Adaptation to Environmental Change: Contributions of a Resilience Framework

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Abstract

Adaptation is a process of deliberate change in anticipation of or in reaction to external stimuli and stress. The dominant research tradition on adaptation to environmental change primarily takes an actor-centered view, focusing on the agency of social actors to respond to specific environmental stimuli and emphasizing the reduction of vulnerabilities. The resilience approach is systems orientated, takes a more dynamic view, and sees adaptive capacity as a core feature of resilient social-ecological systems. The two approaches converge in identifying necessary components of adaptation. We argue that resilience provides a useful framework to analyze adaptation processes and to identify appropriate policy responses. We distinguish between incremental adjustments and transformative action and demonstrate that the sources of resilience for taking adaptive action are common across scales. These are the inherent system characteristics that absorb perturbations without losing function, networks and social capital that allow autonomous action, and resources that promote institutional learning.

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INTRODUCTION

Adaptation involves change. Adaptation is, therefore, standard practice in the human world as individuals, communities, and societies adjust their activities, life courses, and locations to take advantage of new opportunities. But adaptation is often imposed on societies and localities because of external undesirable change. Efforts to respond to these changes frequently entail reducing vulnerability and enhancing the capacity to adapt, in effect, to enhance the resilience of people and places, localities, and ways of life. Much theoretical and empirical research on resilience, however, derives from a disciplinary focus different than that of adaptation. In this chapter, we explore how resilience is related to adaptation in the context of environmental change. We review whether resilience offers a new or alternative ways of understanding adaptation and of analyzing strategies to promote adaptation to environmental change. We propose that adaptation to environmental change is best formulated as an issue of system resilience, drawing on perspectives from newly emerging research on governance, adaptive capacity, and the robustness of response strategies.

Adaptation: the decision-making process and the set of actions undertaken to maintain the capacity to deal with current or future predicted change

Vulnerability: the susceptibility of a system to disturbances determined by exposure to perturbations, sensitivity to perturbations, and the capacity to adapt

Resilience: the amount of change a system can undergo and still retain the same function and structure while maintaining options to develop

Presently observed global environmental change provides significant challenges that require substantial adaptations and even transformations in social organization, resource use, and settlement. Adaptation is imperative for three reasons. First, many future environmental risks are now more apparent and predictable than ever. We know that demographic changes, technological shifts, and land-use change are creating risks that are amenable to adaptation responses. Second, even where risks are not quantifiable, environmental changes may be hugely significant. Projected future climate change, for example, is likely to require system transformations as areas and economic activities may be no longer viable in particular places over the next century. Nevertheless, it is increasingly recognized that adaptation to environmental change does not take place in isolation; it is inevitably the result of actions of multiple actors and usually in response to multiple stresses and stimuli. The idea of multiple stresses is central to current research on vulnerability to environmental change (1). Third, environmental change, although often the outcome of multiple drivers, has indisputable human causes. Thus, adaptation and adaptation assistance are increasingly demanded by those made vulnerable by increased exposure to risk (2). This is most apparent in the arena of climate change where issues of climate justice, compensation, and government responsibility for reducing vulnerabilities through adaptation are central to policy debates (2–5).

Whatever the demands for adaptation, actions that constitute adaptation are observed at a variety of scales. They may be local or global in scale, and they may be spontaneous or the result of deliberate policy processes. But despite the diversity of actors, motivations, and institutional arrangements for adaptation, analytically adaptation is most often narrowly conceptualized as a set of technological or technical options to respond to specific risks.

The policy focus is on outcomes, which presupposes future conditions in order to evaluate the value of specific actions. We argue in this review that formulating adaptation as a set of discrete policy or technology choices limits the credence and usefulness of adaptation policies because it skews the priorities away from long-term system viability. We believe that conceptual, as well as normative, understandings of adaptation must be broadened.

Response to environmental change is captured by the concepts of mitigation and adaptation. Mitigation refers to actions that reduce exposure to changes, for example, through regulation, location, or technological shifts. Adaptation refers to the adjustments that populations take in response to current or predicted change. Mitigation, however, is insufficient to fully protect or buffer populations from change, and recent literature is replete with examples of drastic, often irreversible, changes (see, for example, Reference 6). In response to the increased awareness of change (6, 7), there has been a corresponding increase in documented efforts to ameliorate risk through adaptation actions (3, 6, 8, 9). Researchers and policy makers are working to identify analytical frameworks that provide the necessary tools for analyzing human adaptations in light of current and future environmental change (8). The first step in this analysis has often been identification of vulnerabilities to change (10–12); a key objective of most adaptation actions is the reduction in vulnerability. Much emerging evidence inevitably shows that adaptation actions concentrate on where immediate benefits can be gained and actors can mobilize resources, but persistent and intractable vulnerabilities often remain despite much adaptation actions.

To explore the central question of what a resilience framework can contribute to growing understanding of adaptation, we begin with a comparison of how the concepts of adaptation are currently applied in environmental change literature and within a resilience framework. The rest of the review is divided into four sections: multiple states, adaptive capacity, trade-offs, and the governance of adaptation. These sections represent key aspects of a resilience framework that provide insights into the process of adaptation in social-ecological systems. Each of the sections discusses contemporary research and highlights critical research questions.

CONCEPTUALIZING ADAPTATION

We define *adaptation* as the decision-making process and the set of actions undertaken to maintain the capacity to deal with future change or perturbations to a social-ecological system without undergoing significant changes in function, structural identity, or feedbacks of that system while maintaining the option to develop. At the collective level, process and action are predicated on effective governance and management structures. Adaptation can therefore involve building adaptive capacity, thereby increasing the ability of individuals, groups, or organizations to adjust to changes and implementing adaptation decisions, i.e., transforming that capacity into action. In this context, adaptive capacity refers to the preconditions that are necessary to enable adaptation and includes social characteristics and physical and economic elements (13). Both dimensions of adaptation can be implemented in preparation for, or in response to, impacts generated by environmental or other changes. Hence, adaptation is a continuous stream of activities, actions, decisions, and attitudes that inform decisions about all aspects of life and that reflect existing social norms and processes. There are many classifications of adaptation options (summarized in Reference 14) categorized by their purpose, mode of implementation, or on the institutional form they take.

