Ecological Resilience[i]

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Background

Resilience is the capacity of complex systems of people and nature to withstand disturbance without shifting into an alternate regime, or a different type of system organized around different processes and structures (Holling, 1973). Resilience theory was developed to explain the non-linear dynamics of complex adaptive systems, like social-ecological systems (SES) (Walker & Salt, 2006). It is often apparent when the resilience of a SES has been exceeded as the system discernibly changes, such as when a thriving city shifts into a poverty trap, but it is difficult to predict when that shift might occur because of the non-linear dynamics of complex systems.

Ecological resilience should not be confused with engineering resilience (Angeler & Allen, 2016), which emphasizes the ability of a SES to perform a specific task consistently and predictably, and to re-establish performance quickly should a disturbance occur. Engineering resilience assumes that complex systems are characterized by a single equilibrium state, and this assumption is not appropriate for complex adaptive systems such as SES. In the risk governance context this means that compounded perturbations derived from hazards or global change can have unexpected and highly uncertain effects on natural resources, humans and societies. These effects can manifest in regime shifts, potentially spurring environmental degradation that might lock SES in an undesirable system state that can be difficult to reverse, and as a consequence economic crises, conflict, human health problems.

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Resilience and risk governance

A premise of any SES is that surprise and uncertainty are inherent to the system. Risk governance, as defined by the International Risk Governance Council, implies enabling societies to benefit from change while minimizing the negative consequences of the associated risks. However, achieving and managing for trade-offs between benefits for societies of change while reducing risks is difficult and does not adequately address surprise and uncertainty in system behaviour. SES management and governance have therefore, to a large extent, struggled over the long term to ensure the maintenance of ecological regimes that are desirable for humans in terms of consistent delivery of ecological goods and services while systems undergo change. Regime shifts, such as the collapse of commercial fisheries, have often been the consequence of the sustained overuse of natural resources.

Resilience-based management benefits risk governance in two ways. First, when systems are in a desirable state for humans, management can focus on fostering and enhancing the resilience of this regime by assuring that functional attributes relevant for processes that deliver ecosystem services are diverse and imbricated. Second, systems in undesirable states can also be highly resilient. Where systems are in undesirable states resistant to change, that is when an undesirable state is resilient, it may be necessary to reduce the resilience of the system and to induce a shift in the system to a regime that is more desirable, and then to manage the system to foster the regime of this desirable state.

Adaptive management

Adaptive management was developed as a way to conduct safe-to-fail experiments for ecosystems, and a way to allow management to occur in the face of uncertainty while allowing flexibility and enhancing learning. Managing for resilience therefore consists of actively maintaining a diversity of functional attributes in the system, accounting for thresholds and the non-linear dynamics that occur at thresholds, and implementing adaptive management and governance. Managing for resilience requires an improved understanding of system-level behavior, rather than specific, detailed knowledge of parts of the system. Adaptive management and governance are critical to managing for resilience, as they treat policy and management options as hypotheses to be put at risk, and thus enhance learning and reduce uncertainty (Allen et al., 2011).

The following propositions constitute the core of managing for resilience in social-ecological systems:

1. Identify the conditions that indicate loss of resilience for the particular system (Angeler & Allen, 2016). Recent research demonstrates that there are system-specific conditions that indicate a system is losing resilience and approaching a regime shift. These indicators are measurable (see below), and will differ between ecosystems.
2. Identify and maintain a diversity of system elements and feedbacks that help keep a system within a desired regime. Maintain the distribution of ecological functions within and across scales that contribute to system resilience.

Measuring resilience

Resilience theory explicitly accounts for the hierarchical organization of SES. It considers discrete scales of space and time at which patterns of structure manifest and processes unfold. For instance, small and fast processes such as the turnover of leaves on trees are orders of magnitude different than the large and slow processes, such as climate, that drive the location of boreal forest on a continent. Resilience can be assessed by examining how functional attributes are distributed within and across the scales present in the system of interest. Resilience is considered to increase with an increasing redundancy and diversity of functional attributes, both within and across scales. Higher redundancy and diversity of functional traits can buffer against disturbances, maintain processes and stabilize feedbacks of desired system regimes.

Fundamental to the assessment of resilience is the objective identification of the scaling structure of the system to determine within and cross-scale redundancy and diversity of functional attributes. A series of methods have been developed in the ecological sciences that have potential for wider application in the social and ecological sciences (Sundstrom et al., 2014). These methods include Classification and Regression Tree analysis, and their Bayesian implementation, which identify scaling structure based on size characteristics in ecological (e.g. animal size) or urban (city size) systems. Other approaches are based on time series and spatial modelling (Angeler et al., 2016). Time series modelling allows identifying discrete temporal frequencies at which patterns in complex systems manifest. Spatial methods reveal discrete geographical extents and variation in relevant variables and have potential to assess how entire regions beyond ecosystems affect and are affected by local and regional environmental processes and governance (spatial resilience; Allen et al., 2016). Other approaches include early warning indicators, which allow assessing when a system approaches critical thresholds and potentially faces an impending regime shift (Dakos et al., 2012).

Annotated Bibliography

Allen, C. R., Fontaine, J. J., Pope, K. L., & Garmestani, A. S. (2011). Adaptive management for a turbulent future. Journal of Environmental Management, 92(5), 1339-1345.
State of the art article about advantages and limitations of adaptive management

Allen, C. R., Angeler, D. G., Cumming, G. S., Folke, C., Twidwell, D., & Uden, D. R. (2016). Quantifying spatial resilience. Journal of Applied Ecology, 53, 625–635.
Recent paper discussing the foundations of assessing spatial resilience in ecosystems quantitatively. The paper is also relevant for other scientific disciplines.

Angeler, D. G., & Allen, C. R. (2016). Quantifying resilience. Journal of Applied Ecology, 53(3), 617-624.
Paper providing an overview of resilience definitions

Angeler, D. G., Allen, C. R., Barichievy, C., et al. (2016). Management applications of discontinuity theory. Journal of Applied Ecology, 53, 688–698.
Paper provides an overview of quantitative resilience methods and their application to management

Dakos, V., Carpenter, S. R., Brock, W. A. et al. (2012). Methods for detecting early warnings of critical transitions in time series illustrated using simulated ecological data. PLoS ONE, 7(7), e41010.
Describes several alternative methods for predicting critical transitions and applies them to simulated data mimicking systems undergoing regime shifts.

Holling, C. S. (1973). Resilience and stability of ecological systems. Annual Review of Ecology and Systematics, 4, 1–23.
Seminal article introducing the concept of ecological resilience.

Sundstrom, S. M., Angeler, D. G., Garmestani, A. S., García, J. H., & Allen, C. R. (2014). Transdisciplinary application of cross-scale resilience. Sustainability, 6(10), 6925-6948.
Article presenting the application of methods of quantitative resilience assessments from ecology to the social and economic sciences.

Walker, B. H., & Salt, D. (2006). Resilience thinking: Sustaining ecosystems and people in a changing world. Washington, DC: Island Press.
Explains resilience in layperson's terms. Summarizes the work of the Resilience Alliance from the previous decade.