Comparing Ecological and Human Community Resilience

CARRI Research Report 5

Community & Regional
RESILIENCE
Initiative

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COMPARING ECOLOGICAL AND HUMAN COMMUNITY RESILIENCE

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RESEARCH FINDINGS ABOUT COMMUNITY AND REGIONAL RESILIENCE

One of the commitments of the Community and Regional Resilience Initiative (CARRI) is to understand what resilience is and how to get there, based on research evidence.

As one resource for this effort, CARRI has commissioned a number of summaries of existing knowledge about resilience, arising from a number of different research traditions. This paper is one in a series of such summaries, which will be integrated with new resilience explorations in several CARRI partner cities and with further discussions with the research community and other stakeholders to serve as the knowledge base for the initiative.

For further information about CARRI's research component, contact Thomas J. Wilbanks, wilbankstj@ornl.gov, or Sherry B. Wright, wrightsb@ornl.gov.

COMMUNITY AND REGIONAL RESILIENCE INITIATIVE

Oak Ridge National Laboratory's (ORNL) Community and Regional Resilience Initiative (CARRI) is a program of the Congressionally funded Southeast Region Research Initiative. CARRI is a regional program with national implications for how communities and regions prepare for, respond to, and recover from catastrophic events. CARRI will develop the processes and tools with which communities and regions can better prepare to withstand the effects of natural and human-made disasters by collaboratively developing an understanding of community resilience that is accurate, defensible, welcomed, and applicable to communities across the region and the nation.

CARRI is presently working with three partner communities in the Southeast: Gulfport, Mississippi; Charleston / Low Country, South Carolina; and the Memphis, Tennessee, urban area. These partner communities will help CARRI define community resilience and test it at the community level. Using input from the partner communities, lessons learned from around the nation, and the guidance of ORNL-convened researchers who are experts in the diverse disciplines that comprise resilience, CARRI will develop a community resilience framework that outlines processes and tools that communities can use to become more resilient. Of critical importance, CARRI will demonstrate that resilient communities gain economically from resilience investments.

From its beginning, CARRI was designed to combine community engagement activities with research activities. Resilient communities are the objective, but research is critical to ensure that CARRI's understanding is based on knowledge-based evidence and not just ad hoc ideas—we want to get it right. To help with this, CARRI has commissioned a series of summaries on the current state of resilience knowledge by leading experts in the field. This kind of interactive linkage between research and practice is very rare.

In addition to its partner communities and national and local research teams, CARRI has established a robust social network of private businesses, government agencies, and non-governmental associations. This network is critical to the CARRI research and engagement process and provides CARRI the valuable information necessary to ensure that we remain on the right path. Frequent conversation with business leaders, government officials, and volunteer organizations provide a bottom-up knowledge from practitioners and stakeholders with real-world, on-the-ground, experience. We accept that this program cannot truly understand community resilience based only on studies in a laboratory or university. CARRI seeks to expand this social network at every opportunity and gains from each new contact.

www.resilientUS.org

LIST OF RESEARCH PAPERS BY NUMBER

CARRI Report 1:	Susan L. Cutter, Lindsey Barnes, Melissa Berry, Christopher Burton, Elijah Evans, Eric Tate, and Jennifer Webb, *Community and Regional Resilience: Perspectives from Hazards, Disasters, and Emergency Management*, September 2008.
CARRI Report 2:	Susanne C. Moser, *Resilience in the Face of Global Environmental Change*, September 2008.
CARRI Report 3:	Craig Colten, Robert Kates, and Shirley Laska, *Community Resilience: Lessons from New Orleans and Hurricane Katrina*, September 2008.
CARRI Report 4:	Betty Hearn Morrow, *Community Resilience: A social Justice Perspective*, September 2008.

ABSTRACT

Ecological resilience, adaptive cycles, and panarchy are all concepts developed to explain abrupt and often surprising changes in complex socio-ecological systems prone to disturbances. These types of change involve qualitative and quantitative changes in system structure and processes. This paper compares theories of ecological resilience, adaptive cycles, and panarchies between ecological and human community systems. At least five ideas emerge from this comparison. One is that both systems demonstrate the multiple meanings of resilience—both in terms of recovery time from and capacity to absorb disturbances. The second theme is that both systems recognize the role of diversity in contributing to resilience. The third theme is the role of different forms of capital. The fourth is the importance of cross scale interactions. The fifth theme involves the need for experimentation and learning to build adaptive capacity. All of these have broad implications for attempting to manage complex systems with human and ecological components in the face of recurring natural disasters.

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1. INTRODUCTION

On the morning of August 29, 2005, Hurricane Katrina moved inland from the Gulf of Mexico and quickly moved over the city of New Orleans. The storm surge, rainfall, and winds resulted in massive flooding and loss of life and property. It also reminded us of failures by humans attempting to control nature. That control took the form of a complex levee and canal system that was design to withstand flooding of the Mississippi and surrounding lowlands. The storm surge of Hurricane Katrina raised water levels in the sound east of the city, causing levees to fail and subsequent flooding in the city.

The flood damaged components of the coupled social-ecological system at a variety of spatial and temporal scales. Fifty levee breaches were recorded, and much of the levee system needs to be rebuilt. Homes and other municipal infrastructures were destroyed by the flood, with losses estimated at greater than 50 billion U.S. dollars (Kates et al. 2006). More than 1500 lives were lost, and some (estimates of up to one-third) of population of the city has moved away following the storm. While some portions of the system were irreversibly changed, other portions have recovered at different speeds (Kates et al. 2006). Just as temporal scales of recovery are variable, so are the spatial scales of impacts and recovery. At the smallest of scales, vegetation patches are recovering, as are some individual homes. Neighborhoods, especially the downtown business districts, have bounced back, as have components of regional energy production. The U.S. federal government, which takes a lead role in disaster relief, however, was seen as slow to react and incompetent.

