The Bellagio Initiative

The Future of Philanthropy and Development in the Pursuit of Human Wellbeing

Background Paper

Resilience: A Literature Review

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1. It seeks to build resilience that enhances individual, community and institutional capacity to survive, adapt, and grow in the face of acute crises and chronic stresses.

2. It seeks to promote growth with equity so that poor and vulnerable people have more access to opportunities that improve their lives.

In order to achieve these goals, the Foundation provides much of its support through time-bound initiatives that have defined objectives and strategies for impact.

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About the Background Paper

This paper was developed to provide general context to discussions on the state of the philanthropic sector. Unlike the Commissioned Papers for the Bellagio Initiative, its focus is to present a review of existing literature and it has not been subject to a peer review process.
A final version of the paper will be available following the summit of the Bellagio Initiative (November 9th – 22nd 2011)

Resilience: A Literature Review

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Foreword

“Building Resilience” has been a primary goal of the Rockefeller Foundation for the past several years in both our initiative work and for the Foundation as a whole. In 2007, the Foundation made its first major multi-million dollar commitment with the announcement of the “Building Climate Change Resilience Initiative”, which aimed to boost communities’ resilience to the effects of climate change with a focus on poor and vulnerable people across the globe. The initiative framed resilience as “the capacity over time of a system, organization, community or individual to create, alter, and implement multiple adaptive actions in the face of unpredictable climatic changes.”

Given that building resilience is an interdisciplinary, cross-initiative objective at the Foundation, we continue to push our thinking on how “resilience thinking” can be put into practice to improve people’s well-being. This often requires a systems perspective. Crises and shocks present at varied levels of scale and duration and often have interlinking economic, environmental, political, and social dimensions. Resilience building as the Foundation describes it—increasing the capacity of an individual, community or institution to survive, adapt, and grow in the face of acute crises and chronic stresses—is an activity that requires a multifaceted, interdisciplinary strategy and a systems view to grasp the interconnected and cross-sectoral nature of particularly “wicked” problems like chronic poverty and global warming.

The study of resilience has developed in discrete fields that have generated their own definitions of the concept relevant to the class of problems they address. Historically it has been a key concept in the fields of psychology and ecology, and currently it also has a strong presence in disaster planning and organizational management. Few studies, however, have offered a look at resilience—both its theory and applications—across these and related disciplines. This literature review was commissioned by the Rockefeller Foundation to fill this gap. With a particular focus on research of the past 50 years in the areas of engineering, psychology, complex adaptive systems and economics, this review synthesizes both the theoretical underpinnings of resilience and compelling applications for an international development audience looking at issues that affect the poor and vulnerable.

By offering a strong foundation through which to utilize resilience theory across a number of disciplines and evaluate how the theory may be put into practice, this literature review enables a rigorous application of the concept. It is our hope that it will be a useful document for many types of practitioners who are exploring resilience as a highly relevant notion to their work.

Claudia Juech and Bethany Martin-Breen
The Rockefeller Foundation

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How to Read this Document

The Executive Summary, which follows, presents a self-contained overview of the main points of the review, including references to studies highlighted in Section 2, and a summary of opportunities for aid agencies and foundations.

The subsequent review itself is divided into two parts: the first practical, the second theoretical. In Part I we begin by presenting a number of examples of how the concept has actually been used in practice. In presenting the examples, we will avoid the technicalities of the resilience concept and focus on providing readers with an intuitive notion of how the concept can be effectively used. The reader can then refer to Part II for additional technical details. Next, we outline opportunities for applications of existing resilience ideas and research the concept presents for donors (Section 3). Part II is organized around first defining the resilience concept from a number of perspectives and discussion as to how these multiple perspectives might be usefully reconciled.

It is important to note that due to the multifaceted and multidisciplinary nature of the resilience concept, presenting different definitions out of context is not that useful. Thus, before presenting the definitions of resilience from various fields, we present a short discussion of the development of the term through the 20^{th} century in Section 4. Readers may skip this section and proceed directly to Section 5. However, those who read Section 4 will have a better sense of the context in which the term developed and will get more out of Section 5. Finally, in Section 6.1, we address how the resilience concept, from a variety perspectives, is justified, measured, and managed for.

Please note that, in order to avoid excessive qualifiers, the term “resilience”, when not being used in a comparative setting, will refer to its use in the conceptual framework being discussed.

Scope and Specific Exclusions

This document aims for breadth across the fields that are discussed; specific areas or applications are emphasized when they reveal the use of resilience thinking, or are historically important in the development of resilience thought.

The areas of climate resilience and disaster resilience (in community and other settings) have been specifically deemphasized. Such deemphasis should not be viewed as any judgment of their relative importance or historical and conceptual relationships to the broader conceptions of resilience discussed here.

Executive Summary

Why look at resilience? Why is the concept important? Humanity looks to the future, and wants some of what it now values to be there. It wants sustainability, though there are of course questions about *what* should be sustained. We know that there will be crises; the immediate dissemination of the news of any worldwide calamity, as well as the lives of most any human being, have shown us that. These crises often resolve; perhaps naturally, or perhaps with effort and cost. Sometimes they prove to be devastating, plunging a country into chaos, an adult into drug use, or an economy into depression. Such crises are often, but not always, unexpected. Climate change, a bit paradoxically, is expected to bring more of the unexpected.

In order to sustain those things we find most valuable, necessary for human life and flourishing, standard procedure has been to reduce risk, mitigate in anticipation, and bolster the speed and efficacy of crisis response. None of these are *per se* problematic. But they have, as yet, offered no lasting solutions to chronic poverty, or a clear path to sustainability in the face of global warming, population growth, and increased energy demands.

Resilience has, in the past four decades, been a term increasingly employed throughout a number of sciences: psychology and ecology, most prominently. Increasingly one finds it in political science, business administration, sociology, history, disaster planning, urban planning, and international development. The shared use of the term does not, however, imply unified concepts of resilience nor the theories in which it is embedded. Different uses generate different methods, sometimes different methodologies. Evidential or other empirical support can differ between domains of application, even when concepts are broadly shared.

The following review does not survey and synthesize all such conceptual frameworks; such an undertaking would require many volumes, and the results would likely be of more interest to academic historians than practitioners. Nor does it attempt to survey every application toward which the concept has been put. What it does, however, is provide a spectrum of ways resilience can be conceived, such that any particular use can be situated somewhere along this spectrum. It emphases, too, the trade-offs that come as one moves along the spectrum. Case studies and domain-specific applications have been chosen that demonstrate the powers and pitfalls of particular uses.

Towards this end, the review centers on three resilience frameworks, of increasing complexity: Engineering Resilience (or "Common Sense" resilience); Systems Resilience, called Robustness in economics; and Resilience in Complex Adaptive Systems. As one might expect, with simplicity comes ease of measurement and management; with complexity comes accuracy. Nevertheless, even simple approaches can generate novel insight, and complex approaches can translate into concrete action.

It should be stressed that, although each framework has historical roots in particular disciplines, the frameworks themselves can be applied to any domain: Engineering Resilience is utilized in some child development studies; Systems Resilience is often used in governance and management; and the Complex Adaptive Systems approach has been applied to economics, innovation in technology, history, and urban planning. Thus different frameworks along the spectrum offer a choice of perspective; the acceptability of trade-offs between them, and not subject matter, will ultimately determine which perspective is chosen.

Engineering Resilience

At the simplest level, increased resilience implies **bouncing back faster after stress, enduring greater stresses, and being disturbed less by a given amount of stress.** "Stress" can imply both chronic difficulty or an acute crisis. In this basic sense, to be resilient is to withstand a large disturbance without, in the end, changing, disintegrating, or becoming permanently damaged; to return to normal quickly; and to distort less in the face of such stresses.

This is how most people conceive of the term. If a person is resilient, they can recover from a large shock or strain, such as the loss of a job; they recover quickly; and such things don't perturb them as much as someone less resilient, or more vulnerable. C.S. Holling, a justifiably important figure in ecology and ecosystem management, has named this sort of resilience **Engineering Resilience** (Section 5.1). Why? Engineered systems, such as bridges, buildings, and infrastructure, are often designed so as to handle large stresses, return to normal, and return quickly, when the stress is removed.

Although this concept of resilience is colloquial, and it is easy to understand how the concept applies, it can nevertheless give rise to new ways of framing longstanding problems, and to novel findings and new methods to promote sustainability. Crises, disturbances, or stressors are only looked at through the lens of *decreasing the risk and severity of disturbances* and *restoring conditions if there is a disturbance*: one only considers the nature of a crisis, not the properties of what is, or may be, subject to it. Focus on the subject, and a third-prong to preventing breakdown is added.

A significant limitation with this approach is the idea of "restoring conditions" or "returning to normal." Children in poverty who overcome adversities do not stay the same, but they can still be seen as resilient. Cities subject to disastrous events that are notably different afterwards can still be seen as resilient. Crises can even generate *increased* resilience to future adversity, though not necessarily.

One slogan of resilience thinking is "Embracing Change." One part of this is accepting that change in response to adversity is itself normal. Fighting against it, as well, can actually cause a *decrease* in resilience. Try to keep everything the same, and the chance of future catastrophe can actually *increase*.

Systems Resilience

The world is in flux; even if we do not consider global warming, social, technological, economic, and ecological conditions constantly change. There is, for better or worse, no fixed "normal", though it can seem so if we only focus on the short-term. There are, however, fixed *functions* that humans either need to survive, or generally want to maintain: food, water, shelter, medical care, communities, cities, and parks, to name a few. In some of the world, the needs are provided for; in others, they are not, but few would deny that providing such needs is a priority.

Fixity has its benefits. It is easy enough to divide everything in this world into self-contained domains, assuming nothing in any other domain changes. We can sometimes understand things pretty well this way: water cycles, migration patterns, and chemical bonding; some things need a great deal more work, but seem potentially manageable: human psychology, economies, families, communities, democracies. We can understand them with mathematical models, experiments, case studies, histories, and clinical trials.

Humans don't always notice slow change. We think things in the present are mostly static; usually *normal*, sometimes briefly *disruptive*. The focus therefore is to avoid staying too long in the disruptive, even if it is welcome. If it is not welcome, one should try to *prevent* disruption, or *mitigate* its severity. Even the aim of engineering resilience is to prevent change.

But there *are* slow changes; slow, that is, by human time scales. If we try to keep everything as fixed as possible—if we aim for Engineering Resilience alone–we may risk not only disrupting normal, but also making a return to anything *like* normal impossible. Examples in traditional ecosystem management demonstrate this clearly: in trying to prevent all change, the ecosystem undergoes collapse (Section 2.1).

Slow changes, it turns out, can have a significant impact on resilience. But how does one understand how these slow changes relate to resilience? To keep something *functioning*, rather than identical, means that there are parts; indeed, interacting parts. To incorporate an understanding of internal change, we need to consider resilience in **systems**.

Slow changes relate to the how these interactions between parts change in times of relative stability; the fast changes are in response to crises. How the fast changes take place—whether the system keeps functioning or breaks down—depends on the slow variables. If we don't pay attention to them, if we only focus on what happens in times of disruption, a stable system can, over time, become quite vulnerable to disintegration.

The cases highlighted in 2.7 and 2.5 demonstrate this. In the former case, the resilience of households in poverty turns out to depend on laws regarding property rights; in the latter, the recovery of children from the trauma of being forced to become a soldier depends on tonic levels of community violence. One needs to look at the system consisting of laws and households, or communities and individuals, to understand the resilience of those same individuals. It is not just a matter of inherent properties: the income of households, or hardy personalities of people; it is about the system they operate within, and how law and community function—slowly changing variables—affect the resilience of those who have undergone, or who will undergo, expected crisis: a fast change.

But more can be said: system interactions often go both ways, not just from a higher-level system (e.g., legal) to a lower-level one (households). An individual's behavior affects the functioning of their family, which in turn has an impact on them; economic policy and the functioning of the economy both influence each other. Systems are *dynamic*, undergoing constant change. Resilience in these systems can be defined as **maintaining system function in the event of a disturbance.**

The goal of management in this vein is to make sure that relationships between smaller scale systems can still function during crisis: that economic systems rebound from smaller market failures; that government can continue to operate during a blackout; that infrastructure can provide necessary services in the wake of disruptive climate events.

But there are still limitations. If a government collapses, or becomes ineffective, does that mean a community can't be resilient? Clearly the system that includes both has ceased functioning, and a community may very well depend on the government beforehand. But communities can create new systems in response; that is, they are *self-organizing*. Such self-organizing behavior can take place at many levels: ecosystem species and interactions can change; they have an **adaptive capacity** in response to crisis, yet still thrive, maintaining function. Such systems are called *complex adaptive systems*, and require a new way of thinking about resilience.

Resilience in Complex Adaptive Systems

The key feature that distinguishes systems resilience from complex adaptive systems resilience is adaptive capacity or **adaptability**. It is not just adaptation—change—in response to conditions. It is the ability of systems—households, people, communities, ecosystems, nations—to generate *new* ways of operating, new systemic relationships. If we consider that parts or connections in systems fail or become untenable, adaptive capacity is a key determiner of resilience. Hence in complex adaptive systems, resilience is best defined as **the ability to withstand, recover from, and reorganize in response to crises.** Function is maintained, but system structure may not be.

Self-organization is related to novelty and innovation: it generates inherently new ways of operating, ones that previously may not have been considered; certainly not predicted. In the study discussed in Section 2.3, Ernstson et al. argues that dense cities grow because of innovation: the confluence of different people, ideas, and backgrounds generates high degrees of self-organizing behavior, which continually creates novelty. If such innovation extended to the resources the cities used in ecosystems—if citizens of cities looked at cities as *part* of a large system that included these ecosystems—then innovation would generate not only resilience *in* cities, but the resilience *of* cities, which includes their external relationships. This highlights a change in answer to the above question, "Resilience of what?"

Complex adaptive systems also generate new questions: if certain parts or subsystems can fail, which parts do we want to continue to operate? And in the event of which sort of crisis? The simpler systems view obviated both questions, because the resilient system maintains all of its subsystems and interactions between them, and disturbances were of a fixed kind, ones that affected these interactions. But to use resilience in complex adaptive systems, one needs to answer both "Resilience *of* what?" and "Resilience *to* what?"

The flip side of adaptive capacity is **transformability**: the ability of a part of a complex adaptive system to assume a *new* function. Yet these terms are both relative to how we describe that function. The above example of a state-community system can exemplify this relativism: if the function of this system is to *maintain a reciprocal relationship between state and community services*, then a collapse of the state necessarily indicates transformability, since a necessary component of the function was lost. But if the function is to *provide essential services to individuals*, then a collapse of the state doesn't necessarily mean transformation; self-organizing adaptations can replicate its functioning.

When something transforms, from one function to another, we can ask how resilient the *new* function is to disturbance. Ecologists have seen such switches in ecosystems, where a state "flips" from one resilient system to another; there are **multiple attractors**, two distinct ways of functioning, each of which settles around a distinct equilibrium; often one of them does not serve the human uses towards which the other was put.

In Section 2.8, we consider a theory that "poverty traps" are a second equilibrium state of certain economic systems, the other state being a prosperous one. If an individual in poverty tries to grow beyond their equilibrium they will soon enough return back, unless an extraordinary leap is made. Barrett and Swallow explains this phenomena via positing similar dual equilibrium states in businesses, industries, and government services: those who serve the poorest cannot grow, either, because, in part, the poorest are concentrated at an equilibrium; the poor, in turn, have no services with which to grow. The complex system is self-reinforcing; its feedbacks keep it locked in place. The humanitarian goal is not to increase resilience, but to induce **transformation**: change a two-equilibrium state into one.

Tradeoffs

We discuss in Section 6 a number of features related to these three ways of looking at resilience. In order to put resilience into practice, one wants to know what properties indicate resilience (Section 6.2); how to measure or assess resilience (Section 6.3); and how to manage for resilience (Section 6.4). We summarize here the general trends in these across the various conceptions above.

Engineering resilience is the easiest to put into practice: in response to different conditions, one considers responses to various magnitudes of stress; one measures or looks at history to determine the largest type of shock it can withstand, how quickly it returns, and how much it perturbs or bends. Managing to increase resilience is simple: where one can and desires to change conditions to increase resilience, do so.

Systems require more thought for management. Each level of a system can have a certain structure: in a social system, there are connections between individuals (social networks), and individuals fulfill various, different roles (worker, student). These actors interact with each other. Furthermore, these levels interact with other levels to create feedback mechanisms. One thus needs to understand the system structure, first and foremost. Occasionally, one can give a mathematical model of the system; sometimes these can even generate measures of resilience, and predict changes to resilience based on various contemplated actions. More generally, however, a mathematical model is not available, or it is too difficult to generate useful results (i.e., it is non-linear). In such cases, in parallel with the system properties in designed systems, three key systems properties contribute to its resilience: **Diversity and Redundancy**, **Modular Networks**, and **Responsive, Regulatory Feedbacks** (Section 6.2).

While working with such systems, in absence of a solvable mathematical model, does not generate a resilience *measure*, it does at least provide one with a means to assess whether resilience has been increased. Improved redundancy and diversity of the functions of parts, increased modularity and decreased interdependency in the networks of the subsystem, and increasing the responsiveness of a regulatory feedback mechanism all build resilience. Management would then focus on correcting and manipulating these variables. Using this method, one can often say resilience is increased; one can score it on a arbitrary scale, something like the psychologists' inventory, but there is little assurance that such a scale would correspond with any actual degree of resilience.

In complex adaptive systems, it is also important to understand system structure; paying attention to diversity, modularity, and feedbacks is still important. However, self-organization and novelty means that system structure can change, and in fundamentally unexpected, unpredictable ways. Such is the nature of true novelty: we can only attempt to analyze its effects *after* it has emerged. Resilience can be understood in times of stability—when the system structure is not changing much—but there is no comparison of before or after such change.

Ecologists who use the complex adaptive systems approach also understand management as itself *part of the system in question*. One doesn't just study ecosystems, but social-ecological systems, which includes the actions of the managers of the ecosystems, the users, the advocacy groups that seek preservation, and anyone who has some interest in the ecosystem. Management, then, must *also* foster diversity, modularity, and feedbacks. In addition, it must foster innovation and novelty, too: experiment, innovate, allow and encourage endogenous self-organization and novelty. See Section 2.2 for some more details on how to turn such approaches into practice.

It should be mentioned that while managing complex adaptive systems has some empirical support in social-ecological systems, it is mostly unproven outside of that arena (See Section2.1 for some case studies). While many have extended it to other fields, or organizational management in general, there are no clear cases of its effectiveness in promoting resilience, and ultimately sustainability. Ecosystems are fairly well understood compared to other, human created institutions; they have a basis in fundamental natural science. Our knowledge about human institutions is, by comparison, in its infancy.

