# 9

# People, Perceptions, and Process

## Multisystemic Resilience in Social-Ecological Systems

Lilian Alessa and Andrew Kliskey

## Introduction

A growing community of practice has treated human and biophysical systems as linked and has characterized them as a social-ecological system (SES), that is, complex, integrated systems of humans within the ecosystem (Berkes & Folke, 1998; Kliskey et al., 2016; Alessa, Kliskey & Altaweel, 2009; Young et al., 2006). An SES is characterized by feedbacks, which occur between human values, perceptions, and behaviors and the biophysical components of the ecosystems in which people exist resulting in a resilient or vulnerable trajectory leading to sustainability or collapse (Gallopin, 2006). When technology is factored in, these feedbacks result in markedly different outcomes depending on the type of SES; factors include whether a community is able to afford and maintain the technologies that support them as well as how human skills and cognitive abilities are degraded or lost due to an overreliance on technology (Alessa, Kliskey, & Williams, 2010). This is due to the phenomenon through which technology is viewed as no longer a tool to enhance human organization, dynamics, and skills but rather as a solution, and consequently at the expense of all of these facets. Such a phenomenon is particularly marked in the U.S. intelligence and military communities (Bolia, Vidulich, Nelson, & Cook, 2007; Roper, 1997).

SESs are an instance of complex adaptive systems (CAS). In this chapter we make the case for multisystemic resilience in SESs being considered as a social process predicated on accurate perception of constantly changing social and ecological conditions, rather than the conventional notion of resilience as a static configuration or condition. First, we set out key

Lilian Alessa and Andrew Kliskey, *People, Perceptions, and Process* In: *Multisystemic Resilience.* Edited by: Michael Ungar, Oxford University Press (2021). © Oxford University Press. DOI: 10.1093/oso/9780190095888.003.0010

principles of complexity theory and CAS as a foundation for understanding multisystemic resilience in SES. Second, we explore multisystemic resilience in SES as a social process. Third, we examine the role of human perceptions and group dynamics as the key underpinning of the social process of multisystemic resilience. Fourth, we consider how technology factors into multisystemic resilience as a social process and its impact on perception of change in SES. We conclude by providing some suggestions for advancing multisystemic resilience as a social process.

## Complexity Theory: The Origins of Resilience

We live in an era where the fabric of society is comprised of an enormous number of variables that collide to form supportive and destructive actions at multiple scales. The core science governing much of what we see on Earth stems from the science of complexity that is also known as complex systems science. A common miscommunication is that the field of complexity was born at the Santa Fe Institute in the 1980s, but it was first described by Schrödinger (1944) as "order out of chaos." At its most basic definition *complexity* can be defined as a set of emergent structures, processes, or outcomes that arise from the interaction of two or more entities (molecules, organisms, structures, processes) that give rise to new structures, functions, and/or regime shifts at larger scales (Bar-Yam, 2003). Complexity can be framed into disciplinary silos ranging from computer science to societal governance. For example, an illustration of complexity in computer science is the NP versus P problem, a computational efficiency class of problems where P is known as polynomial time and refers to efficient algorithms that use a fixed polynomial of the input size (Fortnow, 2009). However, many related problems cannot be solved using the P efficient algorithm, and instead use NP or nondeterministic polynomial time (Fortnow, 2009). Consequently P = NP refers to problems that have efficiently verifiable solutions ( i.e., NP) and where the solution can be found efficiently, (i.e., P). Likewise, an example of complexity in sociology and political science is the way governance affects equity and social justice (Mercier, 2014). In cell biology an example of resilience predicated on perception comes from the establishment of the developmental axis in zygotes of *Pelvetia compressa*, an alga: successful tissue differentiation, necessary for a healthy organism, begins with the organism's perception of which way is up and which way is down to respond by reorganizing its F-actin cytoskeleton (Alessa & Kropf, 1998); in human organizations such as the U.S. intelligence community, which is comprised of 16 member agencies, the ability to accurately respond to threats requires detection of signals hidden in noise, something the intelligence community has repeatedly failed to accomplish (Shelton, 2011; Zegart, 2019).

Complex systems science is a nuance of complexity defined as "collections of simple units or agents interacting in a system" (Jennings, 2000, p. 286) with a *complex system* being one that is derived from the interactions of agents to establish a system that is both emergent (possessing design) and complicated (many pieces). Systems ranging from chemical reactions, biological cells, neurological systems, ecological systems, human societies, and military systems may be described as complex, emergent systems. The underlying mathematics and physics have given rise to a range of technologies such as genetic and evolutionary algorithms that are used on distributed computing systems to drive artificial intelligence and machine learning (M'Hamdi et al., 2017; Nemiche, M'Hamdi, Chakraoui, Cavero, & Pla-Lopez, 2013). Related to this are CASs in which one or more components within a complex system adjusts its form and/or behavior in response to a perturbation whether negative or positive is the applied form of complexity science. Since this adjustment in behavior occurs in parallel with changes across other components the resulting system features can be described as complex and emergent (Dekker, 2016). Thus responsiveness, and hence resilience, to change is more accurately described as an ongoing process rather than a steady state.

The resilience literature (e.g., Anderies, Janssen, & Ostrom, 2007; Resilience Alliance, 2010) tends to reduce SESs to "neat" systems, that is, as systems in which humans and their resources are simplified to a single resource system, group of users, and governance system (Anderies et al., 2007). One of the more well-known approaches for analyzing the resilience of SESs is Ostrom's (2009) multilevel, nested framework that recognizes the multiple levels of SES at varying spatial and temporal scales. The framework adopts complex systems thinking and applies it to common pool resources. Common pool, or common property, resources refer to family, tribal, or community commons (e.g., pasture, forest, or fisheries) with unrestricted local availability and use of the resource (Ostrom, 1999). Control or management of common property is typically achieved through social checks (e.g., cultural or religious practices). The tragedy of the commons is a well-known case of resource overuse (e.g., overgrazing, overfishing, overhunting) that common property resources can be susceptible to (Hardin, 1968) and is in essence a social and economic trap involving competing individual interests versus the common good when using a finite resource (Ostrom, 1999).