This vignette of natural disaster reveals many of the problems, issues, and challenges facing planners and managers who attempt to understand and manage disasters in human communities (Pelling 2003; Adger et al. 2005; Barthel 2005; Elmqvist et al. 2003; Janssen et al. 2006; Scheffer et al. 2003). From a systems perspective, many natural disasters can be viewed as perturbations or disturbances to a human community system. The speed, severity, and complexity of natural disasters continually challenge the ability of society to generate fitting responses. Kates et al. (2006) suggest that planning for such disturbance may involve trade-offs between adapting to short-term, common events and larger, perhaps costlier disturbances that occur over a longer time horizon. While managers can anticipate some of the types of impacts associated with different disturbances, there is a lot that can’t be known, foreseen, or predicted. Hence fitting responses must include anticipating the unexpected, and never-before-experienced effects and impacts (Holling 1978; Walker and Salt 2006). Also, it is important to understand how previous actions and extant structures may contribute to increased and unforeseen vulnerability (Holling 2001; Kates et al. 2006).

Human communities are systems dominated by people but have extensive ecological components. They can be viewed as complex, adaptive systems (Alberti and Marzluff 2004; Barthel et al. 2005; Elmqvist et al. 2004; Liu et al. 2007). Complex adaptive systems are not easily analyzed or understood but rather characterized by emergent properties, self-organization, historical patterns of abrupt, non-linear change, and unpredictable dynamics (Costanza et al. 1993; Holling 2001).

One premise of this article is that human communities and ecosystems can be characterized using a systems perspective. That is, they are both systems in the sense of being comprised of internal structures and processes, which are in turn subject to external variation or perturbations. By conceptualizing both as systems, then emergent, systemic properties such as resilience or adaptive capacity can be compared. The extent of the similarities and differences between these systems is explored in this article.

The remainder of this article is structured in four sections. The first section describes theoretical frameworks largely derived from study of ecological systems. That ecological literature describes different models and metaphors of change in systems over time, including resilience and adaptive capacity of ecological systems, and adaptive cycles and panarchy models. The second section describes how understanding of ecological resilience applies to human community systems and disasters, in context of anticipation of events, understanding vulnerabilities to change, developing adaptive responses, as well as robust renewal and recovery. The third section attempts to tie together these ideas by using a systems perspective on how community resilience could be fostered and maintained. The final section presents some insights on key similarities and important differences between the ecological and human community resilience.

2. ECOLOGICAL THEORIES OF CHANGE

2.1 Resilience and Adaptive Capacity

Resilience can be traced to the Latin word resalire, which translates to “walking or leaping back” (Skeat 1882). As such it has the meaning in many different disciplines as the capacity to rebound or recover after a shock or event. Some scholars use the term resilience to describe the amount of time needed to recover following an external force or perturbation. Holling (1996) distinguished two types of resilience that have been applied by ecologists; one is engineering resilience and the other is ecological resilience. Engineering resilience is the time to recovery—how long an ecosystem takes to recover following a disturbance. Ecological resilience was first described by Holling (1973) to describe two different aspects of change in an ecosystem over time. His (op.cit.) first characteristic of resilience involved the “the persistence of relationships within a system and the “ability of systems to absorb changes of state variables, driving variables and parameters, and still persist.” The second defining characteristic described resilience as “the size of a stability domain or the amount of disturbance a system could take before it shifted into alternative configuration” (op cit.). These two views of resilience are not incompatible, yet the major difference is whether or not the system of interest returns to a prior state or reconfigures into something very different.

Ecologists who work in disturbance-driven ecosystems found that ecological resilience was a more applicable concept to the complex changes that they were observing. These scientists observed qualitative changes in both the structure and function of ecosystems (Gunderson 2000; Scheffer and Carpenter 2003; Folke et al. 2004) or the ecological regime or identity (Walker et al. 2006; Walker and Salt 2006). Many examples are recorded. Walker (1981) and Dublin et al. (1990) found dramatic shifts between grass dominated and shrub dominated in semi-arid rangelands that were mediated by interactions between herbivores, fires, and drought cycles. Scheffer and Carpenter (2003) describe two alternative states (clear water with rooted aquatic vegetation and turbid water with phytoplankton) in shallow lake systems. Gunderson (2001) described shifts in wetland vegetation as a result of changes in nutrient status and disturbances such as fire, drought, or frost. Coral reef systems shifts between coral domination and macro-algae domination have been demonstrated (Hughes 1994; Nystrom and Folke 2001; Bellwood et al. 2004). Many pathways have been documented for this phase transition, including overfishing and population decline of key grazing species, increase in nutrients, and shifts in recruitment patterns (Hughes et al. 2003). Estes and Duggin (1995) and Steneck et al. (2004) have shown how near-shore temperate marine systems shift between dominance by kelp and sea urchins, as a function of the density of sea otters and other grazers. At even larger scales, the transition between the Sahara and Sahel has been described as regime shifts (Foley et al. 2003) and is driven by internal and external factors.