Management practices that both work *towards* resilience of something external and work *within* resilience as part of the system, are indeed novel; to adopt either approach is, at base, an experiment. The true test of a theory is its ability to give new predictions, and to confirm them. A paradigm shift is only seen in retrospect; it depends on its future success, not merely past failure. Current approaches are clearly not working in some places, and resilience thinking offers some explanation as to why; it may be untried, but it may also be the best chance humanity has.

Ethical Obligations

We have so far assumed that the objectives of resilience building are clear; yet resilience is ultimately value neutral. And, as we have seen, it can apply to nearly anything in any of its guises. It should be no surprise then that promoting resilience can still generate normative questions about goals and values.

That a forest burns, a business fails, or an innovation or social policy isn't successful: by risking these events, resilience is promoted over a larger scale. Their failure or destruction seems a reasonable cost to bear in promoting a sustainable forest, market economy, and experimentation, respectively. But when we consider people, alone or within families and communities, immediate ethical obligations may overrule the longer-term, or higher-level, view.

Faced with famine, an epidemic of acutely fatal infectious disease, or a natural disaster, the humanitarian response is geared towards preventing death or permanent disability. Yet to prevent this, one might need to overexploit resources to provide food and shelter, or to use antibiotics in a way that might increase the chance of resistant infections in the future. Until resilience has been built up enough, such difficult choices between present urgency and long-term sustainability still need to be made.

Value Conflicts

There is also the question about what one should be building the resilience *of*. Clearly it is not always desirable; chronic poverty is a highly resilient state. Those excluded from the process of governance may not wish to see current functioning sustained. And, given limited resources, one may have to decide, for instance, whether to promote the resilience of a city or an ecosystem.

Some studies, such as Lebel et al. (2006), indicate that building resilience of an ecosystem requires including marginalized groups that use it in management, promoting social justice, and proving accountability at all levels. But to be related is not to be identical: more resilience with respect to social justice may still mean less for the ecosystem. Like natural resources, human resources are limited, and difficult decisions about what we most value, what we most want sustained, must still be faced, and made. One not only needs to answer the questions "Resilience of what?" and "Resilience to what?", but also "Resilience for whom?"

Opportunities

There are numerous opportunities for both using the specific applications on resilience, and the concepts of resilience. However, actual projects or policy based on resilience-frameworks are currently mostly limited to ecosystems and disaster management.

Findings addressing vulnerable populations do have some clear implications for policy: make structural changes that promote existing *strengths* that even those in poverty or vulnerable states can develop. One shouldn't focus exclusively on addressing deficits; sometimes doing so prevents endogenous strengths from developing.

Understanding how a particular system works, especially a multilayered one, allows missing links, or fragile connections, to be spotted. The emphasis on efficiency reduces resilience, as does universal connectivity, and a "top down" flow of information. Such a view goes against much rhetoric of climate change, and promoting an understanding of the necessity of resilience could have significant political and social impact.

More generally, one can apply basic critical systems design principles to spot ways to maintain any system's function in the event of a crisis:

- Maintain a diversity of mechanisms to provide identical functions.

- Make sure networks (social or otherwise) are modular enough so damage or "infection" of one portion does not immediately propagate to all others.
- Maintain or establish feedbacks to, in the simplest case, establish fail-safe mechanisms in case of malfunction.

One can maximize efficiency over all of these variables; however, such optimization assumes full working knowledge of the system. In adaptive systems, such optimization is often detrimental to the adaptive processes; such processes will be, before some crisis that breaks the current system, serving a redundant or seemingly unnecessary function. Fruitful novelty cannot be predicted or made on demand, but it can be prevented altogether.

Besides these *external* ways to promote resilience, there are also *internal* ways: there is no "best" solution to a problem, when conditions are likely to change, so a *diversity* of strategies are needed. Secondly, projects should aim to be less dependent on others: one failure should be contained, and not propagate to others. Lastly, foster innovation by decreasing the rigidities of disciplinary and institutional structures: bring people from a wide variety of backgrounds to address problems, even where they have different aims. Fostering novelty in an organization setting seems to enjoin one to *ignore* existing institutional norms.

Part I

Applications and Opportunities

1 Introduction

Resilience implies stability in the face of change, but to define it as such leaves open many questions: What is stable? Which sort of change? Over what span of time? Answers to these questions cannot be simply answered; some framework is necessary in which to place the resilience concept. There are a plethora of these frameworks available; a survey of all of them would be a monumental task. These various conceptions of resilience, however, lie somewhere along a path: from resilience in individuals or single objects, to systems, to complex adaptive systems. There is often no clear best perspective, but history has often shown us that simplifying can have significant costs: in ecology and economics, simplistic perspectives lead to actions with undesired, sometimes paradoxical, outcomes. That said, even the simplest approach to resilience can generate new insight, as it has in psychology. Which perspective one should take is not an easy question to answer; but we offer here a guide to making such a choice.

In psychology, where one considers resilience in individuals, the resilience concept emerged as a competitor to a *deficit* model of child development. The latter approach views child development as a linear process; deviations from this process, resulting in deficits, are, through empirical studies, related to certain adversities. This model provides a simple mandate when addressing those subject to a high risk of adversity, such as children in poverty: decrease the risk of adversity; when it strikes, try to rectify it.

Those few who faced significant adversity and did not show deficits were rarely studied; no one had asked if anything contributed to their *resilience*. They were thought to be anomalies. Studies beginning in the 1970s (discussed in Sections 5.2 and 4.1) turned their attention to these supposed outliers. Significant relationships were established between high-risk children who were resilient — showed few or no deficits as adults — and family functioning, school environment, and community services. Studying resilience in individuals identifies **protective factors** in addition to risk factors.

While most studies in psychology have focused on high-risk, usually impoverished children in developed countries, the approach clearly has utility in other settings. Studies discussed in 2.5 bring together, for instance, psychologists and disaster theorists to look at the factors, environmental and psychological, that affect the resilience of children after a significant trauma from war and natural disasters. Section 2.7 identifies key legal and social factors that can promote, or hinder, the resilience of impoverished families in the developing world.

The key insight using this approach is that individual resilience is not only about relatively rigid personality traits, but broader environmental factors, more amenable to intervention. It can be fostered. This opens up a wide range of policy strategies: beyond limiting risk, and helping those who have succumbed to adversity, promote environments that foster resilience to those adversities. Resilience is not (all) about luck.

However useful it may be, this approach makes many, sometimes questionable, assumptions. The properties of individuals are identified in isolation: they are suffering from mental illness, are employed, are abusing alcohol, have a criminal record. The resilient individual returns to the fixed course, the same course those who never faced adversity follow.

In this "Engineering Resilience" view, lasting change is to be avoided; if a rod is permanently bent, this indicates failure. If we assume the linear trajectory of healthy development is fixed, then resilient people don't deviate from that trajectory; if they do, they have succumbed. This seems incorrect: even resilient people *change* with adversity; they can learn and grow through it. Environments can change too: a resilient person may be so in part *because* they can change their environment. Understanding resilience through adversity and change requires understanding the processes and dynamics within people and between them and their environment.

When we see individuals this way, new questions emerge. How does adversity change people, resilient and not? How does a resilient person affect their family, and how does the family, in turn affect them? What about social structure? To understand the nature of the changes that individuals go through, or the dynamic relationships between individuals and families, communities, and social structure, we need to take a different approach: to look at them as *systems*.

The resilience concept in systems is most highly developed in the context of ecological and environmental systems—that is the system to be *managed* is a natural one—but has developed into a much broader set of concepts applicable to almost any type of system. Resilience here describes general features of systems such as measures of how far a system can be perturbed before it changes configurations (e.g. Anderies et al., 2002; Carpenter et al., 1999b), (or shifts into a new regime), its adaptability or transformability (e.g. Walker et al., 2004, 2009). The focus on system properties that emphasize constant change and reorganization has been a great strength of this resilience concept. Ecological resilience studies draw attention to several archetypal features of systems and forces policy analysts and policy makers to think about the consequence of policies at the system level—i.e., the many potential unintended consequences of policy choices. The history of environmental policy is littered with stories of unintended consequences that result from policies that are too narrowly focused or do not account for the endogenous change they may induce. In this sense, resilience thinking is very valuable in framing and discussing aspects of sustainability and sustainable development. Further, this resilience concept is highly flexible and can be applied to a range of systems across a range of scales from individuals to households, communities, regions, and nations.

As with any theoretical construct, the strengths of this resilience concept, associated with its focus on dynamics and emergent system-level properties, comes with some limitations. These limitations emerge when thinking about issues relevant to policy analysts and practitioners that affect individuals - livelihoods, ethics, equity, and fairness - and when confronted with actually applying the concept in practice. Resilience scholars in ecosystems management have put in a considerable effort to address these limitations, at least in terms of practice. For example, in 2006 there appeared a special issue focusing on application of resilience theory to 15 actual case studies (see Walker et al., 2006) both in terms of what case studies can tell us about resilience theory and practice.

There remains a considerable amount of work before resilience in systems will be a useful *off-the-shelf* concept for practitioners. Nonetheless, at its present state of development, resilience thinking provides several important themes and tools that can be brought to bear to better frame policy problems and provide a more sophisticated context in which to conduct policy science.

The key elements of using resilience thinking relevant for framing and analyzing policy issues can be summarized as follows:

- **resilience** in systems, broadly defined, refers to the capacity of a **system** to continue to function given external shocks.

- Most differences in interpretation stem from issues of organizational and spatial scale. More specifically, confusion results from lack of a clear definition of the *system* to which the resilience concept is being applied. A system can consist of an individual, a household, a group, a village, a group of villages in a region, a nation, or the entire earth system. See Section 5 and Section 5.3 for a detailed discussion.

- The term resilience is often used in conjunction with other terms such as **vulnerability, adaptation, adaptive capacity, transformability, and robustness**. These terms are closely related, and again have to do with scale. Traditionally, the term *vulnerability* (which is simply the opposite of resilience) and *adaptation* have been used to refer to individuals or households (which are taken to be the minimal decision-making unit). In this case the system is taken to be an individual decision-making unit and its environment. The terms adaptive capacity, transformability, and robustness, on the other hand, traditionally are used to refer to collections of decision-making units (villages, cities, nations, etc.).

- **Vulnerability**, again, is most naturally used as an antonym of resilience. Seeming paradoxes with this usage highlights that "resilience" is highly contextual. Ascriptions (and comparisons) only makes sense after one has specified *resilience to what*. For instance, consider the oft-made characterization of those in poverty as both more resilient and more vulnerable than other economic groups. Poverty is associated with a significantly higher risk of certain adversities (economic, medical, psychiatric) to which those in other economic brackets are not. If these other populations were subject to the same adversity, who have not been as exposed to adversity, they may indeed fare *worse*. Thus, poverty is associated with a greater resilience to their specific adversities faced *in poverty*. But if we look at resilience to *adversity associated with one's environment*, then those in poverty are indeed more vulnerable; their environment presents them with more risks and lacks many of the services available at higher income levels.

- **Sustainability** is a broader concept than resilience. Sustainability is about preservation of some thing or some function, usually used in a way so as to imply the desirability of what is preserved. Sustainability may be promoted in ways that don't involve resilience: risk aversion, crisis recovery, increased efficiency. If one adopts, however, the additional thesis that disruptive events of a certain magnitude cannot be avoided, then sustainability *over time* requires resilience at *each time*. The relationship between these two terms is, then, theoretical, not semantic.

- Similarly, the issue of temporal scale is critical. **Robustness**, like resilience, refers to the capacity of a system to continue to function given external shocks. However, robustness ideas are typically applied to a fixed system and a fixed set of external shocks. This implies that the system is studied over a short (small time scale) period during which the fundamental properties of the system and exogenous shocks do not change. Resilience, on the other hand, emphasizes learning and transformation that occur over long periods (on a large time scale). With this interpretation, *on short time scales, robustness and resilience are roughly equivalent concepts.* Resilience is a broader concept that incorporates a broader range of temporal scales of analysis. See Section 4.2 for further detail.

- The terms **adaptive capacity** and **transformability** are *aspects* of resilience. Adaptive capacity refers to the capability of a particular system to effectively cope with shocks. Given that the term is applied to a particular system, it is implicitly focused on smaller time scales. Transformability, on the other hand, refers to the capability of a system to reorganize into a new system when it can no longer cope in its existing form. If we refer to the set of actors and relationships that constitute the structure of a particular system as that systems **identity**, then transformability refers to the ability of a system to change identity. Implicitly, such changes occur over long periods, and thus transformability is an aspect of resilience that is relevant over longer periods (larger time scales). See Section 4.2.2 for further detail.

- There are two features of systems that are core to the resilience concept. The first is the idea that systems do not tend toward single, stable identities (*sensu* the definition above), but rather have the potential to exhibit multiple identities, and can rapidly shift between them. The second is the idea that systems move through cycles of change. That is, system identities are not *static*; for instance, ecological communities do not tend toward a stable distribution of species, but are always changing in a cyclical way. These are referred to as adaptive cycles. Finally, these adaptive cycles can be connected across spatial and temporal scales and levels of organization to form a **panarchy**. See Section 4.2.3 for further details.

2 Applications

The number of studies that employ some manifestation of the resilience concept are vast. A comprehensive review of interesting applications would occupy several volumes. Given the space available in this literature review, we will present only a select number of examples. The examples have been chosen to help provide the reader intuition concerning how the ideas that constitute resilience theory, or perhaps better, resilience thinking translate into practice.

As discussed further in Section 4.2.4 studies that use the term *resilience* may not actually utilize any of the theory that is associated with it. For example, Hamel and Valikangas (2003, page 2) define resilience in a business context as "the ability to dynamically reinvent business models and strategies as circumstances change". Such a definition could be ascribed to any number of terms. In terms of the collection of resilience concepts reviewed in this paper, what Hamel and Valikangas (2003) call resilience would be called *transformability*, which is only one aspect of resilience. Further, the term resilience is used only in a descriptive sense.

Conversely, settings where the term *resilience* is not used may utilize many of the theoretical structures of resilience theory, often in disguise or in nascent form. Section 2.7, for instance, uses a terminological framework from international development (coming from Sen and Nussbaum) to make an argument best understood as referencing the resilience of an adaptive system.

2.1 Ecological and Social-Ecological Systems

The title of this section reflects the fact that most resilience scholars who work in the ecological domain were among the first to discard the ideal that there are pristine ecosystems (typically meaning without people in them) and the goal of management should be to restore ecosystems to their pristine state wherever possible. Fewer and fewer ecologists cling to this ideal. Most ecosystems, past and present, have been strongly influenced by human activities. Berkes et al. (2003) formalized a shift from this ideal by coining the term *social-ecological systems* (SESs). The types of applications fall into the two main categories of resilience theory: multiple stable attractors (multiple system identities) and the adaptive cycle (see Sections 4.2.1 and 4.2.3).

Several early applications in ecology focused on understanding what processes lead to flips from one identity (technically a basin of attraction - see Section 4.2.1) to another. Much work has focused on lakes that can flip from an oligotrophic state (clear, blue water) to a eutrophic state (green, turbid soup)(Carpenter, 2003; Carpenter et al., 1999b; Scheffer and Nes, 2007; Scheffer, 2004; Meijer et al., 1999; Scheffer et al., 1993). Such shifts are often induced by human activity. In the case of lakes, the most important factor is phosphorous loading (run-off from agricultural activities). The social component of the system is related to attempts to manage the key process that may induce flips - phosphorous loading in the case of lakes. For example, Carpenter et al. (1999a) explore the interaction of social and ecological dynamics in two management models. First, they consider a case in which a market manager attempts to influence the phosphorous loading in a lake by a group of emitters through controlling information about the lake available to emitters. Next, they consider a situation in which a governing board, elected by the emitters, sets phosphorous loading levels. The key element of resilience theory employed here is the existence of multiple system identities (multiple stable attractors). The authors show that neither management model (social process) can prevent flips. In fact, other work has shown that apparently rational attempts to maximize the value of a coupled lake-agricultural system to society can lead to collapse of the lake (Peterson et al., 2003).

Many types of systems exhibit multiple stable attractors. For example, analysis of a similar flavor to that just described has been applied to rangeland and savanna systems (Anderies et al., 2002; Janssen et al., 2004; Walker et al., 1981). Here the two system identities consist of one with a balance between grass and shrubs with periodic fires and one with little or no grass, dominated by shrubs. A flip can be induced by an extreme drought. Here, the human influence is through grazing decisions and fire suppression. Again, the social component in these studies focuses on the impact of various mechanisms to control grazing and fire suppression on preventing the system from flipping to an undesirable identity (basin of attraction). Increased grazing and fire suppression can reduce the resilience of the desirable basin of attraction (the one with plentiful grass and few shrubs) to a drought.

Some studies have extended the resilience idea to focus more on the social aspect of the systems and have attempted to understand what process would lead to a flip in the socio-economic configuration. Such studies are more difficult than those that focus on a single ecosystem because such "flips" can take decades and we have few cases to observe. The main cases we have are historical or archaeological and there has been considerable work that applies resilience theory to archaeological cases. For example Anderies (2006) studies the transition in the Hohokam cultural sequence from a large scale system, covering much of present-day Arizona, that relied on a range of resources, to a small scale system, concentrated in the Phoenix basin, focused mainly on irrigated agriculture. Using a simple bioeconomic model that coupled resource dynamics (wild plant and animal and cultivable soil resources) with economic dynamics (labor allocation to wild resource harvesting or irrigated agriculture), Anderies (2006) illustrates the existence of two stable configurations (socio-economic identities), one with a mixed economy with trade, and one focused on agriculture. He illustrates that as human population rises, the system becomes less resilient to a shock to the wild resource base, e.g. a drought, that leads to environmental changes which, in turn, feeds into the economic system. Shifts in the economic system induce more reliance on irrigated agriculture, setting into motion a positive feedback loop of soil degradation and increased agricultural intensity. This process can then lock the system into a degraded state (soil degradation) with high reliance on irrigated agriculture. This is an example of a story of the sustainability of a particular socio-economic configuration in the face of environmental variation, and is relevant to the sustainability discourse of today.

The cases described above emphasized the impact of human-induced environmental pressures on the resilience of particular system identities, i.e.m the chance that the system will flip out of the desirable identity (a nice clear blue lake with many aquatic organisms) into an undesirable one (a green, turbid lake with fewer organisms). Another set of studies focus on aspects of the system in question on resilience -

specifically diversity. For example, several authors have studied the role of biological diversity in enhancing resilience in general (Reinmoeller and Van Baardwijk, 2005; Folke et al., 2004; Elmqvist et al., 2003), and for particular systems - e.g. coral reefs (Mumby et al., 2007; Bellwood et al., 2003; Hughes et al., 2003). Likewise, the impact of resilience in the social domain has also received attention. Newman and Dale (2005) study the diversity of types of links in social networks and its impact on proactive resilience building. Nelson et al. (2011) study aspects of social diversity, manifested in material style and social conformity that influence the resilience of SESs over the long term using an archaeological case study from the US southwest.

