# Ecosystems and Disaster Resiliency: Contributions to a Holistic Theory of Recovery

by

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## Disaster Recovery and the Natural Environment: Contributions to a Holistic Theory of Recovery

Human modification of the natural environment is increasingly being recognized as an important factor in the escalating problem of disaster impacts (e.g., Adger et al. 2005, Chapin et al. 2009). Recent literature has stressed that because disaster risk derives from larger processes of local and global change, its reduction must involve promoting ecosystem resilience. *The Global Assessment on Disaster Risk Reduction*, a consensus document from leading scholars in the ecological sciences, called for a novel application of an ecosystem theory to disaster reduction whose principles include, among others, maintaining and enhancing the resiliency of the natural environment that generate ecosystem services that offer critical life support functions for human communities (UNEP 2008).

Considerable research under this approach focuses on how pre-disaster actions such as deforestation (Chang et al. 2006) and wetland destruction (Costanza et al. 2008) degrade ecosystem resilience that exacerbates risk to human communities, and on factors that affect decisions to limit development in hazardous areas and conserve protective natural environmental features like coastal wetlands and mangroves forests (Burby 1998, Stevens, Berke, and Song 2010). In contrast, little is known about how ecosystem resilience generates ecosystem services that benefit people during disaster recovery, and how pre- and post-disaster decisions affect ecosystem resilience and, in turn, future disaster risk. Such knowledge can help inform policies to break the vicious cycle of disasters linked to environmental degradation.

This paper offers a critical review of the major contributions of research and gaps in knowledge about resiliency of ecosystems, and the process of protecting and restoring natural environmental features that generate ecosystem services through pre-disaster recovery planning and post-disaster adaptive actions. The review will be guided by an assessment of how well research has addressed five critical dimensions of the role of the natural environment in the context of disaster recovery:

1) Are humans intensifying risk from hazards due to degradation of natural environments and the associated decline in ecosystem services?;
2) What are the differential impacts in the decline of ecosystem services on different population groups, especially among socially vulnerable population groups?;
3) What strategies are most effective to maintain ecosystem resiliency to sustain ecosystem services that protect against hazards and facilitate recovery?;
4) What types of frameworks (and measurements) are needed to organize scientific, local and traditional sources of knowledge to describe and explain complex relationships between human and natural ecological systems before and after a disaster?; and
5) How does recovery planning influence the capacity of institutions and governing systems to use eco-science based knowledge and take collective action to maintain and restore the resiliency of ecosystem services after a disaster?

### 1. Are humans intensifying disaster-related damages due to degradation of natural environments and the associated decline in ecosystem services?

An ecosystem is a dynamic complex of plant, animal, and microorganism communities and the nonliving environment interacting as a functional unit. As elements of the ecosystem are degraded, those functions can be lost.

People receive substantial benefits from ecosystems; these benefits have been termed ecosystem services. Three major classes of ecosystem services benefit people: 1) *provisioning* *services* (food and fiber), 2) *cultural services* (visual amenities, recreation), and 3) *regulating services* (climate moderation or flood reduction) (MA 2005, p. v-vi). Few ecosystems have not been affected by human action, intentionally and unintentionally. People modify natural environments to increase the supply of ecosystem services that they desire, and develop institutions to govern access and use of these services. Importantly, people do not exist independently of natural systems. Humans and their associated economic, cultural, social and political systems are an integral part of the 'environment.' Human and natural systems are coupled. Humans-in-nature are part of a complex, interconnected and evolving socio-ecological system that has thresholds, feedback loops and interdependencies that extend from the local to global level. However, we are living in an era characterised by human domination of the earth – described by Nobel Laureate Paul Crutzen (2002) and colleagues (Crutzen & Stoermer, 2000) as the 'Age of the Anthropocene.'

Knowledge about the decline of globally-regulating ecosystem services is well-established. Human modification and simplification of natural environments to produce food, fiber and fuel, has lead to a decline in regulating ecosystem services. The supply of approximately 60% (15 of 24) of the ecosystem services that were assessed by the *Millennium Ecosystem Assessment* (MA 2005) has been found to be in decline (see table 1). At the same time, consumption of over 80% of the services was found to be increasing. In other words, the flow of most ecosystem services is increasing at the same time as the total stock is decreasing. In a consensus document, *Ecosystems and Disaster Risk Reduction*, a leading group of ecologists stated, "This decline is expected to result in both more variable ecological dynamics and more human exposure to hazard" (UNEP 2008, p. 5). Indeed exposure to natural hazards due, in part, to degradation of ecosystem services has increased globally since the 1950s and this growth is faster than global population growth or the growth of the global economy (UNEP 2007).