Ecological regime shifts have been observed in hundreds of cases, including marine, freshwater, and terrestrial ecosystems (Gunderson and Pritchard 2002; Scheffer et al. 2001; Folke et al. 2004; Troell et al. 2005). In all of these systems, the transitions among regimes, or the resilience of the system, can be traced to a small number of variables, including biological and physical controls and recurring larger scale perturbations (or disturbances). A key insight is that ecological resilience is mediated and lost due to the interaction of variables that operate at distinctive scales of space and time (Holling 1986; Holling et al. 2002), which is discussed in the following paragraph, followed by a section on adaptive cycles and panarchy.

One source of ecological resilience is provided by the biodiversity within an ecosystem (Peterson et al 1998; Holling 2001). In this case, biodiversity refers to the range of organisms and the roles or functions that the different species perform within an ecosystem. For example, some plants fix nitrogen in ecosystems, other plant species have differential tolerances of droughts, different plants provide different sources of food for other organisms (some eat leaves, some eat shoots, some eat shoots and leaves). Tilman and Downing (1994) and Tilman et al. (1996) demonstrated how the loss of biodiversity decreased the rate of system recovery (engineering resilience) following droughts. Walker (1992) and Walker et al. (1999) showed that functional attributes of species and redundancy of those functions provide ecological resilience. In animal components of ecosystems, the removal or decline of functions (such as predation which controls certain populations) led to the loss of ecological resilience as well (Estes and Duggin 1995; Folke et al. 2004). Moreover, the loss of functional biodiversity across scales can erode resilience (Peterson, et al. 1998; Holling 2001).

2.1.1 Adaptive Cycles and Panarchy

Holling (1986) proposed an adaptive cycle as a metaphor of temporal change in ecological systems. It suggests that systems at specific scale ranges exhibit four distinct and usually sequential phases of change in the structures and function of a system. As systems begin to form (such as primary or secondary succession in ecosystems), systems exhibit a growth phase. The growth phase is characterized by a relatively rapid accumulation of structure (biomass and complexity). During this phase, competition is a scramble for resources, as winners are able to obtain and quickly convert raw materials to structure and organization. Over time, structure accumulates and the system becomes more diverse and more connections appear among the system components. Gradually, net growth slows, as more of the acquired resources and energy are allocated to system maintenance rather than growth of new structure. Because structures and resources are accumulated and stored, this phase is the conservation phase. During the conservation phase, the system becomes increasingly connected, less flexible, and more vulnerable to external disturbances. These first two phases correspond to system development, in which energy and resources go into building structure and connectivity, whether they are ecosystems (Holling 1986), cities (Elmqvist et al. 2004), ancient cultures (Redman and Kinzig 2003), or human organizations (Westley 2002). These phases also represent system maturation and increasing vulnerability to external variations or disturbances.

When forces external to the system stress or perturb the system, the system enters the next phase of the adaptive cycle, a period of creative destruction. This period is characterized by a release of accumulated capital or structure. This phase is also called the omega (or end) phase (Holling 1986; Holling and Gunderson 2002). Forest fires, pest outbreaks, harvesting of stocks, and hurricanes are all examples of the omega phase; they are relatively quick periods of destruction or unraveling of previous accumulated forms of capital. The destruction phase is quickly followed by a reorganization (also called alpha or beginning) phase, where a new system emerges, leading to the growth phase of a new cycle. The new trajectory may be very similar to the previous trajectory, or it may be quite different.

The phases of creative destruction and reorganization are the phases of this cycle in which ecological resilience is expressed. The reorganization and renewal following a disturbance, such as fire, drought, or even temperature variations, are when the system will flip into an alternative regime. That flip can be idiosyncratic and random, a result of what types of colonizers, entrepreneurs, or organizers can establish and take hold for the next phases of growth and development. It is also during these phases that other variables, especially slowly changing ones, can come into play. For example in the Florida Everglades, the historic marsh vegetation has been subject to fires and droughts for thousands of years. Yet, when the soils are enriched with nutrients, a fire or drought leads to a change in vegetation, where cattails replace the native marshes (Gunderson 2001). Similar flips can be seen in organizations and management systems following perturbations, whether they are natural disasters or human-created instabilities, such as budget shortfalls, elections, or changes in personnel (Scheffer et al. 2003; Westley 2002).

This pattern of rapid, then slowing growth, swift destruction, and reformation has been observed in many systems (Walker and Salt 2006). These include ecological examples, such as pest outbreaks and fires in temperate forests (Holling 1986), and social-ecological systems, such as water management history of the Everglades (Gunderson et al. 2002) and aboriginal cultures (Berkes and Folke 2002; Berkes et al. 2003; Delcourt and Delcourt 2004).

The dynamics conceptualized in the adaptive cycle are for systems at a particular scale range. That is, the dynamics of growth, conservation, destruction, and renewal can be observed for specific ranges of structures (Figure 1). Two examples, one ecological and the other human community system, are illustrative. The leaves on deciduous plants exhibit phases over an annual cycle of growth, senescence and abscission, followed by the emergence of new buds the following year. This cycle is driven in large part by external variation in seasonal cycles of sunlight and temperature. Over a time frame of years, the deciduous plant goes through a growth phase, a senescent phase, death, and regeneration. Patches of forest go through these phases of succession on cycles of decades, as indicated by periodicities of fire or pest outbreaks. An example of nested structures in a human community setting can be described by rooms that make up houses and houses which, in turn, make up city blocks and blocks that make up neighborhoods. Rooms can be repainted or remodeled every few years, houses can be remodeled or rebuilt over multiple decades, and blocks over slightly longer time frames (Brand 1994). How these different structures interact over different scales of space and time provides the origin of panarchy theory.