Another key feature core to resilience thinking is scale, both in the ecological and the social domains. A key study in ecology (Peterson et al., 1998) focuses on the relationship between species diversity and ecological function, and scale. They argue that species interact with scale-dependent sets of ecological structures and processes and that ecological resilience is generated by diverse functions within scales and by redundant species that operate at different scales which reinforce function across scales. This cross-scale nature of diversity enables regeneration following shocks over a wide range of scales. This idea of overlapping scales is analogous to policyentric, nested governance structures discussed in Section 2.2. For example, Nelson et al. (2010) explore the cross-scale interplay between social and biophysical context in three archaeological irrigation societies in the US southwest. They use these cases to understand how different scales of social organization regarding water management and settlement patterns affect the resilience of these systems.

The reader will no doubt recognize that the adaptive cycle concept does not appear in the examples presented here. There are, of course, many examples but they tend to be descriptive rather than analytical. In other words, looking at an historical sequence for a given system, one can attempt to locate particular phases of the adaptive cycle and discuss what processes may have moved the system through different phases.

2.2 Institutions and Governance

As a result of the historical development of the substantive resilience concept in ecology and resource management, there are many studies of institutions and governance in SESs. Having said this, the insights derived from these studies easily transfer to other contexts. There are two main aspects of institutions and governance that emerge from the resilience literature:

- Institutions and governance structures cannot be separated from the context in which they operate. For example, with environmental issues, we must study the *coupled* social-ecological system. We cannot study institutions and governance in isolation (Berkes et al., 2003).
- Innovation and novelty is critical for resilience, and institutions and governance structures are critical in promoting innovation.

Before proceeding, we must carefully define the terms institution, organization, and governance. In the literature of interest here, the term institution refers to rules that structure human interactions *sensu* Ostrom (1990), North (2009), and Williamson (1998) (all three are Nobel Laureates). Organizations, on the other hand, refer to collections of agents, infrastructure and institutions. For example, in the academic literature, universities aren't institutions of higher learning, they are organizations of higher learning. Rules, informal norms, and regulations (laws) that govern our lives are institutions. Governance refers to the collection of institutions and organizational structures that, together, shape the process by which decisions and actions are taken regarding the entity being *governed*.

Finally, the work of E. Ostrom has had a very strong influence within the ecological resilience community, largely due to her focus on natural resource systems. Her work has focused on developing design principles that enable successful collective action and promote the resilience of SESs over time as well as understanding governance structures that do the same. Design elements that have emerged from her work in include trust, minimal rights to organize, conflict resolutions mechanisms, nested enterprises (overlapping, multilevel organizational arrangements that operate across spatial and temporal scales) and polycentricity (multiple, interacting centers of decision making authority - i.e. power).

Many studies focus on how institutional and governance structures contribute or detract from resilience. Note that one key aspect of resilience is the ability to adapt to shocks and change given a particular system identity (as distinct from the ability to transform to a new system identity - See Section 4.2.2). A second key feature is the existence of multiple levels of organization both in the social and biophysical domains. Most studies of governance and institutions vis à vis resilience deal with these two issues. For example, Lebel et al. (2006), study how governance structures affect the capacity to manage resilience in the context of regional resource management by comparing 10 examples of SESs in Australia, Sweden, USA, Canada, Thailand, and Indonesia. They explore three propositions relating to governance:

- Participation builds the trust, and deliberation the shared understanding, needed to mobilize and self-organize;
- Polycentric and multilayered institutions improve the fit between knowledge, action, and socio-ecological contexts in ways that allow societies to respond more adaptively at appropriate levels; and
- Accountable authorities who also pursue just distributions of benefits and involuntary risks enhance the adaptive capacity of vulnerable groups and society as a whole.

The authors find some support for these propositions across the cases. The authors, of course, note several limitations of the study. First is the problem of measurement - capacities of individual actors or relationships among them are extremely difficult to assess. Second is the problem of determining causality. Although the study indicates that the capacity to manage resilience may influence the form of governance, ecological feedbacks may constrain both governance and this capacity. This is an important reflection on the point we made earlier: Institutions and governance structures cannot be separated from the context in which they operate. Social-ecological systems consist of multiple, coupled, feedback loops that interact in very subtle and complex ways. It may, therefore, be impossible to understand how governance structures influence biophysical dynamics. This has important implications the *design* of institutions and governance structures. Finally, the authors draw attention to the role of experts in the governance process. Analysis of governance structures reveals ethical issues regarding conservation and resource management in which livelihood needs or the rights of minorities (properties at the individual scale) are passed over in the interests of maintaining, say, ecological resilience (a system level property). Thus, scale issues creep into ethical concerns.

In the example described above, "resilience" is not used in its full richness. Standard social science concepts are used in service of understanding what features affect the resilience of the system. We next illustrate a more focused use of resilience concepts in the study of institutions and governance. As mentioned above, E. Ostrom's work has had enormous influence in this field so we will draw examples based on her and her collaborators' work. To apply resilience ideas in their full richness in social science, we must think about social systems as part of a complex adaptive system (see Section 5.3), consisting of a coupled social and environmental system (here we use the term environment broadly, it need not be the natural environment, it could be the built environment depending on the question at hand). Further, such studies should include the possibility for multiple stable attractors and interactions across scales. To our knowledge, very few social science studies have been framed in this way. However, Ostrom has been studying institutions and governance in SESs for 40 years. Many of the tools and ideas she has developed map very cleanly onto resilience concepts. She and her collaborators focus on systems composed of individuals making local decisions and her analysis focuses on system level properties that emerge from these individual local decisions, specifically the capacity for collective action and self governance. This perspective is faithful to the resilience perspective in that it focuses on self-organization, i.e. emergent properties of multi-agent systems. It thus represents the richest application of resilience ideas in the social sciences.

She and her colleagues have extended these ideas specifically to address resilience from an institutional and governance perspective (Anderies et al., 2004, 2003; Janssen et al., 2007; Janssen and Anderies, 2007). This line of work attempts to understand specific properties of institutional and organizational arrangements that at once increase the capacity of systems of interacting agents to engage in collective action and cope with uncertainty and change (be resilient). Because these studies focus on specific systems over relatively short time intervals, the term robustness is often used which, in this case, is interchangeable with resilience. Many of the studies have focused on small-scale irrigation systems. Irrigation systems are excellent units of study because they are archetypes for all human systems: they involve natural capital (land and water), physical infrastructure (canals, gate structures), and "soft" infrastructure: institutions and organizational structures that enable the governance of the system.

There have been two types of studies in this domain: large N - comparisons across many systems, and detailed analysis of specific systems. The foundation of Ostrom's Nobel Prize winning work was the large N study of many SESs from which she extracted design principles for self-governance. They are (Ostrom, 1990):

- Principle 1: Well-defined boundaries: the presence of well-defined boundaries around a community of users and boundaries around the resource system this community uses is essential for successful self governance.
- Principle 2: Congruence between appropriation and provision rules and local conditions. That is, rules must "fit" the biophysical context. As trivial as this seems, many governance failures are a result of a lack of institutional fit to local conditions.
- Principle 3: Collective-choice arrangements: most individuals affected by the operational rules must be able to participate in modifying the operational rules
- Principle 4: Monitoring: governance systems require monitoring and monitors should either be members of the community or otherwise accountable to those members. Again this seems obvious, but it can be difficult to achieve in practice. There are many examples in which governance fails because this condition is not met (e.g. recent financial crisis?).
- Principle 5: Graduated sanctions: graduated sanctioning systems help to maintain community cohesion (trust) while genuinely punishing severe cases and maintaining proportionality between the severity of violations and sanctions.
- Principle 6: Conflict-resolution mechanisms: systems with low-cost conflict resolution mechanisms are more likely to survive.

- Principle 7: Minimum recognition of rights: external government agencies do not challenge the right of local users to create their own institutions. This point is particularly important for poor and vulnerable populations.

- Principle 8: Nested enterprises: governance activities are organized in multiple layers of nested enterprises that map naturally on to the various important scales of the system being governed.

These principles have been applied to the question of robustness - i.e. do these principles generate robustness in SESs? Cox and Ross (2010) applied ideas that flow from these principles to assess the robustness of community governance structures in community irrigation systems - the Taos valley acequias - in a large N study involving 51 communities. They find that the acequias' ability to maintain crop production is hampered by property rights fragmentation and urbanization. Property rights fragmentation works against Principle 2 (the system boundaries - who are the resource users and how do they use the resource - become blurred), and urbanization against Principle 1 (boundaries of different governance agencies and resource boundaries overlap and become blurred so that the congruence between rules and the resource is lost).

In contrast to the large N study of acequias, Cifdaloz et al. (2010) conduct a detailed analysis of a single irrigation system in Nepal. The authors develop a dynamic mathematical model of the irrigation canal system and rice paddy cultivation to understand the adaptive features of the institutional arrangements governing water use. The authors demonstrate that the adaptive water distribution arrangements can, in fact, significantly increase the robustness of the system to existing water shocks of drought, late arrival of the monsoons, and late season flooding. They also demonstrate that the success of these institutions is tightly coupled to biophysical factors: the size and layout of the irrigation system, the size of the community, and the fact that the collective action problem is one of *coordination* rather than *cooperation*. As a result, the authors argue that the present governance structure may be vulnerable to factors associated with globalization such as loss of labor to other economic enterprises, may suffer from weak conflict resolution mechanisms outside of water distribution issues and such structure further lacks the institutional capacity to effectively distribute new types of resources (state or international aid).

2.3 Urban Resilience

As noted above, the approach of the systems ecologists has been increasingly put to use elsewhere; here we outline an extension of the concept to urban systems as put forward in Ernstson et al. (2010). The authors argue that (1) the rapid growth of the urban system is driven by the exponential growth (relative to population size) of social network connections between those of disparate backgrounds, which connections drive urban innovations, and (2) the "culturally-biased" notion that the natural environment that supports an urban system is fundamentally distinct from it and has limited the impact of these innovations to the built environment.

Managing for resilience is a matter of focusing on "slow variables" (Walker et al., 2002), not the fast changes that define the critical events. Slow variables determine how the system, an urban system in this case, responds to these critical events. If humans manage them effectively, the resilience is increased (if desired). If they are ineffectively managed, or, as is often the case, ignored, then the resilience will be decreased (if not desired). Slow variables relate to connections at a certain scale (diversity, network topology) and to connections between scales (feedbacks and signaling).

Cities are large systems composed of smaller ones: utilities, buildings, weather, businesses, open spaces, transportation networks, financial markets, and so on. But it also includes the *people*: politicians, planners, advocacy groups, workers, schoolchildren, the unemployed, poor, and impoverished. As Ernstson et al. are interested in urban-ecological interaction, they are focused on those who have an impact on land development: planners, builders, politicians, social movements, and 'knowledge sources', such as ecologists, local land-users, and finally, innovators across a broad stripe (who may, of course, include individuals who fall under one of the former roles).

Ecologists can study types of networks only at one scale, such as food-webs. Similarly, social-networks emerge when one studies interactions amongst individuals, irrespective of their role in another system (e.g., political); in contrast to energy distribution networks, social networks themselves are quite dynamic: "a continual recursive communication process that eventually allows people to understand each other, share values and beliefs, and generally work together to achieve their aims Ernstson et al. (2010, p. 8)." Notwithstanding the role such networks play in creating *opposing* beliefs and aims, we can concur at least with the distinction between a mere flow of matter of information and the dynamic interplay of human agents that allow them to make collective change.

In complex adaptive systems, one slow variable has to do with self-organization and novelty. In response to severe crises, for instance one that causes a collapse of the government, communities and individuals can exhibit some degree of local organization to meet the needs of its members. This sort of response is *novel*, in that it can't be designed or predicted. But some self-organization is ongoing, not just in response to crisis or abrupt change.

One of the principles of managing complex adaptive systems, like the urban system described here, is that novelty should be fostered, so systems have a better way to self-organize in response to crisis that disrupt normal regulatory mechanisms (Gunderson et al., 2008). Novelty in human systems involves experimentation, learning, and innovation; these are the sources of novelty that allow self-organizing behavior in response to crisis (and, it should be noted, to take better advantage of sudden and unexpected *beneficial* changes.)

What drives urbanization—that is, why does the density of urban centers increase rather than just the physical size? While energy consumption per capita drops in dense urban centers, and the number of businesses grows linearly with population, interactions among agents grows exponentially. These interactions are generative of novelty when the agents involved are from different backgrounds—the nodes of the urban social network (agents, individuals) must have diverse properties (skill sets, beliefs, traditions, knowledge sources, and so on). The potential for innovation in such a setting is thus substantially higher than a city of the same population but lower density, or an urban setting with a stable population and more uniform backgrounds.

So far we've only considered the system structure *within* cities. But cities are also large users of resources *outside* of them; they are not **closed systems** or self-contained; rather, they are **open systems**, interacting both ways with systems geographically outside of them. Ecosystems, vitally, supply urban needs for energy, food, and water. Innovation, argued to the driver of urbanization, can often increase the use, and damage, to ecosystems, further putting strain on resources.

Ernstson et al. blame this not on innovation *per se*, but the innovator's narrow view of the urban system. Urban populations often view cities as distinct from the (often rural) environments where the resources (farms, dams, power plants) that serve them are located. Such belief limits the ends of social innovation, however it may bolster the resilience of urban systems with respect to *internal* disruptions.

> The challenge lies in harnessing urban innovation towards sustainability and learning at various scales and across sectors. This implies the need to construct discourses that undermine the artificial and culturally biased notion that society and cities are separated from nature and

> countryside, and instead view cities as reciprocal parts of regional ecosystems and dynamic landscapes, constituted out of social-ecological processes from ecosystems across the globe(Ernstson et al., 2010).

Such lessons would apply to the practice of urban planning, first and foremost, for such planning often fails to account for the effects of urban-ecosystem interaction. Three cases of such blind urban planning are presented: New Orleans' increased vulnerability due to trying to keep a city's urban geography fixed despite changes in the wetlands surrounding it (pp. 4-5); how Phoenix's sprawling boundaries and low-density has made it more vulnerable to droughts and energy cost fluctuations (pp. 6-7); and how Cape Town's social inequalities have led to an urban landscape that undermines ecosystem services, including those that mitigate strong prevailing winds.

The paper advocates a new sort of link between systems (the third type of slow variable: cross-scale or feedback mechanisms): if urban innovators understand themselves as part of an urban-ecological system, not just an urban one, then innovation will work to build the resilience *of* cities; not just *in* them. The "slow variable" that matters here is a cultural belief: the wide-spread "artificially and culturally biased notion" that ecosystem resources of the city are not part of the city: that there are one-way dependencies. How to change such a beliefs is, however, a different problem, not addressed by the study.

2.4 Social Innovation

In the past decade, resilience-based ideas, especially those based on the adaptive cycle, have been applied to innovation in formal organizations and in informal social networks. Applications in the management literature that use the term resilience emphasize the need for organizations to constantly reinvent themselves (Hamel and Valikangas, 2003; Reinmoeller and Van Baardwijk, 2005). However, how is this to be accomplished? How do resilience ideas contribute to the process of reinvention (organizational innovation)? Moore and Westley (2011) show how resilience theory and the adaptive cycle can serve as a useful framework for understanding how humans may move beyond these traps and towards the social innovation that is required to address many complex problems. They relate the dynamics of the adaptive cycle (see Section 4.2.3) to innovation in organizations. In business, the front loop of the adaptive cycle which involves the acquisition of resources and institutionalization of norms is represented as the classic "S curve", where an organization becomes increasingly efficient as it moves up a learning or performance curve. Eventually, growth leads to a mature system and reduces diversity, making it vulnerable to major disturbances. In the event of a disturbance (financial crisis, or major political change), the system may go through a "creative destruction" phase *sensu* Schumpeter (1942). Now the system exists in a more diverse and unstructured environment, where different sources of knowledge are more likely to lead to the emergence of novel ideas. The adaptive cycle of learning and increased efficiency through movement along the fore loop, followed by collapse and reorganization through the back loop, begins anew.

While such analysis would apply to innovations in other contexts, additional hurdles are present when considering *social* innovation. Social innovation differs from innovation in formal organizational contexts (governments and businesses) in a number of ways: the goals of social innovation are not clearly defined beforehand; innovators do not have immediate access to formal and informal networks to allow innovations to be developed and deployed to scale; and a broader consensus needs to be reached across disparate groups.

Paralleling the discussion above in Section 2.3, Moore and Westley (2011) identify properties of social networks that contribute to proper conditions for fostering social innovation. They conclude that:

> …the actual invention of the innovation may require lots of weak and diverse links, but the adoption of the innovation requires strong bonds and trust so the network structure must evolve throughout the process. (§The Explanatory Power of Network Theory)

But network analysis is static; if a societal segment fails to have the necessary weak and/or strong links, innovations will both fail to be wholly "social" both in origin and in purpose. How, then, are such links fostered? Towards answering this, Moore and Westley (2011) look to the individual level; in particular, to identifying the particular skill set possessed by those "institutional entrepreneurs" who are able to develop the requisite links across societal boundaries.

From a number of case studies, they conclude that such individuals are able to:

- Understand patterns that keep innovations local and unrepeated
- Build and broker relationships
- Broker knowledge and resources

Notably, the entrepreneur is not engaged in a public, "heroic" position, although the innovation itself may serve such a function. Rather, they "work in obscurity to manage the emergence that they cannot actually control (§Ideas for the Future)."

One can ask a further question: under what conditions are entrepreneurs likely to emerge? How can they themselves be fostered in hitherto socially disconnected groups? What barriers present themselves to these groups in forming networks that are not present in those with at least some knowledge of existing power structures? Until such questions are answered, the research does not appear to be at a stage where possible intervention points stand out. Yet work such as described here points at what to look out *for*: cases in which individuals in marginalized segments have become "institutional entrepreneurs." It is only they who can describe how they came to be, and the hurdles they have faced.

2.5 Individual Response to Disaster and Trauma

We briefly discuss here a case-study from a recent special section of the journal Child Development that emerged from a unique interdisciplinary convening of scholars from child development, disaster studies, international development, and others fields (see Masten and Osofsky (2010) for an overview of the methods and findings). The included studies assessed, based on data limited by the post-traumatic setting, the relationship between three variables: a disaster's type, extent, and context; post-traumatic negative outcomes; and an individual's psychological traits, family structure and community after the trauma.