The Ostrom (1999) SES framework characterizes common-property resources as decomposed into resource systems, resource units, governance systems, users, and the interactions between these elements. It has been shown to be generalizable for many community-based common property resources in specific locales, for example, coastal fisheries in Mexico's Sea of Cortez (Basurto, Gelcich, & Ostrom, 2013). However, this describes a relatively neat system; other SES approaches build from this generalized framework for common pool resources but incorporate more robust data that reflect SESs as complex and messy systems. Complex SESs are typically less easily framed and less compliant with the theoretical descriptions of the "ball and basin" analogy (e.g., Berkes & Folke, 1998).

To move from CAS to the concept of resilience we must look at its multisystemic origins. Resilience, in part derived from physics, is defined in materials science as the ability of a material to absorb energy when it is deformed elastically and release that energy upon unloading (Motamedi, Iranmanesh, & Nazari, 2018). Proof *resilience* is defined as the maximum energy that can be absorbed up to the elastic limit, without creating a permanent distortion (O'Brien & Hope, 2010). Other definitions took this analogy and applied it to a range of settings, for example, in psychology and social work resiliency and resilience theory is presented as three waves of inquiry. The identification of resilient qualities was the first wave characterized through phenomenological identification of developmental assets and protective factors. The second wave described resilience as a disruptive and reintegrative process for accessing resilient qualities. The third wave exemplified the postmodern and multidisciplinary view of resilience, which is the force that drives a person to grow through adversity and disruptions (Richardson, 2002). This construct was subsequently adopted by ecologists to describe disturbance in habitats and vegetation patterns (Chapin, Kofina, & Folke, 2009).

Resilience in messy SESs can be characterized as a set of processes that map to systemic resilience (Ungar, 2018). It is notable that resilience as a systemic process does not have a single corresponding match in messy SESs since the set of processes in messy SESs taken in toto denote resilience as a process. As dynamic, complex systems, the resilience of messy SES is inherently process-based. This is analogous to ends and means in planning, where ends refers to an end goal or end state as the focus of planning, while means refers to the approach or the process for achieving an objective as the focus of planning (Banfield, 1959). Consequently, resilience in messy SESs describe a means for examining and understanding resilience, rather than an ends (Alessa et al., 2009; Sem, 2013) comprising a complex set of interactions (Table 9.1).

Messy SESs involve the simultaneous use of multiple resources by diverse users and the technologies they employ. Each of these facets must be explicitly considered as both related and independent (Alessa et al., 2009). Such a viewpoint can more readily accommodate the inherent complexity of SESs than strictly neat SESs. For example, an SES comprising a

**TABLE 9.1 Comparison of Characteristics of Resilience as a Process in Messy SESs**

| Messy SES Resilience | Qstrom SES Resilience | Ungar Systemic Resilience |
|---|---|---|
| Development of diverse options | Property rights system; resource unit mobility | Diversity |
| Interactions across landscape | Clarity and size of resource system; Interaction and spatial distribution of resource units | Open, dynamic, complex |
| Retention | Productivity of resource system | Trade-offs between systems |
| Distribution over space | Spatial and temporal distribution of resource units | Promotion of connectivity |
| Persistence over time | History of use | Learning |
| Collectivism in community | Government organizations; collective choice rules | Participation |
| Variability | Number of users | Diversity |
| Directionality of trajectory | Growth rate of resource | Experimentation and learning |
| Identifying substitutability | Dependence on resource | Redundancy |
| Communicating across networks | Information sharing among users; networking activities; network structure | Promotion of connectivity |
| Minimization of risks | Frequency of long-term hazards (e.g., economic, major and large-scale environmental catastrophes) | Contexts of adversity |

Based on Alessa et al. (2009) and Altaweel et al. (2015), with elements in common pool resource systems (Ostrom, 2009), and systemic resilience (Ungar, 2018).

town in the American West and the mountain landscape in which it exists (e.g., Altaweel, Virapongse, Griffith, Alessa, & Kliskey, 2015) is not only subject to the consequences of regional, national, and global economies and global climate change effects on precipitation and temperature; it is also influenced by policies governing resource use and conservation, with norms and cultural idiosyncrasies that shape and affect perceptions. Regardless of the example the resilience process in messy SESs begins and continues through the ability to accurately perceive change. Accurate perception (P) determines the types of information and means needed to successfully respond to changes.

## Resilience as a Process

Writ large, resilience as a field of inquiry is essentially a social construct built within individual disciplines with a range of descriptors and there has been a great deal of effort to reconcile these disciplinary constructs toward a unifying foundation (Olsson, Jerneck, Thoren, Persson, & O'Byrne, 2015; Ungar, 2018). In other words, resilience is often portrayed as a state or configuration (a static thing). A person or a society is said to be resilient when a certain number of indicators, variables, traits, and/or features are present (Cutter, Barnes, Berry, Burton, & Evans, 2008; Scheffer, Dakos, & van Nes, 2015). Conversely, in the absence of these a system is described as vulnerable (Beroya-Eitner, 2016; Hinkel, 2011). Since so many constructs assign resilience as a "thing," the search for unity may not only be unnecessarily complicated but also misleading.

In messy SES resilience is a process that implicates people, perception, and place—the communities and the landscapes in which communities reside and includes the built and technological environments that support them. Resilience as a process is predicated on the ability to accurately sense, perceive, and/or evaluate change trajectories, frequency, and magnitude (Williams et al., 2018). Social-ecological resilience refers to the ability of communities and landscapes to detect physical, social, or economic changes; identify their nature; and respond to it while retaining core social and physical functionality (Alessa et al., 2015). This establishes the adaptive capacity of communities through a measure of their ability to respond proactively, versus reactively, to slower changes and maintain a level of functionality and cohesion during acute or catastrophic ones (Alessa et al., 2009; Altaweel et al., 2015).