Panarchy (from the Greek god of Pan, which roughly translates to “rules of nature”) is a term to describe how variables at different scales interact to control the dynamics and trajectories of change in ecological and socio-ecological systems (Gunderson et al. 1995; Holling 2001; Gunderson and Holling 2002). Panarchy is a theory that suggests, in ecological and other complex systems, abrupt changes occur as a result of the interaction of slow and broad variables with smaller, faster variables. Top-down control occurs when slow, broad features constrain and control the small, fast ones. For example, geology and soil types interact with climatic variables (temperature, photoperiod, rainfall) to determine the suite of plant and animal species that thrive at a given locality. In human systems, the types of climate and building materials dictate the types of structures that can be built for human dwelling. Much empirical evidence

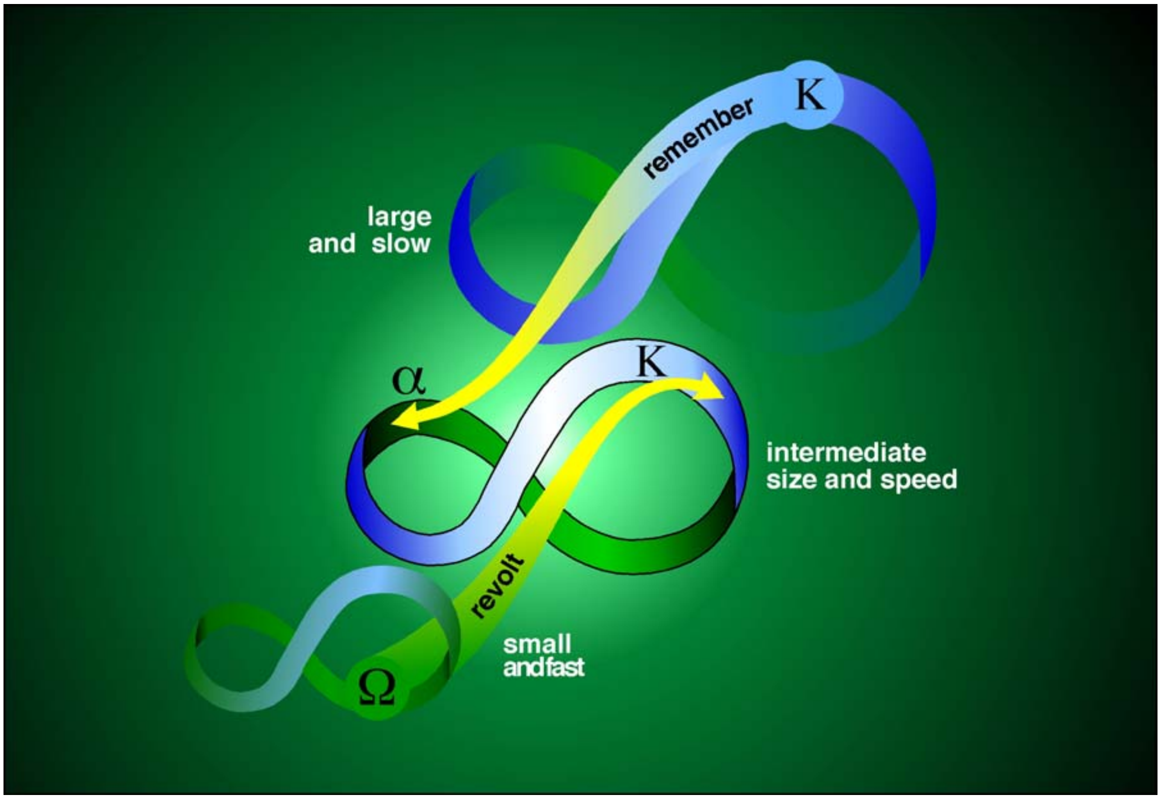

Figure 1. Adaptive cycles within a panarchy, indicating cross scale influences. Reprinted with permission from Holling, C. S. and L. H. Gunderson 2002. "Resilience and adaptive cycles." In *Panarchy: Understanding Transformation in Human and Ecological Systems,* Washington, D.C.: Island Press, pp. 25–62.

supports hierarchical or top-down controls. Panarchy theory was proposed to suggest that both top-down and bottom-up interactions occur. That is, while top-down control does exist, there are many bottom-up or cascading phenomena that occur. Many disturbance dynamics, such as forest fires or forest pest outbreaks, are not the result of top down or control by slower variables but examples where faster, smaller variables appear to control the system for periods of time. A panarchy has three ingredients: (1) subsystems of adaptive cycles that represent system dynamics at a specific scale range, (2) dynamic systems that occur at different scale ranges, and (3) coupling of those systems across scales. All of these structures are posited to change in phases described by the adaptive cycle, but at a given scale.

Panarchy dynamics that link up scale have been named "revolt," suggesting that small events can cascade up to larger scales. When a level in the panarchy enters a phase of creative destruction and experiences a collapse, that collapse can cascade up to the next larger and slower level by triggering a crisis, particularly if that level is at a conservative phase where resilience is low. One example is in the dynamics of urban fires, which is similar to fire in ecosystems. The lighting of a match, strike of lightning, or short circuit of an electrical circuit is a small, local phenomenon. Under many conditions the local fire is either quickly extinguished or never begins a fire. However, under certain conditions (such as extreme droughts or low humidity), local ignitions can create a small ground fire that spreads to the crown of a tree, then to a patch in the forest, and then to a whole stand of trees. Each step in that cascade moves the transformation to a larger and slower level. So if not extinguished, fire can consume a house or similar structure and spread to other houses in a neighborhood. Such processes occurred in the late 1990's in central Florida, and in 2003 and 2007 in southern California. Hence part of the connotation of revolt is used to describe how fast and small events overwhelm slow and large ones. And that effect could cascade to still higher slower levels if those levels had accumulated vulnerabilities and rigidities.