The psychologically informed studies are thus looking at factors that determine (individual) resilience:

> Studies with a resilience focus typically aim to assess positive as well as negative patterns of adaptation after disaster and also seek to identify the factors or conditions that appear to promote or protect good functioning during crisis or recovery period (Masten and Osofsky, 2010, p. 1034).

That is, to look at resilience in a disaster setting is to ask: which factors can lead to overcoming the adversity of the disaster (in the absence of directed, external treatment)? This is a question that has rarely been addressed: resilience studies themselves are relatively new in psychology, and have tended to focus on chronic conditions, such as poverty or mentally ill parents.

As stressed elsewhere in this review (Sections 4.1, 6, 5.2), most research had ignored identifying protective factors, i.e, what factors predicted resiliency in children as they progress through adolescence into adulthood.

The conceptual and historical reasons and implications for such a gap will not concern us here; we shall highlight some of the findings, and if and how they might be applied to policy or interventions.

The study by Klasen et al. (2010) sought to establish risk and protective factors in 330 former Ugandan child soldiers, nearly half of which were female. The factors were divided up into losses of family or exposure to violence, psychological-dispositional traits, post-traumatic psychological relationships to the trauma event, and post-traumatic social setting. Almost three-quarters of the children interviewed (72.4%) showed evidence of psychopathology; the remaining 24.6% were operationally defined as *resilient*. The question asked was: Which variables could differentiate the resilient from the vulnerable?

Oddly, it had little to do with the duration or extent of the trauma itself: only age of abduction contributed; the other contributing factors were: levels of post-traumatic exposure to familial or community violence, assumptions of guilt, motivation for revenge, and spiritual support. More interestingly, other variables in this vein one might expect to be important, such as social support, having a hardy personality, a positive outlook on life, loss of parents, and even gender, did not contribute significantly to the prediction of resilient outcomes.

The policy implications here would generate specific interventions for boosting the numbers of resilient children subject to similar trauma in similar cultural contexts: focus on reducing familial and community violence, as well as increasing support for spiritual institutions (Klasen et al., 2010, Implications for Intervention). Note that these recommendations do not indicate intervention policies for those who did or will develop pathologies; nor do they address mitigating the risk and/or extent of an abduction. While addressing these latter two problems are clearly important, and may even be priorities, the last can be seen as the "missing" third-prong of a general harm-mitigation approach. Especially where time-limited disasters have occurred, studies such as this provide humanitarian and supportive governments with ways in which to promote resilience in the affected population in the aftermath.

2.6 Climate

Self-organization is a primary feature of SESs, and having mechanisms in place that not only allows such behavior but is able to incorporate such self-organization is a key feature of building resilience. Adger (2003) argues that the relationship between social networks and state has a significant impact both on the extent and the efficacy of self-organizing behavior in response to climate change.

In the current environment, there is adaptation to climate change, but it is mostly post-hoc, and often goes against building resilience to future disasters:

> Some types of adaptation are undertaken by individuals in response to threats to the climate, often triggered by individual extreme events. Others are undertaken by governments on behalf of society, sometimes in anticipation of change but, again, often in response to individual events (Adger, 2003, p. 388).

Such responses are short-sighted, and can even contribute to a worsening of the threat: droughts and water shortages in Melbourne, Victoria have, for instance, spurred the building of an energy-intensive desalination plant and creation of a pipeline to divert water from upstate (Barnett and O'Neill, 2010, pp. 211-2). Increased energy usage, along with a new dependency on a pipeline, certainly don't work to increase resilience.

Even where consensus is reached about the threats of climate change, appropriate action is difficult to obtain. Individuals feel powerless, the most vulnerable have no choice but to focus on the short-term, governments in democracies are bound by the demands of voters, and scientists' message is lost in media reporting. Each may have good intentions, yet social structure, coordination problems, immediate needs, or institutional norms can constrain effective action. Collective action is needed, but rarely found.

If adaptation to climate change is going to be effective, that is, if deliberate changes that build resilience in the face of climate change are to be made, it is becoming increasingly clear that a better way to coordinate actions is vital. How does one begin to understand the nature of the interactions between different agents, and indeed different *types* of agents? Adger (2003) argues that the concept of **social capital** is required to address these issues:

> …collective action requires networks and flows of information between individuals and groups to oil the wheels of decision making. These sets of networks are usefully described as an asset of an individual or a society and are increasingly termed social capital (Adger, 2003, p. 389).

A high degree of social-capital can make certain types of state functions inefficient; if a state's function is to promote the rational allocation of resources, a high-degree of social capital can create redundancies in state functions and obstacles to effectively and efficiently carrying them out. A highly efficient state would obviate the need for networking social capital, at least when it is functioning well. The problem with efficiency, however, is it engenders vulnerability: if the state becomes ineffective in performing some function, then the lack of networking social capital means citizens cannot mobilize, as a group, in response. They cannot self-organize, and their adaptive capacity is diminished. Some redundancy between social and state functions are necessary for building resilience.

A state can also work *with* existing networking social capital. The state interacts with endogenous means of organization and decision making that its citizens engage in, rather than trying to replace the function of the latter in the name of efficiency. This relationships empowers citizens, households, and communities: their social-capital is not wasted, or stifled. When crisis affects the functioning of one, the other will have some capacity to take over these functions.

We should note some features of this ideal social-political system: first, information flows both ways. Governments are responsive and nurture social organizations, while social organizations influence policy through "open processes of democratic participation (p. 394)." Each receives and responds to information and actions from the other: this is a **feedback** between levels of systems. A lack of feedback, going either direction, would increase the vulnerability of the social-political system.

Second, this ideal relationship does not *combine* the social and political networks into one. Why not? This would make the entire system more vulnerable: if the social-organizations and the functioning of the state are too dependent on each other, then the ineffectiveness of disintegration of one would propagate to the other. The systems property that describes a degree of functional independence is **modularity**; responsive connections are vital for resilience, but too many **dependencies** create vulnerability. A resilient system can withstand the loss of some of its parts, but its parts are still connected.

With regards to climate change, Adger argues that such a social-political system would give social capital a sense of legitimacy that the state only aspires to (p. 401). Individuals who themselves organize to positively and sustainably adapt, and a state that supports this ability, are more likely to be accepted by the society as a whole. Secondly:

> When actors perceive adaptation to and the risk of climate change as being within their powers to alter, they will be more likely to make the connection to the causes of climate change, thereby enhancing their mitigative, as well as adaptive, capacity (Adger, 2003, p 401).

The conclusion is noteworthy, for it implies that good-will alone will not promote resilience. Again, individuals or households may have no or little agency when it comes impacting climate change. Democratic governments are limited in what they can do by voters. Powerlessness on both sides causes a myopic focus only on current climate changes; such changes, however, usually decrease resilience in the long-run.

The argument ultimately states social-political system needs to be transformed in order to promote the resilience in the face of long-term threats, where the temptation is to respond only to individual events. If this is the solution to climate change, the next problem is finding a way to change existing social-political systems to conform to this model. This latter problem may, unfortunately, be no easier to solve.

2.7 Poor or Vulnerable Populations

"Vulnerability" in resilience-informed literature in economics, psychology, and ecology generally corresponds just to a state of low resilience; i.e., they are inverse measures. But it has another meaning in international development, coming from research inspired by the pioneering work of Sen (Sen, 1992). We look here at a way to understand the results of one study (Moser, 1998), couched in an international development framework, as part of a resilience-based framework.

Terms employed in the development framework include "vulnerability", "assets", "capabilities", "sensitivity" and "resilience". Roughly, "vulnerability (development)" is the equivalent of **individual vulnerability**, and thus is the antonym of **individual resilience**.[1] "Resilience (development)" and "sensitivity" are both determiners of the **engineering resilience** of individuals, respectively meaning the speed at which a person returns to normal and the degree of disturbance they are subject to when facing a certain magnitude of crisis.[2]

"Assets" and "capabilities" jointly determine **robustness** (how much damage can be sustained to an individual's relationships and abilities in the face of crisis) and **adaptive capacity** (or a disposition to establish new relationships between parts and maintain function in the face of crisis). Robustness and adaptive capacity both contribute to resilience (in our sense), and thus vulnerability (in the development sense). (See Section 4.2 for a description of robustness and adaptive capacity, and Section 6.2 for how they correlate with resilience.)

The current study, the data of which comes from 1992, looked at urban low-income communities in Chawama, Zambia; Cisne Dos, Ecuador; Commonwealth, Philippines; and Angyalföld, Hungary. They were chosen because each city suffered through economic adversity in the late 1980s, the cities were dense, and the communities themselves were built-up through "invasion" or "squatting" (except in the case of Angyalföld). The study assessed the presence of certain types **assets** of the poor populations in these areas. The asset types were divided into: Labor and Employment, Human Capital (e.g., education, food, and health), Housing, Household, and Social Capital.

Some of the conclusions from the study are not surprising; labor, skills, education, health, food, and shelter are all important assets. These each bear an intimate relationship to income, which has historically determined what poverty is. While one can translate these findings into a resilience framework, no new insight is gained; improving the economic circumstances through promoting employment, which requires skilled, healthy workers, are already priorities in development. Speaking of "resilience" here may help unify terminology, but offers no additional interventions.

[1] See Section 5.2 for a discussion of individual resilience
[2] See Section 5.1 for details of engineering resilience.

The more interesting findings relate to the other types of assets, often ignored or assumed to be unimportant: household management, household relations, and social capital. We discuss each of these in turn.

Housing, besides being a basic need, is also a productive asset for many urban poor; it can provide both income (from renting rooms) and familial stability (by having many generations live in one area, able to share household responsibilities). Where urban poor housing is informal, regulations can have a significant effect on the resilience of this asset. If they have no legal title to their homes or land, then there is decreased incentive to maintain such housing. Thus …"…the ability of home owners to use their housing to reduce vulnerability is dependent on on the regulatory framework (Moser, 1998, p. 10)."

Unregulated land markets in Cisne Dos, for instance, have allowed or motivated families to "nest", or build additional housing on the land for extended family, such as young households or elderly parents. Where land is regulated, such as in Chawama, many families must rent, draining resources. Rents have additionally risen in response to the demand; "nesting" is, here, uncommon (Moser, 1998, p. 10). The *lack* of regulation creates more stability; in essence, poor families with land make themselves more resilient.

Household relationships—family relationships—have also traditionally been an asset in poor communities, albeit one not usually considered when poverty is defined. Resilient families, not surprisingly, promote the resilience of individuals within them:

> In times of economic difficulty, households act as critical safety nets, long before outside assistance is provided. As short-term "shock-absorbers", they reduce the vulnerability of individuals who join them (Moser, 1998, p. 11).

The view is a bit simplistic, in that individual resilience, reciprocally, influences the resilience of families. Yet the insight is nevertheless quite important, because policy that looks only to increase income can have detrimental effects on household and family contributions to individual resilience. For instance, the increased entry of women into the labor force, combined with cultural practices that continue to make women bear responsibility for child rearing and household management, can erode family-relationships and household resilience (Moser, 1998, p. 9).

Finally, individuals in poor communities often have a great deal of social capital: informal reciprocal relationships between individuals and families, including broader informal and formal social networks, such as community organizations. These can provide sources of strength, both ongoing and after a crisis:

> Short-term reciprocity, centered mainly on money and response to crisis such as death and illness, and longer term reciprocity in food, water, space, and childcare, are often a precondition for the trust and cooperation that underlie community-based organizations (CBOs)(Moser, 1998, p. 13).

In the case of social-capital, the same social belief that women should be income earners and household managers, has a significant negative impact (Moser, 1998, p. 14). The high burden on women to both earn and manage the household reduces their time building and maintaining community relationships, and thus building their household's social capital.

A common theme across resilience-based fields is that building resilience includes providing governance and regulation that encourages *existing* or *endogenous* sources of resilience. The current framework, although couched in terms of assets and vulnerability, has the same message:

> The asset framework goes beyond a "static" measuring of the poor, toward classifying the capabilities of poor populations to use *their* resources to reduce their vulnerability (Moser, 1998, p. 14, my italics).

The poor are not helpless; that is, they already organize so as to build resilience. Provision of only direct solutions to poverty—building new housing, providing employment, health care services—may indeed reduce adversity, and even move someone out of poverty, but they do not *necessarily* build resilience; it may even erode the existing resources that contribute to it (see Section 2.8, below). This message is echoed in both the psychological and ecological literature on resilience: humans and ecosystems have endogenous ways to cope with adversity and to self-organize to increase resilience (they have some **adaptive capacity**). Poorly designed institutions, even well meaning ones, can often erode this.

New housing that separates families can damage or destroy both housing assets and household assets; creating new jobs for women without attending to the disparity in working hours between men and women can damage both household assets and social capital; community violence can, likewise, erode social capital.

Another message from this study is that resilience is nurtured or suppressed by changes in "slow variables": conditions that change in non-crisis functioning. For housing, the slow variable is whether their households have some legal protection. In the case of households and social-capital, the slow variable is the belief that women should manage households *and* be income-earners.

The article also points out that not all the vulnerable all poor. This is a common themes across resilience-focused fields: children who suffer little adversity may lack the resources to psychologically cope with minor, even expected, crisis; ecosystems that are maintained in supposedly "pristine conditions", especially those that are managed, may collapse given even a small perturbation. In the communities considered in this article, someone who has been lifted out of poverty, but who lacks both social capital and supportive household relationships, may be significantly vulnerable to economic shock, even if they are currently employed, have adequate health care, and access to adequate food and shelter.

Conversely, someone in poverty with rights to their home, a supportive household, and a high degree of social capital can weather a great deal already. Policy targeting only economic aspects of impoverished communities can reduce these existing sources of resilience if the latter are assumed to be "helpless victims" (Moser, 1998, p. 3); recognizing these existing sources of strength, and fostering them, are necessary steps to promoting their resilience.

2.8 Economics

For an individual or family, poverty can be transitory or chronic. While transitory poverty puts individuals and families at risk for adversity, with potentially long-lasting negative effects, it presents quite a different problem than does chronic poverty. Indeed, those who suffer through poverty and recover can be seen as financially resilient: they suffer economic adversity but are able not to succumb, although they may need to change in significant ways in order to do so[3].

Chronic poverty presents a different problem. In Sections 2.7, 4.1, based on international development and child development perspectives, respectively, one looks for existing sources of resilience in conditions of such chronic poverty. At this level, poverty is assumed to be continual: it will continue to exist, but policy can affect how people and families function within it, or how individuals can escape it. But what of affecting the conditions that lead to chronic poverty generally?

The term "poverty trap" is used to name the answer to such question, but in itself the term doesn't tell us much about the cause or how to eradicate it. Standard economic models of growth argue that the poverty "trap" is not so much determined by overall structure but by history: two (or more) distinct groups

[3]One must be note that financial resilience does not imply other sorts; someone who leaves poverty with an anxiety disorder, for instance, would be financially, but not psychologically, resilient.

of people follow different paths of growth, converging on different points (Barrett and Swallow, 2006, p. 3). These two paths are shown in Figure 1, comparing the welfare at some time t and some later time $t+1$. Equilibria, that is, places where welfare stays the same over time, are those points of intersection with the diagonal line.

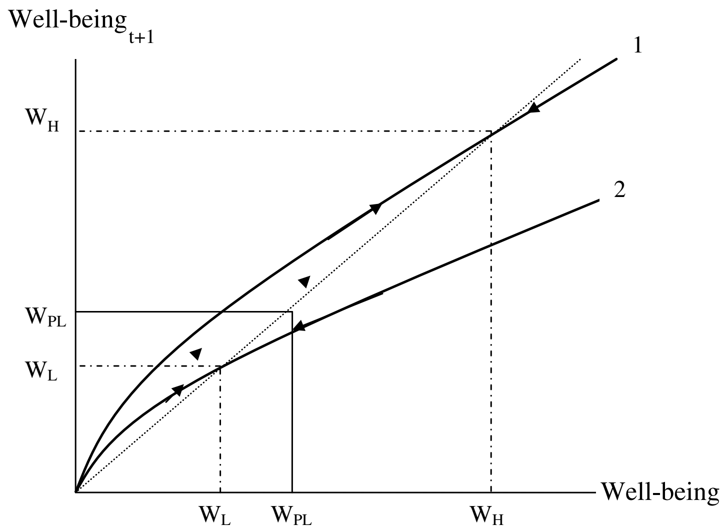

Figure 1: Welfare Dynamics under the Convergence Hypothesis. Adapted from (Barrett and Swallow, 2006)

But this model doesn't provide any answers, either. Why are there two groups? Some people fall into poverty and some can escape it, how is it that they change groups? Such diagram seems to split a country into two economies, treating them as wholly independent. Against this view, Barrett and Swallow argue that the state of poverty is one of the equilibria of the economic welfare of the *entire* population. That is, there is one curve with two equilibria, rather than two curves with one equilibrium each. This is represented in Figure 2: the two equilibria are the same as in the previous figure, but there is only one curve. This highlights the idea of **multiple stable attractors**.[4]

Two features are worth pointing out: first, there is a third unstable point where the diagonal meets the curve, W_C. If someone starts out in welfare just slightly above it, they will tend towards the higher state W_H; if slightly below, they will tend towards the lower, poverty state W_L. Second, if someone is in poverty, they need a "large push" in order to surpass the unstable equilibrium, that is, to pass a **threshold** and move into a new state[5]

How does this relate to resilience? The S-curve gives us two equilibria, such that if one's welfare suddenly deviates from an equilibria, but not too much,one will return to the initial welfare state. How much deviation keeps someone in their initial equilibrium and how quickly they return to it determines the resilience of each equilibrium.[6] If the "push" required is very high, as it may be in many countries with large amounts of poverty, then few will be able to escape it; similarly, one would also expect the "pull" or amount of negative disturbance someone at the upper equilibrium may absorb to be quite low. That is, we can conceive of chronic poverty as a *resilient economic state*. If, further, the prosperous state is relatively *vulnerable*, then

[4]See Sections 2.1 and 4.2
[5]See Section 4.2.2.
[6]The range around each equilibrium from the edge to the unstable point is their **stability domain**; see Section 4.2.2

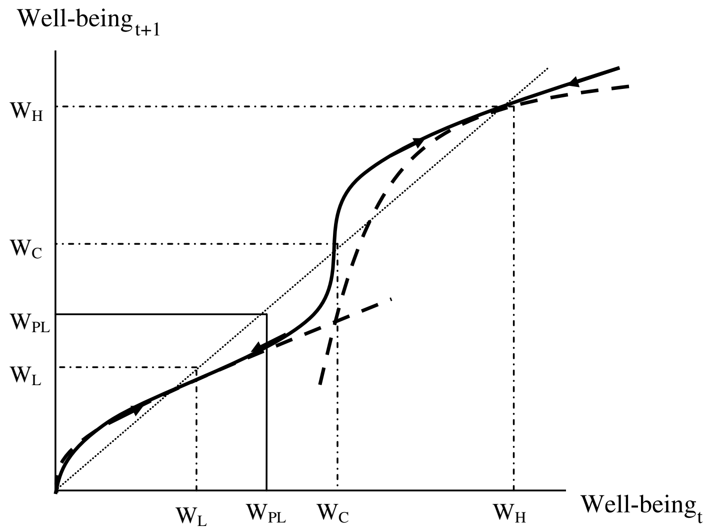

Figure 2: Welfare Dynamics under the Poverty Trap Hypothesis. Adapted from (Barrett and Swallow, 2006)

we go someway towards explaining chronic poverty: people who fall into poverty cannot easily escape, and, further, it is easy for people to fall into poverty.

