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Modeling Multisystemic Resilience

Connecting Biological, Psychological, Social, and Ecological Adaptation in Contexts of Adversity

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Introduction

Although resilience has been studied across a great number of scientific disciplines with a substantive body of knowledge established in fields like psychology and systems ecology, transdisciplinary approaches to studying resilience are still lacking. This situation can be attributed to a range of problems such as definitional ambiguity of the construct, disciplinary blinders, difficulty funding multisystemic research, methodological challenges designing good studies, and problems with analyzing complex sources of data that are typically not included in the same models. Despite these challenges, there is growing interest in thinking about resilience as a multisystemic concept.

The term *resilience* enjoys many different definitions, although all emphasize the same shift in focus from breakdown and disorder to processes of recovery, adaptation, or systemwide transformation before, during, and after exposure to adversity (Masten, 2014; for exception, see Brown, 2016; Xu & Kajikawa, 2017). Even when focused on a single organism (i.e., a human being or a coral reef), the process of resilience is concerned with the changing condition of one or more systems when they are exposed to an atypical amount of stress. A child, for example, demonstrates resilience when she shows positive developmental outcomes despite early exposure to adversity related to extreme neglect often associated with abusive parents or placement in substandard institutional care (Masten, 2006). By its very nature, then, resilience implies an interaction between nested or contingent and co-occurring

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systems (e.g., a child's individual strengths, a foster placement that compensates for a difficult start in life, and human services that address a child's developmental delays) that help one or more of these systems do better than expected when disturbed.

To glimpse how complicated a systemic understanding of resilience can be, one has only to try to define a system itself. In general, a system is "a group or set of related or associated things perceived or thought of as a unity or complex whole" ("System," 2018). Defining a system by its internal relations and distinction from other systems, however, creates its own problems. The medical, psychological, and social sciences, for example, tend to think about systems as having easily perceived boundaries that distinguish one from the other even as they interact. To illustrate, our neurological stress response system, the hypothalamic–pituitary–adrenal axis, is distinct from, but interacts with, our microbiome and our genome at a biological level; likewise, our response to stress depends on the quality of our interactions with our family, peers, and other social systems like online communities and the economy, as well as the toxicity of our natural and built environments (Böbel et al., 2018; Doan et al., 2016; Ungar & Perry, 2012). Social ecological systems scholars, meanwhile, tend to view a system as embracing all the elements that interact at different scales of a single, unified system. Whereas the medical anthropologist might see an intricate weave of *different* systems, the ecologists sees a *single* system with many different layers, or scales (Figure 1.1). The distinction is subtle but significant when developing theory as, depending on one's perspective, multiple systems could be seen holistically as a single system with multiple scales or as multiple systems in their own right that are contingent on one another's actions. For ease of discussion (and because I am more a social scientist than social ecologist), I will talk about mutually dependent supraordinate and subordinate *systems* (rather than scales) whenever there is a reasonable assumption that a cluster of "related or associated things" work closely together. Regardless of how a system is defined, the science of resilience

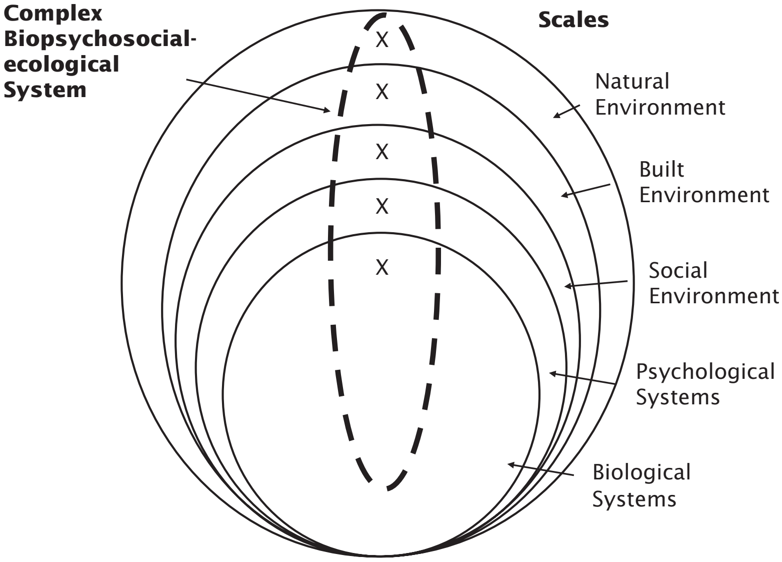

FIGURE 1.1 A system comprised of interacting scales.

requires that multiple systems (and scales of systems) are accounted for as no single variable can be wholly responsible for the complexity of the processes associated with resilience and the outcomes that result. System variables can, in fact, look very different from one another. They might be the neurons of the parasympathetic system of the brain that moderates trauma, the economic and political aspects of a community recovering from a hurricane, or the interacting flora and fauna of a forest rejuvenating after a fire. With the term *system* defined (albeit arbitrarily), it becomes easier to see a shift in thinking occurring from single system explanations for complex social and biological processes (like resilience) to more contingent models that account for the way systems cope with external and internal threats to their sustainability.

When brought together, systemic thinking and theories of resilience produce new ways of understanding processes of change that involve human and nonhuman systems and their many parts. In the area of trauma research, for example, we now understand the need to stop asking individuals who have been traumatized, “What is wrong with you?” and instead ask, “What happened to you that is causing you to behave the way you do?” This second question shifts attention away from a single system’s (i.e., the individual) responsibility for recovery, adaptation, or transformation and focuses instead on the environmental triggers that influence patterns of change (i.e., in the case of human resilience after exposure to war, protective factors include being resettled in a host country as a refugee, access to health care, and family reunification; Ott & Montgomery, 2015). When studying the resilience of human populations under stress, the most pertinent question is, “What happened to individual lives that made them different from what would be expected given the amount of stress they have experienced?” This pattern of inquiry reflects a change in thinking from simple explanations for complex behaviors to a multisystemic understanding of interactions between two or more systems (i.e., people and their environments), with as much emphasis on the interactions between systems as the pattern of adaptation evidenced by any one system (Folke et al., 2010).

The Many Definitions of Resilience

Regardless of definition or discipline, resilience researchers share a common understanding of resilience as a process associated with change over time that produces a preferred outcome for one or more systems or parts of systems. For example, social ecological systems, an area of scientific study focused on the interactions between natural environments and human activity, have explored extensively the dynamic interplay between resilience (change) and stability, first discussed by C. S. Holling. Holling (1973) expressed resilience as the “persistence of relationships within a system and a measure of the ability of these systems to absorb changes of state variables, driving variables, and parameters, and still persist” (p. 17). These ideas have been expanded by many social ecological system scholars, including those most interested in studies of international development. As Bousquet et al. (2016) explain, resilience is “the capacity to cope with change and continue to develop” (p. 40), whether that development takes place in fisheries, forests, freshwater ecosystems, or the communities that depend on each of these natural ecologies for their survival.

In other areas, including the physical sciences, these same themes of sustainability and change are becoming commonplace. For example, in architecture, the term *resilience* is synonymous with “a process for creating sustainable, successful places that promote wellbeing, by understanding what people need from the places they live and work” (Woodcraft, Bacon, Caistor-Arendar, & Hackett, 2012, p. 16). In computing science, the resilience of networked systems produces a “system that continues to offer an acceptable level of service even in the face of challenges” (Hutchison & Sterbenz, 2018, p. 1).

