Ecological & Social-ecological Resilience - Assessing and Managing Change in Complex Systems[i]

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Introduction

Humans are changing the dynamics of ecosystems in ways that are increasing risk and driving change from local to global scales. The concept of ecological resilience was introduced by C.S. Holling to characterize abrupt, non-linear and surprising change in ecosystems (Holling, 1973). This concept posited multiple configurations of ecosystems—that ecosystems could exist in qualitatively different forms; each characterized by different structures and feedbacks. Ecological resilience was defined as an emergent system property that mediated the transition among different ecosystem configurations or regimes. Over time, scholars have shown that such quasi or meta-stable states exist across all types of ecosystems, from marine to aquatic to wetlands to drylands (Folke, et al., 2004). Walker and colleagues also refined components of resilience as a) resistance to change and b) latitude in capacity to avoid a regime shift c) precariousness and d) panarchy (Walker, Holling, Carpenter, & Kinzig, 2004). Multiple regimes, with transitions among them, have also been described in social-ecological systems due to complex human-environment interactions both within and across scales of space and time. SES resilience is defined in three parts as i) the capacity of linked social-ecological systems to absorb disturbances while retaining essential structures, processes and feedbacks, ii) the capacity for learning and adaptation, and iii) the degree to which the system is capable of self-organizing (Carpenter, Walker, Anderies, & Abel, 2001).

Resilience objectives

The types of change suggested by resilience theory and observed in social-ecological systems imply different responses or practical strategies, because of the types of uncertainties associated with each model of change. Many case histories demonstrate that SES's undergo at least three different trajectories of change: system development toward a planned and relatively stable regime, resilience dynamics when the system flips from one regime to another, and transformation to an entirely new regime of the social-ecological system (Gunderson & Holling, 2002). The first category of change focuses on attempts to control ecosystems to secure steady and reliable ecosystem goods and

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services, for example, managing forests for continued wood supply. Such management approaches remove competition through thinning and attempt to control outbreaks of destructive agents such as fire or forest pests. All of these actions are aimed at optimizing and sustaining production of wood for lumber, fiber or fuel. The second category of change relates to resilience management that usually involves inherent and unresolvable uncertainties, which are generally approached through adaptive management (Walters, 1986). Managing under conditions of high uncertainty requires hypothesis testing and learning. For example, experimenting to determine how mechanisms such as functional diversity in fish communities can help prevent a regime shift to a degraded coral reef. Adaptive management confronts system uncertainties by applying policies and practices structured to iteratively test and evaluate a system's state and trajectory. Transformative change, the third category, involves new social and ecological components, rules, regulations, institutions, and configurations, suggesting strategies of adaptive management and adaptive governance (Gunderson & Holling, 2002). For example, when Chile moved to a democracy small fishers and scientists worked together to develop voluntary agreements that, in combination with reforms and new laws, have begun to chart a more sustainable future for Chilean fisheries.

Resilience assessment

Resilience assessment attempts to better understand change dynamics. The practitioner's guide to resilience assessment developed by the Resilience Alliance (RA) provides an iterative approach to understanding how resilience as a property of social-ecological systems is created, maintained or eroded over time (Resilience Alliance, 2010). The approach described in the practitioner's guide was informed by several decades of theoretical and applied research in ecology, natural resource management, complex adaptive systems and integrated social-ecological systems. Developed by RA researchers, the guide is structured around core concepts that include: defining system boundaries and key issues relevant to stakeholders, identifying potential thresholds and tipping points, describing adaptive cycles of change, exploring cross-scale interactions, and evaluating attributes of adaptive governance. As new understanding and knowledge about the system become available through a set of questions and activities, models are refined, and specific information about the system is updated. The assessment process can be adapted to a particular context, including the degree to which it is participatory vs. expert-driven, the use of primary and secondary data, and in relation to the overall purpose of the assessment. Assessments produced with the guide have been used to develop regional plans, to identify funding priorities, to probe 'wicked problems', to reveal leverage points, and to influence governance systems.

Comprehensive applications of resilience assessment offer practical examples of how a resilience perspective differs from traditional approaches to natural resource management and have informed the RA's assessment guide (Walker, Abel, Anderies, & Ryan, 2009). Engaging multiple stakeholders in the process is key, particularly when the aim is to act on assessment outcomes. A recent assessment framework combining resilience, adaptation, and transformation, further advances the integral role of stakeholder participation and importantly, the development of tailored and more generic indicators (O'Connell, Walker, Abel, & Grigg, 2015). Growing interest in resilience metrics underscores the need for approaches and frameworks that seek to deepen understanding of system dynamics and focus evaluation on key resilience properties (Quinlan, Berbés-Blázquez, Haider, & Peterson, 2015).