As a process resilience shares three ubiquitous phases: perception of environment and change (e.g., sensing [cells, tissues], perception [organisms], communication [populations] and calibration), responses (actions), and outcomes (consequences; see Figure 9.1). With each cycle, n, the environment (milieu) is altered and these changes feed back to the first, and most critical, phase (perception of change in the milieu). Perceptions are fundamental to understanding multisystemic resilience as a social process. Using a standard degrees of belief algorithm based on three meta analyses (Lee et al., 2013; Ungar, 2018; Xu & Marinova, 2013), combined with input from several resilience experts in SES science, three interacting processes that affect resilience as a process were derived. The assumptions made here is that technologies and built environments are inseparable from SESs in the current Anthropocene. In messy SESs, the interacting processes are

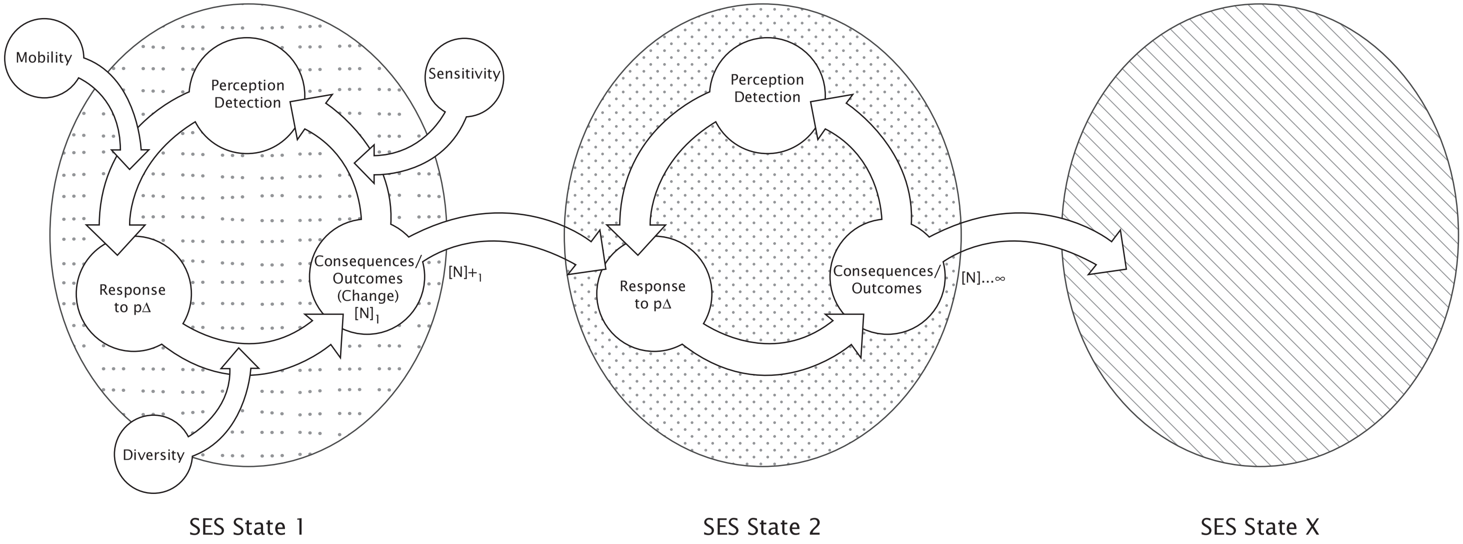

**FIGURE 9.1** Resilience as a process in SES involving diversity in data and information, sensitivity in governance and networks, and mobility in capability and response to change.

1. Diversity (D) of sensors to generate both a breadth and depth of data and information since few decisions are made on scientific data themselves.
2. Sensitivity (S) in the ability of institutions, networks, and governance structures, both informal and formal, to respond in a timely manner to a perceived change requiring response(s).
3. Mobility (M) or the fluidity of responses and the ability to maintain function during sudden, adverse change.

Figure 9.1 illustrates the three interactions defining resilience as a process in the context of a changing environment where resilience is an iterating process that integrates diversity, sensitivity, and mobility. The process represents a continual sequence that may lead to successive and different states of resilience (State 1, State 2, etc.) and the transition to a new state is in part governed by the perception of the community that a transition has occurred (Figure 9.1).

## Perceptions of Change in Messy Social Ecological Systems

Perceptions of the environment held by people are an important filter in human behavior and decision-making with respect to the environment in which they exist (e.g., Golledge, 2008; Golledge & Stimson, 1997). Our attitudes, beliefs, culture, skills (both inherent and taught), and values inform the way we perceive the world around us, not least the environment, and as a consequence perceptions heavily influence adaptive responses to social-environmental change (Williams et al, 2018). This notion can be extended to social-ecological resilience on the basis that resilience as a process, particularly as a human process, is in large part governed by our perceptions of social and physical change affecting communities and landscapes and by our perceptions of perturbations that generate adversity for those communities and landscapes. Thus, perceptions of change are a fundamental part of multisystemic resilience, especially when viewed as a dynamic process.

While some resilience research has focused on technological, demographic, and economic factors that are associated with changing landscapes and adaptive responses, less attention has been given to identifying determinants of decisions and behavior by individuals (Adger & Vincent, 2005; Adger et al., 2009; Engle, 2011; Mimura et al., 2014). There appear to be individual and social characteristics, such as risk perception that, in tandem with values, form subjective limits to adaptive responses. Consideration of social cognition and its influence upon the perception of environmental change can contribute to a better understanding of the subjective limits to adaptation facilitating the communication of science-based information to improve adaptive capacity (Clayton et al., 2015; Grothmann & Patt, 2005; Kunda, 1990; Marx et al., 2007; Spence, Poortinga, & Pidgeon, 2012). The impact of environmental change can be considered a vague risk as those consequences are generally future oriented, uncertain, and frequently detached from individual relevance (Grunblatt & Alessa 2016; Hulme, 2009). Given these cognitive uncertainties, risk perception suggests that individuals may tend toward exploratory interpretations that bypass cognitive processes of logic and data assessment. Consequentially, perception may be based more on simplified representations that are formed through fast, intuitive, and unconscious information processing than on rational logic, probability, and utility (Slovic, Finucane, Peters, & MacGregor, 2004; Marx et al., 2007). Under this paradigm, an individual acquires general understanding of environmental change from diverse sources such as personal experience along with social media and networks (Myers et al., 2013). These diverse sources form an "affective pool" that contribute to heuristic decision making and replaces more deliberative and rational cognitive processes (Slovic et al., 2004). Accurate, fast intuitive perception is heavily modified, often degraded, through exposure to digital technology (Underwood, 2009). This is particularly pronounced in communities such as law enforcement, resource planning, and military and national intelligence (Roper, 1997).