To date, the literature and research domains of adaptation to global environmental change and of adaptation within a social-ecological systems resilience framework have been relatively distinct (15). Each strand of research has developed in parallel from

Adaptive capacity: the preconditions necessary to enable adaptation, including social and physical elements, and the ability to mobilize these elements

Transformation: a fundamental alteration of the nature of a system once the current ecological, social, or economic conditions become untenable or are undesirable historically quite separate disciplinary traditions and with relatively little cross-fertilization. Research on adaptation to environmental change in general, and climate change in particular, expanded rapidly in the early 1990s, drawing upon a variety of mostly social science disciplines, particularly the early work on hazards and disasters (16). These adaptation studies have tended to focus on process, practices, and governance issues. They tend to be prescriptive, normative, and actor based. In contrast, research on the concept of ecological resilience was first elaborated in Holling's 1973 seminal article (17). This perspective developed from population and landscape ecology and applied resource management, and it has a strong mathematical foundation and focus on modeling. The resilience framework is based on complex systems theories and bridges social and physical sciences to understand and identify possible ecosystem management options (18). Social-ecological resilience offers an analytical framework, which often takes on a normative slant. We briefly highlight the state of knowledge in each of these two domains prior to a discussion of the contributions a resilience framework provides for better understanding adaptation.

Adaptation in the Environmental Change Literature

Adaptation to environmental change is defined in the adaptation literature as an adjustment in ecological, social, or economic systems in response to observed or expected changes in environmental stimuli and their effects and impacts in order to alleviate adverse impacts of change (14, 19–22). Emerging key research areas on adaptation to environmental change are (*a*) identifying system thresholds, limits, and barriers to implementing adaptation (3); (*b*) defining successful or sustainable adaptation (reviewed in Reference 8) in promoting appropriate technological options for adaptation (23); (*c*) cognitive processes of risk assessment and formulation (24, 25); and (*d*) the relative role of public and private actors in adaptation (26, 27). Many of these issues are fundamentally about the governance of adaptation.

Recent studies are providing empirical evidence of how actor networks access resources, make actual adjustments, and result in consequences for ecological and social resilience at different scales. For example, Vásquez-León (28) examines how ethnicity is a factor in determining pathways of successful adaptation to drought in southeastern Arizona. Few et al. (29) show how local stakeholders perceive themselves to be constrained in implementing adaptation to climate change on the U.K. coast through complicated multijurisdictional structures and lack of precise information on risks. Yet faced with the same risks, most communities in the United Kingdom differ widely in their perceived resilience and their ability to govern and shape their own future (30).

According to the environmental change perspective then, adaptation is about decision making and the power to implement those decisions. It is a process in which knowledge, experience, and institutional structures combine together to characterize options and determine action. The process is negotiated and mediated through social groups, and decisions are reached through networks of actors that struggle to achieve their particular goals (31). Adaptation is concerned with actors, actions, and agency and is recognized as an ongoing process. Nevertheless, adaptation is considered in respect to specific risks. Therefore, evaluations of adaptive actions are static in nature; they measure levels of risk before and after adjustments have taken place.

Adaptation within a Resilience Framework

System resilience refers to the amount of change a system can undergo and still retain the same controls on function and structure while maintaining options to develop (32, 33). The resilience approach is founded on the understanding that the natural state of a system is one of change rather than one of equilibrium

(17). The type and magnitude of change is not always predictable, but change will occur. As a result, systems need to be managed for flexibility rather than for maintaining stability. A resilience approach also implies that social and ecological systems cannot be considered in absence of one another but must be understood as related, coupled systems. In this sense, a society may be able to cope well with change from a social perspective (e.g., improving irrigation technology and increasing agricultural subsidies), but an evaluation of overall resilience must also include the sustainability of the adaptation from an ecological perspective (e.g., the ecological impacts of increased farming and groundwater pumping) (34).

The ability to adapt, that is, to maintain a response capacity, is predicated on three fundamental characteristics: the degree to which the system is susceptible to change while still retaining structure and function, the degree to which it is capable of self-organization, and the capacity for learning. They have been defined from the ecological resilience school and refined through increasing empirical evidence on coupled social-ecological systems (35). These key characteristics of resilience find parallels in a series of studies on adaptation and vulnerability to climate change. The determinants of adaptive capacity to cope with climate change have been assessed in a group of studies that examine adaptive capacity at the scale of nations, of communities, and of sectors of the economy (19, 36–42). These studies find similar patterns and determinants at these different levels. They find that adaptive capacity is influenced not only by economic development and technology, but also by social factors such as human capital and governance structures.

Because system states are understood to be subject to perturbations and disturbances, the concept of adaptation needs to consider the ability not only to respond but to take advantage of any opportunities that arise. Although disturbances are often portrayed in a negative light, they also provide the opportunity for innovation and development (34). As Smit & Wandel (21) and Gallopín (43) suggest, adaptation includes processes that allow societies to survive, flourish, and maintain their quality of life. Thus, managing for resilience requires directing a system in a way that provides flexibility during times of disturbance and that allows a way to take advantage of the latent diversity within the system and the range of opportunities following release.

The resilience framework has developed to incorporate ideas of complex systems and in so doing emphasizes the functioning of the social-ecological system as a whole. The focus is on the relationships between the system components, not on the functioning of individual components in isolation. Rather, it is concerned with context, feedbacks, and connectedness of system components (18). This is a fundamental difference with the adaptation to environmental change literature, which is focused on actors. We argue that reconciliation of actor- and system-oriented approaches represents a major challenge in this domain. Actor-based analysis looks at the process of negotiation and decisions, and the systems-based analysis examines the implications of these processes on the rest of the system. The systems perspective also contains a temporal element that is important to the concept of adaptation. It considers adaptation not in light of specific activities but rather in how activities feedback, either positively or negatively, into the system as a whole through time. Because the focus is on maintaining flexibility, current adaptation today must be evaluated on the basis of how it will affect future flexibility; this has implications for the sustainability of adaptations and required trade-offs.

Components of Adaptation

The development of the distinct actor perspective and the system perspective on adaptation arise from specific historical evolutions in trajectories in different disciplines and from application in different contexts. However, all analysis of adaptation is, we suggest, at its core concerned with relationships between

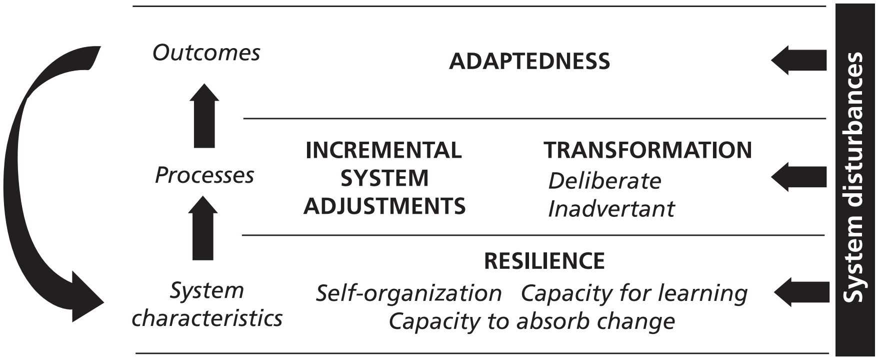

Figure 1
Characteristics, processes, and outcomes of adaptation actions.

characteristics, processes, and outcomes, and our objective here is to explore these relationships rather than to make a case for definitive meanings or new interpretations. Working definitions of the terms used in this review are provided in the margins of the text.