**Table 1**: Use and Supply of Assessed Ecosystem Services

| Provisionig ES | | Regulating ES | | Cultural ES | |
|---|---|---|---|---|---|
| Crops | + | Air quality control | + | Spiritual and Religious values | + |
| Livestock | + | Global climate Regulation | + | Aesthetic Values | + |
| Capture fisheries | - | Local climate Regulation | + | Recreation Ecotourism Values | + |
| Aquaculture | + | Water flow Regulation | + | | |
| Wild foods | - | Erosion control | + | | |
| Timber | + | Water quality Regulation | + | | |
| Cotton | +- | Disease control | + | | |
| Wood fuel | +- | Pest control | + | | |
| Genetic resources | + | Pollination | + | | |
| Biochemicals | + | Natural hazard Regulation | + | | |
| Freshwater | + | | | | |

Numeric sign shows change in use. Color shows change in supply Green= increasing supply, red = decreasing supply, and yellow = supply more or less stable

Source: Adapted from *Millennium Ecosystem Assessment* (MA 2005) .

These findings have major implications for risk to human communities which are closely dependent on ecosystem services and on institutions charged with protecting them (Beatley 2009). Yet, few decision makers and the general public clearly understand the dependency of human communities on ecosystem services. Still fewer are effectively carrying out management strategies that recognize this dependency.

Key questions that identify major research gaps include:

1.1 How can values for different types of ecosystem services be determined in terms of the degree to which each service generates risk reduction benefits for human communities?

1.2 What improvements in knowledge are needed to prioritize services that generate the most benefit, but are under highest threat?

1.3 To what degree do state and local governments account for ecosystem service protection in current pre-disaster recovery plans? What factors motivate integration of such information into these plans?

## 2. What are the differential impacts in the decline of ecosystem services on different population groups, especially among socially vulnerable population groups?

Socially vulnerable populations consist of key social characteristics (women, racial/ethnic minorities, low-wealth, and the elderly) that create a disproportionate susceptibility to harm from disasters and constrain capacity to respond (Cutter, Boruff and Shirley 2003, NRC 2006, chs. 2-3). They are people who are more affected by the loss of ecosystem services, because they often face racial discrimination and class inequalities, and the uncertainty, distrust, and suspicion that accompanies these conditions, and often have less capability to replace lost ecosystem services through technology, financial investments, or other measures.

Research on links between the types of benefits (i.e., outcomes) generated by ecosystem services and socially vulnerability is limited to individual case studies (Turner 2010). While evidence is limited, the accumulation of research suggests that global changes in the loss of supply of ecosystem services have been disproportionately detrimental to socially vulnerable populations (MA 2005). In New Orleans, for example, damaged areas from Hurricane Katrina that were predominately lowest in elevation were 45.8% black, compared to 26.4% in undamaged areas, and 20.9% of households had incomes below the poverty line in damaged areas, compared to 15.3% in undamaged areas (Logan 2006). The lowering of elevation was largely due to urban development that destroyed ecosystem services produced by wetlands. Draining of wetlands changed soil chemistry and promoted oxidization that reduced the capacity of soils to regenerate which, in turn, caused the land within the drained areas to subside.

The poor also experience significant declines in access to ecosystem services due to the expropriation of natural resources. For example, in tropical countries like Thailand coastal fisheries that formerly provided ecosystem services like protection from coastal storms, and an inexpensive source of protein and supplemental income, have been destroyed due to shrimp farming and other forms of aquaculture. The forces of economic globalization are increasingly pushing the benefits of aquaculture to a small group of entrepreneurs who are external to local communities, while the costs are imposed on the local poor (Berke et al. 2008).

In sum, systematic research on the relationship between ecosystem services and social vulnerability is limited. Studies tend to be case specific because of the complexity in specifying how various ecosystem services benefit diverse types of population cohorts of human communities. There is a need for studies that offer cross sectional and longitudinal research designs which allow for systematic comparison across locations that vary in composition of ecosystem services and human populations. Key questions that remain unanswered include:

2.1 What are the risk reduction outcomes of different types of ecosystem services on socially vulnerable population groups?