The mental and perceptual processes that shape the way a person extracts information has been expressed in construal level theory (CLT; Liberman, Trope, McCrea, & Sherman, 2007). CLT establishes four dimensions of psychological distance (temporal, spatial, social, and certainty) and proposes that psychological distance contributes to how a person mentally forms perception. A larger psychological distance supports a more general and abstract construal while a smaller psychological distance supports more concrete construal and specific detail (Spence et al., 2012). Focusing on far-off concepts and abstract goals emphasizes the processing of psychologically distant information. As a consequence, a larger psychological distance promotes consideration of high-level abstractions and may lead to perceptions that are defined distinctively by an individual and that individual's values (Spence et al., 2012). Perception of change in the local environment can also be subject to cognitive biases due to an individual's attitudes and values (Kunda, 1990; Nickerson, 1998). CLT and cognitive biases suggest that rational cognition is typically circumvented in risk assessment and decision-making. An additional element is the Dunning–Kruger effect, whereby perception is eroded due to the inability to improve the accuracy of perception through seeking and incorporating diverse inputs into decision-making (Dunning, 2011). The influence of Dunning–Kruger is apparent, for example, in the U.S. intelligence community where a lack of qualifications makes individuals more susceptible to inaccurate perception (Alessa, Moon, Griffith, & Kliskey, 2018). Grothmann, Grecksch, Winges, & Siebenhuner, (2013) incorporate adaptation motivation (threat appraisal or risk perception) and adaptation belief (coping appraisal) to explain subjective human responses to natural hazard assessment in a model of institutional adaptive capacity. Adaptive motivation and adaptation belief are intended to represent psychological factors of adaptive capacity that result from the subjective perception of objective conditions.

One example in which the role of perceptions is manifested in systemic resilience as a process can be found in the manner in which the perceptions of environmental change held by natural resource managers correspond with documented measures of environmental change. Accurate perception of system change is considered a prerequisite for adaptive response in resilient systems (Weber, 1997). When there is disparity between perceptions of change and measured change there is a likelihood of an inappropriate or even maladaptive response to social-ecological changes—a condition termed the *difference*, or *delta*, between perceptions of environmental change and instrumented measures of environmental change, or P Δ I (Williams et al., 2018). This has been demonstrated in groups of natural resource managers with respect to changes in Pacific salmon fisheries in Alaska. Natural resource managers do not always accurately perceive change in the environment that is consistent with instrumented measures of change. While managers' perceptions of change were aligned with measured change for summer rainfall, land use development, and Chinook salmon size, their perceptions of change in summer and winter air temperature, stream temperature, and Chinook salmon abundance were disparate (Williams et al., 2018). Well-informed decisions and policies that are intended to support adaptive responses, and consequently enhance system resilience, are contingent on decision-makers accurately perceiving change. To the contrary, decisions are frequently made on perceptions rather than data (Robbins & Judge, 2013; Weber, 1997). The more accurately a change is perceived (P Δ I), the smaller the delta (Figure 9.2). Smaller deltas generally result in more accurate responses and thus better resilience outcomes. The process of perception and responses to environmental changes and the feedback of the consequences of these

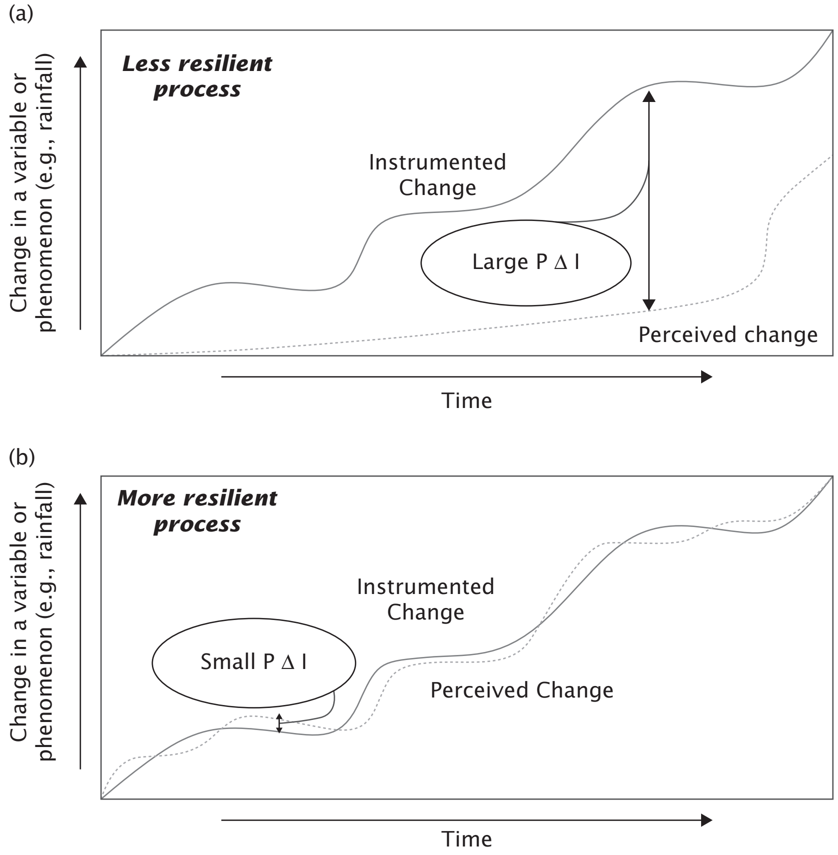

**FIGURE 9.2** Difference between perceived change and measured change (P Δ I) as a factor in resilience as a process depicting: (a) Less resilient process and (b) more resilient process. Adapted from Williams et al. (2018).

actions constitutes a stable process. Thresholds of change, sometimes referred to as tipping points, can be avoided when P Δ I is small (Figure 9.2). When P Δ I is large response to environmental change is likely to be either delayed or nonexistent (Figure 9.2) giving rise to maladaptive responses (Williams et al., 2018).