The term *resilience* has also become well recognized in the psychological sciences where there has been intense scrutiny of promotive and protective processes that function when human biological, psychological, social, economic, and political systems become stressed. Masten (2014), a developmental psychologist, is known for her definition of resilience that has evolved to take a more systemic approach. She writes:

> Resilience can be broadly defined as the capacity of a dynamic system to adapt successfully to disturbances that threaten system function, viability, or development. The concept can be applied to systems of many kinds at many interacting levels, both living and nonliving, such as a microorganism, a child, a family, a security system, an economy, a forest, or the global climate. (p. 6)

The study of human psychology has shown that this pattern of adaptation can appear in many different ways, ranging from persistence in one’s behavior when confronting stress to forcing systems to transform themselves in ways that result in entirely new regimes of behavior to avoid a stressor altogether. For example, victims of sexual abuse may choose a number of viable strategies to cope with their abuse. Where they perceive the consequences of disclosure as too high (e.g., stigma or being blamed for the abuse), a possible coping strategy may be to avoid the abuser and persist with previous patterns of behavior, sublimating potentially traumatizing thoughts and feelings. This is not an optimal strategy for the individual victim or society as a whole, but it is a contextually reasonable adaptation in contexts where victims of abuse may risk further abuse if they disclose (Priebe & Svedin, 2008). When social movements give victims a collective voice (e.g., the #MeToo movement), a different pattern of resilience becomes possible, one that transforms broader social institutions and the individual’s identification of himself or herself as a victim with rights. In this sense, manifestations of psychological resilience are a reflection of how broader systems interact with individual choices to produce patterns of coping that are more or less effective.

It is becoming increasingly clear (as the chapters in this volume show) that there is a synergy in how resilience is defined when describing the functioning of different systems. Masten’s definition, for example, shares much in common with those in distantly related fields like disaster resilience, where the focus is on “the ability to prepare and plan for, absorb, recover from or more successfully adapt to actual or potential adverse events” (Cutter, 2016a, p. 742). My own work on the resilience of human systems that accounts for changes in multiple psychological, sociocultural, and institutional systems integrates dimensions of social justice, defining resilience as the capacity of systems (whether that system is an individual, a community, or an institution) in contexts of adversity to navigate to the resources necessary to sustain well-being and the ability of these human systems to negotiate for promotive and protective resources to be provided in contextually and culturally meaningful ways (Ungar, 2011).

Although these definitions all focus on the functioning of different systems or parts of systems, they share a number of similarities. First, resilience only exists where there has been a perturbation that is unusual and stressful for one or more interdependent systems. The result is destabilization that threatens the capacity of the system to maintain its functioning. Second, all resilient systems engage in processes of one kind or another that give them opportunities to persist, resist, recover, adapt, or transform (I will discuss each of these processes later). What these contextually specific processes look like, however, is always a reflection of the stressors placed on a system, the resources that are available to protect the system's functioning, and the desirable outcomes that are sought. In this sense, resilience is contextually specific, much as evolving thinking in the field of public health now emphasizes "precision public health" that identifies localities most at risk and then targets interventions to their unique contexts, rather than always looking for generalizable mechanisms that sustain the well-being of entire populations (Dowell, Blazes, & Desmond-Hellmann, 2016). The third quality of resilience reflects this need for sensitivity to the local context, acknowledging the different levels of power each system (or part of a system) has and its capacity to influence the individual or collective well-being of a system (or systems) as a whole. This expression of power is always a matter of negotiation that leads to trade-offs as different parts of systems compete for the resources each needs to cope with internal and external stressors. A system is perceived as showing resilience only when it functions in ways that are valued positively by its constituent parts or co-occurring systems. In practice, this means that a family that embraces criminal behavior as a way of managing social marginalization or an economy that resists modernization to preserve the livelihoods of a few individuals may both be described as resilient from the perspective of those who benefit from these patterns of adaptation (Ungar, 2016).

While these three aspects of resilience (i.e., exposure to an atypical perturbation, contextual specificity of the protective processes, and negotiated outcomes) may seem abstract, in practice, resilience in response to a disturbance that produces patterns of adaptation that benefit some parts of a system more than others has been the basis for voluminous amounts of study in many different disciplines. For example, Annarelli and Nonino (2016) have adapted Hollings's work on social ecological systems to examine the resilience of supply chains, linking their resilience to the functioning of the multiple systems upon which they depend. These include both distal environmental systems (e.g., disruptive weather and political strife can be disruptive to supply chains) and the everyday practices used by management (e.g., labor strikes and poor financial decisions can affect the planned production of goods and services). While it may seem that the only desirable outcome of supply chain resilience is stable production (recovery), a return to business as usual is too narrow an understanding of what resilience can look like. A system that recovers may, in fact, be one that has failed to account for changes in its environment or adapted to mismanagement when it resumes doing what it did before a crisis. While resilience may in such circumstances be synonymous with recovery, with recovery comes a trade-off if ineffective management systems are allowed to persist at the expense of the entire business adapting to changing market conditions. Seen from the perspective of the long-term viability of the enterprise, a better outcome might be the removal of the current management and their replacement with a new system of governance that prepares a business for the next unanticipated stressors in the marketplace, diversifying the goods and services it produces, finding new markets, or sourcing new inputs.

Whether such a broad definition of a process that characterizes so many systems is useful is a point of debate (Brown, 2016). What is likely most useful about a more systemic understanding of resilience is the potential it brings to discern patterns across systems that explain how the resilience of one system might influence the resilience of other co-occurring systems. The more we know about how resilience works, the better we will be able to influence systems to change in ways that are desirable to different parts of those same systems. Seldom, however, have researchers in the natural and human sciences explored collaboratively the full extent of the links between the resilience of one system and the resilience of mutually dependent, co-occurring supraordinate and subordinate systems (for exception, see Brown, 2016; Xu & Kajikawa, 2017).

In this chapter, I propose an algebraic expression to conceptually guide studies of systemic resilience as a way to account for all the complex reciprocal interactions that make resilience contextually responsive. Elaboration of the model is followed by the presentation of seven principles common to the resilience of different systems. In the final part of the chapter, I explore the implications of systemic resilience for the design of interventions and social policies that have the greatest potential to make the resilience of human, built, and natural systems more likely to occur.

A Model of Multisystemic Resilience

All systems have the potential to show resilience, but that resilience will reflect the capacity of multiple co-occurring systems to interact well together under stress. Patterns of resilience are always responses to the quality of the stressors that a system experiences. This is one way in which the study of resilience is distinguished from fields like positive psychology, population health, and ecology, all of which include research on the factors that maintain normative functioning associated with expected patterns of change and growth. For example, while adults need a sense of self-worth, efficacy, and problem-solving skills, under conditions of war or forced displacement due to climate change these aspects of cognitive functioning may look quite different as individuals adapt how they think about themselves and to whom they attribute the locus of control for change (Tol, Song, & Jordans, 2013). There may also be protective psychological processes like social withdrawal that are functional only in contexts of exposure to overwhelming amounts of external stress (Obradović, Bush, Stamperdahl, Adler, & Boyce, 2010). Resilience, then, always occurs in contexts where the amount of stress a system experiences is above that which is accepted as optimal for the system's functioning (some stress is, after all, necessary and can inform the development of healthy coping strategies for all systems). Expressed algebraically, there must be above-normal levels of exposure to adversity to trigger resilience. This can be summarized as $\sum A >$ average A for a population where A is adversity.

