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Resilience reconciled

Craig R. Allen
University of Nebraska - Lincoln, callen3@unl.edu

David G. Angeler
Swedish University of Agricultural Sciences, david.angeler@slu.se

Brian C. Chaffin
University of Montana, brian.chaffin@umontana.edu

Dirac Twidwell
University of Nebraska-Lincoln, dirac.twidwell@unl.edu

Ahjond Garmestani
U.S. Environmental Protection Agency, garmestani.ahjond@epa.gov

comment

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Resilience scholarship continues to inspire opaque discourse and competing frameworks often inconsistent with the complexity inherent in social–ecological systems. We contend that competing conceptualizations of resilience are reconcilable, and that the core theory is useful for navigating sustainability challenges.

Craig R. Allen, David G. Angeler, Brian C. Chaffin, Dirac Twidwell and Ahjond Garmestani

Resilience as a scientific concept exploded in the early 2000s and is now being adopted by a range of disciplines and by a wide diversity of actors, from city planners to networks of global protected-area managers. Resilience concepts are now integrated within national and international calls for proposals, research initiatives and centres in both the biophysical and social sciences. However, resilience scholarship has encouraged abstract discourse including many new and derivative frameworks aimed at re-conceptualizing resilience. Competing frameworks contribute to a loss of clarity about the original concept and theory of resilience; these frameworks often differ only minimally from each other and, most importantly, are often inconsistent with the complexity inherent in social–ecological systems (SESs)[1]. We believe that this is because the concept of resilience has both an attractive simplicity, and a rich underlying complexity, which leaves key aspects open for debate.

Despite apparent discrepancies among numerous competing frameworks and the recognition that a diversity of approaches is healthy for scientific progress, we contend that the prevailing definitions of resilience, such as those rooted in ecological stability (for example, recovery, robustness and persistence), are reconcilable under the umbrella of the original theory of ecological resilience (the amount of disturbance needed to cause a regime shift; for example, a clear-water lake changing to a turbid lake)[2]. Reconciling definitions of resilience is not trivial; our collective understanding and application of resilience has widespread implications for how we, as a society, understand and navigate global change. A view of the Earth as nested SESs — systems of dynamic, linked feedbacks between humans and the biophysical environment (for example, the influence of political economy on landscape shifts and vice versa) — is essential for definitions of resilience to resonate. Currently, resilience is applied as a descriptor, a measure, and a tool for relative analysis of system dynamics. Here we revisit three core uses of the term: resilience as a process, a rate, and an emergent property of SESs[3]. We reconcile these core uses with ecological resilience[2] and provide examples of successful application and growth of the concept.

Resilience as a process

Resilience as a process is prevalent across many disciplines but is most prominent in the disaster response and international development communities. In particular, actions are taken to build or enhance resilience of specific social, ecological or built aspects of SESs in response to disturbances such as hurricanes, earthquakes or floods. For example, floodwalls are built, wetlands are restored and economies are diversified in anticipation of future disturbances; some of these actions increase resilience of SESs while others increase system rigidity, decreasing resilience to specific disturbances. Cutter et al.[4] define resilience to include "…those inherent conditions that allow the system to absorb impacts and cope with an event, as well as post-event, adaptive processes that facilitate the ability of the social system to re-organize, change, and learn in response to a threat." When applied in the anthropocentric context of hazards and disaster adaptation and mitigation, resilience is often normative — as if resilience is always a desired system property — which is problematic. First, normative connotations of resilience risk the introduction of fallacies inherent in the unequal power relations created by resilience discourse[5]. That is, who promotes enhanced resilience to specific disturbances (for example, hurricane preparation ignoring sea-level rise), who benefits from enhanced resilience (potentially those with more privilege), who does not (potentially those in poverty), and at what expense? In other words, resilience to disturbance is not equally distributed across society. An increase in resilience for some may decrease resilience for others: building levees around riverine communities on flood plains protects the local community but can exacerbate flooding downstream. Second, a normative designation of 'desired' or 'undesired' provides no information regarding the ability of a SES or system component to respond to disturbances. For example, a SES in an undesired state can be highly resilient (for example, poverty traps or oppressive dictatorships). Other systems in undesired states (for example, turbid lakes or toxic algal blooms) may be more amenable to management actions (restoration to a clear-water state), which highlights the potential 'desirability' of lower resilience in these states. These examples directly relate to the use of terms such as sustainability and resilience (as a process), although sustainability is more naturally a normative concept, implying a state that can be managed by humans to persist. Resilient systems, however, are not necessarily sustainable, nor are sustainable systems inherently resilient to disturbance and change. Ideally, sustainable systems are resilient in a desired state and have a high likelihood to maintain that desired state over time.