What are the then options for alleviating such an ill? If the prosperous state is actually resilient, then a costly, but potentially permanent approach would be to significantly increase monetary welfare to impoverished individuals. These two basic considerations guide the first two policy implications:

- Provide significant short lived monetary transfers to individuals, households and communities, to allow them to switch states.
- Improve safety nets to prevent the prosperous from falling back into poverty.

Both recommendations seems reasonable, but given that there is no explanation for the current shape of the curve, i.e., why things are the way they are, it also seems reasonable to question them as permanent solutions.

A second option would be to change the shape of the curve; to flatten it out. Such changes would transform the system itself[7] The desired transformation would *decrease* resilience of the poverty state, and *increase* resilience of the prosperity state; or, in other terms, it would make those in the poverty state *more* vulnerable to switching states (i.e., moving up), and those in the prosperity state more resilient. But obtaining this objective requires understanding why the curve is the shape it is, as, in contrast to the above recommendations, people are not merely being picked up and dropped somewhere else along it.

Barrett and Swallow go on to propose an interesting and intuitively reasonable explanation for the S shape: if we look at curves at other scales of analysis—community services, social networks and local businesses, and at higher scales of sector investment—they *also* have the same S shape. Those businesses, services, or sectors operating in the lower portion find it difficult or impossible to grow or improve, as any small growth is negated in time.[8]

[7]The ability to transform the system, to change the shape of the curve, is called **transformability**. See Section 4.2.2.
[8]Such repetition across scales makes this multi-dimensional system *fractal*; hence the title "Fractal Policy Traps."

Why could this be? At the sector level, they argue that past "high development" theories, which believed that investments in the most efficient sector would spill over to others, have made other sectors underdeveloped and trapped in the lower equilibrium W_L. [9]

At the community level, businesses that serve the poor may find it difficult to expand due to lack of access to financing (p. 9); if property rights, for instance, deny the poor legal protection to their homes or land, then there is little incentive and a lot of risk to undertake improving housing, infrastructure, or developing community services.

There are, finally, individual and household limits to growth, as well. The case we consider above in Section 2.7 emphasizes that poor households *do* have endogenous resources that promote resilience, but political and social conditions often negate or stifle such resources.[10]

In each case, the absence of mid-level supports—that is, in the area of the unstable equilibrium W_C—make poverty a resilient state. Policy that tries to bridge these gaps would transform the system into a desirable one. Barrett and Swallow provide specific guidance, which overlaps somewhat with the recommendations in Section 2.7:

1. Improved access to "growth-promoting" services, such as with improved infrastructure and transportation to serve existing housing, and micro-finance and other mid-level financial markets to give access to credit and insurance.

2. Decentralizing, and devolving responsibility as much as possible to the "lowest possible scale within which the associated externalities can be fully internalized and at which provision of the good or service can be done efficiently."

One should take all this with a grain of salt. This theory of S curves at every level is a conjecture with some limited case-study support: demonstrating the sorts of dynamics required to generate the curves is next to impossible; the authors admit as much (p. 6). But the "two curve" classic economic theory was not demonstrated either, and it fails to explain anything about poverty traps. Classical economic theory also provided the motivation for focusing investment only on the most efficient sector to promote growth; this may have, counter to the original aims, contributed to the persistence of poverty traps. New conjectures are at least an improvement over past failures.

3 Opportunities for Intervention

There are three broad ways to use the above resilience frameworks. One can use the findings of particular studies to bolster the resilience of the poor and vulnerable, as well as cities and large urban networks, and to build climate change resilience in vulnerable communities.

Unfortunately, studies are currently limited; clearly more needs to be done to foster research, especially interdisciplinary research, which many interventions require. There is some cross-talk between psychologists and disaster theorists, as well as complex systems theorists and economists, though international development scholars often work within a completely separate framework.

That said, one needn't look to projects or findings that speak of "resilience" in order to put resilience into action. The study highlighted in Section 2.7 comes from an international developmental perspective,

[9] This is related to the principle that a focus on efficiency can harm resilience (Section 6.2); the focus on efficiency at the expense of diversity and redundancy also relates to the exploitation phase of the adaptive cycle, see Section 4.2.3

[10] This can be true even if the objective is to *help*, e.g., moving families from "shanty towns" to government-built housing, eliminating existing housing resources and the incentive to improve the same.

using different terminology and focused on "capabilities", "assets", and "vulnerability". Yet it is shown to be concordant and understandable as an essentially resilience-based approach; the policy implication from such findings are quite explicit.

Studies in psychology and international development address chronic poverty in children, families, and communities. Many have clear policy implications. As mentioned, ecologists have successfully rehabilitated or maintained ecosystems that provide resources or value for humans; extension of these practices to the management of larger natural resources, currently threatened by patterns of human use, would promote their resilience.

More broadly, resilience thinking provides general recommendations in many domains where one can conceive of a target as a system: infrastructure, governance, social services, social networks. Where sustainability of some ongoing, multilayered system is the goal, then one needs to emphasize a diversity of overlapping methods or services (often at the expense of efficiency); modularity of connections, so failures or damage to one part does not spread far and wide; and proper feedbacks, including information feedbacks, so changes in one part are responded to by changes in another. All of these are *slow variables*: they are properties of the system that are adjusted in relatively stable conditions.

The attention to diverse mechanisms for the same function, modular networks, and responsive feedbacks, while often considered a hallmark of resilience or systems thinking, are not essentially new: they have informed the design of engineered critical systems (nuclear power plants, airplane control systems) for over half a century. Yet it is only more recently that they have begun to be applied to systems where human agency plays an essential role; popularizers such as Donella Meadows have worked admirably in communicating essential insights of systems design to policy-makers and others who wish to effect change across multiple scales.

However, in systems which are adaptive (or are considered as such due to our ignorance of mechanisms), self-organization and novelty add a new dimension. This is often under-realized by even well-intentioned institutions; such resource for building resilience is often stifled. One of the case studies we highlight (Section 2.7) shows how people and households in poverty already have a number of resources available for coping with crises; but they can be eroded by policy, sometimes policy even intended to bolster their economic well-being. Understanding the ways in which people are already resilient, and promoting policy that supports and nurtures these endogenous capacities, can go a long way towards promoting resilience in those most at risk.

In Section 2.8, "poverty traps" are explained as being a highly-resilient state of a system. How does one *decrease* the resilience of this state, *transform* the system? Direct approaches, such as by boosting income, may make people well-off for a time, but if the system has not changed, the trap of poverty will likely rear its head once again. The solution? Promote mid-level services, those that give impoverished households and the businesses and industries that serve them access to services, such as credit and education, whose current absence hinders escape except for the most extraordinary of individuals. Again the message is about moving "slow variables", access to services, not large-scale, one-time efforts. Growth out of poverty may be natural when the conditions are right.

Harder to apply are the related ideas of the adaptive cycle and panarchy (Section 4.2.3). While each has been applied to explain a large number of disparate phenomena (so many as to risk vacuity, according to its authors (Gunderson and Holling, 2002)), they have little present application in either prediction or in generating specific management proposals; at best, it is a useful utility for framing a *description* of a problem. Moore and Westley (2011), for instance, uses the adaptive cycle and panarchy to elucidate the agency of actors in scaling up and "out" social innovation.

Finally, resilience can be applied to governance and management themselves; if we believe the relationships between organizations and the work they seek to accomplish is best seen as a complex adaptive system, then working internally to promote resilience requires the same strategy as working externally:

1. Increase the diversity of solutions, at the expense of some efficiency and redundancy. Some approaches will fail when conditions unexpectedly change; having a multitude of simultaneous approaches allows failure to be withstood.

2. Decrease interdependencies; the success of one project should not depend on the success of others.

3. Make sure information feeds from all levels: often local knowledge, especially knowledge from socially excluded communities, is not assessed or otherwise ignored, even when projects are directly related to improving their well-being. When projects target them, or resources they depend on, their feedback is *essential* to understanding changing circumstances, when new approaches might be necessary, and building trust and cooperation.

4. Foster innovation: this requires allowing some degree of self-organization by decreasing the rigidity of disciplinary, organizational, and social boundaries. True novelty, true innovation, not only cannot be forced into rigid systems; forcing it will prevent it from happening.

The above can, of course, be indefinitely extended to any level of a system in which the institution is a part.

While not exhaustive by any means, the above recommendations do highlight how resilience can stimulate both new ways of understanding "wicked problems" and new ways of developing solutions to them.

Part II

Theoretical Foundations

4 Evolution of the Resilience Concept

4.1 Resilience in Psychology

Within a number of disciplines—psychology, notably, but also sociology and eduction—the construct of resilience has become increasingly accepted; studies have been done on multiple targets; and policy and interventions strategies have begun to be applied. Resilience studies in this tradition have focused their attention on individuals and families; they are often, but not always, focused on those who have faced significant acute adversities, or those in highly-vulnerable situations. The earliest examples include E. Werner's longitudinal study of 698 children born in 1955 on the island of Kauai, many of them into poverty (Werner, 1993); the sociologist A. Antonovsky's study in 1971 of adults who survived concentration camps (Antonovsky et al., 1971); and R. Hill's study in 1949 of family separation and reunion due to the second world war (Hill, 1958). It was only in the 1980s that the construct became an active area of research, most notably in family theory and child development, which we focus on here.

There is unfortunately little consensus about the definitions of "resilience", "adversity", "positive adaptation", "positive outcome", and so forth, even if one confines themselves to looking at a sub-discipline, such as child development. Sometimes concepts clearly related to resilience are used without ever mentioning the word. There are some notable attempts to survey or unify the field, such as VanBreda (2001) and Luthar et al. (2000), but the impact has been limited. Despite these theoretical hurdles (or battles, in some cases), resilience and related concepts are *used* in these fields in a fairly uniform manner;

Early studies on individual resilience focused on child development in adverse settings, especially poverty (Masten, 2001; Werner, 1993; Rutter, 1987). The more traditional approach to studying adversity in child development was through identifying risk-factors: identifying those psychological, familial, and environmental factors that put these children at risk for negative outcomes, such as mental illness, unemployment, criminal activity, or drug abuse.

The "risk factor" approach, as this has been called, leaves a policy-maker or clinician with two points of intervention: reduce risk where possible, and treat or rehabilitate when necessary. It was assumed that most people subject to multiple risks, born into poverty for instance, would have some adverse outcome; those few who were able to thrive, those "invulnerable" or "invincible" individuals were seen just anomalies, statistical noise (Masten, 2001).

Early studies showed, to the contrary, that those high-risk individuals who were able to avoid or overcome adversity shared many features. They weren't noise. Indeed, in the Kauai study mentioned above, a full one third of the children born into high-risk situations developed into "competent, confiding, and caring" adults, and certain variables of their personality and environment could distinguish the two groups.

What distinguished the resilient group from the others was, in this study, quite ordinary. Some factors seemed intrinsic: resilient children were engaging to other people, could recruit substitute caregivers (when families were abusive or absent), have a talent that is valued by peers or elders, and believe their actions can affect their lives. Yet there were other contributing factors to resilience in this study: having an extended family, caring neighbors, teachers, mentors, or youth workers. It is easy to see that these are, to various extents, modifiable by clinicians, social workers, and policy-makers. (Werner, 1995, p. 83).

Notably, most of the environmental factors were community-based: support services that came from outside the community tend to be far less effective than those that the community already has (Luthar and Cicchetti, 2000, pp. 16-17). Furthermore, those support services that focused on improving family processes has been shown to increase the resilience of vulnerable children: for instance, children of depressed parents show better outcomes when they understand the nature of their parent's illness (Luthar and Cicchetti, 2000, pp. 15).

Such programs try to foster existing relationships, in families and communities, rather than "come to the rescue" when acute adversity strikes. Communities and families are resilient systems; policy that respects them, rather than tries to control them, can significantly affect positive outcomes.

Individual personality traits, especially those of young children, can seem difficult if not impossible to modify when they are looked at this way. But this is based on a confusion; identifying protective factors is only the first step. After this, one needs to dig deeper to see the *mechanisms* at play:

> Having done this [identified protective factors], the next phase——an essential one for this generation of researchers—entails efforts to understand the mechanisms that might explain the effects of salient vulnerability or protective factors (Luthar and Cicchetti, 2000, p 3).

Some psychologists also noted that it was not only the environment that affected the resilience of the child, but that the resilience of a child had impacts on their environment. To take one example, how a child develops has a significant impact on her family, especially the mother's future parenting style; and the mother's later parenting, in turn, will affect the child. Reciprocal relationships are harder to show outside of the family; a child can affect their family much more than their school or community. But this insight, nevertheless, places a child within the context of a *system*, indeed an adaptive system:

> The new frontier is understanding these processes at multiple levels, from genes to relationships, and investigating how the individual as a complex living system interacts effectively and ineffectively over time with the systems in which it is embedded (Masten, 2001, pp. 234-5).

Saying something is an adaptive system does not mean one can easily study it. Indeed, studying adaptive systems requires new tools (Sections 6.2 and 6.3).

Family stress theory going back to the 1940s had long ago understood that you cannot look at an individual in isolation when you look at a family (Hill, 1958; McCubbin et al., 1980). A family is more than just a sum of individuals; and indeed it is more than just a set of related individuals, for those relationships change; they are dynamic. Illnesses affect caregiving relationships; adolescence changes power relationships. But how a family functions also depends on how the individuals function: the personalities, coping strategies, and physical health of individuals affects the families that make them up. Dependencies run both ways, as they do in social-ecological systems, or between economics and economic policy. The definitions from F. Walsh is representative:

> ...family resilience seeks to identify and foster key processes that enable families to cope more effectively and emerge hardier from crises or persistent stresses, whether from within or from outside the family 1996, p. 263.

When talking about resilience in families versus the individuals that make them up, already we have to deal with the issue of **scale**: resilient families are not necessarily made of resilient individuals, when those individuals are view in isolation. Indeed, a highly resilient family may be one that continues to function well *despite* the significant vulnerability of some of its members. The lesson from the complex adaptive systems approach —that to speak of resilience you first need to answer "resilience of what?" (Section 5.3)—applies equally here.

The findings in family resilience based on theories of adaptive change are significantly less robust than those individual resilience. Family systems theorists use the same methods as psychologists studying individuals: scale-based inventories based on interviews, and statistical analysis. But the theory of family dynamics has become quite complex; traditional methods seem inadequate for resilience assessment (VanBreda, 2001, p. 139). Studies tend to generate long lists of family traits, sometimes in the hundreds, in order to describe and understand family these dynamics (McCubbin et al., 1996). But to look at adaptive systems, new tools must be used; using "Engineering Resilience" approaches to understand elaborate dynamic systems is messy, and likely quite inaccurate.

The most important lessons from the existing psychological literature is less about particular findings and more about perspective:

1. Individuals are rarely born resilient or "invincible"; family and community have a profound effect on fostering resilience.

2. Increasing resilience can be seen as a new tool, in addition to risk management, especially when the root cause of adversity is difficult or impossible to address.

3. There are almost always *existing* mechanisms that enable resilience; existing literature has identified many of these in mostly high-risk contexts.

4. Fostering these existing mechanisms can be much more effective than an intervention from outside of the community (Luthar and Cicchetti, 2000, p. 18).

In terms of research, most resilience research *outside* of the psychological tradition stops at the community level; within the tradition, significant results are obtained only up to the family level. Bridging these gaps would likely encourage both the use of psychological findings in understanding social, urban, and more inclusive systems; in addition, the tools of complex systems can be usefully applied to models of family and individual dynamics.

That multiple, independent threads of research have coalesced around a broad theoretical structure of resilience, on different subjects, methods, and terminology, is quite surprising, perhaps serendipitous. But perhaps there is a reason, if we consider the similarity between the subjects in question. Humanity, as well as familial and communal structures have, like ecosystems, been around a long time relative to existing political, economic, and broader social structures. They have persisted despite diverse changes to the world; they persist in many types of conditions, including a great deal of adversity. They are all, in a broad sense, naturally resilient. However, those social-systems that are relatively new in comparison can significantly affect such resilience, for better or for worse.

4.2 Resilience in Complex Adaptive Systems

It would be difficult to exhaustively trace the origins of the concept of resilience as it applies in the ecosystems management community today. We will thus concentrate on the history of the present-day *usage* of the concept from the 1970's to the present. Even this coverage will be limited given space constraints. **Resilience originally was a reaction to the "stability" concept in ecology**. Given work in mathematical ecology on simple population models such as the early work on fisheries due to Lotka (1925), and Volterra (1927), there was a focus on factors that might stabilize neutrally stable systems that arose in these simple models. The dominant theory in the 20^{th} was due to Clements (1916) which built on ideas of community succession in which ecological communities reach a *stable* climax configuration given climatic conditions.

Although C.S. Holling produced significant contributions regarding predator-prey dynamics that can, in fact, stabilize the Lotka-Voltera predator-prey dynamics(Holling, 1959), his work (both individually and with others) on the spruce budworm system (Ludwig et al., 1978) convinced him that fluctuations are essential features of ecological systems (Holling, 1973). That is, **ecosystems do not evolve toward a single stable climax state, but undergo periodic cycles of change**. These periodic cycles of change are fundamental to the operation of ecological systems as in the case with the budworm system and familiar systems such as fire driven forest dynamics. This idea ran counter to the basic management principle of holding systems in equilibrium and is the basis of Holling's adaptive cycle. We will track two developments that flow from this observation: Non-linear dynamics and multiple attractors and the Adaptive Cycle.

