information and diseases.

One interesting observation that emerges from a network perspective is that the number of links increases during periods of reorganization, in part because sleeping links are activated in periods of crisis. Another interesting observation is that there is no clear indication how connectivity is related to resilience, in contrast to the suggestion in the original model of the adaptive cycle proposed by Holling (1986). The consequences of structural properties of systems are context-dependent, and we are only in the initial phase of unraveling the specifics. We foresee two important developments required before a network perspective for the resilience of SESs will be become really useful. The first requirement is the systematic collection over time of network relationships in SESs across different case studies. Second, model studies of theoretical SESs are necessary to develop a rough understanding of the expected importance of various characteristics of network structures such as connectivity and centrality for different archetypal social-ecological networks and their derivatives. Such model exercises may help guide systematic data collection.

Scale mismatches in social-ecological systems: causes, consequences, and solutions

Many of the problems encountered by societies in managing natural resources arise as a consequence of a mismatch between the scale of management and the scale of the process being managed (Cumming et al. 2006). This hypothesis is examined using examples from southern Africa and the southern United States that address four main questions: (1) What is a scale mismatch? (2) How are scale mismatches generated? (3) What are the consequences of scale mismatches? (4) How can scale mismatches be resolved? Scale mismatches occur when the scale of action of interacting components and/or processes at different levels in an SES is altered in such a way that one or more functions of the system are disrupted. Scale mismatches between social and ecological components, it turns out, are widespread. Although they often arise as a natural consequence of patterns of human social and economic development, they may also be exacerbated by poorly designed policy and management initiatives. Recognizing and resolving scale mismatches is thus an important aspect of building resilience in SESs.

Governance and the capacity to manage resilience in regional social-ecological systems

The point of departure for Lebel et al. (2006) is the assertion that interventions in social-ecological systems immediately confront issues of governance. In the context of resilience, who decides what should be made resilient to what, for whom is it to be managed, and for what purpose? This paper draws on insights from a diverse set of case studies to address the question: How do certain attributes of governance function in society to enhance the capacity to manage resilience? Three specific propositions were explored: (1) participation builds trust, and deliberation leads to the shared understanding needed to mobilize and self-organize; (2) polycentric and multilayered institutions improve the fit between knowledge, action, and social-ecological contexts in ways that allow societies to respond more adaptively at appropriate levels; and (3) accountable authorities that also pursue just distributions of benefits and involuntary risks enhance the adaptive capacity of vulnerable groups and society as a whole.

Some support was found for parts of all three propositions. However, the authors note that these findings are necessarily tentative. The collection of case studies was assembled post hoc and was not designed to address questions about governance. Much of the variation in the association between governance arrangements and the capacity to manage resilience remains unexplained. Further, the authors raise theoretical and practical issues, including the problem of measurement, the role of experts, and causality. The capacities of individual actors and the institutionalized relationships among them are not straightforward to assess. The role of experts in, e.g., promoting resilience theory, is problematic, because they may dismiss the livelihood needs or rights of local people in the interests of maintaining, say, ecological resilience. Trade-offs between social and environmental objectives are and should be political rather than left to experts and models. Finally, the authors indicate that it is possible that the capacity to manage resilience may influence forms of governance and that ecological feedbacks may constrain both governance and capacities. That is, the complexity of SESs makes it difficult to determine the effect of developing particular capacities in the system, e.g., to manage resilience, on its capacities to manage other tasks.

Shooting the rapids: navigating transitions to adaptive governance of social-ecological systems

“Shooting the rapids” is used as an organizing metaphor in Olsson et al. (2006) and an analogy for the periods of abrupt change or turbulence observed in managed social-ecological systems in which previous rules and social mechanisms may no longer apply. Successful transformation to a new kind of SES that meets social welfare expectations consists of two distinct phases, a preparation phase and a transition phase, linked by a window of opportunity. They are followed by a phase of building resilience in the new trajectory. A comparison of five quite different case studies shows that two components, (1) building knowledge and networking and (2) leadership, are always critical in preparing the system for change. The existence of shadow networks that can be triggered into action by a crisis is an important attribute that enables transformation toward a system of adaptive governance. Leaders can prepare an SES for change by exploring alternative system configurations and developing strategies for choosing from among possible futures. The key attributes of leadership that enable successful transitions include the ability to reconceptualize issues; generate and integrate a diversity of ideas, viewpoints, and solutions; communicate and engage with key individuals in different sectors; move across levels of governance and politics, i.e., span scales; promote and steward experimentation at smaller scales; recognize or create windows of opportunity; and promote novelty by combining different networks, experiences, and memories.