These three components, system characteristics, adaptation processes, and outcomes, are presented in **Figure 1**. The ability to adapt is a function of system characteristics, which are captured by the concept of resilience. Many definitions conflate resilience and adaptive capacity in part or in whole. *Adaptive capacity* is a way to describe the preconditions necessary for a system to be able to adapt to disturbances. It is represented by the set of available resources and the ability of the system to respond to disturbances and includes the capacity to design and implement effective adaptation strategies to cope with current or future events (13). Resources include economic capital, technology and infrastructure, information, knowledge, institutions, the capacity to learn, and social capital (38, 40, 44, 45). Adaptive capacity also has direct implications for the type and scale of adaptation that is possible for the system to achieve.

Adaptedness: a state in which a system is effective in relating with the environment (48) and meets the normative goals of stakeholders

We highlight the capacity to absorb change without losing system function to draw attention to a specific resilience characteristic. This characteristic is often referred to as engineering resilience and is distinct from the concept of adaptive capacity. In fact, these concepts are sometimes held in opposition to each other. For example, there can be highly resilient systems that reside in undesirable states. These resilient systems are often described as being "pathologically" resistant to change and can withstand efforts to change (46). Thus, in system transformations, adaptive capacity may need to be activated in order to overcome resilience in a system.

System transformation is a process that creates a fundamentally new social-ecological system (**Figure 1**) (47). Transformational change results from crossing ecological or social thresholds. For example, because of impacts of a changing climate, an ecosystem may no longer be able to support traditional livelihood systems such as farming or ranching (47). Social-ecological systems may also transform owing to changes in social goals. For example, irrigated agriculture may no longer be a policy goal if groundwater pumping has negative effects on maintaining socially desirable riparian areas. Through a planning process this system may shift to a tourism-based economy. The second type of adaptation process is system adjustments, which may include improving agricultural systems, redesigning the built environment, or implementing new management decisions. These adjustments are undertaken in order to reduce risk and to improve the level of adaptedness of a system.

The outcome of the adaptation process is *system adaptedness*, the level of effectiveness in the way a system relates with the environment (48) and meets the normative goals of system managers and stakeholders. Adaptedness is never permanent, and the level of adaptedness will change on basis of the types, frequencies, and magnitudes of system disturbances. A system may be highly adapted to the current environment, although it may be incapable of responding to novel or more extreme environmental variation. Adaptations are seldom permanent (49), rather they should be understood to be adjustments to the current system context, which will change and will likely require a new set of responses.

System disturbances not only affect the level of adaptedness but also influence system characteristics and the types of adaptation processes that are possible or appropriate. These disturbances represent the uncertain, but inevitable, sources of change in systems. They may be social, biological, or physical in nature. But all of them will affect the relationships and the feedbacks within a social-ecological system.

CONTRIBUTIONS OF A RESILIENCE FRAMEWORK

We have discussed the way in which adaptation is treated in the environmental change literature and within a resilience framework. This section describes how a resilience framework can contribute to adaptation studies in order to better understand the processes of adaptation and the wider implications of those processes. The section addresses four issues arising from resilience analysis: multiple states, adaptive capacity, trade-offs, and governance and normative issues. We discuss the current state of knowledge and also present key challenges for environmental change and resilience-oriented adaptation for each of these issues. The challenges are intended to promote discussions and to suggest research areas that continue to explore the relationship between adaptation and resilience.

Multiple States

A fundamental contribution of the resilience framework is the understanding that most social-ecological systems can organize around a number of possible states (18). This effectively increases the range of adaptation options beyond simply responding to perturbations or stresses because it envisions the possibility of changing the system state itself. The following discussion addresses two aspects of multiple states: desirable states and thresholds.

Desirable states. A system is defined by the array of existing state variables, and without human intervention, ecological controls would determine the arrangement of the variables and the system state. From an ecological perspective, there is no presumption that any state is more desirable than another. But social goals and desires serve as a point of comparison for evaluating the desirability of a given state. For example, a particular ecological system may be able to support shrubs, grazing animals, and grasses in a variety of combinations (47). Therefore, a given state may be less desirable than others. In a ranching community, the desired state may be few shrubs, lots of grass, and many cattle. Another community, less dependent on livestock production, may prefer that the system provide more shrubs, fewer cattle, and less grass. Thus, the types of services provided and the state in which the system resides are a product of negotiation as individuals and societies seek to direct and manipulate social-ecological systems on the basis of their knowledge and goals (50).

A changing array of ecological and social factors means that this negotiation process is never complete. State variables may change, and management goals may shift as a result of contentious decisions that fall short of the desires of all those affected, individuals who may have competing values and world views. Increasing understanding and reducing uncertainty also influence changes in management goals and decisions.

Thresholds. Thresholds represent the boundaries around a system state, which if crossed represent the transition into another system state (18). Complex systems are defined by nonlinear feedbacks, and thus it is difficult, if not impossible, to identify the precise location of thresholds. A threshold may become apparent only after system transformation has occurred or as it is occurring. Because thresholds are not fully predictable, system characteristics such as self-organization and learning are critical to negotiate the changes brought about through purposeful or inadvertent threshold transgression. Thresholds in ecological systems are difficult to identify, but there has been progress toward demonstrating tipping points through physical, nonlinear changes and locational shifts in species ranges that represent significant thresholds in distribution as well as in physiological process changes leading to species changes (51–53). Many of these threshold changes are associated with climatic changes and may represent key vulnerabilities at the global scale (54).