2.2 What is the spatial distribution of the ecosystem services that generate protection from hazards compared to the distribution of social vulnerable populations?

## 3. What strategies are most effective to maintain ecosystem resiliency to sustain ecosystem services that protect against hazards and facilitate recovery?

Research on ecosystem resilience has advanced the understanding of interactions between natural environments and human communities. Earlier conceptions of ecosystem resilience emphasized stability of a system to maintain steady-state. Historically, the goal of ecosystem management strategies was to maintain stability to produce ecosystem services for human benefit. Stability requires emphasis on minimization in change and maximization in the speed at which an ecosystem system returns to equilibrium following disruption (Chapin et al. 2009).

In contrast, current conceptions of resiliency emphasize adaptability with recovery responses aiming to return ecosystem services to the pre-disaster levels or create a “new normal” that involves ecological transformation and associated improvements in services. Such transformations can be unintended consequences of a disaster event that lead to systemic and irreversible declines in production of ecosystem services, or intentional responses that tie social processes to ecological processes through monitoring, evaluation, feedback, and action (Chapin 2009). From the integrated social-ecological process perspective, communities are likely to be better off if they learn and adapt, arriving at an entirely new post-disaster equilibrium.

The critique of steady state stability conception is consistent with early research on disaster recovery of human communities. The early work oversimplified recovery as an orderly, predictable and linear sequence of stages (NRC 2006, ch. 3). By contrast, more recent research emphasizes that recovery may be experienced at different rates and non-linear sequences by different sectors and population groups (NRC 2006, ch. 3). This requires a more nuanced understanding about the human dynamics of resiliency that aligns with contemporary knowledge on ecosystem resiliency.

Ecologists Holling (1986) and Gunderson and Holling (2002) observe that adaptive strategies should be based on the state of ecosystem resiliency, and that ecosystems tend to transition across phases (or states): development; conservation; creative destruction; and reorganization which then returns leads to a new cycle of development. Ecologists further argue that ecosystem recovery opportunities for maximizing ecosystem services should be based on the phase at the time of a hazard event (disturbance). They identify four classes of strategies that individual species can adopt that favor survival when recovering from disturbance. As indicated in Table 2, specific strategies correspond to different phases in the adaptive cycle as indicated by, for example, strategies used by plants to recover from fire that correspond to each phase.

**Table 2**. Strategies that plants use to respond to different phases of a fire regime, and generalized strategies for dealing with change.*

| Phase in Adaptive Cycle/ Strategy for Enhancing Resiliency | Reorganization | Growth | Conservation | Creative Destruction |
|---|---|---|---|---|
| Strategy for coping with fire | Colonize burned areas | Regenerate quickly | Resist fire | Regulate fire regime |
| General Strategy for coping with disaster | Learning | Insurance | Disaster Resistance | Disturbance initiation |

*A learning strategy that attempts to understand system dynamics so that knowledge can be used to reconfigure a future system (e.g., a plant strategy of colonizing new burned areas); an insurance strategy that involves investment so that when a system responds to a fire event, quick re-growth is possible (e.g., quick growth by a plant following a fire by storing energy in its root system to invest in growth following the loss of above ground biomass, or plants that only release seeds following the heat of a fire); a resistance strategy that attempts to control systems dynamics to prevent disturbance from happening (e.g., a plant species copes with fire with thick bark to enable a plant to survive low intensity fires; a disaster management strategy attempts to control the timing and nature of change or disturbance rather than prevent it (e.g., a longleaf pine tree sheds flammable needles that burn readily, encouraging frequent low intensity fires that longleaf survive, but oaks, an ecological competitor cannot).

Source: Adapted from UNEP (2008)

These strategies can be employed by particular species of a system to deal with systemic change at a larger scale. Ecosystems containing species that embody a wide diversity of strategies will be more resilient than those that are less bio-diverse.

To maximize resiliency of ecosystems for human benefit, pre-disaster recovery plans and post-disaster decision-making in disturbance-prone geographical settings should use a portfolio of strategies. Multiple strategies are necessary to maximize the flow of resources and services for a given ecosystem. They offer adaptive responses to the variability of natural disturbances instead of limiting variability through simplified solutions (e.g., dams and levees) in attempts to maintain a steady state as is often done in conventional resource management (Holling and Meffe 1996).