Leadership can work both ways in systems undergoing change, and examples of failed transformations lead the authors to some concluding questions. When might reliance on one or a few key individuals make change highly vulnerable to accidents of history? Are there ways to institutionalize, diversify, and secure leadership functions? What is the role of bridging organizations for this purpose? From the comparisons, they nevertheless conclude that there are a number of actions that can be taken and suggest 14 guidelines, most of which have to do with being prepared for change.

THE FUNERAL AND A WAY FORWARD FOR THEORY

Almost 30 yr ago, an important paper was published titled "Epitaph for the concept of maximum sustainable yield" (Larkin 1977). Nevertheless, today maximum sustainable yield (MSY) is still the dominant paradigm in resource policy and management. All that has been revealed by the analyses of these 15 social-ecological systems (SESs) has confirmed that a top-down, command-and-control approach to achieving some optimized outcome doesn't work. So why has it not been buried?

The answer has two parts. First, the idea of MSY relates to a larger literature concerning the application of optimal control techniques to resource management problems. The predecessor of optimal control, the calculus of variations, can be traced back to the brachistochrone problem posed by Johann Bernoulli (Kamien and Schwartz 1991). These techniques were mainly applied in theoretical physics but made their way into economics in the early 20th century (e.g., Hotelling 1931). Pontryagin et al. (1962) turned the calculus of variations of the 1950s into the more general optimal control theory, which was applied to problems in aeronautics, chemistry, and management science and subsequently adapted to problems of renewable resource management (Clark 1973, 1976, Dasgupta 1982). Dynamic programming, the technique very often applied to problems containing an element of uncertainty, was also developed in the 1950s by Bellman (1957) and was applied to resource problems (e.g., Clark and Kirkwood 1986) not long after. These mathematical techniques " ... are now nearly standard in economics and management science" (Kamien and Schwartz 1991:4), and therein lies the problem.

Optimal control techniques have become a standard part of academic resource economics, not because they are necessarily the most useful for understanding resource management problems but because they are elegant representations of the sorts of generalized problems embodied by resource management issues. There have been many variations on the theme set out by the models developed 40 yr ago (see Sethi et al. 2005 for a recent example), but the main insights have changed very little. The problem is that to remain tractable, even numerically, the models have to be kept quite simple and thus can only yield themes related to resource management; the resulting control laws cannot typically be applied in practice. In fact, when the objective is to actually control a real system such as an airplane, the approach to control is quite different. The objective is often to find not an optimal control, but one that performs well under a range of conditions, i.e. under uncertainty. This problem is the core focus of the field of robust control (Zhou and Doyle 1998). This latter approach, focused on real-world problems, may have more potential to address resource management issues than does mathematical optimal control, which is more difficult to transfer from theory to practical situations.

The second reason for the persistence of optimal control theory in resource management is the fact that there has not been an alternative theory or framework to replace it. Robust control is a possibility, but it, too, leaves quite a gap between theory and practice. Both robust and optimal control work very well in systems that are much better defined than social-ecological systems. It is in the space between these types of problems and actual management practice that a resilience framework similar in spirit to robust control can play an important role.

The value of having a well developed theory is that it allows generalization of findings from one place or SES to another. We contend that it is premature to think of a fully fledged resilience theory for SESs, although a well constructed resilience framework can meet many needs in management practice. Optimization, or MSY, is a theory for SES policy and management that served well in the early development phase of resource use industries, although it runs into trouble with strong nonlinear behavior and increasing uncertainty. We need to move on to an era in which something like a resilience framework forms the basis for policy and management. We can no longer allow the attraction of having a simple, elegant, and, above all, understandable theory trump the attraction of having a theory that is difficult to understand in its entirety but better captures the workings of the real world.

We think a future direction for research must carefully examine what is meant by resilience theory. As mentioned in the introduction, it does not seem appropriate to describe resilience-based inquiry as a theory. It is better described as a collection of ideas about how to interpret complex systems. In the same way that there are complex adaptive systems approaches, there is no complex adaptive systems theory. However, if we accept that resilience theory is a systematic approach for studying SESs, then the mechanics of this approach deserve careful consideration and development. It is perhaps in the development of the resilience approach that future research in resilience theory lies. Although it is very phenomenological, it is a powerful tool for categorizing observed patterns, asking questions, and taking the insights from one SES to aid in the understanding and management of another. Many papers about resilience theory are either mainly descriptive or are combinations of ecological and economic theory applied to specific systems with particular nonlinearities. Nonetheless, there is a generic structure to the method of linking theories in the resilience context and the nature of the resulting analysis.