The word "remember" describes interactions from the broad to the small scale. This type of cross-scale interaction is important for recovery and renewal at a specific scale. Once a catastrophe is triggered at a level, the opportunities and constraints for the renewal of the cycle are strongly organized by capital and resources that are made available from higher (larger) scale. After a fire in an ecosystem, for example, recovery and subsequent ecosystem development trajectory is a function of remnant resources (unburned roots and available nutrients) as well as seeds supplied from other areas. Accumulated capital, evolved structures, and other components of ecosystem memory (Berkes and Folke 2002) come into play at this stage, hence the choice of the word "remember."

Adaptive cycles and the cross scale dynamics of panarchy theory have been applied to human community systems and disturbances (Elmqvist et al. 2003, 2004). These applications are further developed in the following section.

3. CONTRASTING COMMUNITY AND ECOLOGICAL RESILIENCE

In this section, I'll attempt to compare and contrast concepts of ecological resilience as outlined in the previous section with those developed by scholars of community resilience. The community resilience framework was developed in a context of how communities cope with natural disasters. The framework consists of four phases, which are somewhat similar to the four phases of the adaptive cycle of Holling (1986). Human community can go through phases of anticipating some disasters; they can manage vulnerabilities before disaster; they can respond during a disaster and recover following natural disasters. Each of these phases is discussed in the following paragraphs.

3.1 Anticipation

There is no evidence that ecological systems can anticipate disturbances or disasters. There is no ability among these assemblages to recognize or conceptualize such or manage such events as human communities can. Components of ecological communities can adapt to recurring disasters, but this is done through mechanisms of selective pressure. For example, many pine trees produce bark that is resistant to fires as a result of selective pressures over millennia. Anticipation is also referred to as the human capacity for foresight and intentionality (Holling 2001). Yet, inherent unpredictability of disasters (and other ecological dynamics) can limit the ability of humans to anticipate complex dynamics (Carpenter et al. 1999). However, human communities find ways to anticipate and plan for disaster.

There are at least two components to the ability of communities to anticipate natural disasters. One is the predictive capacity of knowing when and where a disaster might occur, and the second is to anticipate the impact of those disasters on communities. Both of these components generally rely on past experience or history of natural disasters.

During the 20th century, a tremendous amount of technology has been developed to increase our abilities to predict the occurrence of natural disasters. Many governmental agencies collect and analyze information about when and where natural disasters might occur. These programs provide different types of information over different time and space scales. These programs also develop and apply multiple methods or techniques of anticipation. Take for example, the activities of the U.S. National Hurricane Center to predict hurricanes. The NHC has a historical record of hurricanes in the Atlantic basin going back over a hundred years. Those data have been used to develop long-term (multi-decadal) and broad-scale (regional) patterns of hurricane occurrence. One such pattern is the probability of landfall of a hurricane for segments of the eastern coastline from Texas to Maine. Gray and colleagues (Gray et al. 1992; Blake and Gray 2004) also publish seasonal and monthly predictions of tropical cyclones in major ocean basins. At even finer scales, the NHC coordinates weekly and daily forecasts using a suite of computer models, combined with forecasters’ understanding and experience. In spite of this daunting array of tools and experience, however, there are still great uncertainties about when and where disasters will occur.

The second component of anticipation of natural disasters is the capacity to foresee the impacts of these events. This is a much more difficult task, and many times is only learned by going through repeated disasters when understanding is built through experience. One reason for this difficulty is the inherent unpredictability of complex systems that arise from synergies, nonlinearities, and cross-scale interactions (Holling and Gunderson 2002). Kates and Clark (1996) make a similar distinction between surprises from events and those from consequences of events.

3.2 Vulnerabilities: Factors that Influence Ecological Resilience

Case studies of ecological resilience (Gunderson and Pritchard 2002; Walker et al. 2006; Walker and Salt 2006) suggest that while it is important to know and understand patterns of occurrence and impacts of natural disasters, resilience is a more difficult property to understand. Part of that difficulty is that there are few (if any) direct metrics or measures of ecological resilience (Carpenter et al. 2001). One reason is that thresholds (or boundaries) between alternative regimes are the result of multiple factors and are constantly changing (Carpenter 2003). While it useful to employ methods such as modeling (Carpenter and Gunderson 2001) or scenarios (Cumming et al. 2005), the indices of ecological resilience remain problematic.

One reason that it is difficult to measure and assess ecological resilience is because it is an emergent property of the system, and only recognized when it is declined. The loss of resilience is revealed when a disturbance that had previously been absorbed by the system all of the sudden creates a regime shift. One such example is from the wetland marshes of the Everglades. For thousands of years, the marshes of the Everglades have been subject to recurring droughts, floods, and fires (Gunderson 2001). These disturbances maintained a landscape of sawgrass-dominated marshes and non-emergent vegetated wet prairies. This changed following fires and droughts in the mid 1980’s, when cattail plants dominated these marshes. The regime shift was due to a slow increase in soil nutrients, associated with runoff from agricultural fields interacting with the disturbances that have occurred for millennia. In this case, disturbances (fires, droughts) created a regime shift because of slowly changing system variables. This is one example of how variables operating at different speeds (Holling 1986; Gunderson and Holling 2002; Folke et al. 2004) contribute to the property of resilience.