Resilience as a rate

Resilience as a rate has a long history in stability research (Fig. 1). Resilience as a rate of recovery from disturbance is inherent in the definition of engineering resilience (also termed recovery, bounce back or resiliency[6]). Measuring resilience as a rate can be useful for assessing how long it takes for a system to recover after a disturbance. However, this definition is limiting because a system seldom recovers without intervention if it has undergone a regime shift. That is, a turbid lake requires substantial management to be restored to a clear-water lake. In the management of SESs, considering resilience purely as a rate is insufficient and can be dangerous because it suggests that we can severely degrade systems, but that they will inevitably recover, provided sufficient time. A further problem with a focus on rate or 'recovery' is that recovery targets are often untenable or obsolete in a rapidly changing world[7]. This debate over how to select appropriate baselines for ecological restoration is long, ongoing and

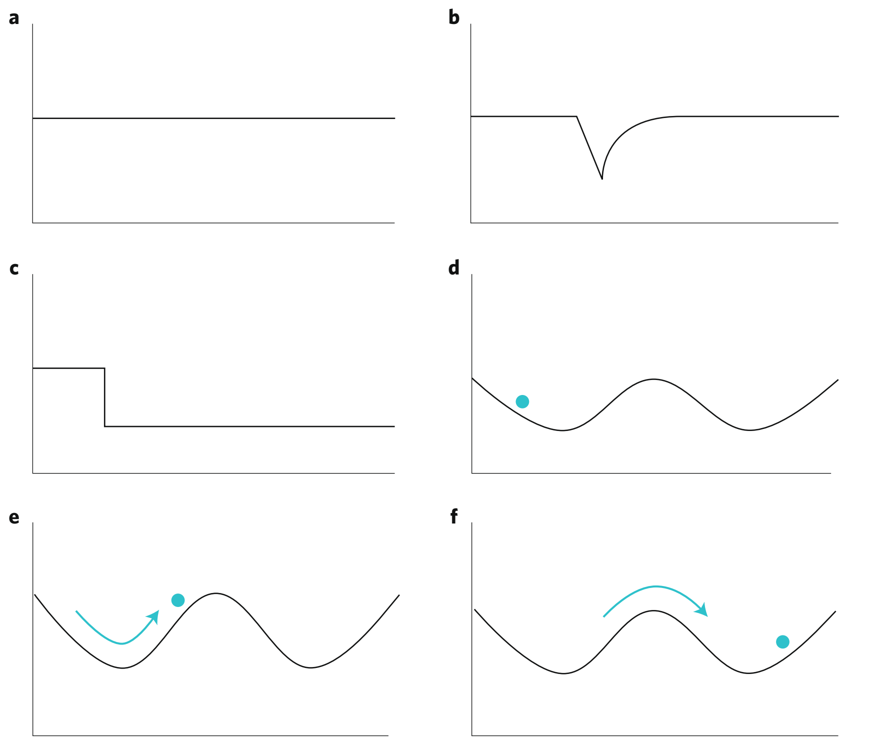

Fig. 1 | Competing models representing the resilience response of systems over time and to disturbances. Resilience is shown in terms of hypothetical system trajectory (*y* axes) and time (*x* axes). **a**, A stationary system (no change over time) without disturbance. System trajectory does not change or vary. **b**, A stationary single-equilibrium system with disturbance. System trajectory drops with disturbance but bounces back with time. Here, the only metric is the time required to bounce back to equilibrium. Use of this model could lead to the erroneous conclusion that all systems will recover given sufficient time. **c**, A stationary single-equilibrium system with an alternative configuration of trajectory. This model, as with figure 1 in Grafton et al.[9], fails to capture the potential for systemic changes between regimes that lead to completely different trajectories following disturbance. **d–f**, Resilience is considered from a complex adaptive systems point of view. **d**, Ball-and-cup diagram of alternative states (cups) in a non-stationary, non-equilibrium system without disturbance. The diagram shows the state of the system (blue circle), which emphasizes its complex adaptive nature, rather than a specific system structure. **e**, Ball-and-cup diagram of alternative states in a non-stationary, non-equilibrium system with disturbance. In this case, disturbance (shown by the blue arrow) does not exceed the resilience of the system. System trajectories are expected to vary but are maintained within a single basin of attraction (that is, it has adaptive capacity conferred by ecological-stability measures)[10]. **f**, Ball-and-cup diagram of alternative states in a non-stationary, non-equilibrium system with disturbance that exceeds the resilience of the system. The system is moved into an alternative basin of attraction, with completely different system-level properties (performance, function, structures, processes and feedbacks).

increasing in relevance as the rate of global change increases.

Resilience as an emergent property