A limitation to the development of portfolios of strategies is the lack of knowledge about the effects of tradeoffs between degrees of protection of ecosystem services and human outcomes (Turner 2010). While some ecosystem services are linked directly to a human community outcomes (e.g., crop production as a provisioning service), others are more difficult to connect (e.g., flood mitigation of wetlands as a regulating service). There is greater understanding of the links between ecosystem services and human outcomes for outcomes that are most direct, immediate, and quantifiable (e.g., pounds of potatoes and volume of drinking water supply). Other outcomes that tend to be associated with the social sciences (e.g., property values, social equity) are not as well understood because the links between outcomes and services are indirect.

In sum, while an extensive body of scholarly research has developed around phases of ecosystem resilience and the adaptive strategies that can protect and/or restore resilience, there are several gaps in knowledge. Major limitations include the limited understanding of how diverse strategies affect resiliency, and the effects of tradeoffs between degree of protection of different types of ecosystem services and human outcomes.

Key questions that remain unanswered include:

3.1 What portfolios of strategies can be used in adaptive responses to maximize the flow of ecosystem services in diverse social and ecological systems subject to hazard events?

3.2 To develop effective portfolios of strategies, what are the effects of tradeoffs between the level of ecosystem services and human risk reduction outcomes?

4. **What types of frameworks (and measurements) are needed to mobilize, synthesize and integrate scientific, local and traditional knowledge to describe and explain complex relationships between human and natural ecological systems before and after a disaster?**

Institution and governance researchers have criticized the established adaptive management approach for relying on expert-driven knowledge. They conclude that too much emphasis is placed on reliance of experts from the science and technology fields in the formulation of management strategies aimed at ecosystem resiliency (UNEP 2008, Folke et al. 2002a). Elinor Ostrom, the 2009 Nobel Laureate, concluded that success in avoidance of a “tragedy of the commons [should be] based on the assumptions that individuals can learn how to devise well-tailored rules and cooperate conditionally when they participate in the design of institutions affecting them” (Ostrom 1998, p. 3). Due to the complexity involved in creating and adapting ecosystem management strategist to dynamic conditions it is too difficult for one or a few people to possess the range of knowledge needed to self-organize entire communities, respond, and learn and adapt to the impacts of disaster events (Folke et al. 2002a, Folke et al. 2002b, Schoon 2005 ).

While only a few studies enquire into resilience from the standpoint of how human communities relate to their natural environments after a devastating disaster, the concerns raised by these studies parallel many of the limitations raised by Ostrom and the institutional and governance research community. Namely, that scientific knowledge is needed to enhance efforts to sustain social and ecological systems, but the social and ecological sciences have developed independently and do not combine easily.

A core challenge is to improve the understanding of why some social and ecological system interactions are resilient whereas others degrade or even collapse. Social systems are conceived here as intentional efforts to create coordinate inter-organizational arrangements and adopt strategies that govern use and protection of ecosystem services. Understanding a complex whole of factors that explain the resiliency of interactive social and ecological systems requires knowledge about specific variables and how their component parts are related (see, for example, Tierney and Bruneau 2007). Thus, knowledge should be created in ways that allows for understanding complexity, rather than eliminating it from such systems. The process is complicated, however, because different models, theories, and frameworks are used by different disciplines to analyze distinct parts of the complex whole. A common, classificatory framework is needed to facilitate multidisciplinary efforts toward a better understanding of interactions among hazards generated by natural systems, impacts of hazards, and human system capacity to anticipate and respond.

Research has begun to address this need through the development of frameworks that specify propositions about the influence of alternative designs of post-disaster aid delivery programs on the capacity of local people to take collective actions aimed at restoration of critical ecosystems services (e.g., food and production and income generated by coastal mangrove forests). Propositions include, for example: aid delivery strategies should account for local knowledge of effective approaches in ecosystem restoration; pre-disaster local institutional capacity in the form of social capital should be mobilized and used to take collective action during the aftermath of a disaster event to focus on recovery; and imposition of top-down external aid delivery can degrade (or empower) local institutional capacity to restore and sustainably manage local ecosystems (e.g., Berke, Chuenpagdee, Juntarashote, and Chang 2008). Thus, rather than perpetuating the science versus local / traditional knowledge debate, there is a need to explore the co-production of knowledge about how to build the resilience of coupled social-ecological systems through the mobilization, synthesis and integration of science with local and traditional knowledge and understanding.