Ecological resilience can be eroded through a number of mechanisms. One of the earliest observations (Holling 1986) was that practices that stabilize or homogenize key elements of the system erode resilience. A common example is in the suppression of forest fires in fire-adapted systems. The longer that fires are excluded from these systems, the more fuel accumulates. The amount of fuel and spatial distribution increases the likelihood of a more intense fire that could lead to a regime shift (Holling 1986). A similar story occurred in the mid 1990's in central Florida, as human community development occurred in fire-adapted pine forests. As houses were constructed in the previous decades, many homeowners would allow trees and shrubs to grow in their yard and surrounding areas. When fires started during dry periods in the 1990's, the higher fuel loads led to an increase in fire damage and many homes were destroyed.

Another way in which ecological resilience is eroded is through changing pathways of biogeochemical cycles. The Everglades nutrient described above is one such example. Algal blooms and vegetation shifts in shallow freshwater lakes (Carpenter 2003; Scheffer and Carpenter 2003; Scheffer et al. 2001) are another example. Many inland waters, such as the Baltic Sea (Troell et al 2005) have undergone regime shifts because of nutrient introductions.

In human community systems, biogeochemical cycles are modified directly by the construction of systems to distribute and supply water to houses, to protect areas from flooding, or to dispose of wastewater. Stream communities in human community settings undergo shifts in species assemblages because of flow and nutrient modifications (Alberti and Marzluff 2004). Flood plains and wetlands that are drained for development become vulnerable to flooding when the capacity of the system is overwhelmed (Klein and Zellmer 2006).

The loss of ecological resilience and ensuing regime change can be due to a shift in key controlling processes. Nutrients are such controls in ecosystems, as suggested in the previous paragraph. A set of well-documented regime shifts have occurred in aquatic systems as a result of changes in the trophic structure. Coral reefs (Hughes et al. 2003, 2005), kelp forests ecosystems (Estes and Duggin 1995; Steneck et al. 2004), and freshwater lakes (Carpenter 2003) all have undergone regime shifts as a result of the over harvesting of key species.

But are there analogous situations in human communities to trophic cascades observed in ecological systems in communities? The parallel in human communities would entail the removal of key functional roles during or after a disaster that would lead to different and undesirable outcomes. Perhaps the loss of law enforcement personnel in areas immediately post-disaster that could lead to a collapse into anarchy is such an example.

3.3 Responses

The role of diversity in ecological systems response to disturbances has been studied and debated for over three decades. Indeed, a growing body of experimental evidence indicates how biotic diversity can stabilize ecosystems subject to perturbations (Tilman et al. 1996). Biological diversity refers to both the different types of species and the different functional roles of species. Tilman et al. (2001) demonstrated that more diversity helped recovery of ecosystem functions (productivity, biogeochemical cycling) after a disturbance. This is very similar to Berke and Campanella's (2006) observation that a diverse economy can contribute to human community resilience (capacity to rebound following destruction). These studies refer to an engineering form of resilience (or stability) because of the notion that diversity helps a system more quickly return to pre-disturbance conditions.

For three decades, other ecologists have explored the relationship between biological diversity and resilience (Peterson et al. 1998). Aspects of biodiversity (especially functional redundancy) have a positive influence on ecological resilience (Walker et al. 1999; Peterson et al. 1998; Allen et al. 2005). For example, overgrazing in rangelands selectively removes drought-resistant species. When droughts subsequently occur, the system suddenly flips into shrub-dominated ecosystem. Elmqvist et al. (2003) demonstrated similar linkages between response diversity and resilience in a range of ecological systems. Elmqvist et al. (2004) argue that spatial forms of functional diversity (land use types) build resilience of human community landscapes.

Over time, systems develop and adapt by buffering the impact to recurring disturbances. Buffering in this sense refers to the moderation (lessening) of impacts by the disturbance. By moderating disturbances, the system can be very resilient. In water management systems, levees and canals provide buffer against floodwaters (at least to a designed extent). Two other examples of buffering can be found in coastal ecosystems. In the state of Florida, governmental policies protected coastal mangrove forests from development. One reason is that these forests provide buffers against storm surges (Berke and Campanella 2006). This was demonstrated in south Florida in 1992, when Hurricane Andrew severely impacted coastal mangrove forests; these forests took the brunt of wind and wave energy, thereby sparing the inland areas. Others argue that the protection of barrier islands is critical for similar reasons (Pielkey and Fraser 2003). Following Hurricane Katrina, Day et al. (2007) demonstrated how management that led to the loss of coastal wetlands in Louisiana increased the vulnerability of the area to hurricane impacts.

3.4 Renewal and Recovery

Holling (1986) labels a post-disturbance period of renewal and recovery as the alpha phase. This is the period immediately following a disturbance or creative destruction. It is the phase that is most vulnerable to random and chance events.

This is also the phase in which many opportunities emerge for alternative system configurations. Olsson et al. (2006) describe this as a “window of opportunity,” in which new actions and arrangements are possible. One of the differences between ecological and community systems is that the human-dominated systems have the ability to conceptualize and look forward into the future (Westley et al. 2002; Scheffer et al. 2003; Redman and Kinzig 2003), whereas ecological systems do not. As a result, communities can develop alternative plans for recovery and renewal (Berke and Campanella 2006). This is similar to Gunderson et al.’s (1995) view of policy renewal following ecological crises.