Janssen et al. (49) suggest that social-ecological systems are vulnerable not only to changes in the physical environment, but also to changes in the policy and institutional environments. In fact, social-ecological systems also produce institutional change through system feedbacks. These feedback linkages make it difficult to conceptually separate discourse, institutions, and ecological processes. Social systems are, however, similar to ecological systems, in that they are bounded by thresholds that may be triggered by nonlinear and abrupt responses to particular events or through aggregate change through time (52, 55). There is evidence that similarities in public values and attitudes are influenced by focusing events or disturbances as well as by opinion leaders (52, 55). These threshold changes are often abrupt and have obvious implications for adaptation because they represent the shifts in what are socially acceptable management goals (56). In the United Kingdom, for example, there is some evidence that policy responses to flood risk directly followed significant high-profile flood events. These events spurred the public, policy advocacy groups, and policy makers to undertake regulatory reform and invest in flood protection infrastructure at specific periods during the past 50 years (57). These opportunities for change are known as policy "windows." Although institutional inertia works to maintain the status quo, changes in policy goals are made once current strategies are proved to be wrong—either through normative or empirical evaluations (46).

Adaptation actions are seldom one-off activities; hence systems are only adaptable if their institutional structures are conducive to maintaining ongoing activities. Public agendas, however, are notoriously fickle, and limited space for maneuver or meaningful change is available at any given time. One critical challenge for research is, therefore, to understand how institutions are influenced by, and in turn influence, overarching and often divisive environmental change discourses and ideologies.

Adaptive Capacity

As we mentioned at the beginning of this chapter, adaptive capacity is the set of resources, and the ability to employ those resources, that are prerequisites to adapation. In this section, we consider adaptive capacity in light of its relationship to types of potential adaptation processes, the different types of possible system surprises that warrant responses, and the scale of systems and adaptive activities.

Adaptation processes. The relationship between system characteristics and actions, from marginal adjustments to transformation processes, are depicted in **Figure 2**. In order to activate adaptive capacity and undertake actions, a social or biophysical trigger must occur, and the appropriate institutional framework must be in place. We distinguish between transformation as a directed, desirable process and transformation associated with the effects of inadvertently crossing thresholds. The former is a planned,

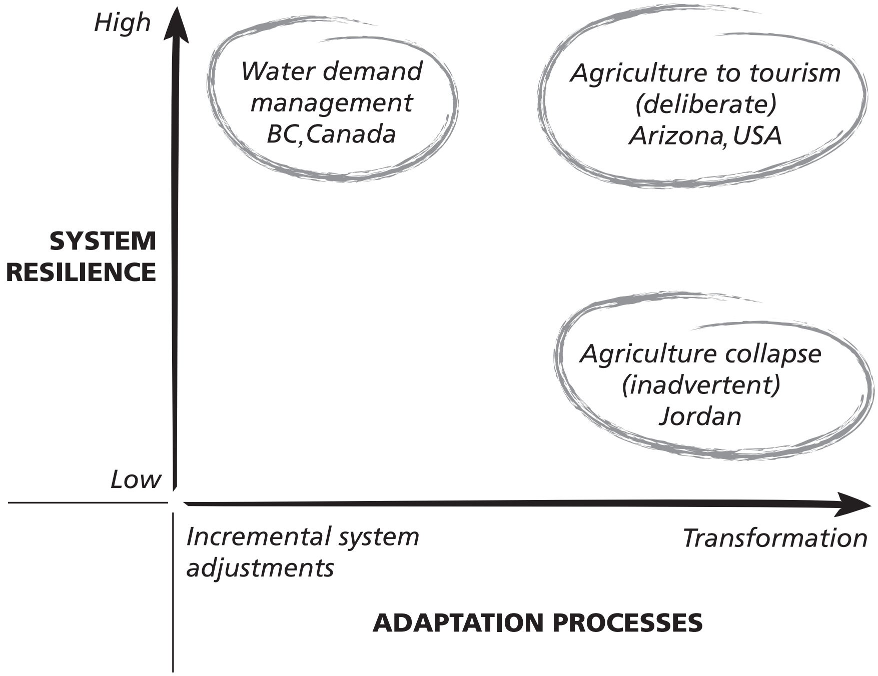

Figure 2

Examples of incremental adjustments and transformations of social-ecological systems with different levels of resilience.

deliberate process, whereas the latter is an uncontrolled process, which results from insufficient system resilience. One would expect that inadvertent transformation is more likely to lead to undesirable system states with low productivity and less human well-being.

The upper-left oval represents a system in which managers responded to climatic factors. In the Okanagan Basin, British Columbia, water management groups were alerted to the need for change by the occurrence of a multiyear drought, supply and demand models for the region, as well as climate scenarios (58). In response to these triggers, the groups implemented a number of system adjustments using water demand management strategies, which included water metering, reclamation, and amalgamation of separate municipal utilities in the region.

The other two cases are examples of system transformation, one deliberate and one inadvertent. The northern Arizona case represents the deliberate transformation from an agricultural economic base to a system relying on tourism and regional service provision. For decades the economy of the Show Low community has been based on agricultural production, which included crops and livestock. This was encouraged by city council policies that limited growth and development. Over the past five years, the council has changed its stance, in part as a response to the increasing difficulty of maintaining a viable agriculturally based economy (59). Incentives, including financial ones, are used to promote the region as a major tourism and services hub.

Historical agricultural collapse in Jordan (lower-right oval in **Figure 2**) represents a case of low system resilience that resulted in an inadvertent transformation. Resource management or lack thereof, in communities in ancient southern Jordan, reduced the resilience of the social-ecological system, which precipitated system collapse (60). The extent of land degradation and fragility of the system owing to overexploitation of natural resources were hidden by the ability of the communities to expand the spatial scale of resource use and through improvements in agricultural technology. Redman (60) suggests that a series of years with increased climate stress may have triggered the collapse of the system and the abandonment of the agricultural economy of Jordan.

This third case is an example of a system that inadvertently crossed a threshold and collapsed owing to a lack of adaptive capacity or the inability to mobilize adaptive capacity in order to respond to changes. The other two cases present more adaptable systems. In both, the social-ecological systems have proven resilient to external stressors over the years. Both also demonstrate high levels of adaptive capacity, and both were responding to ongoing stressors (climatic and economic) considered in light of future pressures. The difference is that, in the Canadian case, managers chose to work within the existing system state to prepare for future change. Because of predicted reduction in rainfall, actors in the system chose to mobilize adaptive capacity to make adjustments in the way in which water is managed and used. In contrast, the adaptation in Arizona required overcoming the resilience of the system to cross into what is believed to be a system more resilient to future changes. Portions of the community recognized that climatic and economic factors were likely to undermine the agriculture base in the years to come. Thus, the community mobilized its adaptive capacity to initiate transformation of the system state.