4.2.1 Non-linear dynamics and multiple attractors

Given the concept's roots in mathematical ecology, **there has always been an emphasis on nonlinear dynamics, stable attractors, and transitions between them** (Walker et al., 1981; Ludwig et al., 1997; Carpenter et al., 1999b; Perrings and Walker, 1997; Folke et al., 2004; Holling, 2009). Given a relatively clean, geometrical (at least in lower dimensions) definition of the boundary of a basin of attraction, resilience can be defined as some function of points on the boundary and on the stable attractor. If the stable attractor is simple, such as a single point in R^n (for example, see Carpenter et al., 1999b; Anderies et al., 2002, 2006), **resilience could be defined as the minimum distance between the stable fixed point and all points on the boundary of the attractor**. If the attractor is more complex, such as a limit cycle of some sort (i.e. has infinitely many points) this is more difficult. Further, in higher dimensions, boundaries of basins of attraction can be fractal and extremely difficult to define.

The idea of resilience, thus, is fundamentally about the geometry of a basin of attraction. However, researchers immediately realized that the geometry of these basins changes over time (or as external drivers change) as shown in Figure 3 . Specifically, one can typically identify multiple temporal scales in dynamical systems which we can call "slow" and "fast" variables. Typically the mathematical analysis treats the "slow" variables as fixed and focuses on the fast variables. Then, it seeks to understand how changing the slow parameter affects the geometry of the basins of attraction (again, for example, see Carpenter et al., 1999b; Anderies et al., 2002, 2006). This interplay between fast and slow variables, both in the social and ecological subsystems in a social-ecological system (SES), generate the basis for "resilience" interpreted more broadly. Namely, two concepts emerged, as part of resilience: adaptability (or adaptive capacity), and transformability (Walker et al., 2004; Folke et al., 2003; Olsson et al., 2004; Folke et al., 2010).

4.2.2 Adaptability and Transformability

"Adaptability" has been defined is several ways with a recurrent theme: the capacity to maintain a system in its current stability domain (Berkes et al., 2003), i.e. the ability to influence resilience (Walker et al., 2009) by maintaining certain processes despite endogenous and exogenous change (Carpenter and Brock, 2008). There have been many studies focusing on factors, both social and ecological that contribute to adaptability (e.g. diversity Elmqvist et al., 2003). However, a moment's reflection reveals the practical implications of focusing on adaptability. Work on grazing systems suggests why. Rangelands

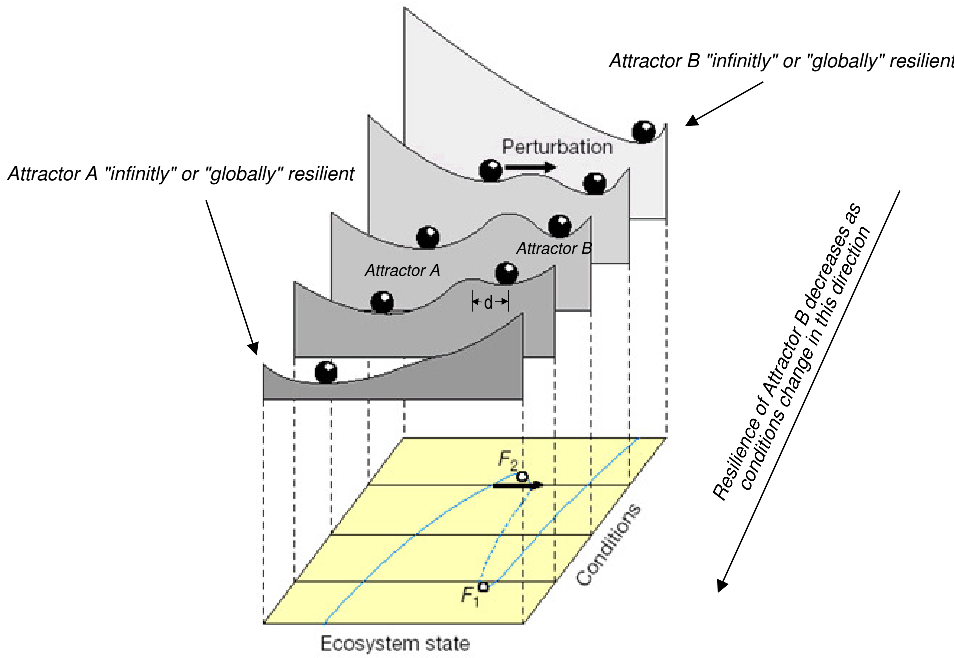

Figure 3: *Illustration of the concept of multiple stable states. The quantity d (if the system is 1-dimensional) is a measure of the resilience of the system. This figure illustrates how the geometry of the basin changes as an external driver (usually a "slow" variable) changes over time. Adapted from Scheffer et al. (2001a).*

can flip from an open, grass-dominated community with limited woody shrub cover (maintained through and adaptive cycle involving fire) to a shrub dominated system with no grass (and no fire) (Anderies et al., 2002). In the former , livelihoods are generated by sheep grazing within the associated socio-economic context. This SES generates livelihoods through grass and if the ecological system flips to the shrub dominated state, the sheep-based system cannot generate livelihoods. However, if the socio-economic context can be transformed so that goats (which browse on shrubs) are valuable, then livelihoods can be generated in either ecological state. In this case, the capacity to transform the social subsystem to accommodate the second basin of attraction increases the resilience of livelihoods. **The capacity to transform part of the system is "transformability", i.e. "the capacity to create a fundamentally new system when ecological, economic, or social structures make the existing system untenable"** (Walker et al., 2004). Obviously, critical to "adaptability" are thresholds - namely in order to transform, the location of key thresholds must be know. These thresholds separate different domains of attraction, or regimes as they are now called (Carpenter, 2003). It turns out that ecosystems can "flip" - i.e. change regimes quickly, a phenomenon that has drawn considerable attention from resilience scholars (Scheffer and Carpenter, 2003; Scheffer et al., 2001b; Folke et al., 2004; Kinzig et al., 2006; Biggs et al., 2009). There is an enormous literature on rapid regime shifts in social systems, but most of this work does not full under the resilience label. However, Brock (2006), who has worked with ecologists on resilience studies has done work on rapid regime shifts in social systems.

The distinction between adaptability and transformability as sub-concepts of resilience highlights an important issue: scale. If we draw the social system boundary around "grazing livelihoods" rather than "sheep grazing livelihoods", and we define as part of the original social dynamics the capacity to move between different types of economic arrangements, then the need for the concept of "transformability" is obviated. "Adaptability" spans multiple basins. Thus, the idea of transformability has more to do with the analyst's perception of the system than a property of the system itself.

Thus the geometry of multiple stable attractors and how it changes has been core to resilience (Folke et al., 2010). The mathematical treatments have produced elegant insights but only relate to part of "resilience". The other key concept, the adaptive cycle (see Figure 4), is much more difficult to rigorously apply. **The idea of the adaptive cycle is simple - systems go through four phases of change: reorganization, exploitation, conservation, and release**. If we think of agents (from chemicals up to animals) as network nodes, and relationships (predation, photosynthesis, respiration, competition) as network links, the network equivalent (roughly) of the phases is shown in the corresponding boxes. Note that this conceptual diagram is not necessarily fundamentally different from the mathematical treatments discussed above. The dynamic model of a fire driven rangeland system developed by Anderies et al. (2002) (or any reasonable model of fire dynamics, for that matter) generates the dynamics shown - a build up of biomass of multiple species, increased competition, a triggering event (fire), a release of nutrients, and regrowth. However, the adaptive cycle metaphor (and the associated panarchy, are more flexible and amenable to studies that emphasize social science.

4.2.3 The Adaptive Cycle

Much of the work described above relates to SESs with an emphasis on biophysical dynamics. This is natural given the roots of the resilience concept. **Early social science applications of the resilience concept were dynamic resource management problems** (Perrings and Walker, 1997; Carpenter et al., 1999b). These studies address the question of what the best strategy a benevolent social planner should adopt to maximize the social welfare from a resource that exhibited multiple stable attractors. Carpenter et al. (1999a) extend the social planner problem for lake eutrophication to include more complex political dynamics in the management process. The "multiple stable attractor" aspect of resilience has been extended in other directions, most notably regarding hysteretic effects in social systems (e.g. see Scheffer et al., 2000, 2003).

The adaptive cycle, with its inherent flexibility has been used somewhat more broadly in the social science domain than has the "multiple stable attractor" view (note the excellent example presented by Carpenter et al. (1999a) combines the two). It has often been used to descriptively to analyze cycles of change in cases studies rather than in an analytical or predictive sense. It has been used, for example, to analyze broad change in large agricultural regions (Allison and Hobbs, 2004; Evans, 2008), specific transitions (parts of the adaptive cycle) in specific SESs (Abel et al., 2006; Baral et al., 2010), and in archaeological cases (Redman and Kinzig, 2003). It has also been used to structure actual participatory processes, e.g. in promoting innovative processes (Westley, 2008).

Throughout this document we have stressed the importance of scale and the challenging problems it raises for resilience theory. For example, what one might call transformability on a given time scale is simply adaptive capacity on a larger time scale. The issue of scale has also been incorporated into the adaptive cycle via the concept of the "panarchy" (Gunderson and Holling, 2002), a set of adaptive cycles linked across temporal and spatial scales as shown in Figure 5. The idea is that fast levels generate novelty (revolt) and the slower levels stabilize the overall system and provide memory of past successful, surviving experiments with novelty(Gunderson and Holling, 2002). Thus, when the multiple levels are taken together, the whole panarchy both creates and conserves information.

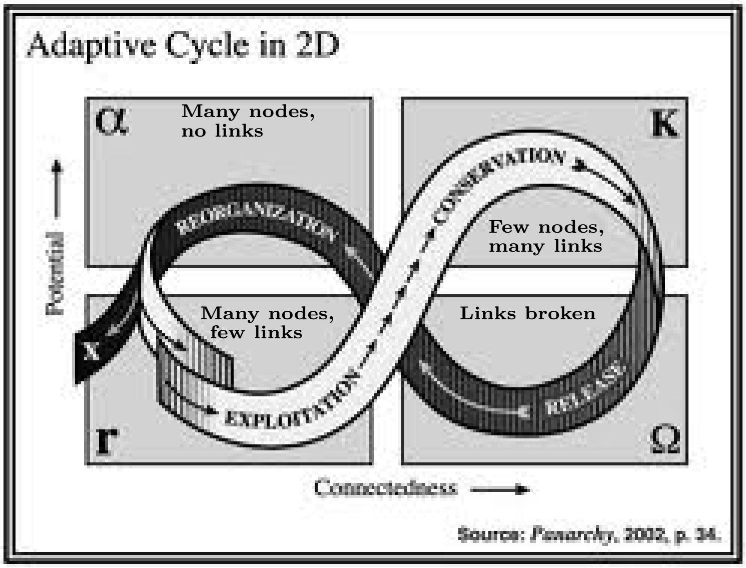

Figure 4: *Adaptive cycle diagram with network descriptions. The arrow labeled "X" indicates the potential for systems to jump between adaptive cycles at different scales. Adapted from Gunderson and Holling (2002).*

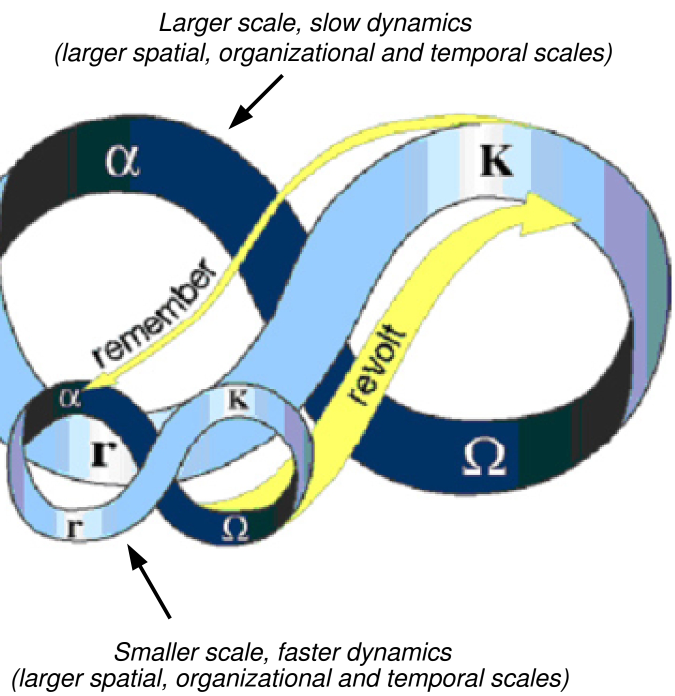

Figure 5: *Panarchy illustrating adaptive cycles coupled across scales. Adapted from* `www.resalliance.org/index.php/panarchy`.

4.2.4 Development in Parallel with Other Concepts

Beyond the examples discussed above, the application of resilience ideas in social science, are often more related to the ancillary concepts of self-organization, complex adaptive systems, "learning", and in the social sciences "social learning", that are often related to resilience in the literature. Of course, these are complex, multifaceted concepts in their own right, and social science applications in the resilience domain tend to focus on standard ideas from social sciences as the may contribute to building resilience, and how acknowledging the "complex adaptive nature" of social systems be built into governance structures to improve their performance *vis à vis* some resilience measure. Thus, such studies are motivated by the idea of resilience, but do not necessary apply the concepts underlying resilience *theory* faithfully. Representative titles of such studies would include terms like "managing *for* resilience", "managing the resilience of..", "participatory processes for building resilience", "governing for resilience". That is, resilience is and end, not the theoretical framework for the study.

Although the potential studies in social science are vast, there are three threads worth mentioning. First is the recent work the vulnerability and livelihoods tradition in geography. Vulnerability studies typically focus on the household as a unit of study. However, resilience theory with its emphasis nonlinear dynamics, multiple stable attractors with their associated thresholds, and cross-scale interactions suggests that what households do will map up to higher levels in unpredictable ways. These studies focus on how local vulnerabilities are nested and "teleconnected" by globalization (Adger et al., 2008, 2007; Eakin et al., 2009), how individual (or local) vulnerability maps up to broader system-level attributes such as sustainability Adger et al. (2010); Nelson et al. (2007); Eakin and Wehbe (2009), and how feedbacks between scales may affect the adaptive capacity of local regions (i.e. global feedbacks changes individual household behavior that then feeds back up to the intermediate regional scale) (Eakin et al., 2009).

Second is the study of the impact of social networks on resilience, both in general (Janssen et al., 2006) and specific cases (Olsson et al., 2004; Bodin and Crona, 2009, 2008; Crona and Bodin, 2006; Bodin et al., 2006). **Third is the work from the areas of institutional analysis *sensu* Ostrom (1990) and political economy that focuses on challenges associated with governing common-pool resources (or *the commons*)**. This work focuses more on the self-organizing aspect of complex systems in the sense of self-governing SESs. This work has relied on a concept related to resilience: robustness (Anderies et al., 2004; Janssen et al., 2007; Janssen and Anderies, 2007; Anderies et al., 2007; Anderies, 2006; Anderies et al., 2003). The concept of robustness is similar to resilience: the maintenance of system performance in spite of exogenous and endogenous uncertainty and change. This strain of work emphasizes the *designed* nature of human system and thus has adopted the term robustness which is typically associated with designed systems. The focus of this work is to understand how institutional and organizational structure affect the capacity of a SES to successfully govern common-pool resources in the face of pervasive uncertainty and change. It attempts to understand human decision-making behavior, how it is influenced by institutional, organizational, and biophysical context, and how it generates system level dynamics. Finally, it seeks to understand how these various factors affect the robustness of SESs. Similar to Ostrom's goal of uncovering design principles for successful common-pool resource governance (Ostrom, 1990), the institutional analysis/robustness approach seeks to uncover uncovering design principles for robust common-pool resource governance. Robustness is closely related to resilience as we shall see below.

This short history of the development of the concept of resilience is necessarily limited. It has focused key developmental threads of the concept in resilience literature appropriate to describe the social, economic and cultural adaptive capacity of communities and individuals in the context of an increasingly globalized world. The description of the resilience concept in this section has only scratched the surface. Different aspects of the resilience concept and its applications will be unpacked in the following sections. Most relevant for understanding social, economic and cultural adaptive capacity of communities are the threads relating to social innovation, relationships between resilience and vulnerability (in the context of household livelihoods) analysis, institutional analysis and the robustness of SESs.

5 Defining Resilience Across Disciplines

Defining resilience is difficult because it describes properties of either an isolated object or a *system*. We need to clarify the nature of *what* is being considered before we can ask about any property it possesses, including resilience.

The case of an object presents few problems; we can speak of anything as if it were a unified whole: an ecosystem, person, city, government, bridge, society. We can call them healthy, diseased, ineffective, brittle, strong, resilient, or vulnerable. Such view is informs the the Engineering Resilience framework, discussed in Section 5.1. It is also implicit in the historically early psychological definitions, discussed in Section 5.2; but, as discussed there, the field is increasingly situating resilience in what are, essentially, systems.

In order to define resilience in systems, however, we need to unpack the latter term. Here we use *system* to define a collection of agents and relationships among those agents. Agents are the minimal set of *actors* in the system, i.e. those entities that interact with one another. The choice of the minimal set of agents, whether it be atoms, people, or villages depends on what question will be asked about the system in question. For most systems relevant to policy science, international development, or vulnerability studies, the agent will typically be individual people or households. Then, depending on this choice and where the system boundary us drawn (again an arbitrary choice depending on the motivation for defining a system), the system can represent a household, a village, a group if villages in a catchment, a region, a nation, or the entire globe.

Given this enormous range of possible system definitions, the definition of resilience must at once be somewhat flexible and maintain the same flavor, namely, the capacity of the *system* to function in spite of external drivers (both shocks and directed change). Examples include individuals who are resilient to emotional distress, irrigation communities that are resilient to floods, pastoralist systems that are resilient to drought, an urban community that is resilient to crime, modern societies who are resilient to global economic fluctuations, or world systems *sensu* Wallerstein and The Vancouver Institute (1974) that are resilient to global climate change. Thus, in order to utilize the resilience concept, one must first answer the question "*The resilience of what to what?*" (Carpenter et al., 2001).

Unfortunately, no single discipline that we are aware of deals with systems that range across all these possible scales. Thus, different disciplines have generated their own definitions of resilience relevant to the class of problems they address. Since questions associated with the social, economic and cultural adaptive capacity of communities and individuals in the context of an increasingly globalized world involve all these scales, it is important to be familiar with a range of different uses of resilience from a range of different disciplines. Most people have an intuitive notion of resilience - the capacity to sustain a shock, recover, and continue to function and, more generally, cope with change (Walker et al., 2004). Within the scientific domain that focuses on interactions between people and the environment, "resilience" has evolved into an intellectual framework for understanding how complex systems self-organize and change over time. Carpenter and Brock (2008) have described resilience as a "broad, multifaceted, and loosely organized cluster of concepts, each one related to some aspect of the interplay of transformation and persistence."

