Panarchy[i]

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Background

Panarchy theory describes the hierarchical organization of complex systems (Allen et al., 2014). Contrary to hierarchy theory, which assumes system control from the higher to lower levels, in a panarchy control acts both from the bottom up and top down. A further distinction between panarchy theory and hierarchy theory is that the former considers dynamic system organization while the latter has more static assumptions. Hierarchical dynamic organization is an emergent property of complex systems and is characterized by the vertical separation of low-frequency dynamics of large extent (e.g., plate tectonics) and high-frequency dynamics of small extent (plankton dynamics in lakes). The partitioning of system dynamics manifests in the compartmentalization of patterns of structure and processes, which provides complex systems with common properties, including enhanced adaptive capacity to withstand disturbance. This ability to cope with disturbances arises from self-organization into hierarchies, whereby disturbances that affect particular scales can be absorbed by other scales in the system (Nash et al., 2014). In turn, this enhances the resilience of complex systems due to the interaction of variables that interact with the system at distinct scales and create self-reinforcing patterns (through positive feedbacks) resistant to change (Gunderson & Holling, 2002).

The dynamic character of a panarchy is described as a set of nested adaptive cycles, whereby adaptive cycles at each scale describe the processes of development and decay in a system (Gunderson & Holling, 2002). An adaptive cycle operates over a discrete range of scale in both time and space (Angeler et al., 2015), and is connected to adjacent adaptive cycles. Because adaptive cycles operate over specific ranges of scale, and a panarchy is composed of multiple adaptive cycles, a system's resilience is dependent upon the interactions between structure and dynamics at multiple

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scales. The number of levels in a panarchy varies, but corresponds to dominant scales present in a system.

Panarchy and risk

In a world of increasing connectedness, understanding scale-dependent processes and structure is critical for navigating a turbulent future. Panarchy provides us with a powerful tool for unveiling the dynamics of scale dependent structure and processes in complex systems. Panarchy serves as a perspective for understanding ecosystems, linked social–ecological systems and governance, and can serve as a framework to envision and quantify risk. The concept is essentially linked to resilience and follows from attempts to characterize and assess resilience in complex systems. As a heuristic, panarchy can help envision the organization of seemingly complicated systems and be linked to risk assessments related to pressures deriving from global environmental change. Panarchy can be utilized in the abstract conceptual sense for establishing qualitative mental models for risk assessment. Panarchy can also serve as a model of system dynamics that allows for concrete and testable hypotheses regarding the risks associated with environmental change.

Applications of panarchy for risk and resilience analysis

Panarchy has served as a model of complex systems organization for exploring a range of social-ecological system challenges that are relevant in a risk governance and assessment context. These explorations include the investigation of the linkages between adaptive cycles in social systems and ecosystems focusing on cycles of destruction and renewal; linking environmental change to social phenomenon such as migration; linkages between system organization and the provision of ecosystem services; managing abrupt change; identifying scales; identifying aspects of resilience including causes of population collapse; and links between resilience, regime shifts and thresholds in systems (Allen et al., 2014).

In a social systems context, panarchy theory has been used in a variety of contexts, such as evoking panarchy as a framework for understanding the linkages between social and ecological systems, which helps with the general understanding of the institutional and organizational change needed to cope with risk and enhance resilience. In urban systems, empirical analyses reveal that urban systems are partitioned into discrete scales separated by thresholds, showing that small cities grew faster than average and large cities grew slower than average (Garmestani & Gunderson, 2009). This demonstrates the potential for a panarchy framework to deal with risks associated with uncertainty in urban ecology, for example the effects of unsustainable growth and urban sprawl. Also, in firm size distributions, the distribution of functional aspects in firm organization is associated with indices of resilience (employment volatility; Garmestani et al., 2006). There is a current consensus among many legal scholars that existing law is too inflexible to accommodate resilience approaches explicitly, and therefore panarchy theory as well. Thus legal reform and new laws, laws which themselves have ant of resilience and that foster resilience in social ecological systems will be required to allow for resilience-based governance (Green et al., 2015).

Quantifying panarchy

Panarchy theory has the potential to develop into a framework for envisioning and assessing risk. Panarchy covers many aspects of complex system dynamics such as adaptation, conservatism and reorganization, which are impossible to frame within a single hypothesis. However, hypotheses that explicitly test the underlying premises of the theory can be formulated and put at risk. Following from panarchy theory are fundamental predictions regarding both the organization and dynamics of environmental, governance and other social aspects related to risk that should manifest if the propositions are true. It presents opportunities to test specific hypotheses regarding resilience and structuring processes in complex systems, and regime shifts, among others. Many of these manifestations have been tested empirically, some have been modeled, and some not tested at all because of data constraints (Allen et al. 2014). Panarchy theory has implications for two important, interconnected, but poorly understood phenomena: novelty arising from change, and regime shifts. Understanding both are essential ingredients for understanding the tradeoffs related to change and the risks those changes entail to human societies. Given the importance of these phenomena for understanding resilience, panarchy theory has great potential to make operationalization of these phenomena explicit, ultimately improving ways for quantification and measurement of risk.

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