There is not a clear break-off point between incremental adjustments and transformative action. Rather, as the examples in **Table 1** demonstrate, the two categories of action fall along a continuum. The first example highlights adjustments that are reactive

Table 1 The sources of resilience and observed adaptive actions to various resource stresses in social-ecological systems

Adaptation to:	Adjustments or transformative action	Sources of resilience
Drought in Kenya and Tanzania[a]	Switching occupation, selling assets, drought relief	Social networks, remittances
Drought in northeast Brazil[b]	Private actions: livelihood diversification, risk management in agriculture, patron-client relationships Public actions: humanitarian relief, crop insurance, seed distribution, irrigation schemes	Lessons learned from past drought events, e.g., honed emergency relief mechanism, social networks, social security payments
Coral reef stress associated with physical damage, eutrophication, and fisheries decline in Tobago, West Indies[c]	Development of community-based resource comanagement, community monitoring of reef use, consensus building for future zoning and limitations on sewage disposal	High diversity in use between tourism and subsistence activities, heightened awareness of critical thresholds and well-defined user communities, learning through consensus building
Actual and potential disruption from hurricane risk in Cayman Islands, West Indies[d]	Regulatory changes: enhanced building codes and zoning to increase waterfront setback, development of National Hurricane Plan Organization changes: creation of National Hurricane Committee and inclusion of diverse interests within it	Self-efficacy facilitated by high government revenue stability; recent experience of hurricanes (Hurricane Gilbert 1988, Mitch 1998, Michelle 2000, and Ivan 2004) promoted urgent learning from each experience accompanied by a willingness to learn from past mistakes[d]; strong national and international support networks

[a]Reference 39.
[b]References 62 and 63.
[c]Reference 64.
[d]Reference 61.

and short-term in nature, which could be termed coping strategies. The second case offers examples of adjustments that are longer term but still tend to be reactive. The final two cases present situations in which communities are making long-term, proactive adjustments. **Table 1** highlights the relationship between the types of possible actions and available social sources of resilience. These are necessary to respond to change and to facilitate organization. They include adaptive capacity characteristics such as learning and memory, as well as specific actors and the roles they play (65). As sources of resilience increase so does the ability to adapt. In **Table 1** the systems with reactive and limited actions are those that have the most constrained sources of resilience. Similarly, the cases with broader, proactive actions have more expansive sources to draw upon. The sources in all four cases are similar (e.g., learning, developing networks), but the difference is found in the extent and cross-scalar nature of these sources. In the latter two cases, the social networks are larger and scale from local to international communities.

Key challenges for research in this area concern the types of adaptive capacity, or arrangements of adaptive capacity, that are necessary to prepare for system transformation and renewal and how these compare with those required for making system adjustments. Furthermore, are different types of adaptive capacity required for deliberate and inadvertent transformations? Specific knowledge on the degree to which some aspects of adaptive capacity are generic or transferable (across time, different impacts) would usefully inform theoretical understandings of adaptation and inform policy.

Surprise. Much of the present research on adaptation has an implicit focus on minimizing exposure to specific risks. This entails action designed to anticipate particular events and their impacts. Anticipatory action is argued to be both more equitable and more effective than responses after events (8, 66). However, to be truly effective anticipatory action must not be concerned solely with the maintaining equilibrium but must also focus on preparing for surprises and system renewal. Surprises refer to any discontinuity between ecological processes and the processes that were expected to occur (67–69). Expectations are characterized by prior experiences and belief systems as well as through shared communication (68, 70).

Surprises have been classified within a number of related typologies (see, for example, References 69 and 70). Gunderson (67) refers to a three-part typology. The first is local surprise, which refers to unexpected discrete events at a small scale. The second is cross-scale surprise, which encompasses discontinuities in long-term trends over regional and global scales. Novel surprises are disturbances that are unique or not previously experienced by the social-ecological system and produce unpredictable consequences. Surprises can result from specific discontinuities or through synergistic couplings (70, 71). These synergisms, or emergent properties, are functions of feedbacks between system components and result in collective system behaviors that may include abrupt, nonlinear change (71). Kates & Clark (69) make a further distinction between surprise that arises from unanticipated events and surprise that results from unexpected or wrongly attributed consequences of an event.

Surprise is a function of uncertainty and unpredictability (72). Uncertainty can cause surprises to be incorrectly labeled as low probability, effectively removing them from discussion (71). However, uncertainty relates not only to the occurrence of an event but also to its timing and intensity. For example, in many regions of the world drought is an expected event—in the sense that the region displays a history of low-rainfall years. It may be unpredictable, or considered an anomalous event, thus unexpected at any particular point in time. Nevertheless, many societies have adapted to periodic drought events. A changing climate, however, which is predicted to increase the variability and frequency of perturbations (7), will introduce new variability into a system, increasing the possibility of surprise.

In semiarid northeast Brazil, for example, rainfall is predicted to become scarcer and the intra-annual dispersal more varied (73, 74). Even with similar levels of rainfall, the higher predicted temperatures will increase already extreme levels of evapotranspiration (74, 75), making dryland farming even less viable than today. Research on social response to natural hazards shows that increased frequency of events may erode limited coping ability and reduce the thresholds beyond which losses are irreversible (21, 76, 77). These systems may become impoverished through loss of potential and diversity, and the decreased resource bases limit the possible responses of individuals and communities. Thus, even if climate change precipitates surprise events similar to those previously experienced, and to which a population has learned to cope, the frequency and magnitude of climate change impacts are likely to stretch the abilities of systems to cope and recover.

Cross-scale surprises are attributable to interactions between variables that operate at different scales (67). Slowly changing variables define system thresholds to the degree that they control the range of activity of faster variables (48, 78). There are two types of slow variables: those that are slow to change and those with a slow frequency of change. These slow variables may include climate, soil, sediment concentrations, hydrologic cycles, land use, and long-lived organisms (32, 79). Young et al. (48) suggest that some of the previously large-scale, slow variables are beginning to reduce their timescales and approximate the timescales of faster, lower-level processes. Climate, for example, is a slow variable but is beginning to change within time frames (years and decades) that are relevant to humans (80). Historical climate anomalies provide some examples of the destructive cross-scale synergisms that will continue to occur in the future (70).

Surprise is not inherently negative, nor does it always produce undesirable outcomes. Surprises may have mixed consequences, which may become evident only with an evaluation that considers all stakeholders over long periods of time (70). In addition, many surprises are considered positive, creating windows of opportunity that may be used to increase the ability to manage environmental changes or to fundamentally transform systems (69, 81). Timmerman (82) distinguishes between negative and positive surprise—what he terms "shocks" or "catastrophes" and "epiphanies." He suggests that a resilient social-ecological system is one that is able to foster epiphanies and avoid catastrophes.