In this section we review the resilience concept across a range of disciplines. In each case, the usage of the resilience concept is related to some aspect of the interplay of transformation and persistence and differences in definitions are mainly a matter of scale and level of precision. In our discussion, we will move from small to larger scales - starting with individual agents such as in engineering and psychology and moving up to collections of agents.

We begin with the way resilience is used in engineering because it is perhaps the clearest and simplest case. If someone were asked on the street to define resilience, they would most likely provide a definition close to the engineering one. It is unlikely that they would begin with a discussion of the relative "connectedness" and "potential" at various phases of an adaptive cycle (Figure 4), or of how the geometry of multiple basins of attraction influence the dynamics of complex systems on short time scales and how this geometry changes over large time scales (Figure 3). The serious practitioner, on the other hand, needs to understand the full range of definitions before resilience concepts can be used to their full potential.

5.1 Engineering

We look at engineering resilience not for any intrinsic interest in engineering, but rather for the reason that it provides a useful and rigorous way of formalizing a very common, colloquial use of resilience.

The use of the term resilience has a tradition in materials science, a field that applies the fundamental sciences of chemistry and physics to understanding the behavior and properties of specific materials, such as metal rods. Understanding these properties helps engineers understand appropriate materials to use for a specific purpose—from building bridges to space shuttles to furniture—and for developing new materials that better meet the needs of these purposes.

When an external force is supplied to an elastic material (a "stress"), the material changes shape and bends (the "strain"). If the force is lifted, the material will eventually return to its initial shape. For instance, if we place a weight on an I-beam, it will bend (or break); and when that weight is removed, it will straighten out (or remain deformed). Three questions about instances of this process relate to the resilience of the material. First, how much does the material bend to a given force; that is, how much does it resist being bent? Second, how quickly will the material return to its original shape? Lastly, how much stress or force can the material take such that it does not break or permanently bend?

There are terms to describe each of these features engineering (Bodin and Wiman, 2004). The first term is a measure of **resistance**, the second a measure of **elasticity**, the last describes the **stability domain** of the material. Increasing any or all three of these increases the resilience of the material to stress; however, the overarching term used to describe the combination of these properties here is not generally resilience, but rather **stability**.

Immediately we can see that stability is closely related to the colloquial usage of resilience: something is resilient if it can resist external forces, shocks, and disturbances and can quickly return to its normal state. In common usage, a resilient person is less perturbed by life stresses, including significant ones such a the death of kin or the loss of a job, and can quickly return to a normal state. A resilient economy, in this sense, will better resist a wide spectrum of economic changes, from increased taxes to a collapse of an industry, and will quickly return to its normal state. A resilient city rebuilds after a flood, tourism rebounds, and things get back to normal.

In ecology, some have equated resilience with stability (Pimm, 1984). C.S. Holling, in a critical vein, describes stability as an **Engineering Resilience** (Holling, 2009); not applicable to ecosystems, where one should look at **ecological resilience**; that is, the resilience of complex adaptive systems, defined below in 5.3.

To use engineering resilience (in any setting), one must make a number of assumptions:

- There is only one equilibrium or normal state.
- The object returns to this state after a disturbance it can handle.
- The type of disturbances are expected (Ludwig et al., 1997; Holling, 2009).

When we make these assumptions, certain key features become apparent. First, resilience can be modeled and measured by relatively simple mathematics. Second, the management of resilience can concentrate exclusively on increasing resistance, elasticity, and the domain of stability. The features of engineering resilience make plain the appeal of using it, metaphorically or more rigorously, in other fields: it is simple to understand, accords with plain usage, and generates simple management strategies.

Engineering resilience was traditionally the dominant paradigm of resilience in developmental psychology; yet the assumptions above have become increasingly questioned there. As in ecology, where the ideal of the pristine, human-free ecosystems is losing pull, the ideal of an adversity-free, linear development trajectory is similarly being supplanted.

5.2 Psychology

There are two streams of thinking about resiliency in psychology. One originates from the study of the impacts of crises and abrupt changes impact families; the other looks at how certain children, often in situations of poverty, are able to avoid falling victim to many of the traps that most of their peers do.

In brief, family stress theory, originating from the 1940s, has resilience is a property of a *family system*; you cannot assess resilience by ignoring the interactions and dynamics between family members within it, which depends, and influences, the properties those agents have. In developmental psychology work stemming from the 1980s, the definition has slowly mutated, from the engineering view to, again, a systems view. Simplicity is slowly giving way to accuracy; at the expense, however, of established empirical methods. Neither stream, however, utilizes a CASs frameworks, as discussed in 5.3.

In developmental psychology, definitions of resiliency have historically been operational; that is, they are made with respect to the very outcome being measured, rather than given independent conceptualization and definition. To determine resilience, one chooses the outcomes being measured (unemployment, criminal activity, mental illness) and the risk factors (poverty, a parent with mental illness or substance abuse issues, lack of access to adequate education); a lack of negative outcomes in those individuals subject to many risks indicates resilience.

The novelty of the approach lies not in any novel theoretical upheaval, but rather looking at subpopulations once overlooked: not the risk factors of adverse outcomes, but rather the **protective** factors of outliers that can overcome such risk.

Resilience has thus not been historically regarded as an abstract construct that can be applied generally across domains, even psychological ones. Thus, we have resilience defined as "good outcomes in spite of serious threats to adaptation or development (Masten, 2001, p. 238)." Sir Michael Rutter, an early a proponent of looking at developmental outcomes in terms of resilience says a resilient individual possess "relative resistance to environmental risk experiences, or the overcoming of stress or adversity (Rutter, 2006, p. 2)." Emmy Werner, who led a study described in more detail in 4.1, defines resilience as "good developmental outcomes despite high risk status, sustained competence under stress, and recovery from trauma (Werner, 1995, p. 89)." Resiliency here is defined with respect to a fixed ideal: the "normal" development of a child, i.e., the development of children not exposed to the adversities or risks in question.

A recent critical review of the of the concept of resilience in developmental psychology takes a different approach, defining resilience as "dynamic process encompassing positive adaptation within the context of significant adversity." (Luthar et al., 2000, p. 543). Others have likewise adopted this view: "Resilience in development is defined in relation to positive adaptation in the context of significant adversity (Masten and Reed, 2002, p. 117)." It is noteworthy that neither of these definitions make reference to "good" or "normal" development trajectories: they deny the first and second assumptions of engineering resilience. To understand resilience requires evaluating processes.

Even further towards a systems theory approach is the situating of adaptation within an organization theory of development:

> Adaptive outcomes at given stages of development derive from transactional exchanges between the child and her or his current environment, as well as from the developmental history that the child brings to these exchanges (Yates et al., 2003, p. 249).

Resilience is then defined as a ongoing process of continual positive adaptive changes to adversity, which changes enable *future* positive adaptive changes. Such definition assumes bidirectional interactions as well as recognition that the history, including previous adaptations, determine (positive) adaptive outcomes. Such views fit naturally into a systems perspective.

Within family theory, given that a family involves a number of interacting individuals, changing over time, it is not surprising that the simple engineering view was inadequate. An early and highly influential theory of resilience comes from the sociologist Reuben Hill's study of the processes of change and adaptation in war separation and reunification (Hill, 1949) . Called the ABC–X theory, it consists of noting the inputs and outputs of a family's response to crisis: A, the event, B, the resources of the family to deal with crisis, and C the understanding the family has of the event all generate X, the family's response to the event (McCubbin et al., 1980). It is now common practice to view of a family as a dynamic, open system, that adapts in response to influences from above (community support, job loss) and below (biological illness) and within the family unit (spousal abuse, feeding one's children) (Walsh, 2002, p. 131).

Resilient families are thus open systems that adapt to stress:

> A focus on family resilience seeks to identify and foster key processes that enable families to cope more effectively and emerge hardier from crises or persistent stresses, whether from within or from outside the family (Walsh, 1996, p. 263).

Conceptions of family resilience has clear parallels to ecological resilience: an increased resilience implies an increased ability to positively adapt to stress or crises, internal or external. Understanding a resilient family requires tools that go well beyond existing empirical methods. If ecosystems are best understood as complex adaptive systems, it would seem likely that a family system—or more generally kinship groups—are best understood that way, as well.

5.3 Complex Adaptive Systems

In engineering and psychology, the system under study is typically defined at the individual scale, i.e. a single mechanical structure or a single person. In this and the next section, we move to systems defined at a higher level - i.e. by groups of interacting agents. The first of these is the so-called *Complex Adaptive System* or CAS. Note that a CAS is a type of system and resilience is a property of systems. Thus, although many resilience studies involve CASs, resilience is not necessarily bound to CASs. As such, there is no definition of "resilience" from a Complex Adaptive Systems perspective. In fact, many important studies of resilience focus on model systems that are not CASs but, rather, are non-linear dynamical systems (e.g., Carpenter et al., 1999b; Anderies et al., 2002; Anderies, 2006; Anderies et al., 2006). Non-linear dynamical systems can give rise to extremely complex behavior (e.g. multiple stable attractors) even though they are not "complex" or "adaptive" (May and Oster, 1976; May, 1976). They thus provide an excellent foundation for theoretical resilience studies.

However, non-linear dynamical systems are *deterministic* in the sense that once we write down the model, its future behavior is completely determined and depends only on the initial conditions (i.e. where we chose to start the model). The fact that the future dynamics are deterministic does not mean that that this future behavior is simple or predictable. In fact, unless we know the initial conditions *exactly*, for most dynamical systems, we cannot predict future behavior, no matter how accurately we measure the initial conditions (short of *exactly*). In practice, we can never measure anything *exactly*, so for most dynamical systems, we can never predict their future behavior. This fact is at the root of some very deep discussions about the meaning of uncertainty (Ruelle, 1993). Although deterministic dynamical systems can generate behavior sufficiently complex to be of interest to resilience studies, they cannot capture key elements that are of interest to resilience scholars: novelty, and adaptation. These concepts are core to systems that evolve, and all SESs fall into this category. Thus, dynamical systems are limited to the study of SESs at a particular point in time (with a fixed configuration) and cannot capture their evolutionary dynamics.

The class of systems referred to as CASs, on the other hand, are aimed at capturing the key features of systems that do evolve. There is no widely accepted, precise definition of CAS, but Levin (1998) suggests that they have the following features:

- Sustained diversity and individuality of components
- Localized interactions among those components
- An autonomous process that selects from among those components, based on the results of local interactions, a subset for replication or enhancement

Given these general properties, one could ask questions like: Are CASs resilient? In what sense? What are the dynamic features of CASs? Do they exhibit unavoidable regime shifts on certain time scales (i.e. punctuated equilibrium theories of evolution)? Do they exhibit periodic cycles of change? That is, we can ask resilience-based questions about CASs, but CASs do not necessarily inform resilience theory. In fact, there is no well-developed theory to study CASs. In that sense, CASs provide a perspective on how systems are self-structuring over time.

5.4 Economics

Economics traditionally used basic equilibrium analysis based on dynamical systems ideas discussed in Section 5.3. Economists recognize the limitations of equilibrium analysis (which essentially eliminates the dynamics from the system and focuses on states where the dynamics are *balanced*, i.e. supply equals demand), and have increasingly begun to consider more complex dynamics. Indeed, there have been several applications in economics, mainly in the subfield of resource economics, of resilience ideas including the idea of multiple equilibria, using traditional non-linear dynamical systems ideas (e.g. Brock, 2006; Carpenter et al., 1999a,b; Perrings and Walker, 1997; Janssen et al., 2004; Brock et al., 2002). The issue of multiple equilibria has received considerable attention as well (e.g. Benhabib et al., 2001; Cazzavillan and Pintus, 2004; Fujita and Ogawa, 1982; Masson, 1999; Xie, 1994) but this work is not related to resilience, *per se*. The ideas of CASs, related to resilience as discussed in Section 5.3, have received some attention in economics as well (Anderson et al. (1988); Arthur et al. (1997)). The emphasis is on the idea of non-equilibrium dynamics and continuous change. While a clear departure from traditional equilibrium analysis that emphasizes ideas within the spirit of resilience, this work is not closely linked to resilience research.

5.5 Relating Resilience to Other Concepts

As we saw above, "resilience" has a clear definition within engineering and psychology but not so within the Complex Adaptive Systems research domain or in Economics. The term resilience also often appears with terms such as sustainability, vulnerability, and robustness. The relationship between these various terms was discussed in Section 4.2. Again, the relationships are often quite loose and are often used to describe particular ends rather than theoretical constructs, e.g. increasing resilience contributes to sustainability, etc. Likewise we described the concepts that have grown out of the resilience concept through its historical development such as adaptability and transformability. Finally we discussed the very closely related term of robustness which is typically applied to designed (at least in part) systems rather than predominantly self-organizing systems where resilience is more commonly used. However, there are two terms, adaptation (which is different than "adaptive capacity") and coping that deserve further attention.

5.5.1 Adaptation

Adaptation is adjustment in the face of change. It may be positive, negative, or neutral. Change may be based on immediate conditions, knowledge of past conditions, or new information about predicted conditions. A person, society, or species can adapt.

As opposed to adaptive capacity (or adaptability), a property of a complex adaptive system, the use of "adaptation" and "adapt" spreads far and wide. It is a key concept of evolutionary theory: if it is true that a species adapts to its environment, rather than being made for it, then one can look at the mechanism of adaptation. Wallace and then Darwin developed a theory of such mechanisms. The term also appears in a great deal of psychology, including some discussed above. It is related to coping, a certain type of adaptation process, discussed below in Section 5.5.2.

Regarding subjects of interest in this review, the term has been employed most heavily in the climate change literature, with varying relationships to adaptive capacity, resilience, and vulnerability. Some key definitions:

> [Adaptation is] an adjustment in ecological, social or economic systems in response to observed or expected changes in climatic stimuli and their effects and impacts in order to alleviate adverse impacts of change or take advantage of new opportunities (Neil Adger et al., 2005, p. 78).

> Adaptability refers to the degree to which adjustments are possible in practices, processes, or structures of systems to projected or actual changes of climate. Adaptation can be spontaneous or planned, and can be carried out in response to or in anticipation of change in conditions (Smith et al. (2000, p. 228), citing Lovett (1997)).

> Adaptation refers to adjustments in ecological-social-economic systems in response to actual or expected climatic stimuli, their effects or impacts (Smith et al., 2000, p. 225).

A few points about these definitions are worth noting. Smith et al. (2000) emphasizes that, when discussing a particular adaptation or proposed adaptation, one needs to answer: (i) Adapt to what? (ii) What adapts? and (iii) How does it adapt?

Although these questions clearly apply generally, we will focus on answering them in the context of climate change. With respect to the first question, the definitions make clear that adaptation is not *to* climate change. It is to "observed or expected changes of climate", "projected or actual changes of climate", or "actual or expected climactic stimuli"; that is, to climate conditions that have changed, or are expected to change. Since climate is a regional or local notion, and climate change is a global one, these apply only to actual or potential *effects* of climate change. In climate locales, such changes may create increasingly hot summers in places, or storms of a previously unexperienced magnitude.

Towards answering the second question, consider the following example of a recent adaptation (Neil Adger et al., 2005, p. 78): in response to a series of hot summers in Britain, the sales of cars and air conditioners has increased. What has adapted here? The individuals who buy these products have adapted, clearly. In addition, the businesses that sell air conditioners and autos; and there are further downstream adaptations by economic, energy, and transportation systems. There are notable differences between the sorts of adaptation each of these subjects has undergone; an answer to the third question will differentiate them.

Smith et al. (2000) provide a useful typology of adaptation responses: passive, reactionary, or anticipatory; and spontaneous or planned. In our example, the individual consumer's adaptation was reactionary (they did not buy air conditioners prior to the increasingly hot summers) and planned (they made a decision to do so based on climate conditions). From the perspective of other entities, such as Britain's energy production and distribution network, an adaptation to the changed climate would be passive, given they did not anticipate the increased energy needs based on the climate alone; the increasing demand would generate spontaneous changes, but any changes made in response to this network (increased costs to consumers, development of new power plants, and so forth) would be planned adaptations.

Adaptation due to climate change thus fundamentally describes *behavior*; it does not evaluate it. Behavior may reflect short or long-term perceptions of local climate conditions. Adaptation may be undertaken by individuals, communities, regions, sectors, or policy-makers. It may be done spontaneously or planned for; in respect of current or past climate history, or future predictions of climate.

Adaptation does not imply accurate predictions; nor does imply rational responses. However, the normative goal of adaptation *research* is, however, an understanding of how to align adaptation with the actual impacts of climate change, both short and long-term:

> The whole point of the work on adaptation processes is to have risks (and opportunities) associated with climate change (or other environmental changes) actually addressed in decision-making at some practical level (Smit and Wandel, 2006).

How, then, does adaptation relate to resilience? To increase adaptive capacity of a system to climate change, as defined above in Section 5.3, would require adaptation that accurately and efficiently responds to climate change risks. That would require adaptation processes that are anticipatory; that act on the best models of climate change impacts; and that are effective in creating systems that are able to maintain their state in response to the unexpected crises arising from climate change. Increased adaptive capacity, through such adaptation, increases resilience of the system in question at that time.[11]

[11] The assumption is that people, business, and institutions all want to sustain the same things, theoretically in perpetuity; different rational adaptive strategies would emerge if values conflict.

It should be noted that two other variants of "adaptation" can be found in the climate change literature. First, it may be used in the sense of "actions that increase adaptive capacity with respect to climate change." Secondly, it is occasionally used to describe what is otherwise termed mitigation of climate change (e.g., in Parry (2002)); that is, to describe changes made in order to lessen the extent of climate change or related climactic events.

Finally, "climate change" can be replaced in the definitions and relationships above, *mutatis mutandis*, with other events, adverse or not: immigration, novel technology, water scarcity, increased taxes. What "positive adaptation" means in some of these cases is up for debate. It requires an answer to the question: what is it that should be sustained?

5.5.2 Coping

Coping as a theoretical construct began with the studies of the psychologist R.S. Lazarus (1966), whose view of the coping process is still the basis for current research (e.g, Swanson (2000); Sowa (1997); Matthews and Zeidner (2003)). Lazarus took coping to be an iterative process associated with three actions: *primary appraisal*, whereby one perceives a threat; *secondary appraisal* is the consideration of the appropriate action; and *coping*, which is when one carries out that action (Carver et al., 1989).