## Agent Types and Perceptions of Change

Historical and contemporary relationships between people and the changing environment in which they live can offer insights for anticipatory environmental modeling and management that promote social-ecological resilience, even under unfamiliar conditions of change. Changes in resource use patterns by people responding to their environments may affect feedbacks in resource availability and quality. Such feedbacks offer lessons on adaptive responses and have the potential to impact the resource use patterns of human communities (Wilbanks & Kates, 1999). The outcomes of adaptive responses are determined not only by inherent environmental conditions (Alessa et al., 2010), but also by social responses arising from perceptions about the need to adapt to environmental conditions (i.e., anthropogenic influence) that differ based on an individual's role in a community's response to change, that is, the type of agent of change. Agent types in human communities have been distinguished as initiators of a response to change (α agent), supporters of a response to change (β agent), and detractors of a response to change (γ agent; Alessa & Kliskey, 2012). We propose that the latter component is critical and strongly dependent on the composition of the agents who comprise the community. For example, if resources (e.g., water) are perceived as scarce and there is concern for collective well-being, a community may successfully implement a water management plan that includes the use of technology, incentives, and/or enforced social norms (Wang, Xu, Huang, & Rozelle, 2005), thus changing feedbacks between human–hydrological systems resulting in more favorable outcomes. Similarly, unfavorable outcomes may result if there is lack of awareness of resource conditions (Alessa et al., 2010) and an inadequate or inappropriate response. Consequently, understanding and projecting future scenarios of change relies on an understanding of the physical resources (e.g., hydrology) as well as social dynamics, such as the influence of values, perceptions, social networks, and the types of agents (Alessa & Kliskey, 2012).

Societies and communities are highly heterogeneous with respect to individual perceptions and responses to change. Ultimately, cumulative behaviors determine responses to change such that anthropogenic feedbacks to systems supersede factors such as climate change and are manifested at finer temporal and spatial scales (Gardner, Hargrove, Turner, & Romme, 1996). In other words, human activities elicit changes at finer spatial scales more quickly than natural processes at broad scales (Alessa, Kliskey, & Williams, 2007). The types of perceptions of, and responses to, change in which a community engages depend on the composition of agent types within the community. Consequently, the recognition of agent types is a crucial element in multisystemic resilience as a process, affecting the way in which adaptive responses develop and are implemented.

## Technology-Induced Environmental Distancing

A further consequence of the role of perceptions on multisystemic resilience is found in the way in which technology affects perceptions. Overreliance on technology, whether it be GPS or water infrastructure, can impact the awareness of a person or a community to change in the environment (Alessa et al., 2007). For example, evidence suggests that community members in rapidly modernizing resource-dependent communities became desensitized to awareness, or perception, of change in river flow and water availability as a consequence of the installation of water technology (Alessa et al., 2007, 2009). This phenomenon is termed technology-induced environmental distancing (TIED). The ability to turn on a tap to have water reduces the effort involved in acquiring and using it and effectively increases the distance between the user and the water resource. This is tantamount to Aldo Leopold's caution on the "spiritual dangers . . . of supposing that breakfast comes from the grocery, and . . . that heat comes from the furnace" (Leopold, 1949, p. 12). That is, a decreased awareness of a resource, or distancing, can result from the adoption and use of technology. This TIED effect encumbers trade-offs between short- and long-term system resilience.

## Testing the Resilience Process Using Technology as an Inhibitor

For all these reasons, human decision-making to promote resilience in SESs relies on a complex set of neurocognitive functions that have evolved through the need to integrate a range of complex landscape, situational, and social-emotional variables using both simple and advanced tools. Several studies are building a body of knowledge that support the hypothesis that technologies affect spatial reasoning (Iqbal & Lim, 2008) and our own studies and real-time, on-the-ground games have revealed that the use of digital technologies distances individuals from their environments, the TIED effect, and results in a larger delta and less accurate perception of change (Alessa et al., 2007; Williams et al., 2018). This process means that our increasing use of technology to sense our environment (perception phase of the resilience process; Figure 9.2) may exhibit an equilibrium where the very tools we use surpass their capacity to support accurate perception. Instead, they reduce our ability to make appropriate decisions in an on-the-ground context, particularly in noisy SESs. Several other studies have made correlations between exposure to unbuilt environments (e.g., natural and wilderness settings) and mental health and personal resilience (e.g., Bratman, Hamilton, & Daily, 2012). Our own pioneering work has demonstrated community-scale effects of the introduction of technologies into primarily subsistence-based social groups both in real and modeled worlds (Alessa et al., 2007, 2010). We propose that, in SESs, resilience as a process can be tested to (a) assess the range and types of TIED; (b) potential consequences of TIED in different populations (e.g., vulnerable); (c) reveal possible interventions that could mitigate and/or eliminate the TIED effect; and (d) protect and evolve the advantages of technologies that assist, rather than hinder, the resilience process (e.g., community-based observing networks and systems coupled with instrumented observing systems).

The concepts of P Δ I and TIED are both manifestations of the role of human perception in connoting awareness of the state of an SES and, consequently, in conferring multisystemic resilience. While there is still much that is not known about how perceptions held by individuals scale up to communities and other societal groups, perceptions are fundamental to the social fabric that engenders resilience as a dynamic process.