Both the ecological and community resilience literature recognize the importance of the post-disturbance phase of the system to subsequent trajectory or regime (Holling 2001; Vale and Campanella 2005). After disturbances, aspects of both types of systems can recover (return to pre-disturbance conditions) or renew (become something new). This is in essence one of the distinctions that Holling (1973, 1996) makes between engineering and ecological resilience. The ensuing trajectories or regimes have some components that are similar, but in many cases following large disturbances the system undergoes a transformation, or change in identity (Cumming et al. 2005). Vale and Campanella (2005) discuss how the city of San Francisco transformed following the earthquake in1906 into a modern, more progressive city with more efficiency, discipline, and order than the one that existed prior to the disaster. In other words, the disaster provided the opportunity for the city to become a great city. Barry (1997) described a similar transformation (but in the opposite direction) in New Orleans; following the flood of 1927, the city was not the central economic, political, and social seat of power in the southern United States that it was prior to the flood.

Different forms of capital are critical to post-disturbance recovery in both systems. These include natural capital (Folke et al. 2002) and social capital (Putnam 2000), as well as other economically defined forms of capital. Natural capital in this sense refers to the stocks (or goods) in ecosystems that provide service or use to humanity. One example is the release of organic matter from coastal vegetation associated with hurricanes. Hurricane-force winds defoliate trees, and storm surges and tides dislodge organic soils. As a result, estuaries and coastal systems receive large inputs of organic matter, which in turn fuels a post-disturbance pulse in estuarine production of shrimp, fish, and other organisms (Day et al. 2007). One important way in which capital is developed and applied is through different types of networks.

Networks provide sources of resilience in both ecological and social systems. Janssen et al. (2006) provide a useful typology of networks in a context of resilience: those that facilitate flow of resources and ideas and those that facilitate connections among people. Indeed, resilience of a system can be lost by the removal of links within a network. Examples include loss of resilience in marine systems due to the loss of linkages within a trophic network (Estes and Duggins 1995; Hughes et al. 2003, 2005). A parallel example may exist in post-disaster communities that devolve into lawlessness and anarchy because of the loss of key personnel in emergency and law enforcement positions. Formal and informal social networks can also aid in post-disaster recovery. Tidball and Krasny (2007) found community activities such as urban gardens and the creation of green space foster resilience through the development of social networks. Nelson et al. (2007) present examples of how social networks can contribute to more effective management during drastic variations in key environmental drivers, such as droughts.

Post-disturbance recovery is determined in part by remnant components, or what types and forms of capital were not destroyed by a disturbance. Berke and Campanella (2006) refers to these aspects of the system as sticky (not removed by disturbances) and include physical infrastructure (such as underground utilities and foundations) and social or legal relationships that do not change (such as land ownership or allegiance to place). Analogous components in ecological systems would include remnant rootstocks that survive fires, or seed banks in wetland systems. Indeed many fire-adapted plant species only regenerate after fires, as the fire triggers release of seed. Adaptations to recovery in ecological systems can be found across a range of scales and levels of organization, including the individual, species, population, and ecosystem levels.

Processes that interact across spatial and temporal scales influence both ecological and community systems recovery. The temporal dimensions to recovery play out over distinct eras, and cover timescales from days to decades. The panarchy model suggests that at key times, especially following disturbances, cross–scale connections emerge that are critical to system recovery. In ecological systems, Nystrom and Folke (2001) demonstrated how networks at different spatial scales were critical to coral reef recovery following hurricanes. An equivalent model is how state, federal, and international governments come to the aid of local communities following disasters (Adger et al. 2005). That is not only for the short term when basic human needs of water and food are imported to affected areas from larger spatial domains but also how these larger scales influence over longer periods of time. Houck (1985) and Klein and Zellmer (2006) discuss how federal policies of flood protection, flood insurance, and regulatory can help recovery from floods but can also make communities more vulnerable to future flood events. How these processes play out over scales of space and time is one of the key factors in the resilience of a system, whether it is a community or ecosystem.

4. MANAGING RESILIENCE IN COMMUNITIES AND ECOSYSTEMS

In managed ecosystems, the loss of resilience and sudden flip in ecosystem state is often viewed as a surprise (Holling 1986; Gunderson 2003). An ecological surprise is defined as a qualitative disagreement between ecosystem behavior and human expectations (Gunderson 2003). Brooks (1986) provides a useful typology of surprises in describing the interaction between technology and society and defines three types: (a) unexpected discrete events,

(b) discontinuities in long-term trends, and (c) emergence of new information. Gunderson (2003) and Nelson et al. (2007) discuss similar categories in resource systems as local surprise, cross-scale surprise, and true novelty. Natural disasters, such as hurricanes, tornadoes, or tsunamis, can be local surprises if there is no prediction or warning of their occurrence. Cross-scale surprises refer to situations where resilience is lost and a disturbance or natural disaster suddenly causes reorganization into a new configuration. The floods of 1927 and Hurricane Katrina could be considered as cross scale surprises to the city of New Orleans. These categories are relevant because they provide different activities in terms of how people anticipate and manage the unknown (Kates and Clark 1996).

The preceding chapter highlights the difficulties of prediction and management in complex systems (Holling 1978; Walters 1997; Kates and Clark 1996). Effective planning and management, however, require some estimation about "what will happen." Certainly, many things are known, especially the broad and the general. For example, it was well known at least 3 days prior to landfall that Hurricane Katrina was going to strike the Gulf Coast of the United States (with a given probability), yet all of the impacts could not be specifically predetermined. While there are many sources of complexity, and limits to predictability, it is clear that management for resilience must include some learning-based approach that allows for the accumulation and periodic testing of knowledge (Gunderson 2001; Gunderson and Holling 2002).