Some properties of coping should be noted. First, the process is iterative: one may reassess the magnitude of a threat based on the sorts of actions one may take; or one may reassess one's action in the event of failure to execute a coping strategy; or finding the outcome of one's action an inadequate response. Second, the action taken may itself be cognitive in nature: one can respond to a threat by adjusting something one believes, by, for instance, denying the threat exists; or, by changing evaluative beliefs, such as viewing what once seemed threatening as as beneficial and useful. One may problem solve by finding a way to mitigate a threat, or by taking a risky and hasty action. Whether such processes are beneficial or harmful to the individual, employed in an individual instance or chronically, is left open by the definition.

Generalizing this, coping can be seen as the process of individual, intentional change in response to a stressor. We may, of course, consider other subjects as coping besides an individual, but such entity or system must have both some cognitive or information-processing capabilities and agency: the ability to assess threats, evaluate options, and act on them; an ecosystem would not be such a system, but a social-ecological system would, as would an organization or government. The latter have mechanisms for threat and response evaluation, as well as the capacity to act on the chosen response; thus, they may be said to cope with a threat, stressor or crisis.

To consistently use a coping strategy (i.e., to have a disposition to cope in a certain way) will factor into the present resilience of a human or managed system; and to act on a certain coping strategy in response to a threat may change the operation of the system going forward.[12]

6 Justifying and Employing Resilience

While the above elucidated the origins of the concept of resilience, as well as how it has been defined and used, here we try to distill these findings in generality. To do so, we answer the following questions:

1. Why employ the concept? What justifies its utility?

[12] Like adaptation, unless all values are shared, and there is a clear vision of the future, what constitutes a *positive* coping strategy will be contested. Even denial has its benefits.

2. What contributes to resilience?
3. How is resilience assessed or measured?
4. What management strategies or policies should be adopted to modify resilience?
5. When should one increase or decrease resilience, based on one's values?

The concept of resilience has been used to investigate the response to surprise, crisis, or change generally, to any number of objects: individuals, materials, built structures, species, cells; to many types of systems: families and communities, economies, ecosystems, legislatures; and, increasingly, to many types of dynamic systems, or systems that span multiple scales: social-ecological systems, political-economic systems, community-family systems. Certain systems end up being complex, in that they are both non-linear (cannot be used for predictions) and they involve the interaction of internal elements; some may even be adaptive, in that they are capable of self-organizing behavior; i.e., the systems evolve.

Anything can be conceptualized as an object, as part of a system, or as part of a complex adaptive system. An ecosystem can be considered a solitary object, ascribed properties independently of internal parts (e.g., "thriving", "vulnerable"), and a human as a complex adaptive system, encompassing a dynamic interplay of psychological, physiological, and environmental systems. These various conceptions, the object, system, and dynamic system, are subject-neutral.

Below, we answer the questions above across these spectrum of conceptualizations. Differences and trade-offs will emerge between approaches, but so will consistencies. Examples come from specific fields that conceive of their subject somewhere along this spectrum; but this should not lead one into thinking that they *need* to conceive of their subject this way. Resilience is perspectival.

What, then, should guide a choice of perspective? Which type of resilience matters? Pragmatically, this will come down to what one's goals are, how much simplification one is willing to accept, and how much one wants "hard numbers" to measure success or failure. Whether establishing indicators, assessing and measuring resilience, and managing for resilience, one needs to choose a perspective. To use resilience requires answering, first of all, "Which kind of resilience?"

6.1 Is the Resilience Concept Useful?

In studying individual objects, including persons, using resilience can fill in a *knowledge gap*: there is important information captured by studying resilience, information that is traditionally not studied or left out.

In many traditions, planning for adversity meant avoiding adversity if possible; decreasing the risk of such if not; and getting quickly back to normal after adversity. Little attention was paid to the object of adversity; what is being subject to rapid, potentially destructive change? The resilience perspective here does so: increasing resilience makes something or someone better manage with shock; advertises will be less harmful, less likely to end up in catastrophe or loss of function.

Having such knowledge gives managers and policy makers an *additional* tool in their arsenal to prevent catastrophic change. Reduce the of risk of crisis, increase the rapidity of responses to them, and increase the ability of something to withstand, stay functioning, during a crisis. The thinking is simple, but the implications are often ignored. Why such a blind spot exists is an interesting question, but better left to historians of science and cognitive psychologists.

The second justification, from which **resilience thinking** arises, goes further than the first in questioning existing practice: it holds that existing methods for understanding, maintaining, and restoring function in the face of crises are based on flawed assumptions. Risk reduction, crisis response, and resilience are not independent variables. One shouldn't address all three separately, for there are surprising relationships between them: certain types of risk reduction and crisis response can *decrease* the resilience of these systems to future crisis. Resilience in this latter case is not an add-on; it first requires reconceptualizing one's subject.

6.1.1 Studying Resilience to Fill a Knowledge-Gap

Resilience can fill in a knowledge gap: something previously overlooked, assumed to be anomalous, actually can shed light on a common, and indeed quantifiable, phenomenon. We discuss its use in developmental psychology of high-risk youth, but this should only be taken as an example.

Resilience in the study of developmental psychology is distinguished not by its focus on adaptation in general, but rather adaptation in the presence of adversity or in high-risk conditions (Luthar and Cicchetti, 2000). Its key findings relate both to correlations of protective factors that, jointly, determine resilient children (those with no negative outcomes by some measure), and to identifying specific protective factors that relate to specific outcomes.

Risk-factors include both chronic ones (e.g., poverty, a mentally ill parent) and acute ones (e.g., being a victim of violence or abuse). The results of such research have "... overturned many negative assumptions and deficit-focused models about the development of children growing up under the threat of disadvantage and adversity (Masten, 2001, p. 227)." Such deficit models established risk factors for negative outcomes; it showed how poverty was likely to harm; the focus was to work on identifying common deficits (e.g., mental illnesses) and boosting rehabilitate efforts.

Masten goes on to note that many prior popular accounts of resilience in a setting of poverty and high-risk tended to speak of "invulnerable" children, those who *thrive* in adversity; the assumption was that such children were, inherently and unchangingly, exceptional. This is the psychological analog of "engineering resilience": someone's resilience is fixed by the material they are made of.

Were these resilient children just a chance occurrence of reproductive biology, it wouldn't be possible (or, if possible, ethical) to boost their numbers. However, research has found robust connections between a number of environmental factors, such as family rearing methods, educational setting, work-life policies, and other places where clinical intervention or policy-based is possible (see Sections 4.1, 2.5 and 2.7). These *protective factors* are a complement to the *risk factors*.

The general lesson from this findings can be summarized as follows: Even in adversity, it's the ordinary, the routine, that makes resilience. This has some resonance with even the systems approach: *slow* variables go a long way towards resilience, the ones that are often hidden in time of relative stability.

6.1.2 Studying Resilience to Correct Knowledge

The first slogan of resilience thinking is to "embrace change". We can even relate this to developmental psychology, expanding on the above. Consider *low-risk* children. We can ask the same question as above: what would increase their resilience to significant adversity, if they faced it? A high-risk child who failed to succumb to adversity did *suffer* adversity; they have changed through the process of doing so. Someone who is low-risk perhaps has not, and a small disturbance may cause significant, long-lasting harm. Thus a parent may think to give their child more and more responsibility, subjecting them to more and more risk, and thus, sometimes adversity. Allowing some adversity to strike can (but obviously need not) encourage resilience.

Such thinking is, again, common sense in one domain, but is only recently being applied to others. Traditional forest management, for instance, focused on preventing fires; this made the forest more vulnerable to future fires, causing significantly greater damage and perhaps pushing the ecosystem (crossing a **threshold**) into a state where it could never recover (see (Pyne, 1984) for an overview). Overuse of antibiotics has given rise to increasingly resistant strains; trying to preventing infectious diseases across the board, especially in those whose physiology is such that they can recover unaided, may make everyone more vulnerable in the future (Neu, 1992). Methods which attempt to prevent *all* crises, to sustain in the short-term, can decrease resilience in the long term.

"Embracing change" (Walker and Salt, 2006) captures this phenomenon: what one has before and after will not necessarily be identical, but they can serve the same *function*; change in response to adversity is normal, not material identity or keeping every part fixed. Change in stability, too, is normal. But secondly, it means that some disruptions and changes of *parts* or *subsystems* of systems can be beneficial; suppressing them can be harmful when future crises strike. The forest's **adaptive capacity** can handle routine fires; such capacity requires parts of it to be **transformed**, but the forest only adapts; it doesn't transform into a different, undesirable state. But its adaptive capacity often cannot handle the larger wildfires that come from attempts to prevent all fires; in response to such fires that do erupt, many parts still transform (e.g., burned trees), but so, unfortunately, does the entire forest, into something quite different.

To study resilience in the context of systems that change in response to adversity, where some adversity is *necessary* for sustaining functioning in the long-term, requires understanding the nature of adversity that builds or sustains resilience, versus the catastrophic kind. If you understand this, then trying to bolster resilience comes down to two things: letting the system mutate but retain function in response to some adversities, and preventing and mitigating the risk of those adversities that current resilience cannot handle.

This view—a linear systems view—assumes, however, we can *predict* the nature and extent of adversity. Unfortunately, for most systems we are interested, they are complex: prediction is, in essence, impossible. Making sure only adversities that can be handled is impossible. Climate change will cause unknown effects; we can roughly say of what kind, but we cannot understand much about their magnitude, duration, or location.

To understand (and accept) this inherent unknowability (perhaps indeterminacy) is to "Embrace Complexity": simplified models don't account for all changes, and thus give faulty predictions; and management decisions that can result in unwanted effects. We must live with not only present uncertainty, but uncertainty as a fundamental limitation to how much we can understand our world. To accept resilience thinking boils down to embracing change and embracing complexity. It is a big picture approach, which can theoretically encompass everything that exists. How exactly these mantras translate into effective management strategies or policy is a question addressed in the next three sections.

6.2 Correlations

Resilience is not visible; it is a theoretical construct, a dispositional property that relates to an individual's or system's response to future possible events. In order to get a grip on it, one must be able to relate resilience to other properties that one has some means of ascertaining, through observation, directly or mediated by additional theory.

When looking at individuals, the usual method is based on traditional statistical analysis. Developmental psychologists have used this to good effect: Data is collected on risks and adversities faced across some time-frame; environmental and individual characteristics during this same time-frame; and positive or negative outcomes (Masten, 2001). Interviews using inventories are common means of data collection, in addition to relevant public, educational and medical records.

If the study is variable-based, analysis of this data can provide one with correlations between environmental characteristics and the likelihood of overcoming certain adverse events. In systems terminology, such studies provide **specified resilience** (Folke et al., 2010), that is, it specifies the relationships between specific adversities or risks and a specific protective factors.

Longitudinal studies, such as the 32-year study of 608 children born in one year in Kauai (Werner, 1995), separated individuals at each follow-up into a resilient and non-resilient group, based on the presence of *any* adverse outcomes (this was after they first sought risk factors). They were seeking **general resilience**. The results of the study were surprisingly robust, and a number of the findings have been confirmed in other, admittedly Western, populations.

Finding such correlations is the basis of assessment across a range of social-science fields, as well as in some forms of engineering, such as safety assessment. Depending on how one conceives of the subject, this method can be used anywhere one can collect appropriate indicators: measure an ecosystem's response to pollution, based on identifying various adverse outcomes and finding relationships with pollution level, location, or season; assess well-being of those in poverty in response to a tax credit aimed at them; look at history or perform tests to determine the ability of infrastructure to withstand various types of climactic events.

When we expand our view, and the management target is a system rather than an object or individual, such methods do not translate easily. Human actions and the economic system both interact and respond to each other; modifications of the federal funds rate affects economic indicators, which effects future rate changes. A destructive pathogen that strikes a number of families will affect their community, which may respond either by increasing supportive medical resources, or being itself unable to respond, if enough families are infected; the community response in turn affects the health of the families themselves.

At such level, one needs to look at systems properties; to do so requires a model that describes the system in enough detail to capture interactions within and across scales. If the mathematical model is linear—can generate predictions—then one can calculate its change in response to various shocks, human actions, changes in feedback mechanisms, and so forth. Such a system has various inputs which represent current conditions: e.g., in economics, one might consider the current employment level, the current federal funds rate, and the consumer confidence index. Such systems are conceived of as designed (see Section 4.2.4).

In linear systems, the indicators of resilience are those properties—those particular inputs or decisions—that one can mathematically show lead to the ability to withstand a selection of anticipated kinds of shocks. The modeling process can be done deterministically or probabilistically: we may not know either outcomes in certitude, or the extent or time of the shocks anticipated, but one can boost the system's chances of surviving such shocks: increasing resilience to promote sustainability in the face of uncertainty.

For those systems that one can't use mathematical models to predict, the following have been identified as key correlates of resilience in systems:

1. Responsiveness of regulatory feedback mechanisms.

2. Modularity of interactions between parts, entailing failure containment.

3. A diversity of mechanisms for a given function (redundancy)

For complex adaptive systems—systems with heterogenous interacting parts that can generate certain forms of self-organization—there is a forth property:

4. Endogenous self-organizing behavior (all from Walker and Salt, 2006).

These are, however, heuristics; complex adaptive systems are difficult to define, yet alone derive results from. The above is actually close to the definition of a CASs, essentially making the definition of resilience operational. Furthermore, for adaptive systems, those that posses the fourth property above, resilience can only be assessed at times where adaptive change and novelty are silent. Novelty changes relationships, and there is no method for comparing resilience between two *different* systems. It is notable that *all* of these correlates imply a *decreased* efficiency. The "Command and Control" approach, the antithesis of resilience thinking, is often motivated by increasing efficiency: if we understand the system, we should work to decrease the amount of waste (redundancy, overlap).

What the terms "System","Function", "Network", "Mechanism", "Feedback", "State" refer to will be dependent on the particular system being modeled, including the *kinds* of shocks anticipated. The items above are not, strictly speaking, correlates, but rather correlate-types: particular instantiations or mechanisms need to be identified before resilience can be assessed. Looking to history is often necessary to establish the values of these parameters (feedback responsiveness, diversity of failure mechanisms, etc.), as they often become manifest only over time, not just in current conditions.

6.3 Assessing Resilience

Where correlates of resilience are available, and identified via interview (as in an individual or family), internal assessment (as in an organization), or simple observation and common knowledge (as in noting if certain social or political institutions exist), a scale-based rating is the simplest means of resilience assessment. This check-the-box-and-add approach has the advantage of being both easy to compile and easy to ascertain progress or regress across time, especially in response to some resilience management-strategy. One gets a number, and can compare the resilience of two different objects, or the same object two times.

If a system can be modeled by a set of linear differential equations, one can solve the set and test the responsiveness to the system to various sorts of shock, as one would a circuit to various sorts of input. Assessing the resilience of a non-linear or complex adaptive system requires a different approach. No numbers can be calculated. Indeed, if adaptive behavior occurs, one can't even tell whether resilience is increased or decreased. Yet management must be guided by *some* course, if sustainability is the goal.

Using the above heuristics, the Resilience Alliance's Workbook for assessment of resilience in Social-Ecological Systems (SESs) (Gunderson et al., 2010) provides us a good example of how such an assessment would go:

- Identifying the system or systems, including answering the question "Resilience of what, to what?" This involves both setting limits on analysis (what systems are we concerned with?) and clarifying goals (which sorts of outcomes are we trying to avoid?).
- Describing the processes of change, such as **adaptive cycles** (Section 4.2.3), that drive each system, and identifying how far each system can be pushed before it collapses or changes states (i.e, crosses a **threshold**). Both theoretical information and historical information are essential here.
- Explaining the dynamic cross-scale interactions (or lack thereof), such as positive and negative feedback relationships. Again, theory and history might both be needed.

- Understanding how key actors and stakeholders themselves are related to the system being managed; this includes understanding the process of translating policy into action, the sources, reliability, and flow of information, and the specific objective and values that each has. That is, the managers are themselves considered as part of the system being assessed (see below).
- Finally, acting on the previous information to develop both policy targeted towards increasing the resilience of the system, given the limitations, practical and political, of what can be modified.

The process is iterative in that understanding some parts will require adjustments to others, and the expectation is that some equilibrium will be reached. It is ongoing, as well, both because new knowledge about the system is gained, and as adaptive, self-organizing behavior changes the system.

6.4 Managing Resilience

Based on the above, management is fairly straightforward: for those correlates that one can change, alter them so as to generate an increase in resilience. Depending on the particular relationship between the correlate and resilience assessment, this can be as simple as considering each correlate in isolation, or trying to maximize the effect of changes in groups of correlates. The latter case is necessary when certain changes to one related variable have repercussions on others: when there is feedback, for instance, or where statistical analysis has been detailed enough to establish intra-variable effects.

In complex systems, one must also, to reiterate what has been said in many other places in this document, answer the question: "resilience *of* what, *to* what?" before the notion makes any sense. The workbook above also highlights a type of strategy adopted by some complex systems theorists: considering the role of the manager in a broader system that *includes* the manager. Why? Because, like the system being managed, there can be unexpected repercussions to a direct implementation. If a population in a democracy or advocacy group is likely to react harshly, and negatively, to what otherwise would be the best management decision, making it impossible to implement, then ultimately this would be the *wrong* decision. Some more insight into *managing within* complexity is provided in Section 2.2.

Finally, one might wish to *transform* the system—that is, have it *lose* its current function, and switch into a new one. In the example detailed in Section 2.8, one wants to transform the economic system that has two equilibria—the impoverished one and the prosperous one—to change into a system with one. However, what is transformation and what is a change in resilience depends only on perspective; see Section 4.2.2. Thus managing for transformation is fundamentally the same as managing to increase resilience, when the system is viewed at a different scale.

6.5 Normative Considerations in Resilience Thinking

Disagreements may arise as to the desirability or not of *what* is to be sustained: a business may wish to be resilient to change, but the organization may be viewed from the outside as harmful. Such conflicts naturally arise, but the more nuanced problems involve the possibility that all sustainability goals, even agreed upon ones, may not be concurrently possible. Often this is a matter of desirability given limited means; not everything can be sustained at once, because human resources are limited. But it may also be a feature of the system in which we live: current valued ecosystems and current valued types of transportation—e.g., the automobile—may be jointly unsustainable. Choices will likely need to be made—internally, between powerful groups, or as a society—about what should be sustained. Resilience does not provide an answer to this question, and managing for resilience will need to address it.

That is not to say that all sustainability goals are necessarily negatively related. There are sometimes also *positive* links between sustainability goals: a number of examples highlight how managing ecosystems for sustainability *requires* empowering marginalized groups, instituting structures of responsibility, and promoting social justice (Lebel et al., 2006). This does not mean, of course, that this is the best *way* to achieve those latter goals; it shows that trade-offs would become less severe, but they would likely still exist. One needs to answer not just "Resilience of what?" and "Resilience to what?", but "Resilience for whom? (Lebel et al., 2006, p. 21)"

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