Resilience management – adaptive management & governance

A common objective of resilience management involves identifying both the risks and opportunities associated with current management paradigms and governance regimes. Folke, Hahn, Olsson, and Norberg (2005) stress the need for adaptive governance with a focus on the social aspects of governance as a means to gain acceptance of adaptive management and to assure the organizational learning and ability to navigate competing values and interests that are necessary for its implementation. The authors include in their criteria: social capital including trust, common rules, leadership, and experience; networks and bridging organizations within a polycentric governance structure, and a devolution of management rights and power sharing that promotes participation. The reflexive nature of adaptive governance emphasizes the need to regularly revisit and question underlying assumptions. Schultz and colleagues also point out that adaptive governance structures are flexible and thus may be best suited to contexts that leave enough space for innovation and bottom-up initiatives (Schultz, Folke, Österblom, & Olsson, 2015). The authors further suggest that continuous and accelerated change will challenge all forms of governance and attempts to manage social-ecological systems, reinforcing the need for on-going learning and trust-building toward collaborative stewardship.

Annotated Bibliography

Carpenter, S., Walker, B., Anderies, J. M., & Abel, N. (2001). From Metaphor to Measurement: Resilience of What to What? *Ecosystems*, 3 (8), 765-781.
The paper advances the discussion from theory to practice and the need to specify the system (resilience of what?) and the disturbance (resilience to what?).

Folke, C., Carpenter, S., Walker, B., Scheffer, M., Elmqvist, T., Gunderson, L., et al. (2004). Regime Shifts, Resilience, and Biodiversity in Ecosystem Management. *Annual Review of Ecology Evolution and Systematics*, 35, 557-581.
Regime shifts can occur by removing response diversity, functional groups of species, trophic levels; impacting on ecosystems via emissions of waste and pollutants and climate change; and altering the magnitude, frequency, and duration of disturbance regimes.

Folke, C., Hahn, T., Olsson, P., & Norberg, J. (2005). Adaptive Governance of Social-Ecological Systems. *Annual Review of Environment and Resources*, 30, 441-473.
Comprehensive introduction to adaptive governance in the context of social-ecological systems.

Gunderson, L., & Holling, C. (2002). *Panarchy*. (L. Gunderson, & C. Holling, Eds.) Washington D.C.: Island Press.
Panarchy is a conceptual framework to describe evolving hierarchical systems with multiple interrelated cross-scale dynamics. Previously social-ecological systems were described by the authors in terms of adaptive cycles, of growth and development, creative destruction and reorganization.

Holling, C. (1973). Resilience and Stability of Ecological Systems. *Annual Review of Ecology and Systematics* , 4, 1-23.

Contrasts stability, the capacity of an ecosystem to return to a similar state following a disturbance with resilience, the amount of disturbance that an ecosystem can absorb without changing into a new state.

O'Connell, D., Walker, B., Abel, N., & Grigg, N. (2015). *The Resilience, Adaptation and Transformation Assessment Framework: From Theory to Application*. Dickson, Australia: CSIRO.
Framework of resilience assessment modified from Resilience Alliance workbook to include two types of indicators - generic and system-specific.

Quinlan, A., Berbés-Blázquez, M., Haider, L. J., & Peterson, G. D. (2015). Measuring and assessing resilience: broadening understanding through multiple disciplinary perspectives. *Journal of Applied Ecology*.
Overview of the strengths and limitations of assessing and measuring resilience. A set of seven principles for building resilience in social-ecological systems provides a theoretical foundation for integrative efforts to measure resilience.

Resilience Alliance. (2010). *Assessing Resilience in Social-Ecological Systems: Workbook for Practitioners*. Retrieved 04 29, 2016 from Resilience Alliance: http://www.resalliance.org/3871.php
A tool designed to help guide an inquiry into system change. Structured around key concepts of resilience the workbook uses questions to guide an exploration of a system and its key issues from a resilience perspective.

Schultz, L., Folke, C., Österblom, H., & Olsson, P. (2015). Adaptive Governance, Ecosystem Management, and Natural Capital. Proceedings of *the National Academy of Sciences*, 112 (24), 7369-7374.
Comparison of case studies reveals attributes of adaptive governance including its emergence in different places and types of social-ecological systems around the world.

Walker, B., Abel, N., Anderies, J. M., & Ryan, P. (2009). Resilience, Adaptability and Transformability in the Goulburn-Broken Catchment, Australia. *Ecology & Society*, 14 (1), 12.
Comprehensive application of resilience assessment approach.

Walker, B., Holling, C., Carpenter, S. R., & Kinzig, A. (2004). Resilience, Adaptability and Transformability in Social-Ecological Systems. *Ecology and Society*, 9 (2), 5.
Resilience (the capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure, identity, and feedbacks) has four components - latitude, resistance, precariousness, and panarchy - most readily portrayed using the metaphor of a stability landscape.

Walters, C. J. (1986). *Adaptive Management of Renewable Resources*. New York: McGraw-Hill.
Because of the inherent uncertainty in managed resource systems, management should take the approach of recognizing and sorting among multiple hypotheses during assessment, and testing scientific understanding through a process of experimental management that adapts to changing system states.