The assessment of risk, then, is a precondition for understanding resilience. Risk, however, is seldom contained to one or two narrowly defined proximal systems but instead occurs in mixtures of risk factors at different systemic levels. The Centers for Disease Control and Prevention in the United States, for example, describe the exposome as the measure of all the exposures an individual experiences over his or her lifetime and how these exposures influence the individual's health. The study of resilience is not about understanding these risks or their negative sequelae that follow risk exposure, such as disorder, dysfunction, or disease. The study of resilience (in contexts of adversity) focuses attention on the factors that prevent a potentially traumatizing event from causing a system to function poorly.

The challenge when theorizing resilience is to address the complexity of resilience across interrelated systems and create models to capture the interactions between systems (Adger, Barnett, Brown, Marshall, & O'Brien, 2013). The expression in Figure 1.2 is one such effort to account for the many dimensions of resilience as they co-occur within and between systems, whether that system is biological, psychological, social, mechanical, or environmental.

Figure 1.2 is an expression of resilience that adapts the work of famed social psychologist Kurt Lewin. Lewin (1951) suggested that behavior is a function of a person's interaction with his or her environment, expressed as $B = f\,(P,E)$. Expanding that simple expression produces a succinct story of interacting resilience systems and their component parts. The resilience of any single system (Rsystem) is mutually dependent upon the resilience of other co-occurring, supraordinate and subordinate systems at a particular moment in time ($\text{Rsystem}_{1,2,3,\ldots}$), whether those systems are as small as a gene or as large as a family, computer network, government, or biosphere. This reciprocity is captured by the left-hand side of the expression. At the level of each system, resilience is first a function of the system's capacities (S_c) and vulnerabilities (S_v; this includes factors like gender, physiology, and genetics of human systems; social and built capital of community systems; and biodiversity and chemical composition of ecological systems). These interact with aspects of a system's distal and proximal physical and social environment (E) in ways that either sustain a system's current regime of behavior or compel it to change.

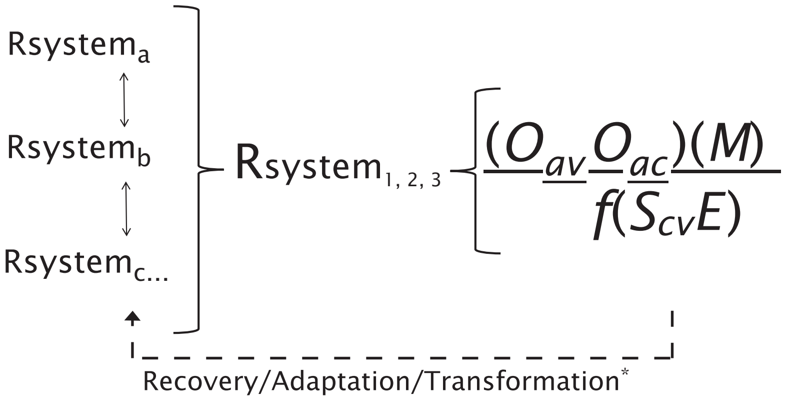

FIGURE 1.2 An expression of resilience (in contexts where a population is exposed to above-normal levels of adversity). R = resilience; O = opportunity; M = meaning; E = environment; av = availability of resources; ac = accessibility of resources; cv = capacities and vulnerabilities. Adapted from Ungar (2011).

These interactions, however, will have a greater or lesser impact on the system's resilience based on the opportunities (O) that are more or less available (O_{av}) and accessible (O_{ac}) to the system, which limit the system's expression of its purpose or function. Available resources may be near at hand but not accessible due to barriers occurring across scales (e.g., a sanctuary for orphaned elephant calves may be available, but weaknesses in funding or transportation infrastructure make it inaccessible to animals that need care and protection). Opportunities are, in turn, influenced by meaning systems (M), which are expressed through the relative power of each part of the system to privilege solutions of one kind over another (Adger et al., 2013). Finally, as systems go through the process of coping with adversity, they exert an influence on other mutually dependent systems (returning again to the left-hand side of the expression). These coping processes can appear as a recovery to a previous regime of behavior, as an adaptation to ongoing adversity through engagement in new coping strategies, or can force the transformation of contingent systems that decreases or buffers exposure to adversity in the future.

A comprehensive model of resilience like this is intended to broaden the scope of research that focuses on patterns of recovery, adaptation, and transformation of any system. The enhanced breadth of factors that should be accounted for may also help to better inform sustainable solutions to "wicked" problems, whether those are the high rates of suicide among racially marginalized and structurally disadvantaged indigenous peoples or ecological problems caused by the Anthropocene era, such as climate change and the decreasing diversity of ecological systems. Besides helping guide the design of resilience research, the expression is also useful for interpreting research findings where multiple systems have been implicated in the successful development of one or more focal systems.

Co-occurring Systems and Resilience

There are many studies in both the human and natural sciences that suggest that a long list of variables must be accounted for to understand developmental processes that result in changes to behavioral regimes of contingent systems under stress that help these systems to remain viable. To date, most studies have only accounted for a small number of factors that explain how the resilience of one system might affect the resilience of other co-occurring systems. A new generation of studies that include far more scope to their data collection, however, is showing that when systems are described in sufficient detail, correlations can be found between conditions in one system and performance of other contingent systems (Kaplan, Collins, & Tylavsky, 2017; Noble, Norman, & Farah, 2005). For example, a U.S.-based study of pediatric neuroimaging and genetics found strong correlations between childhood socioeconomic factors and different aspects of brain structure among 10-year-olds (Noble et al., 2015). Parental educational attainment and family income accounted for individual variation in brain structural development in regions associated with the development of language, executive functions, and memory. While the study was focused on explaining the factors that inhibit brain development rather than those that facilitate positive development in stressed environments, the results are useful in demonstrating that economic systems affect biological systems (brain development) through the moderating effect of parental educational attainment, family income, and social marginalization related to class structure. Given these findings, it is very likely possible (although as yet relatively unstudied) that as opportunity structures change and economically marginalized families are better resourced, they are more likely to raise children with better neurological functioning and improved ability to break cycles of poverty. This is a hypothesis that still needs to be tested, although longitudinal studies of child development without neurological testing have shown that the cumulative effect of multiple resilience factors at different systemic levels are likely to contribute to better than expected outcomes among children who experience early disadvantage (Beckett et al., 2006; Boivin et al., 2013; Werner & Smith, 2001). In this sense, the resilience of one system (e.g., the education system, social welfare system, or political system) can mean that other systems or scales are more resistant to problems and better able to recover, adapt, or transform. Simpler models of resilience that seek to explain resilience as change in just one or two systems are unlikely to produce sufficiently robust accounts for why resilience does or does not occur when problems are complex and solutions unsustainable in contexts where there are multiple forms of disadvantage and stress.