## Conclusion

Resilience in SES is a multifaceted process that is derived from complexity theory—notably the idea of emergent behaviors that are an outcome of the network interactions that occur in the landscapes and communities of an SES. As a CAS, SESs operate near the threshold between complexity and chaos. SESs undergo three phases in the resilience process, affected by three factors: diversity, sensitivity, and mobility. These are exhibited as diversity in the means for sensing change, sensitivity of institutions to respond to perceived change, and the fluidity in responses by institutions to perceived change. Fundamental in this view of multisystemic resilience as a social process is the role of human perception and awareness of change in the environment. Perceptions of change held by individuals and communities are manifested in at least three effects. First, the P Δ I effect suggests that accurate perception of change with respect to measured change is a condition for appropriate response to change and decision-making. The limited studies to date on P Δ I indicate variability in the magnitude of P Δ I for individuals and groups highlighting how understanding multisystemic resilience as a process can contribute to different outcomes in response to change in SESs. Second, agent types presuppose that the collective ability of a community to perceive and respond to change is a consequence of the ratio of different roles assumed by individuals with respect to their capacity to perceive change and institute appropriate behaviors as a response. Third, the TIED effect shows how overdependence on technological tools and solutions may also afford a reduced ability to perceive change in the environment and consequently contribute to maladaptive responses and behavior. The TIED effect is potentially significant and should be incorporated into resilience research in the future. Technology is inherent in SESs and can lead to a transition in the trajectory of that SESs subject to accurate perception and decision-making, that is, the P Δ I effect. In summary, resilience is a social process rather than a state.

## Key Messages

1. Resilience in SESs is a process governed by human perceptions rather than data, per se.
2. Perceptions in SESs are manifested in individual and group differences between the perceived change in the environment and the measured change in the environment.
3. Perceptions contribute to resilience in SESs through technology, particularly when technology acts as a barrier to awareness of, and response to, change.
4. Multisystemic resilience in SESs can be characterized as an iterative process involving consequences and outcomes of environmental change, the perception of those changes, and the detection and response to perceived change.

## Acknowledgments

The authors acknowledge the support of the University of Idaho through the Center for Resilient Communities. The work was funded by the National Science Foundation (award numbers SES-1639524, PLR-1642847, SES-1856059, and PLR-1927713). Any opinions, findings, or recommendations expressed in this paper are those of the authors and the Center for Resilient Communities, and do not reflect the views of NSF.

## References

Adger, W., & Vincent, K. (2005). Uncertainty in adaptive capacity. *Comptes Rendus Geoscience*, *337*(4), 399–410. doi:10.1016/j.crte.2004.11.004

Adger, W., Dessai, S., Goulden, M., Hulme, M., Lorenzoni, I., Nelson, D., Naess, L., Wolf, J., & Wreford, A. (2009). Are there social limits to adaptation to climate change? *Climate Change, 93*, 335–354.

Alessa, L. & Kliskey, A. (2012). The role of agent types in detecting and responding to environmental change. *Human Organization*, *71*(1), 1–10. doi:10.17730/humo.71.1.y7692065g232w1g1

Alessa, L., Kliskey, A., & Altaweel, M. (2009). Toward a typology of social-ecological systems. *Sustainability: Science*, *Practice*, *& Policy*, *5*(1), 31–34. doi:10.1080/15487733.2009.11908026

Alessa, L., Kliskey, A., Gamble, J., Fidel, M., Beaujean, G., & Gosz, J. (2015). The role of Indigenous science and local knowledge in integrated observing systems: Moving toward adaptive capacity indices and early warning systems. *Sustainability Science*, *11*(1), 91–102. doi:10.1007/s11625-015-0295-7

Alessa, L., Kliskey, A., & Williams, P. (2007). The distancing effect of modernization on the perception of water resources in Arctic communities. *Polar Geography*, *30*(3–4), 175–191. doi:10.1080/10889370701742761

Alessa, L., Kliskey, A., & Williams, P. (2010). Forgetting freshwater: The effect of modernization on water values in remote Arctic communities. *Society and Natural Resources*, *23*(3), 254–268. doi:10.1080/08941920802454813

Alessa, L., & Kropf, D. (1998). Role of F-actin in the establishment of developmental polarity in pelvetia compressa zygotes. *Development*, *126*(1), 201–209.

Alessa, L., Moon, S., Griffith, D., & Kliskey, A. (2018). Operator driven policy: Deriving action from data using the quadrant-enabled Delphi (QED) method. *Homeland Security Affairs Journal*, *14*(6). Retrieved from https://www.hsaj.org/articles/14586

Altaweel, M., Virapongse, A., Griffith, D., Alessa, L., & Kliskey, A. (2015). A typology for complex social-ecological systems in mountain communities. *Sustainability: Science*, *Practice and Policy*, *11*(2), 1–13. doi:10.1080/15487733.2015.11908142

Anderies, J. M., Janssen, M. A., & Ostrom, E. (2007). A framework to analyze the robustness of social-ecological systems from an institutional perspective. *Ecology and Society*, *9*(1), 18. Retrieved from http://www.ecologyandsociety.org/vol9/iss1/art18/

Banfield, E. (1959). Ends and means in planning. *International Social Science Journal*, *11*(3), 1–8.

Bar-Yam, Y. (2003). *Dynamics of complex systems (Studies in nonlinearity)*. Boulder, CO: Westview Press.

Basurto, X., Gelcich, S., & Ostrom, E. (2013). The social-ecological system framework as a knowledge classificatory system for benthic small-scale fisheries. *Global Environmental Change*, *23*(6), 1366–1380. doi:10.1016/j.gloenvcha.2013.08.001

Berkes, F., & Folke, C. (1998). *Linking social and ecological systems: Management practices and social mechanisms for building resilience*. Cambridge, UK: Cambridge University Press.

Beroya-Eitner, M. (2016). Ecological vulnerability indicators. *Ecological Indicators*, *60*, 329–334. doi:10.1016/j.ecolind.2015.07.001

Bolia, R., Vidulich, M., Nelosn, T., & Cook, M. (2007). A history lesson on the use of technology to support military decision making and command and control. In J. Noyes, M. Cook, & Y. Masakowski (Eds.), *Decision making in complex environments* (pp. 191–200). Aldershot, UK: Ashgate.