The elements of the type of resilience framework identified by the findings from earlier work (Gunderson and Holling 2002), fall into two main areas: (1) social-ecological systems, in the main, have nonlinear dynamics that result in multiple stability domains, and (2) the pattern of their dynamics over time tends to conform to one of the variants of linked adaptive cycles at multiple scales. The insights from the studies described above identify components within these two areas that now need attention.

Multiple domains

The development of formal models with multiple threshold-type behavior to explore the management and governance implications of multiple thresholds is needed. This effort should be accompanied by the analysis of case studies that exhibit effects that can inform the modeling.

Key insights from network and dynamical systems approaches need to be brought together to better understand how the structure of agent-agent and agent-resource interactions affects the topology of the dynamics in SESs that both generate the possibility for alternate system regimes and drive the system between them.

The continued development of a typology of thresholds that will help identify potential thresholds before they are reached is essential. Thresholds have been identified as levels of controlling (slow) variables in which feedbacks change. Further research should focus on system measurement to develop heuristics to either avoid or promote as appropriate such changes in feedbacks.

Adaptive cycles and multiple scales

To extend the understanding of resilience theory captured in the broad sense in the adaptive cycle metaphor, formal models that generate backloop dynamics must be developed. Such models must be coupled across scales and used to study the basic properties of and the effect of management actions on such systems. This type of modeling should attempt to develop an understanding of system attributes that lead to backloop behavior and should assess the social and ecological conditions under which adaptive cycles actually occur. It may be that the conditions under which they occur are restrictive. In addition, it is more common that only parts of the cycle occur in formal models, with the result that these parts must be qualitatively patched together to form true cycles.

A better theoretical treatment of the inherent mismatch between scales in SESs and their implications for management and intervention is needed. One such mismatch is core to the entire sustainability debate: what one might call individual time scales and social time scales. The implications of this mismatch are very well understood, but are there others and, if so, how important are they?

Adaptive governance

Several of the papers highlight system attributes that enhance adaptability and transformability and place an emphasis on the need for new kinds of adaptive governance. We need to learn how to manage with and for change, rather than against it, as identified in the earlier resilience work of Yorque et al. (2002). The new insights presented here are still based on descriptive accounts of how leadership, trust, shadow networks, sleeper links, polycentric governance arrangements, and so forth contributed to the capacity of SESs to avoid undesired regime shifts. These insights must now be incorporated into formal models of governance. Models of this type will allow us to explore different forms of adaptive governance as part of a collaborative adaptive governance process. The development of such models is a major challenge facing social science.

A WAY FORWARD FOR MANAGEMENT

In some ways, the management of social-ecological systems (SESs) may be more of an art than a science. In many activities in life such as sports, music, games, etc., the practitioners say, “Sorry, I can’t tell you how to do this. You’ve just got to get a feel for it.” You cannot tell someone how to surf. You can only give him a surf board and some pointers, and tell him to have a go. The pointers are, of course, very important. Surfing lessons help. They reduce the number of accidents and shorten learning time. They are the “theory” behind surfing. However, on their own they will not lead to successful surfing. Why doesn’t science work in this case? In theory, we should be able to apply Newtonian mechanics (gravity, etc.) to the person on the surf board, along with fluid mechanics (traveling waves and partial differential equations) and engineering concepts (flow over a hydrofoil), and design a controller or a set of rules for perfect surfing. Why doesn’t this work? Complexity and subtlety. And timing. For the same reasons, machine-made furniture will never match the beauty of hand-made furniture. Machines miss the subtleties in the wood that a fine artisan would accentuate. We can make a computer play chess very well, but can we make a robot play tennis? Yes, but not very well. The nuances of the game will likely always escape it, at least for the foreseeable future.

The point here is that, if we can improve the art of SES management to complement the basic science, the likelihood of successful outcomes will be higher than if we persist with pure science. Context and experience matter, and there can be no “one size fits all” set of recommendations for resilience management. The resilience paradigm can help here. And how do we do that?

One important way is through active adaptive management (Walters 1986), which takes as its starting point that all intended management activities are hypotheses about how the system will respond. Components of adaptive management include developing a model about how the system behaves under management interventions, providing a framework for revealing assumptions, and sorting through alternative explanations or hypotheses about system dynamics. This evolving model is used to pose better questions about system behavior rather than to predict policy consequences. These questions are then evaluated or tested over time through management actions. This method acknowledges the lack of certainty in science and adopts an iterative, adaptive approach to achieving success. The real challenge for adaptive management is to get past the modeling stage and actually carry out the managemnt experiments suggested by the collaborative modeling process. While reflecting on actual attempts at adaptive manangement, Walters (1997) notes that very few move beyond this stage because experimental policies are seen as too costly and too risky. Rather than being viewed as opportunites, they are considered threats to the status quo upon which many livelihoods depend.