It is not surprising, then, that increasingly complex models are being proposed to account for reciprocity between systems as they change, with empirical evidence that show that processes like recovery, adaptation, and transformation by one system contributes to concurrent or sequential change in other subordinate and superordinate systems or scales. To illustrate this pattern with an example that reaches beyond the human sciences, Hutchison and Sterbenz (2018) have shown that the design of resilient computer architecture is dependent upon the resilience of the critical infrastructure that it needs to function, like the Internet; management structures in the corporation that hosts it; and the capacity of end-users to exploit the technology in ways that are meaningful and improve their lives. If one thinks, for example, of handheld devices as a networked computing system, then it is clear that their sustainability as a communication tool relies on software systems, especially social media platforms, and mobile phone companies to ensure handheld devices continue to fulfill a meaningful function for consumers. The technology, then, is a system networked to other systems, even the biology of the users (e.g., the production of stress hormones like cortisol is influenced by the use of handheld devices) and the political environment created by humans (e.g., election meddling and the proliferation of "fake news" on social media). Much has been made of the cascading negative effects of a technology like handheld devices or the potential for negative outcomes when these computer networks are stressed by outside agents.

The resolution of risk and enhancement of resilience to sustain connectivity and convenience depend on more than their hardware and software (two important, mutually dependent technical systems). Hutchison and Sterbenz (2018) propose the formula D^2R^2+DR (defend, detect, remediate, recover; then diagnose, refine) as the stages in a recurring process by which the architecture of a computer system evolves its capacity to withstand attacks. Each part of the process is reliant on contingent systems like government regulation (that prevent security breaches), financial markets (that monetize these networks and support their proliferation), and psychological systems (that create favorable attitudes toward new forms of communication). Together, these and many other systems create recursive environments that respond to expanding computer networks.

In this regard, resilient systems (whether biological, psychological, social, or engineered) are malleable over time. When they work well, they benefit multiple systems at once with fewer negative trade-offs, while still being responsive to the exigencies of systems coping under stress. There is, however, always a danger that strategies to make one system more resilient can inadvertently compromise the capacity of other co-occurring systems. One example of this pattern is found in discussions of regrettable substitutions (Scherer, Maynard, Dolinoy, Fagerlin, & Zikmund-Fisher, 2014), which are solutions to complex problems that result in adaptations that make one system better but compromise the functioning of other contingent systems. This concept has been used to explain the unintended consequences of interventions like chemical coatings on household objects that retard fire or make plastics more durable but that are later proven to be toxic to humans. A solution that appears to enhance resilience of one system may compromise the resilience of others.

Examples like these suggest that resilience has both trade-offs and a potential "pay forward" function, with the resilience of one system likely to influence negatively or positively the resilience of other systems. This pattern can be seen in all systems, whether biological, built, or natural. Therefore, the capacity for systems to withstand stress (to demonstrate resilience) is unlikely to be a function of a single system's self-righting capacity. As Hutchison and Sterbenz (2018) explain in regard to computing networks:

> [Because] attacks can happen at any layer of the communication stack (e.g., hidden attacks exploiting vulnerabilities of web application in legitimate network packets), various detection and protection mechanisms usually co-exist at different levels to mitigate security threats. However, if security management is localized only to corresponding layers, the security related information will be fragmented, which fails to give a big picture for situation awareness and prompt and correct responses. (p. 3)

The better integrated resilient systems are, the more likely they are to benefit from each system's efforts to remain sustainable.

The downside to this systemic understanding of resilience is that no one study is likely to account for every dimension of resilience found in Figure 1.2. The science, however, is continuing to build toward a comprehensive understanding of recovery, adaptation, and transformation under stress through incremental research that investigates more than one system at a time (this trend is evident in the chapters that are included in this volume). This incrementalism is, for example, demonstrated by many multidisciplinary studies, such as those by Böbel and his colleagues (2018) in the field of molecular psychosomatics and Dinan and Cyran's (2013) work on immunology. Both programs of research have proven a link between the diversity of the human microbiome (e.g., gut bacteria) and the ability of the human immune system to suppress inflammation and reduce the incidence of a range of psychiatric disorders including depression and anxiety. For example, in a recent study of the potential protective function of exposure to a more diverse natural biome, healthy young men who spent the first 15 years of their lives on farms with animals were compared with those who grew up in an urban environment without animals (Böbel et al., 2018). A number of characteristics distinguished the two samples. First, when given the Trier Social Stress Test in a laboratory setting (a test of public speaking skills and stress reactivity), urban participants raised in the absence of animals showed increases in stress-related immune system secretion of the interleukin 6 and suppressed anti-inflammatory secretion of interleukin 10. These two types of cytokines, or proteins, help cells signal one another and have been linked to different levels of inflammation that affect neurological and psychological functioning. This pattern of biological response suggests that urban participants had more immunoregulatory deficits when stressed. Participants were also subjected to a number of psychological tests and had samples of their plasma cortisol and salivary α-amylase (a protein enzyme) assessed, all of which showed that rural participants experienced the Trier Social Stress Test as more difficult. Although the results are still preliminary due to the relatively small sample size and use of a nonclinical population, studies like this are providing an interesting clue to the potential benefits of exposure to a healthy and diverse natural environment and its positive influence on human biological and psychological processes, particularly the "missing-microbes" or "old friends" (Rook, Lowry, & Raison, 2013) as some bacteria have come to be known. From an evolutionary point of view, the presence of these microbes likely helped establish regulatory (i.e., protective) immune pathways that are now lacking in urban environments because of increased sanitation, water treatment, the overuse of antibiotics, lower rates of breastfeeding, and cesarean sections (it is believed that during the birthing process the mother's microbiome is transferred, like a baton, to the child during a vaginal birth). Once again, systems that potentiate greater resilience of one system, like better sanitation, may inadvertently compromise the resilience of other systems, just as the resilience of co-occurring systems can also create cascades of positive change.

These theories have been proven in laboratory experiments and through careful sampling of populations with differential rates of exposure to more diverse ecosystems. Combined, they suggest that exposure to the right amount and type of stressors (such as bacteria) can produce a "steeling effect" (Rutter, 2012) that make systems more robust when exposed to future stressors. For example, children from more traditional Amish communities in the United States had better immune system activation than Hutterite farm children where the farm work is more mechanized (Rook & Lowry, 2008). Thus, Stanford, Stanford, and Grange (2001) proposed the "hygiene hypothesis," which attributes recent spikes in psychiatric disorders and diseases to compromised immune systems among people in industrialized and heavily urbanized settings where there is minimum contact with natural environments. It appears to be a truism of resilience research that the right amount of stress is required for successful development of all systems. Stress a system too much, however, and it fails. Stress a system the right amount, and it will demonstrate increased capacity for resilience when dealing with future disturbance.

This understanding of resilience as a systemic process is found in numerous other studies of very different systems. Looking outward toward the quality of the natural environment (rather than its component microbial parts), Lederbogen and his colleagues (2011) were able to show that a 90-minute walk in a natural, but not urban, setting was able to decrease self-reported rumination and concurrent neural activity in the subgenual prefrontal cortex of human subjects. The findings indicate a heightened capacity of people to withstand stress following contact with nature. In this example, an externally diverse, natural environment is able to enhance the capacity of neurological resilience to stress, which makes the placement of green spaces contiguous to urban environments a potentially important buffer against the physiological changes that follow from urbanization. Not only might these enhanced spaces increase neurological capacity to cope with stress, they might also permit greater access to microbial diversity that could produce yet another positive influence on the human biological system. It is these complex and reciprocal relationships between resilient systems that justify the need to account for multiple systems at the same time when studying resilience.