Forms of social learning occur following natural disasters and other ecological events. That learning is forced when the failure of extant policy is undeniable (Gunderson, Holling, and Light 1995). One such type is episodic learning, when the previous models or schemes are no longer tenable because of a single event or crisis (such as the faith in levees to control flood waters prior to Hurricane Katrina). Episodic learning involves the creation of new policies or approaches to solve the problems revealed by the ecological event. Ongoing planning, experimentation, and management can lead to episodic learning, such as has occurred in the Great Barrier Reef and Grand Canyon resource systems over the past decade (Hughes et al. 2007). Transformational learning is characterized by cross-scale surprise and/or the emergence of novel solutions. In these cases, learning involves solving problems of identifying problem domains, among sets of wicked and complex variables (Westley 2002). Another type of learning, called transformational learning, involves several levels in a panarchy, not simply one level (Holling and Gunderson 2002; Gunderson et al. 2006). The development of Everglades restoration is one example of transformational learning. In this case, a number of problem domains (ecological, social, and economic) were solved by viewing restoration as a win-win solution for all sectors and not a zero-sum game of conflict for water among agricultural, urban, and conservation sectors (Gunderson and Light 2006). In both forms of learning, an environmental event or natural disaster can create a "window of opportunity" for collective action in socio-ecological systems (Olsson et al. 2004, 2006) as well as human community systems (Berke and Campanella 2006).

5. SUMMARY AND CONCLUSIONS

At least five themes emerge from this comparison between ecological and community resilience (Table 1). One is that both systems demonstrate the multiple meanings of resilience—both in terms of recovery time from and capacity to absorb disturbances. The second theme is that both systems recognize the role of diversity in contributing to resilience. The third theme is the role of different forms of capital. The fourth is the importance of cross scale interactions. The

Table 1. Similarities and differences between ecosystems and human communities with respect resilience and adaptive capacity in the face of natural disasters

Theme	Ecological systems	Human community
Definition of resilience	Two meanings; one is defined as return time following a perturbation, the other as the amount of disturbance to shift regimes.	Multiple meanings, but primarily refers to return or recovery time. Limited application to regime shifts.
Anticipation of disasters	No ability to anticipate, ecological systems can only adapt through selective pressures.	Human communities can anticipate disasters through foresight and experience.
Responses to disasters	Functional forms of biodiversity across scales provide resilience. Networks and connectivity can provide resilience.	Functional components provide resilience. Disaster effects can be intentionally buffered by technology. Networks, linkages can provide resilience through increased communications.
Recovery after disasters	Can return to prior configuration, transform to degraded regime.	Can return to prior configuration, devolve into degraded regime, or evolve into desired regime.
Renewal and novelty	Dependent on cross scale inputs (seeds, carbon, energy) and remnant forms of capital.	Also dependent on cross scale inputs. More novelty, creativity in creating new configurations. Different forms of capital can be substituted.

fifth theme involves the need for experimentation and learning to build adaptive capacity. Each of these is discussed in the following paragraphs.

Scholars of both ecological and community resilience recognize that at least two different types of resilience exist. Vale and Campanella (2005) define urban resilience as "*the capacity of a city to rebound from destruction*," which is very similar to the Holling (1996) definition of engineering resilience. Yet, other authors apply ecological resilience concepts to community resilience. This involves a regime change, in which the structures and processes and identity of community either evolve into a more desired configuration or devolve into a lesser desirable state. Examples of the former include the transformation of San Francisco into a "modern" city following the earthquake of 1906 (Vale and Campanella 2005) or the decline of New Orleans as a regional center of culture, economic, and political power following the 1927 flood of the Mississippi River (Barry 1997).

Diversity is important to providing ecological resilience. Numeric diversity (different types of entities) is probably less important functional diversity (Walker and Salt 2006). Also, the ways in which functional units are connected is a critical factor contributing to system resilience (Berke and Campanella 2006).

Various forms of capital are critical to ecological and community resilience. Capital is developed during phases of system growth and development. That capital, as well as the influx of capital from broader areas, is critical to system recovery and in determining system trajectories (MEA 2005). Especially important to natural disasters is the role of maintaining or restoring natural capital, in the form of ecosystem goods and services (Liu et al. 2007; Olshansky and Kartez 1998). Wetland ecosystems, whether forested or not, are critical buffers to mitigating hurricane impacts of coastal areas (Day et al. 2007). Floodplain ecosystems provide similar functions during extreme floods.

Panarchy is a theoretical model that suggests how complex systems interact across scales of space and time. Panarchy suggests that certain properties, such as connectivity, can lead to system vulnerability in the form of perpetuating or cascading disturbances that can expand across wider spatial and temporal scales. Panarchy theory also suggests the critical importance for cross scale interactions—when the broader and slower variables are critical to post-disturbance recovery and resilience.

Coupled systems of humans and nature are complex, in terms of how they anticipate and respond to natural disasters. These complexities present great uncertainties for many facets of society. The capacity to deal with the types of uncertainty and surprises will requires novel approaches, creative combinations of strategies, and the ability to adapt in a changing environment. Accelerating learning and supporting novel approaches that limit vulnerability and expand our understanding of the occurrence and impacts of natural disasters seem to be critical components of building community resilience.

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