Bratman, G., Hamilton, J., & Daily, G. (2012). The impacts of nature experience on human cognitive function and mental health. *Annals of the New York Academy of Sciences*, *1249*(1), 118–136. doi:10.1111/j.1749-6632.2011.06400.x

Chapin, F., Kofina, G., & Folke, C. (Eds.). (2009). *Principles of ecosystem stewardship: Resilience-based natural resources management in a changing world*. New York, NY: Springer.

Clayton, S., Devine-Wright, P., Stern, P., Whitmarsh, L., Carrico, A., Steg, L., . . . Bonnes, M. (2015). Psychological research and global climate change. *Nature Climate Change*, *5*(7), 640–646. doi:10.1038/nclimate2622

Cutter, S., Barnes, L., Berry, M., Burton, C., & Evans, E. (2008). A place-based model for understanding community resilience to natural disasters. *Global Environmental Change*, *18*(4), 598–606. doi:10.1016/j.gloenvcha.2008.07.013

Dekker, S. (2016). *Drift into failure: From hunting broken components to understanding complex systems*. London, UK: CRC Press.

Dunning, D. (2011). The Dunning-Kruger effect: On being ignorant of one's own ignorance. *Advances in Experimental Social Psychology*, *44*, 247–296. doi:10.1016/B978-0-12-385522-0.00005-6

Engle, N. L. (2011) Adaptive capacity and its assessment. *Global Environmental Change, 21*(2), 647–656. doi:10.1016/j.gloenvcha.2011.01.019

Fortnow, L. (2009). The status of the P vs NP problem. *Communications of the ACM*, *52*(9), 78–86. doi:10.1145/1562164.1562186

Gallopin, G. C. (2006). Linkages between vulnerability, resilience, and adaptive capacity. *Global Environmental Change*, *16*(3), 293–303. doi:10.1016/j.gloenvcha.2006.02.004

Gardner, R., Hargrove, W., Turner, M., & Romme, W. (1996). Climate change, disturbances, and landscape dynamics. In B. H. Walker & W. L. Steffen (Eds.), *Global change and terrestrial ecosystems* (pp. 149–172). Cambridge, UK: Cambridge University Press.

Golledge, R. G. (2008). Behavioral geography and the theoretical/quantitative revolution. *Geographical Analysis*, *40*(3), 239–257.

Golledge, R. G., & Stimson, R. J. (1997). *Spatial behavior: A geographic perspective*. New York, NY: Guilford Press.

Grothmann, T., Grecksch, K., Winges, M., & Siebenhüner, B. (2013). Assessing institutional capacities to adapt to climate change: Integrating psychological dimensions in the adaptive capacity wheel. *Natural Hazards and Earth System Science*, *13*(12), 3369–3384.

Grothmann, T., & Patt, A. (2005). Adaptive capacity and human cognition: The process of individual adaptation to climate change. *Global Environmental Change, 15*(3), 199–213. doi:10.1016/j.gloenvcha.2005.01.002

Grunblatt, J., & Alessa, L. (2016). Role of perception in determining adaptive capacity. *Sustainability Science*, *12*(1), 3–13. doi:10.1007/s11625-016-0394-0

Hardin, G. (1968). The tragedy of the commons. *Science*, *162*(3859), 1243–1248.

Hinkel, J. (2011). Indicators of vulnerability and adaptive capacity: Towards a clarification of the science-policy interface. *Global Environmental Change*, *21*(1), 198–208. doi:10.1016/j.gloenvcha.2010.08.002

Hulme, M. (2009). *Why we disagree about climate change: Understanding controversy, inaction and opportunity*. Cambridge, UK: Cambridge University Press.

Iqbal, M., & Lim, S. (2008). Legal and ethical implications of GPS vulnerabilities. *Journal of International Commercial Law and Technology*, *3*(3), 178–187.

Jennings, N. (2000). On agent-based software engineering. *Artificial Intelligence*, *117*(2), 277–296. doi:10.1016/S0004-3702(99)00107-1

Kliskey, A., Alessa, L., Wandersee, S., Williams, P., Powell, J., Wipfli, M., & Grunblatt, J. (2016). A science of integration: Frameworks, processes, and products in a place-based, integrative study. *Sustainability Science*, *12*(2), 293–303. doi:10.1007/s11625-016-0391-3

Kunda, Z. (1990). The case for motivated reasoning. *Psychology Bulletin*, *108*(3), 480–498. doi:10.1037/0033-2909.108.3.480

Lee, J., Nam, S., Kim, A., Kim, B., Lee, M., & Lee, S. (2013). Resilience: A meta-analytic approach. *Journal of Counseling & Development*, *91*(3), 269–279. doi:10.1002/j.1556-6676.2013.00095.x

Leopold, A. (1949). *Sand County Almanac, and sketches here and there*. New York, NY: Oxford University Press.

Liberman, N., Trope, Y., McCrea, S., & Sherman, S. (2007). The effect of level of construal on the temporal distance of activity enactment. *Journal of Experimental Social Psychology*, *43*(1), 143–149. doi:10.1016/j.jesp.2005.12.009

Marx, S., Weber, E., Orlove, B., Leiserowitz, A., Krantz, D., Roncoli, C., & Phillips, J. (2007). Communication and mental processes: Experiential and analytic processing of uncertain climate information. *Global Environmental Change*, *17*(1), 47–58. doi:10.1016/j.gloenvcha.2006.10.004

Mercier, J. (2014). Equity, justice, and sustainable urban transportation in the twenty-first century. *Administrative Theory & Praxis*, *31*(2), 145–163. doi:10.2753/ATP1084-1806310201

M'Hamdi, A., Memiche, M., Pla-Lopez, R., Ezzahra, F., Sidati, K., & Baz, O. (2017). A generic agent-based model of historical social behaviors change. In M. Nemiche & M. Essaidi (Eds.), *Advances in complex societal, environmental and engineered systems* (Series 18, pp. 31–49). Cham, Switzerland: Springer. doi:10.1007/978-3-319-46164-9_2

Mimura, N., Pulwarty, R., Duc, D., Elshinnawy, I., Redsteer, M., Huang, H., . . . Sanchez- Rodriguez, R. (2014). Climate change 2014: Impacts, adaptation, and vulnerability. In *Part A: global and sectoral aspects. Contribution of working group ii to the fifth assessment report of the intergovernmental panel on climate change* (pp. 869–898). Cambridge, UK: Cambridge University Press.