Scale. Scalar issues permeate adaptation and resilience research. Questions of how to translate models and data between scales (upscaling and downscaling) and how to characterize the relationships of different components and domains across time and space are critical to the ability to develop assessment tools and to model change and impacts (83–85). Similarly, analysis of adaptive capacity confronts issues of scale. Adaptive capacity is specific to (*a*) the length and frequency of perturbations, (*b*) the spatial scale at which perturbations occur (48), and (*c*) the organizational scale of focus (86). Therefore, the scale at which adaptive capacity is analyzed has implications for evaluating resilience. There are two scalar issues that we highlight here. The first relates to identifying commensurate scales of change and of adaptive capacity (*a* and *b*, above). The second issue relates to the boundaries of social-ecological systems and the horizontal and vertical linkages and networks that are used to capture and mobilize resources (*c*, above).

Environmental disturbances occur and interact with social processes over a vast range of spatial and temporal scales. However, environmental and social processes do not always have corresponding time or spatial scales (83). Disturbances may occur at a household, regional, or global scale. Some disturbances have a quick onset and last a short period of time (e.g., tornados, hurricanes), whereas others have a slow onset, e.g., long wave events that last years or decades (e.g., drought events, warming periods). Social processes vary in spatial scale from household-level activities to global-scale demographic and political patterns. They vary in temporal scale from daily processes to those that cover many years, such as population growth (83). Thus, the composition of adaptive capacity necessary to effectively respond to disturbances will differ in respect to the relationship between scales of social and ecological processes.

Increased global connectivity in terms of mobility of resource flows, connections between markets for resources and products, and greater penetration of communication technologies, lead to greater cross-scale connectedness of systems (87). Although some commentators suggest that global interconnectedness means that some social systems are in effect decoupled from their local ecosystems (88), the reality is that no resource system acts in isolation, and vulnerabilities can be "teleconnected" from one part of the globe to another. Adger and colleagues (89), for example, demonstrate how coffee expansion in Vietnam, combined with frost events in Central America, create livelihood vulnerabilities among Mexican, Honduran, and other smallholder coffee-farming communities—vulnerabilities are transferred across levels and scales.

Janssen et al. (49) provide an example that highlights the substitutability of local adaptive capacity. Polynesian islands that experience a low frequency of cyclones have transformed their historically diverse agricultural system to a monoculture that caters to a world market. The transformations in the social-ecological systems have made the systems highly vulnerable to cyclones, in contrast with the islands that maintain the traditional agricultural and social system. People on the transformed islands depend on subsidies from outside the region to guarantee survival when hit by cyclones. Local adaptive capacity has been supplemented, or replaced, by help from outside.

Supplementing or subsidizing local systems with inputs from other scales is a common occurrence in human cultural evolution (60). However, the resources in many of the historical systems described by Redman (60) were overextended through increasing spatial expansion, which decreased system resilience and increased vulnerability, leading to system collapse. Similarly, Cumming et al. (86) argue that when social and ecological scales are out of step with each other there is a corresponding loss of adaptive capacity. A research gap concerns how substituting adaptive capacity at different scales affects the overall resilience of a system.

Trade-offs in Resilience and Adaptedness

We have argued in this chapter that standard adaptation approaches foster adaptation that will lead to a state in which the social-ecological system deals effectively with perceived risks. Adaptation in a resilience framework, by contrast, promotes managing the capacity of the system to cope with future change. It is premised on managing uncertainty and on having the right mix of system characteristics in place to deal with uncertain future events. These differences result in a tension between achieving high adaptedness and maintaining sufficient sources of resilience. Walker et al. (90) highlight three ways in which high adaptedness can undermine system resilience: Adaptedness in one location may decrease resilience in another location or region, a system may become so tuned to a particular type of shock that it becomes vulnerable to other unknown shocks, or increased efficiency through adaptation may lead to loss of response diversity. Therefore, defining adaptation success simply in terms of the effectiveness of reducing risk is clearly not sufficient.

Nevertheless, the most frequently cited measure of adaptation to environmental change is a reduction in the negative effects of actual or expected disturbances (14). In effect, the objective is to reduce risk to a tolerable level. However, although an action may be successful in terms of one stated objective, it may impose externalities at other spatial and temporal scales. Actions that appear successful in the short term may turn out to be less successful in the longer term. Additionally, even though an action may be effective for the adapting agent, it may produce negative externalities and spatial spillovers, potentially increasing impacts on others within the same community or reducing their capacity to adapt. Upstream increases in water abstraction or an increase in hard coastal defense in one area threatened with erosion can impose reduced resilience on neighboring or downstream systems.

It is possible for a social-ecological system to become highly adapted to a range of variability through specialized institutions. However, if the range of variability changes, through social, economical or climatic influences, the social-ecological system may become highly vulnerable. In northeast Brazil, risk reduction has been carried to such an extreme that the principal government adaptation to drought is humanitarian aid (63). Efforts to reduce the level of vulnerability or to increase resilience are overshadowed by the levels of resources dedicated to maintaining the food and water supply during droughts. Although drought impacts are significantly lower than in the past, the rural population continues to be exposed and susceptible to future drought events and remains highly vulnerable to a range of other shocks (62).

Both adaptedness and the resiliency of a system are part of a path-dependent trajectory of change. The decisions of the past influence the range of options today, and today's decisions have implications for future management flexibility. Anderies et al. (91) discuss a water catchment in southeastern Australia that experienced rising water tables and increasing salinization. For many years, management efforts were directed at promoting efficiency through engineering solutions. Eventually, the investment in technology and infrastructure eroded the response diversity of the system, and it became impossible to consider other options to deal with the threats. As a result, the catchment today is highly vulnerable to any increase in the length of wet periods. This example highlights the inherent tension in complex systems between increasing efficiency and diminishing flexibility (60).

Trade-offs between adaptedness and resilience have significant implications for management decisions and decision-making processes. A balance must be negotiated between what is an acceptable level of risk to current system stressors and the breadth of flexibility necessary to respond to future change. These decisions are, in effect, about managing vulnerability. Vulnerability analyses are designed to identify the most vulnerable populations and determine adaptive actions to reduce their vulnerability to stressors while promoting sustainability. Yet this is a challenging task in light of evidence that reducing exposure to current risks can adversely affect future vulnerability and resilience to future unknown events (49, 72, 78, 91). A resilience perspective assumes that vulnerability is an inherent characteristic of any system. Reducing vulnerability in one area creates or increases vulnerability in another area or time. This does not imply that it is acceptable to ignore vulnerable populations. Rather, it becomes incumbent on decision makers and citizens to outline acceptable levels of vulnerability, who will be vulnerable, and to what type of events. The difficulties involved in negotiating these issues place significant importance on management abilities and the role of governance and institutions (47).