Returning to Figure 1.2, there is plenty of evidence from studies of multiple systems (from the microbiome to the engineered systems like computer networks) that by strengthening any one system, other co-occurring and contingent systems will also benefit, although the lines of causality are far from linear. That is because it remains difficult to privilege any single behavioral regime of one or more systems as a resilience ideal. Every behavioral regime benefits some portion of an entire ecosystem (Holling, 1973). Change opportunity structures, meaning systems, or the context in which a system operates and what resilience looks like will also change. Indeed, one always needs to ask, “Resilience to what? Resilience for whom?” (Cutter, 2016b). Even when a system is not anthropomorphic, the same question can be adapted to ask, “Resilience to what, and for which part of a system’s benefit?” Researchers of human resilience, however, have tended to privilege certain outcomes over others, positing resilience as a process of recovery to a previous level of functioning, adaptation to new ways of coping with stress, or the forced transformation of one or more systems to ensure that individual and social systems thrive in ways that are socially constructed (Cutter et al., 2008). There is typically a bias, however, in the psychological and social sciences toward positive (socially desirable) outcomes that benefit human systems as a whole over those that benefit natural systems or subsystems (Rutter, 1987). An increasingly complex story of systemic resilience is showing that the teleological view, which sees some systems as worthwhile only if they serve the needs of human beings in the short-term, is being challenged as we come to realize that even systems with the potential to threaten human health may, in the long-term, be in our best interest to maintain. Thus, a less anthropocentric understanding of resilience leads to the conclusion that a resilient system does not always function for the benefit of humans and that even behavioral regimes of human systems that are labeled as suboptimal can sometimes protect contingent systems. For example, social withdrawal after a traumatic event like child abuse may help to maintain lower levels of cortisol and preserve biological homeostasis, even if that coping strategy compromises long-term social development (Alink, Cicchetti, Kim, & Rogosch, 2012).

Resilience cannot, therefore, be understood as a linear set of causal relationships without accounting for trade-offs. Where ecological and human understandings of resilience intersect, the resilience of ecological and human systems has been found to be mutually dependent (Quinlan, Berbés-Blázquez, Haider, & Peterson, 2015). In the example of the “old friends” discussed earlier, protective factors like access to antibiotics, which enhance opportunities for health and improve the resilience of human beings to debilitating diseases, may actually compromise the viability of other systems necessary for the resilience of the same organism they are meant to sustain.

Seven Principles

Despite this potential for cross-disciplinary modeling, there has been little effort to synthesize our diverse conceptualizations of resilience. Ecologists have remained largely focused on patterns of resilience in the ecosphere, although social ecological systems theorists like Folke (2006), Brown (2016), and Gunderson (Gunderson, Allen, & Holling, 2010) point to the impact of humans on the resilience of natural environments, and vice versa. Ecopsychologists and epigeneticists, meanwhile, talk about environmental triggers, but their conceptualizations of resilience focus mostly on individual human processes (Ellis & Del Giudice, 2014). Some authors have suggested that despite a common lexicon, the fields are fundamentally too different to bring together into a single model (Olsson, Jerneck, Thoren, Persson, & O'Byrne, 2015). There is plenty of resilience-related research that suggests otherwise. A recent review of the principles that govern resilience across diverse bodies of research (Ungar, 2018) identified seven common principles that can account for much of what we understand about how resilience functions when a system (human, built, or natural) is stressed. These include (1) resilience occurs in contexts of adversity; (2) resilience is a process; (3) there are trade-offs between systems when a system experiences resilience; (4) a resilient system is open, dynamic, and complex; (5) a resilient system promotes connectivity; (6) a resilient system demonstrates experimentation and learning; and (7) a resilient system includes diversity, redundancy, and participation.

Resilience Occurs in Contexts of Adversity

Studies of resilience can be distinguished from related research on mental health, social capital and even ecology by their explicit focus on systems under stress. While systems show periodic changes in behavioral regimes due to maturation, or adjustments to expected and normal changes in the environment over time (e.g., animals experience seasonal changes; children must adjust when they are first sent to school; communication systems grow as the number of users increases), a system shows resilience when it is able to recover, adapt, or transform under conditions of *atypical* stress.

To illustrate with an example from the psychological sciences, Oshri, Duprey, Kogan, Carlson, and Liu (2018) studied changes in the future orientation of abused children over a three-year period starting in early adolescence. Rather than focus on normative developmental processes, however, they put an unusual amount of effort into assessing children's social environments to better understand how children's anticipation of future consequences and their beliefs that they could influence their futures are associated with the shifting balance between exposure to contextually specific risk factors (e.g., caregiver–child closeness, peer relations, school engagement, positive community environment, and access to services) and the internal and external resources the children experience over time. Findings show that as the equilibrium between risk and resources changes and children are able to cope with an abnormally high burden of expectations placed on them by their families and communities, their level of future orientation steadily increases despite, and possibly as a consequence of, stress exposure. To model this association, Oshri et al. (2018) used growth mixture modeling to distinguish three developmental trajectories for future orientation as a cognitive coping strategy: low start/increasing; high start/decreasing; and high persistent. Each trajectory was explained by the quality of the child's experience with external conditions, including the degree of physically abusive discipline they received, the quality of their peer relationships, their level of engagement in school, the disorganization of children's communities, and their gender. As access to supportive resources improved, children's future orientation (a protective factor against psychological problems) also improved. By disaggregating the data by gender, it was further shown that girls (who are, statistically, more at risk for depression) tended to more consistently report high future orientation. All of this raises questions with regard to how children's experiences of the proximal systems that influence them shape internal cognitive coping strategies. In this example, a commonly assumed metric of personal resilience, children's ability to use cognitive strategies to solve problems and maintain optimism, depends on the capacity of both internal and external systems to manage both proximal and distal stressors. As the example illustrates, resilience only exists when a system is under stress but exhibits a desirable behavioral regime.

Resilience is a Process

Drawing together models of resilience from ecological and human sciences is fraught with ontological and epistemological problems. Ecologists tend to describe resilience as a system state in which equilibrium is reached (Folke et al., 2010), while psychologists lean toward resilience as a process. For example, researchers concerned with ecological systems talk about a system's resilience as its capacity to maintain homeostasis while under threat (Gunderson & Holling, 2002). Psychologists, however, dating back half a century have come to see resilience as a set of protective processes that contribute to positive developmental goals (Rutter, 1987). To reconcile this difference, scholars are concluding that resilience is a process that increases the capacity of a system to withstand or adapt to a present or future insult. A system that shows resilience is one that is able to optimize its capacity to successfully cope under stress.