Contrary to the engineering resilience (recovery) concept, Holling's definition[2] of ecological resilience — the amount of disturbance a system can withstand before it crosses a threshold and fundamentally changes — accounts for the potential of a system to exist in alternative states. Alternative states are 'stable' due to feedbacks that arise from interactions between abiotic and biotic factors, for example between the process of fire and vegetation that promotes fire. That is, systems self-organize into stable states while adapting to and absorbing disturbances (Fig. 1). However, disturbance thresholds exist that, when exceeded, can break those interactions, causing a system to fundamentally change and reorganize (Figs. 1, 2). Such dynamics are observed across a diversity of SESs, including systems with fixed spatial boundaries (for example, lakes) or open landscapes (for example, grasslands shifting to woodlands).

The theory behind the definition of resilience as an emergent property is well-developed and not only embraces complexity and the role of diversity, it also accounts for scale-specific dynamics that are critical in determining and understanding the dynamics of SESs[8].

Reconciliation

Grafton et al.[9] provide a reductionist conceptual model to address challenges to resilience in theory and practice. They suggest attributes with a long tradition in ecological-stability research as a means to resolve conceptual problems in resilience research and to advance management. These attributes are recovery (time to return to equilibrium following disturbance), resistance (the ability of a system to deflect disturbance and avoid impact) and robustness (the range of disturbance a system can withstand, but without mechanisms for learning and adaptation as in resilience), labelled the 'three Rs'. Although the three Rs are useful for quantifying adaptive capacity (the potential of a system to adjust to change[10]) and resilience because they capture critical elements of system dynamics during non-catastrophic change, they do not account for the dynamic and often abrupt response of complex systems to disturbance, inherent in ecological resilience. That is, the three Rs are appropriate only when there are no critical thresholds separating fundamentally different states. But critical thresholds are very common in SESs which can and do shift between alternative states, and that is why consideration of ecological resilience is needed[8]. For example, management of a formerly clear-water lake that has crossed a threshold and undergone a regime shift into a turbid state will be very different under assumptions of recovery time, resistance and robustness as compared to those based on ecological resilience. Management based upon ecological resilience would focus resources on reducing resilience of the current system state (turbid lake) to force an additional regime shift to a new desired state, or whether to sink resources into the system at all (triage) given the level of resilience in its current undesirable state (turbid).

Rapid environmental change requires humans to adapt to local- and global-scale shifts, or to force SES regime shifts to more desirable states (process of transformation) for a sustainable future. Adaptation and transformation are mutually non-exclusive aspects of system change and therefore unify resilience as a rate, process and emergent phenomenon. We argue that resilience concepts rooted in stability research, which include the three Rs[9], are subsumed within the broader systemic organization of SESs that our characterization (and that of