Governance and Normative Issues

Resilience presents both practical and normative challenges in addition to the analytical issues we have so far discussed. On the practical side, there are questions of defining appropriate governance structures, taking into account the variety of possible disturbances and specific contextual factors. Normative discussions revolve around questions of procedural and outcome equity. Finally in this section, we consider the challenges associated with evaluating adaptation from a resilience perspective.

Adaptive governance. Successful adaptation in effect entails steering processes of change through institutions, in their broadest sense. For adaptation to be successful, institutions clearly need to endure and be persistent throughout the process of adjustment and change. But at the same time, they need themselves to cope with changing conditions. What works and what does not work in the context of adaptation? There are many formulations of environmental governance, including hybrids of the traditional market, state, or civil society-based strategies (92). Berkes (87) suggests that the balance of evidence in this area shows that "neither purely local-level management nor purely higher level management works well by itself" (87, p. 239). He further makes the case that lower-level management, and "community self-organisation [tend] toward sustainable practice" (87, p. 142). Thus, the strong normative message from resilience research is that shared rights and responsibility for resource management (often known as comanagement) and decentralization are best suited to promoting resilience.

Comanagement proceeds through devolving responsibility for allocating resources and resolving conflicts among multiple parties and frequently involves multiple stakeholders among governments, civil society, groups representing human and nonhuman interests, and direct resource users. Comanagement regimes are most commonly composed of participants representing divergent interests interacting directly over a period of time to resolve a specific conflict and promote adaptational solutions within the locality or community where they live (93). Multiple benefits to such collective action are often argued. There is the potential of enhanced efficiency of decision making, increased trust in government, and increased capacity at the local scale to undertake, for example, monitoring and enforcement (93–96). In addition, there are often underemphasized, less instrumental benefits associated with greater participation, namely giving a voice to vulnerable and marginalized stakeholders, recognition of diverse knowledge systems, and increases in the depth of civil society and citizenship (see, for example, References 48, 97, and 98).

The "pinnacle" of comanagement is the idea that governance systems can themselves be adaptable through internal learning—both institutional arrangements and ecological knowledge should be "tested and revised in a dynamic, ongoing, self-organized process of trial and error" (99, p. 159) facilitated through high levels of autonomy and decentralization. This idealized situation is rare. And indeed, the ideal has been refuted and critiqued by a pragmatic political economy perspective that suggests that failure to recognize power imbalances between stakeholders simply moves adaptive governance toward reinforcing existing inequalities and the perpetuation of narrow interests (100, 101).

Despite shortcomings, there are potential benefits from adaptive governance and new challenges. Demand for increased participation in decision making requires the inclusion of new social actors, which can lead to increasing complexity in the negotiation of objectives and pathways to achieve those objectives. The global nature of environmental change increases the complexity, in part owing to the simultaneous increase in technical knowledge related to possible future scenarios combined with large amounts of uncertainty.

Adaptive management is premised on the idea that decisions should be part of an iterative process; they should be continually evaluated, and strategies should be altered to meet changing parameters (65, 81, 102). This type of learning-based system is dependent on continuously updated information to make evaluations. Such information could come from traditional science but also from local knowledge systems that provide insights into functioning of local ecosystems and their linkages with the social system (93, 103). Research by Berkes and colleagues (104, 105) in the North of Canada shows how different forms of local and traditional knowledge can be complementary to conventional scientific knowledge, especially in monitoring environmental change. Although local observations of change may not replace scientific measurements, they can contribute to an overall understanding of the phenomena of change and its impacts. In seeking locally supported and appropriate responses, notions of resilience and its cultural significance and meaning are required. For example in Brown et al.'s (30) study of coastal communities in the United Kingdom, local perceptions of resilience and adaptive capacity to climate change impacts were highly diverse in different communities.

In contrast to regulatory and output-based management approaches, we suggest that adaptive management resonates with a resilience approach and has the potential to produce flexibility and platforms for learning. Yet it is unclear how adaptive management is more conducive to balancing trade-offs between society and ecology and between short-term costs versus long-term gains. We need to understand how more open and participatory forms of governance deal with issues of future uncertainty and maintaining flexibility.

Equity. If adaptation to environmental change is solely concerned with maintaining future flexibility, some people, communities, or ecosystems may incur a heavy price in the present. This is a fundamental trade-off in resilience and vulnerability. The issues of equity in process and equity in outcome of environmental decision making are central questions of governance. *Equity in process* refers to the fairness of the institutions, their representativeness, and how they incorporate the diverse values and views of the community and collective as well as the individual good. *Equity in outcome* refers to the distribution of vulnerabilities across stakeholders within a population. As Lebel (106) points out, it is important to ask the questions of who decides what should be made resilient to what, for whom resilience is managed, and to what purpose?

Implementation of adaptation actions focused on reducing vulnerability and enhancing resilience, however, requires resolution of both what constitutes vulnerability and a full account of the authority by which those assessments are made. Inclusion of vulnerable sections of society and representation of vulnerable social-ecological systems within decision-making structures is an important and highly underresearched area. In other words, defining the objectives of adaptation policy in terms of protecting the vulnerable requires confronting issues of distributive justice (who is harmed) and procedural justice (who has say in identifying the vulnerabilities) (see, for example, References 107 and 108). These issues are not well documented in the resilience literature nor comprehensively addressed in existing analytical frameworks.

In many situations and examples, it appears that the incidence of vulnerability within the social and natural systems is not central to decision making and adaptive action. As a result, adaptive actions often reduce the vulnerability of those best placed to take advantage of governance institutions, rather than reduce the vulnerability of the marginalized or the undervalued parts of the social-ecological system. Integrating principles of equity with the identification of vulnerability is therefore an important element of adaptational decision making. Dow et al. (108), for example, argue that Rawlsian principles of justice provide a firm foundation for action to reduce vulnerability to environmental change, and Adger and colleagues (109) argue that rights-based justice rules can also make avoidance of vulnerability central to public policy—rights to a safe environment without inherent vulnerabilities are part of cosmopolitan and universal human rights. These issues are discussed in detail by Adger et al. (5), who show that many present strategies for adaptation reduce the vulnerability of those most able to mobilize collective action and those with greatest access to decision making. Most adaptation, in other words, does not necessarily reduce the vulnerability of those most at risk.