Resilience-promoting processes can look very different depending on the context in which they occur. At least five processes have been found to be associated with resilience: persistence, resistance, recovery, adaptation, and transformation.

a. *Persistence.* Persistence is a system's ploddingly regular behavior that is only possible if outside threats are dealt with by other co-occurring systems that insulate it enough to allow the focal system to continue unchanged. In ecology, a nature preserve with armed guards creates the conditions for rare species of mammals like rhinos to persist with relatively little change in their behavior despite the threats posed to them. In psychology, children who have been described as "orchids" (Ellis & Boyce, 2011) are genetically susceptible to stress but excel in conditions where their social environments protect them (i.e., a child susceptible to anxiety, but also a gifted artist, will thrive in an alternative school where she can avoid bullying). In each example, the resilience of a system under threat is only possible if co-occurring systems protect the focal system from stressors that would force the system to change.

b. *Resistance.* Resistance may look the same as persistence, but the focal system maintains its behavioral regime by actively pushing back against outside threats (i.e., an immune system is activated to avoid infection of the host organism, maintaining the host's health). Most systems will demonstrate a pattern of resistance before they recover, adapt, or transform. For example, communities facing the loss of a large employer may seek government intervention to subsidize an industry that might otherwise fail. In each instance, the focal system is only as resilient as the subordinate and supraordinate systems it can actively mobilize to avoid change.

c. *Recovery.* The process of recovery means that a system's defenses, whether internal or external, were insufficient to resist perturbation and the system's capacity to cope has been compromised temporarily. Recovery is a description of a system's return to a previous level of functioning, although in actual fact systems are changed by their experience of insult and recovery. Hutchison and Sterbenz (2018), for example, suggest that a computing system's recovery is never a return to a previous state, but usually results in an improvement in its engineering as it learns to avoid the same breakdown twice. Likewise, a forest may recover from a fire with increased nutrients in the soil (e.g., potassium, calcium, and magnesium). In each instance, the recovered system may look and function similar to its previous state but is likely to have new capacities as a result of having survived a disturbance.
d. *Adaptation.* Adaptation refers to a system changing in ways that make it possible for it to accommodate itself to stress. For example, an invasive species imposes the need for adaptation on an ecosystem, which may lose some of its diversity—species—to accommodate the intruder or develop compensatory means of coping with the invader (e.g., weaker parts of the system may die off, leaving the remaining parts more genetically robust). In humans, adaptation is particularly common in studies of resilience. For example, O'Brien and Hope (2010) found that elderly persons who live mostly on their own or in substandard nursing homes are more vulnerable to centralized energy systems, which are likely to fail during extreme weather events. Once stressed, elderly people who are socially isolated are more likely to die from heat stroke when air conditioning fails or from exposure or carbon monoxide poisoning when heating systems do not work. One possible adaptation is to provide these people with more localized energy solutions (like home-based solar units that feed energy into the grid) that have more capacity to withstand catastrophic weather events. This change in energy policy facilitates the adaptation of energy systems to the needs of vulnerable elderly even though it does not fundamentally change the conditions that predispose elderly persons to health problems.
e. *Transformation.* A resilient system that transforms under stress must find a new behavioral regime that allows it to continue its previous functions (or perform new functions) by taking advantage of new strategies and resources. All systems have this capacity, whether it is advances to energy storage systems that have allowed renewable energy to transform the energy sector or personal transformation of a heart attack victim who makes dramatic changes to his lifestyle after discharge from hospital. In each instance, systems (human, built, or natural) are fundamentally changed by their exposure to stress, finding a different behavioral regime better suited to the internal and external threats the system faces.

These five processes are not agentic. Systems do not "choose" one coping strategy over another. They, instead, optimize their functioning by exploiting co-occurring systems for resources that make different strategies more or less feasible. Change the resources available, and the meaning of those resources to the system (i.e., their value), and the process a system uses to improve its resilience will also change. In this sense, the locus for change that explains which process a system uses depends as much on the condition of the environment that surrounds a system as it does the system's own resources to cope with unusually high amounts of stress.

There Are Trade-Offs Between Systems When a System Experiences Resilience

The resilience of one system has the potential to influence the resilience of other co-occurring systems (e.g., a biologically diverse natural environment has the potential to enrich the human microbiome, which in turn affects the immune system and mental health). However, resilience cannot be understood as a linear set of causal relationships without accounting for the trade-offs between systems. In the example of the "old friends" discussed earlier, protective factors like better sanitation and antibiotics, which enhance opportunities for human health, compromise the viability of other external systems like one's natural environment, and internal systems like the microbiome where more diverse bacteria (i.e., dirt) would actually be more useful to overall human well-being. By making the environment less rich in bacteria, one could say that the human organism is protected from harmful pathogens and therefore more resilient to diseases like cholera. However, the trade-off is that those same measures to sanitize the environment also compromise access to helpful bacteria. Without accounting for all aspects of system change at multiple systemic levels, there is greater likelihood for unintended (iatrogenic) consequences to interventions that are meant to increase system capacity.

A Resilient System Is Open, Dynamic, and Complex

Systems that show resilience integrate new information when necessary, adding to their complexity in ways that increase the resources available to cope with disruption. For example, a rich literature is emerging that connects threats to environmental sustainability like climate change with reciprocal, bidirectional chains of causality with human aspects of the problem, specifically culture. Adger et al. (2013) deconstruct the complexity of cultural narratives and practices that define the relationships between humans and their environments. As they show through a review of the literature, cultural narratives about the relationship between people and the natural environment interact with beliefs and cultural practices in ways that may prevent rational response to a scientifically demonstrable threat (e.g., the reluctance of some adherents of fundamentalist religions to acknowledge climate change occurring as a result of our exploitive relationship with nature). In such cases, systems are unable to change (to show resilience) because they remain closed, stable, and simple. In such contexts, even advocates for responsible social policy are likely to fail if the changes they propose conflict with the dominant discourse that defines "business as usual" as sustainable. A more resilient system shows openness to new explanations for human experience, is nimble enough to change, and is capable of integrating new technologies and ideologies to effectively address threats to the system's long-term viability. This nod to complexity, and the multiple ways in which resilience is manifest, reflects emerging science across many disciplines, not just ecology. Current thinking in the field of human psychological resilience is also moving from more deterministic and simplified models of human behavior to more complex explanations (Cutuli & Herbers, 2018).

A Resilient System Promotes Connectivity

Resilient systems are connected systems. While connections can also threaten a system's sustainability (as connected systems are vulnerable to contamination, infection, and misinformation), this appears to be a necessary trade-off for systems to share resources and seed growth. The better connected systems are, the more likely they are to provide access to the resources systems need to overcome disruption when the system's own resources become overwhelmed. To illustrate, restorative justice provides an alternative means of dealing with offenders through a community process that keeps those who commit crimes living in their own communities (Ward & Langlands, 2009). Rather than separation through incarceration, and the risks that accompany imprisonment and discharge afterwards, restorative justice maintains offenders in their communities but holds them accountable to those they have harmed through a structured process of healing that strengthens community connectivity. Likewise, returning to the previous example of vulnerable elderly and energy distribution systems, countering both industrial gigantism and the trend toward seniors living on their own, changes to energy infrastructure could make both power companies and elderly persons who are socially marginalized more resilient by connecting small-scale power systems. One could say that decentralized but locally networked power generation through initiatives like rooftop solar power ensure a diversity of resources are available that can become active during a crisis. Connected systems tend to be better at working together to make both energy and human systems resilient.