IMPLICATIONS FOR THE ART OF SOCIAL-ECOLOGICAL SYSTEM MANAGEMENT

We contend that there would be, in most cases, significant differences between existing development and management plans and approaches and those that would have been developed with a resilience perspective. The traditional approach to policy and management for social-ecological systems (SESs) is based on the top-down, command-and-control paradigm that we must bury. This approach typically ignores variations beyond the norm and the complex interactions between system components that determine the system's response to external shocks. It often works well in the beginning but then runs into trouble. Under this approach, the response to uncertainty, crises, and unexpected events involves increased controls, with increasing transaction costs, as the system moves closer to thresholds in key driving variables. Controls aimed at one type of shock can increase vulnerability to other types of shocks. The magnitude of the shock required to push the system across a threshold becomes smaller. An alternative, resilience-based approach embraces change. Rather than focusing on the need to control natural variability and to maintain the system in some perceived optimal state, management and governance based on resilience theory focus instead on key controlling variables, alternate system regimes, and thresholds.

How can this general statement be made operational? Fortunately, this is an easier question than how to further develop theory. As a start, and building on the earlier findings of Holling et al. (2002:396:Table 15-1), the following tentative messages for policy and management emerge from the work in this special issue:

1. Manage for as many potential configurations of SESs as possible. Neither ecosystems nor social systems can be managed in isolation. Their strong interactions and multiple feedbacks must be taken into account.

2. Manage at multiple scales as much as possible. Understand how the focal scale interacts with other scales, what is happening in the levels above and below, and what effect cross-scale processes are likely to exert.

3. Attend to slow variables. Identify the key (slow) controlling variables with threshold effects that determine alternate system regimes. Note that there are typically no more than a few (a handful) of such key variables that are important for any given change.

4. Manage for diversity. Simplifying production, ecological, or social systems for increased efficiency carries with it a reduction in response diversity, so that the system becomes more vulnerable to stresses and shocks.

5. Accept that maintaining resilience incurs costs. It comes down to a trade-off between foregone short-term benefits of high efficiency under narrowly constrained circumstances and the long-term persistence of the existing regime with reduced costs of crisis management.

6. Make strategic interventions. Focus on identifying the key points for intervention in the SES that can avoid undesirable pathways and alternate regimes. Recognize the windows of opportunity for strategic interventions that will not succeed if they are applied at the wrong time. Successful intervention requires investment in adaptive capacity.

7. Understand underlying mental models. Successful outcomes depend on expanding and connecting the mental models that exist across the stakeholder groups so as to increase their overlap, and thereby the social system's capacity to act.

8. Embrace adaptive governance. Introduce flexible, dynamic institutional and governance structures so that key intervention points can be addressed at the appropriate scales and times.

9. Recognize windows for transformation. If a system has already moved into an undesirable regime whose end-point, the notional equilibrium, is unacceptable and efforts to keep away from it are failing, there comes a point at which adaptation is no longer ecologically, socially, or economically feasible. When transformation is the only option, the sooner it is recognized and acted on, the lower the transaction costs and the higher the likelihood of success. Accomplishing this requires attention to the issues described in point 6 above.

10. Recognize that vulnerability cannot be eliminated. Strategies that enhance robustness to particular types of shocks necessarily give

rise to new vulnerabilities in other domains. Management decisions must be continually revisited as system contexts change and additional vulnerabilities emerge.

CONCLUDING THOUGHTS

We have attempted to summarize some of the insights from the application of resilience-based concepts to 15 case studies. It is clear that there is a long way to go before the resilience framework becomes a theory. Nonetheless, we contend that it can be a very appropriate and helpful approach to structuring the study and management of social-ecological systems (SESs). It will not replace particular theories in ecology, economics, and other social sciences but, in addition to bringing new elements of its own, it can help integrate these particular (partial) theories in a way that produces a better understand the dynamic evolution of linked SESs operating at multiple scales. If resilience-based approaches achieve this, they will prove to have been a worthwhile development. Despite its present inadequacies, we propose that resilience-based thinking offers a better basis for successfully intervening in SESs than the paradigm of maximum sustainable yield, which deserves an honorable (re) burial.

Responses to this article can be read online at:
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