Procedural equity in adaptation depends on the ability to participate, to influence, and to have the autonomy to implement adaptation decisions. Brown et al. (30) review participatory mechanisms for adaptation planning in U.K. coastal areas and conclude that climate change poses particular challenges. These, as we have outlined, include scale mismatches between ecosystems and institutions as well as difficulties in dealing with uncertainty and with the public's view of the long-term future. Although in general stakeholders may agree on the goals of adaptation (e.g., environmental protection, maintaining well-being, equity), tensions become apparent in particular situations involving decisions that threaten lifestyles and culturally important assets (55).

Even when the people involved agree that a particular value is important, there may be significant differences in individually assigned levels of importance. The tensions and trade-offs between the need for long-term strategic coordination and the local place-specific short-term responses are highlighted. These dilemmas are features of many aspects of environmental governance, and they further hinder the likelihood of adopting more inclusionary and deliberative decision making in responding to environmental change.

Evaluation. Measuring the resilience of a system is a complex undertaking, but promoting resilience-oriented adaptation will require the development of tools and metrics that will allow decision makers to assess progress and implement sustainable governance structures to facilitate adaptation. From a risk perspective, there are many metrics available for measuring changing levels of risk as well as vulnerability to particular stresses, but measuring the characteristics of resilience in the face of multiple slow- and fast-moving stresses is more difficult. One approach is to measure the constituent parts: stability, self-organization, and learning (32, 110). Carpenter et al. (32) measured the resilience of two social-ecological systems by looking at the stability of the systems, in other words, the capacity of the systems to absorb disturbances before moving into another regime. Yet, it is unclear how widely applicable this approach is because of the need to be highly specific in defining both the system configuration being measured and the type of disturbance considered.

Plummer & Armitage (101) suggest an analytical framework that divides adaptation processes into three components: ecosystem conditions, livelihood outcomes, and process and institutional conditions. This approach has elements in common with those described by Carlsson & Berkes (111), who suggest that evaluation of adaptation management should focus on process rather than results and on function rather than structure.

The principles of environmental governance to promote sustainability, resilience, and robust decision making are, indeed, well known (see, for example, References 92, 112, and 113). Generic principles of governance include the balancing of actions in terms of their effectiveness, efficiency, equity, and legitimacy (26) such that their impacts are harmonious with wider sustainability. Although these principles are described straightforwardly and evaluated individually, the diversity and fluidity of adaptation actions suggest that adjustments are actually undertaken for diverse reasons and with diverse outcomes. We need to develop a better understanding of how to evaluate system resilience in view of multiple stimuli and incremental actions. There is also a need to further explore whether the resilience characteristics are fungible, or whether there is a minimum level for each to assure resilience.

CONCLUSION

Adaptation and resilience studies have evolved from different disciplines and research traditions. Adaptation research is actor based and focuses on reducing vulnerabilities to specific risks. Resilience is based on complex systems studies with a focus on adaptive capacity and maintaining the ability to deal with future uncertain change. Nevertheless, both approaches are concerned with similar components of adaptation, i.e., its characteristics, processes, and outcomes. This review is an analysis of the relationship between the distinct approaches in an effort to identify complementary attributes. We identify areas in which a resilience framework contributes to a broadened understanding of adaptation and the types of analyses necessary to promote successful adaptation to environmental change.

We argue here that a resilience framework provides a dynamic perspective on adaptation processes and the effects of these processes at different spatial and temporal scales. This analytical viewpoint reflects the way in which specific adaptations are linked through feedback mechanisms into larger systems. Adaptive actions not only affect the intended beneficiaries but may have repercussions for other regions and times. Thus, adaptation is part of a path-dependent trajectory of change. Past management decisions influence the range of options today, and today's decisions have implication for future management flexibility. Resilience-based analysis provides the necessary perspective to evaluate these implications.

A key contribution of resilience derives from the core understanding that change is a fundamental aspect of any system. This implies that the level of system adaptedness also changes as the context changes. In light of the transitory nature of adaptedness, a resilience framework stresses the importance of preparation for surprises and system renewal. Whereas much of the adaptation literature is focused on reducing vulnerabilities of specific groups to identified risks, a resilience approach is concerned with developing sources of resilience in order to create robustness to uncertainty and to maintain the flexibility necessary to respond to change. Because of the trade-offs between efficiency and flexibility, a resilience approach recognizes that vulnerabilities are an inherent part of any system. Thus, rather than trying to eliminate vulnerability, the challenges are to identify acceptable levels of vulnerability and to maintain the ability to respond when vulnerable areas are disturbed.

Resilience is not only concerned with maintaining the ability to respond to disturbances, but also considers a distinction between incremental adjustments and system transformation. The conceptual implications of this difference are that societies, in addition to responding to current or perceived disturbances, also have the capability of defining and working to achieve a desired system state. In this sense, resilience broadens the expanse of adaptation while also providing space for agency. This shared space is where the two approaches converge. Actor-based analyses look at the processes of negotiation, decision making, and action. Systems-based analyses complement this approach by examining the implications of these processes on the rest of the system. Current and future research will further our understanding of decision making and governance on the one hand and system resilience on the other, as well as of the implications for appropriate adaptation strategies within a continually changing environment.

SUMMARY POINTS

1. Change is a fundamental aspect of any system, and the level of system adaptedness changes as the context changes. Owing to the transitory nature of adaptedness, a resilience framework stresses the importance of preparation for surprises and system renewal.

2. Social-ecological systems can exist in multiple stable states, which are bounded by thresholds. The desirability of a particular state is a normative classification.
3. The governance of adaptation is concerned with issues of procedural equity and equity in outcome of environmental decision making.
4. There is an inherent tension between high adaptedness and system resilience, which results in trade-offs between current efficiency and future vulnerabilities.

FUTURE ISSUES

1. How do adaptive capacity requirements differ between those for making incremental system adjustments and those required for making system transformations?
2. How are institutions influenced by, and in turn influence, overarching and often divisive environmental change discourses and ideologies?
3. How do diverse, and possibly incommensurable, values mediate societal goals for adaptation?
4. How do more open and participatory forms of governance deal with issues of future uncertainty and maintaining flexibility in light of present sacrifices?
5. How does resilience-focused adaptation affect individual and collective human security?

DISCLOSURE STATEMENT

The authors are not aware of any biases that might be perceived as affecting the objectivity of this review.

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