A Resilient System Demonstrates Experimentation and Learning

Systems that show resilience experiment with innovative solutions to stressors as they occur, learning from each trial and integrating failure and success into future strategies. This praxis of reflection and action can be observed in all systems. For example, Alt and Raichel (2017) have shown that the experience of citizenship and media literacy are protective factors that contribute to personal attitudes that endorse national accountability, reinforce participatory democracy, and support institutional practices like voting. In turn, these protective factors enhance the efficacy of political and legal systems that ensure responsive governance. Each of these systems is, in turn, most effective when they learn from earlier efforts to adapt, and the lessons learned in one system (e.g., providing people with opportunities to be lifelong learners through educational reform) leads to sustained change in many different dimensions of citizenship. For example, digital literacy implicates a number of contingent systems, including cognitive capacities and values (a psychological system), and cultural systems that must be robust enough to help voters distinguish important issues from manipulation by those in power. Alt and Raichel (2017) argue that well-connected people (principle 5) with access to the technology required to connect and a cognitive mindset to seek out opposing points of views (cognitive disruptions) can be created through a personal learning network, which includes information already handy in the environment and social media. The better a system is at learning from past efforts to stabilize and able to be influenced positively by other systems, the more likely that system is to thrive when confronted with an atypical stressor.

A Resilient System Includes Diversity, Redundancy, and Participation

Systems, whether human, built, or natural, do better when they are more diverse and have sufficiently complex coping strategies to create redundancies. In the event of system overload and partial failure, a diverse system with plenty of its components engaged is more likely to be capable of generating new coping strategies to compensate for those that have failed. It is easy to see these traits in the design of airplanes where multiple system backups exist in case of catastrophic failure of any single system (Jackson & Ferris, 2013) or a small-holding farmer who diversifies her crop to ensure that changing weather patterns do not threaten every part of the harvest at once. These examples suggest that resilient systems are those designed with these characteristics in mind.

A good illustration of this principle in action is ride-sharing applications like Uber, where there is direct participation from drivers and riders, sufficient capacity to ensure cars are available (and incentives by way of spike demand pricing to put more cars on the road when they are needed), and a diversity of products to make use of the capacity Uber has created (e.g., Uber Eats). Combined, Uber has been able to withstand regional setbacks and maintain corporate resilience without threatening the viability of the entire company, as well as provide a more efficient use of resources (Cramer & Krueger, 2016).

The Resilience Tangram

Understanding resilience multisystemically, with numerous trade-offs and complex patterns of interaction within and between systems, means that the factors that predict resilience are seldom fixed or predictable across all environments. Visually, resilience is an interwoven set of relationships that look more like a tangram than a picture puzzle (Figure 1.3). Picture puzzles are sets of printed pieces with predictable patterns of association that snap together in only one predetermined way. Each edge of a puzzle piece is intended to properly lock with only one other. Arguably, much of the empirical research on resilience has searched for these “pieces” and their relationship with other pieces. Complexity is introduced by including more and more parts of the puzzle, but the assumption is that the pieces will come together in some orderly way. This approach to empiricism is well-reflected in much of the research cited so far in this paper. Change a mouse’s environment and the pattern of resilience changes in a predictable way. Change an elderly person’s access to energy, and she is less vulnerable to social isolation. Protect a computer system from hacks, and it better fulfils its function for users.

The metaphor of the picture puzzle, however, is not theoretically sound when it comes to explaining the principles of resilience. What we observe through research is an artifact

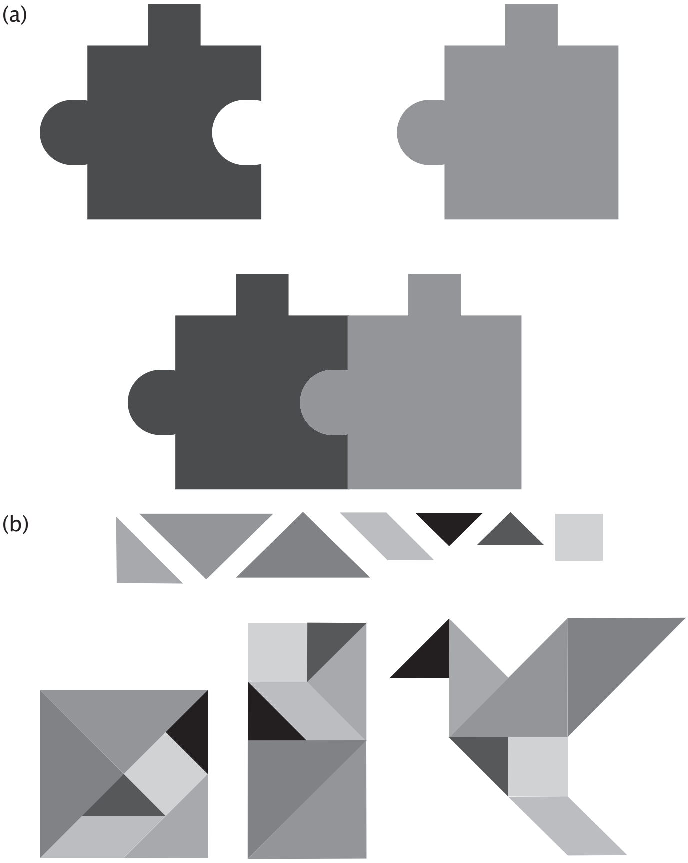

FIGURE 1.3 Visual representations of resilience as puzzle (a) and tangram (b).

of observation and study design. Patterns of adaptation and transformation look predictable because researchers control the conditions of study to select for predetermined patterns. A better metaphor for systemic resilience is the tangram. A tangram is comprised of a set of unique geometric shapes that can associate together to form one shape (a square) or many shapes (a triangle, a bird, etc.). Thinking about resilience as a tangram allows us to appreciate both the equifinality and multifinality of the patterns that predict resilience of one or more systems at the same time. Equifinality is defined as multiple means to a single outcome. Multifinality means there are multiple means to many different outcomes, all of which may be desirable to a system under stress. In the case of the tangram (and unlike a puzzle), there are many different ways of using the pieces in the set to form either the same shape (a square) or using the same pieces to create a number of other imaginative designs.

Studies of family resilience are an illustration of these patterns of resilience and the multiple systems involved (Ungar, 2016). *Family*, and related terms like *clan* or *kinship network*, tends to be defined as a group of people united by sexual and/or affective bonds or legal and/or economic ties, structured as an open, socially recognized, culturally normative system that fulfils a series of fundamental functions for the survival and development of its members and the society of which each family is a part. These functions (much like puzzle pieces) include a long list of possible outcomes, such as procreation and the raising of children; mutual support; or collection, consumption, and distribution of wealth. These outcomes are assumed to be part of one cohesive whole and reflect normative family functioning within a single cultural space (Walsh, 2012). Broader cultural forces (meaning systems) and economic opportunities are often controlled for through purposeful or randomized sampling, which makes it possible to describe families much like puzzles. Each family, depending on sociohistorical factors, seeks to achieve a more or less similar set of outcomes regardless of their form. In this sense, there is equifinality. Many culturally nuanced patterns of behavior are assumed to fulfill the same roles required of families in every context.

Other research, however, suggests that families can also show patterns of multifinality. A study by Hordge-Freeman (2015) on racial diversity within families and the "Russian roulette of genetics" that produces varying skin tones among Afro-Brazilian populations, documented the variability in how families fulfill their basic functions. As an example of multifinality, Hordge-Freeman found that families employ coping strategies that are expedient in the racially marginalizing context they and their children live. Through qualitative research with 116 families, Hordge-Freeman discovered that how love is expressed between parent and child has much to do with a child's phenotype. Parents adapt their child-rearing practices to enhance a child's ability to withstand racism, often using harsher discipline with children who are darker skinned to protect them against future social stigma. Hordge-Freeman does not argue that this strategy is socially just or even effective, but her work, like that of Ungar (2016), documents how many different, contextually relevant patterns of family resilience are associated with the many different outcomes that families strive for in contexts of adversity.