Motamedi, M., Iranmanesh, A., & Nazari, R. (2018). Quantitative assessment of resilience for earthen structures using coupled plasticity-damage model. *Engineering Structures*, *172*(1), 700–711. doi:10.1016/j.engstruct.2018.06.050

Myers, T., Maibach, E., Roser-Renouf, C., Akerlof, K., & Leiserowitz, A. (2013). The relationship between personal experience and belief in the reality of global warming. *Nature Climate Change*, *3*(4), 343–347. doi:10.1038/nclimate1754

Nemiche, M., M'Hamdi, A., Chakraoui, M., Cavero, V., & Pla-Lopez, R. (2013). A theoretical agent-based model to simulate an artificial social evolution. *Systems Research & Behavioral Science*, *30*(6), 693–702. doi:10.1002/sres.2238

Nickerson, R. (1998). Confirmation bias: A ubiquitous phenomenon in many guises. *Review of General Psychology*, *2*(2), 175–220.

O'Brien, G., & Hope, A. (2010). Localism and energy: Negotiating approaches to embedding resilience in energy systems. *Energy Policy*, *38*(12), 7550–7558. doi:10.1016/j.enpol.2010.03.033

Olsson, L., Jerneck, A., Thoren, H., Persson, J., & O'Byrne, D. (2015). Why resilience is unappealing to social science: Theoretical and empirical investigations of the scientific use of resilience. *Science Advances*, *1*(4), e1400217. doi:10.1126/sciadv.1400217

Ostrom, E. (1999). *Governing the commons: The evolution of institutions for collective action*. New York, NY: Cambridge University Press.

Ostrom, E. (2009). A general framework for analyzing sustainability of social-ecological systems. *Science*, *325*(5939), 419–422. doi:10.1126/science.1172133

Resilience Alliance. (2010). *Assessing resilience in social-ecological systems: Workbook for practitioners* (Version 2.0). Retrieved from: https://www.resalliance.org/files/ResilienceAssessmentV2_2.pdf

Richardson, G. E. (2002). The metatheory of resilience and resiliency. *Journal of Clinical Pyschology*, *58*(3), 307–321. doi:10.1002/jclp.10020

Robbins, S. P., & Judge, T. A. (2013). *Organizational behavior* (15th ed.). Boston, MA: Pearson Education.

Roper, D. (1997). Technology: Achilles heel or strategic vision. *Military Review*, *77*(2), 87–92.

Scheffer, M., Dakos, V., & van Nes, E. (2015). Generic indicators of ecological resilience: Inferring the chance of a critical transition. *Annual Review of Ecology, Environment, & Systematics*, *46*(1), 145–167. doi:10.1146/annurev-ecolsys-112414-054242

Schrodinger, E. (1944). *What is life? The physical aspect of the living cell*. Cambridge, UK: Cambridge University Press.

Sem, A. (2013). The ends and means of sustainability. *Journal of Human Development and Capabilities*, *14*(1), 6–20. doi:10.1080/19452829.2012.747492

Shelton, C. (2011). The roots of analytic failures in the U.S. intelligence community. *International Journal of Intelligence and CounterIntelligence*, *24*(4), 637–655. doi:10.1080/08850607.2011.598779

Slovic, P., Finucane, M., Peters, E., & MacGregor, D. (2004). Risk as analysis and risk as feelings: Some thoughts about affect, reason, risk, and rationality. *Risk Analysis*, *24*(2), 311–322. doi:10.1111/j.0272-4332.2004.00433.x

Spence, A., Poortinga, W., & Pidgeon, N. (2012). The psychological distance of climate change: Psychological distance of climate change. *Risk Analysis*, *32*(6), 957–972. doi:10.1111/j.1539-6924.2011.01695.x

Underwood, D. (2009). *The impact of digital technology: A review of the evidence of the impact of digital technologies on formal education*. Coventry, UK: Becta.

Ungar, M. (2018). Systemic resilience: Principles and processes for a science of change in contexts of adversity. *Ecology and Society*, *23*(4), 36. doi:10.5751/ES-10385-230434

Wang, J., Xu, Z., Huang, J., & Rozelle, S. (2005). Incentives in water management reform: Assessing the effect on water use, production, and poverty in the Yellow River Basin. *Environment and Development Economics*, *10*(6), 769–799. doi:10.1017/S1355770X05002524

Weber, E. U. (1997). Perception and expectation of climate change: Precondition for economic and technological adaptation. In M. Bazerman, D. Messick, A. Tenbrunsel, & K. Wade-Benzoni (Eds.), *Psychological perspectives to environmental and ethical issues in management* (pp. 314–341). San Francisco, CA: Jossey-Bass.

Wilbanks, T., & Kates, R. (1999). Global change in local places: How scale matters. *Climatic Change*, *43*(3), 601–628.

Williams, P., Alessa, L., Kliskey, A., Rinella, D., Trammell, J., Powell, J., . . . Abatzoglou, J. (2018). The role of perceptions versus instrumented data of environmental change in decision-making: Implications for increasing adaptive capacity. *Environmental Science & Policy*, *90*, 110–121. doi:10.1016/j.envsci.2018.09.018

Xu, L., & Marinova, D. (2013). Resilience thinking: A bibliometric analysis of socio-ecological research. *Scientometrics*, *96*(3), 911–927. doi:10.1007/s11192-013-0957-0

Young, O. Berkhout, F., Gallopin, G., Janssen, M. A., Ostrom, E., & van der Leeuw, S. (2006). The globalization of socio-ecological systems: An agenda for scientific research. *Global Environmental Change*, *16*(3), 304–316. doi:10.1016/j.gloenvcha.2006.03.004

Zegart, A. (2019). U.S. Intelligence Needs Another Reinvention. *The Atlantic*, September 11, 2019. https://www.theatlantic.com/ideas/archive/2019/09/us-intelligence-needs-another-reinvention/597787/