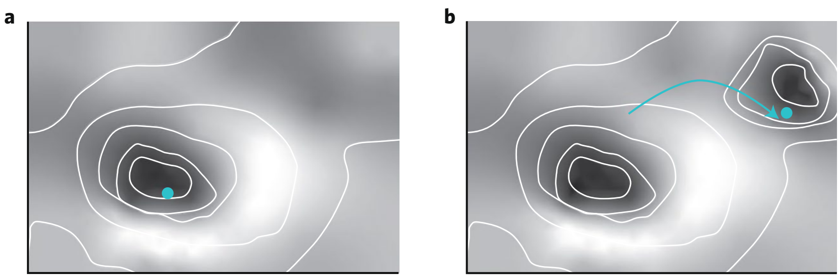

Fig. 2 | Three-dimensional model of stability landscapes. Ecological resilience, as defined by Holling[2], is a metric that comes with a wealth of theory, based on the dynamic non-stationary behaviour of complex systems that are seldom at equilibrium. The panels show hypothetical landscapes, where the *x* and *y* axes depict hypothetical coordinates within the landscape. Contours show the depth of the basin of attraction. **a**, Original state of the system, as shown by the blue circle, within a single basin of attraction. **b**, Disturbance shifts the system from one basin of attraction to another, as indicated by the blue arrow. The new state of the system may or may not produce the same functions, perform in the same way, or be more or less desirable than the original state. The stability landscape itself is dynamic and non-stationary, and basins of attraction may expand, contract or disappear, and new basins may form. Although such figures generally display two alternative basins, this is for convenience only, as real SESs can exist in many different configurations (that is, basins).

Holling) of ecological resilience embodies, and that these different definitions of resilience are therefore complementary, whether or not resilience has a normative connotation. Such reconciliation has now been suggested in quantitative frameworks for resilience assessments[3] that are largely based on approaches inherent in adaptive management[11] and are increasingly used to address complex issues, such as concerted efforts to reconcile environmental law with resilience of SESs[12]. With respect to law, US environmental laws developed in the late 1960s focused on the perspective that ecosystems could be mitigated back to equilibrium after ending environmental disturbances. While that perspective has been useful in some cases (for example, improvements in water quality), it has been less successful for SESs that exhibit multiple regimes and are subjected to disturbances that transcend ecosystem scale and jurisdictional boundaries (for example, many coral reefs). Hybrid governance approaches that incorporate law and policy and also tap into informal aspects of governance (for example, individuals and networks), show promise for reconciling resilience with environmental law.

Despite recent attempts to refine resilience concepts, including the development of additional heuristics and frameworks, a shared definition of resilience that transcends disciplines has not been broadly adopted. Resilience often has very different meanings and connotations for engineers and physical scientists, psychologists, and even between ecologists. Part of the problem is that different disciplines and experts apply the concept at grossly different scales, ranging from an individual's mental health to Earth's planetary boundaries, and another part of the problem is that the application of the concept in different disciplines shows very different traditions regarding the notions of equilibrium and stability. Paradoxically, it is increasingly recognized that nascent and emergent environmental challenges can only be solved through interdisciplinary and transdisciplinary research[13]. The theory that falls within the concept of ecological resilience has so far withstood the test of time and has given rise to many innovative applications, such as a diverse array of resilience assessment tools (https://www.resalliance.org/), and novel concepts such as panarchy (which describes within and across scale dynamics in SESs[8]), transformative governance (governance required to force and navigate SES regime shifts[14]), and spatial regimes (systems without hard boundaries still maintain identity via positive interactions[15]). Interdisciplinary research now provides opportunities for developing and implementing reconciled resilience approaches in times when rapid environmental change in the Anthropocene poses pressing challenges for humankind. We assert that the perspective offered by Grafton et al.[9] has some value, but for linked systems of humans and nature, it is only useful if nested within the broader scope of ecological resilience. ❐

Craig R. Allen[1,2], David G. Angeler[3], Brian C. Chaffin[4], Dirac Twidwell[1,5] and Ahjond Garmestani[6,7]*

[1]Center for Resilience in Agricultural Working Landscapes, University of Nebraska-Lincoln, Lincoln, NE, USA. [2]School of Natural Resources, University of Nebraska-Lincoln, Lincoln, NE, USA. [3]Department of Aquatic Sciences and Assessment, Swedish University of Agricultural Sciences, Uppsala, Sweden. [4]W.A. Franke College of Forestry and Conservation, University of Montana, Missoula, MT, USA. [5]Department of Agronomy and Horticulture, University of Nebraska-Lincoln, Lincoln, NE, USA. [6]US Environmental Protection Agency, Office of Research and Development, Cincinnati, OH, USA. [7]Utrecht Centre for Water, Oceans and Sustainability Law, Utrecht University School of Law, Utrecht, Netherlands.

**e-mail: garmestani.ahjond@epa.gov*

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