This same multifinality can be found in other domains of research such as community resilience. A community's resilience is the capacity of its human, institutional, built, and natural capital to withstand stress (Hobfoll, 2011; Longstaff, Armstrong, Perrin, Parker, & Hidek, 2010; Norris, Sherrieb, & Pfefferbaum, 2011). Although the factors that produce community resilience are many, there have been very few studies that have looked at the interactions between psychological protective factors, ecological protective factors, and the many different ways a community's resilience is manifested. Furthermore, the many different ways communities show resilience have tended to be overlooked in favor of a narrow set of outcomes such as employment, safety, and good governance. Cox and Perry (2011), however, suggest that resilience may be far more heterogeneous. Writing about the McClure fire in western Canada in 2003, they found that the disorientation that comes from catastrophic events like this are long-lasting, challenge identities, destroy social capital, and undermine community cohesion. However, such events sometimes bring unintended positive outcomes (such as improvements in family functioning) and many new regimes of social interaction that have the potential to improve a community in unanticipated ways over the long-term. This tension between predetermined expressions of resilience and multifinality was reflected in their finding of an opening for creative expressions of resilience that was caused by the disaster's disruption. In this example, there are multiple patterns to recovery (a tangram of possible forms that community resilience can take), but very few are privileged. Those that are preferred (like puzzle pieces already printed and ready to assemble) tend to occur fast and celebrate a community's normal capacity to recover. Atypically slower patterns of growth, and new patterns of community social and economic well-being that may be more sustainable, can be just as viable but have not received the attention they deserve. Examples such as this demonstrate that the processes associated with the resilience of systems, whether a community, a family, the human genome, or a natural environment, all exhibit diverse patterns of coping that are influenced by factors within and between systems.

Application to Research and Intervention

These emerging ways of understanding resilience are not only intriguing; they also have the potential to inform both research and intervention. With regard to research, the expression of resilience provided in Figure 1.2 suggests the need to account for many different factors and multiple systems when studying patterns of persistence, resistance, recovery, adaptation, and transformation. Single system analysis of growth in stressed environments is unlikely to show the complexity of the processes that systems use to survive under stress.

The shift from narrow models of resilience that focus on just a few factors to systemic processes is noteworthy but has been fraught with problems. It can be extremely challenging to conduct research on more than one (or perhaps two) systems at a time. For example, it is typical in the biological sciences to identify highly specific molecular processes, such as the influence of telomeres on aging, or to investigate the relationship between the aging process and exposure to toxic stress resulting from intimate partner violence experienced by pregnant mothers. Better and more complicated research designs are showing that exposure to violence during pregnancy not only affects the mother's aging process; its effects are also passed along to her child in utero, affecting the fetus's telomeres (Drury et al., 2014). Preventing family violence, then, is likely to also be a protective factor against shortened life expectancy. However, while human biologists have identified the minutest qualities of DNA to advance theories like this, these studies tend to assume a high degree of homogeneity in the stressors that influence negative developmental outcomes (i.e., stress on the mother is measured as a single, sometimes dichotomous variable). The assumption seems to be that exposure to intimate partner violence is experienced by all women in much the same way (ignoring differences by class, education, or proximity to family supports), while DNA is assumed to be sensitive to a large number of factors, which biologists account for in their designs. Social scientists make a similar error when they control for a single biological marker like salivary or hair cortisol as a proxy for stress while explaining in great detail the psychosocial, political, and economic aspects of a person's life when coping with political violence, war, or a natural disaster. While it goes without saying that no study can account for all the variations in biological, psychological, social, and environmental factors that contribute to risk and resilience (at least not yet), emerging approaches to research, greater capacity to analyze large amounts of data, and the still nascent preference for multidisciplinary teams and transdisciplinary perspectives are introducing more complexity to how resilience is modeled.

A model of multisystemic resilience also has value when designing interventions. Modeling resilience systemically reminds practitioners and policymakers to consider the interrelationships between systems when developing and implementing interventions targeted at increasing the coping capacity of multiple systems at the same time. Narrow thinking about the dynamics of a single system is unlikely to account for such things as trade-offs or encourage the kind of complexity that is required to promote resilience of one system without doing harm to the resilience of contingent systems. To illustrate, in the area of agroecological resilience (the capacity of food systems to withstand perturbations and develop new regimes that ensure continuous supply), many interventions to enhance sustainability target highly tangible, but essentially weak, leverage points (i.e., they use interventions that are easy, like introducing drought-resistant seeds, which increases system adaptability but has limited potential for transformational change; Fabricus & Currie, 2015). In contrast, Cabell and Oelofse (2012) argue for interventions that increase the distributive capacity of agricultural systems, such as expanding local food sources to make systems more resilient. Such change is similar to calls for whole school approaches and improved social support to combat bullying, rather than individually focused treatment for children who are victims (Mishna et al., 2016).

There is, then, an urgent need to focus on less obvious but potentially far more powerful areas of intervention, regardless of the systems that need influencing. All of this suggests that resilience can be a complicated concept to explain and work with. The ontological and epistemological barriers to studying resilience and applying it to practice are not, however, insurmountable. They are a symptom of the lack of communication between disciplines and the difficulty juxtaposing complementary descriptions of resilience for analysis. When effort is made to compare and contrast models of resilience that account for the behavior of multiple systems at once, our understanding of how systems can successfully cope with change is likely to be vastly improved.

Conclusion

This chapter has demonstrated that there is synergy in how the concept of resilience is theorized across disciplines. Each system's resilience is mutually dependent upon the resilience of co-occurring superordinate and subordinate systems. The quality of these interactions is patterned but not necessarily predictable. Constantly changing environments cause systems to enjoy differing access to the resources they need to sustain themselves or be transformed. While it is possible to identify the broad categories of factors that affect a system's expression of resilience, what resilience looks like will always depend on the variability in risk exposure, the availability of resources, and the desired outcomes of competing systems. A set of seven principles is evident in the way systems manage stress and become more resilient. These principles help to explain whether a system will demonstrate resilience when it experiences a disruption to its functioning. They also show that there are useful commonalities across resilient systems that could be used to better understand and model processes of recovery, adaptation, and transformation. When understood this way, resilience processes show both equifinality and multifinality. Furthermore, as this chapter has shown, the more the concept of resilience is described multisystemically, with all its complexity, the more the concept will be of use to scholars, policymakers, and those designing individual, institutional, and environmental interventions.

Key Messages

1. A multisystemic understanding of resilience explains how the resilience of co-occurring systems are mutually dependent.
2. How a system (whether biological, psychological, social, built, or natural) experiences resilience depends on the variability in the system's exposure to adversity, the availability of resources, and the desired outcomes of competing systems.
3. There are seven principles and five processes that account for the patterns that systems show when maintaining their functioning during periods of disruption and stress.
4. The more the concept of resilience is described multisystemically, the more useful it is when designing research and interventions that address the "wicked" problems that individuals and environments face.

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