In sum, at issue is to better understand the conditions that enable disaster prone human communities to self-organize and craft effective strategies that enhance their capacity to sustain high levels of ecosystem resiliency. As noted, maintaining and enhancing the ecosystem resiliency increases the generation of ecosystem services that offer critical life support functions for human communities.

Key questions include:

4.1 What types of frameworks are needed to organize scientific disciplines that use different concepts and languages to describe and explain complex relationships between human and natural ecological systems before and after a disaster?

4.2 How can scientific, and local and traditional sources of knowledge be mobilized, synthesized and integrated to co-produce understanding about the role that ecosystems play in disaster risk reduction and post-disaster recovery?

4.3 What are valid and reliable variables within a framework needed to measure and examine change in human and ecological systems before and after a disaster?

## 5. How does recovery planning influence the capacity of institutions and governing systems to use eco-science based knowledge and take collective action to maintain and restore ecosystem resiliency after a disaster?

A core area of research that has received limited attention involves the emerging initiatives in disaster recovery planning. In concept, pre-disaster recovery planning builds the capacity of institutions to anticipate impacts, and protect and restore ecosystems in the event of a disaster. It is both a technical and social learning process. It should engage vulnerable populations (or stakeholders) that are potentially affected by disaster and the loss of ecosystem services. It should draw on local and traditional sources of knowledge and the best available scientific knowledge to inform stakeholders in the formulation of alternative recovery strategies. An emerging approach to integrating scientific knowledge with stakeholder values involves the formulation of alternative scenarios of plausible disasters and associated impacts on natural systems and other built environment and social systems (e.g., transportation, housing, health care delivery). Stakeholders can interact and iteratively derive a range of strategies to anticipate and facilitate knowledge about ways to adapt and respond to a set of plausible futures.

Recovery planning efforts should include monitoring and evaluation to enhance learning and building capacity for adaptation. Monitoring requires formulation of indicators to track pre- and post-event resiliency ecosystems and human life support services they provide. Indicators should differentiate impacts on human population groups. Ongoing monitoring is critical in evaluating the performance of plans and adapting them to change.

On the one hand, knowledge about the failures of recovery plans that are premised on conventional expert-driven approaches is well-established. This approach fails to build institutional capacity to needed to react to disasters in ways the build ecosystem resiliency. One the other hand, there has been little research on the outcomes of alternative approaches to the preparation and implementation of recovery plans. This observation is surprising given the increasing societal investment in recovery planning. For example, several states in the United States (e.g., Florida and North Carolina) have enacted recovery plans at the state level and require that recovery plans be prepared by local governments. A growing number of local governments are experimenting on their own in preparing recovery plans. Yet, disaster recovery planning has been given less attention by the research community and is less proven than plans that address other phases of disaster – preparedness and response, and mitigation. For example, there exists a long tradition of plan quality evaluation focused on hazard mitigation (Berke and Godschalk 2009). However, little is known about the extent to which recovery plans account for protection and restoration of ecological and social systems, as well as built environments. As a result, significantly less in known on how well pre-disaster recovery plans influence post-disaster adaptive actions by human communities and how these actions affect resilience of ecosystems.

Particular attention needs to be focused on identifying and better understanding perverse policy incentives that run counter to risk reduction and resilience. Understanding the political, economic and other drivers that reduce public safety and sustainability needs focused attention, especially given that 'political stakes' escalate dramatically in the immediate aftermath of disaster. As every effort is made to get 'things back to normal' quickly, short-term pre-event interests tend to prevail over longer-term community safety and sustainability, and especially the concerns of vulnerable groups. Paradoxically, despite the rhetoric to 'build back better,' pre-event vulnerabilities tend to be re-entrenched and socio-ecological resilience becomes an elusive pursuit. Recovery theory and policy needs to be informed by and explicitly address the political and economic drivers and dynamics that undermine ecosystem resilience. Particular attention needs to be focused on the factors that shape pre- and post-disaster choices about short- vs. long-term and public vs. private interests that together construct societal risk and vulnerability and prospects for socio-ecological resilience and sustainability.

Key questions that identify major research gaps include:

5.1 What are the key principles that define high quality recovery plans?

5.2 What metrics can be used to gauge the quality of recovery plans regarding how well they account for ecosystem resiliency?

5.3 How does recovery plan quality influence community response to hazard events and ultimately risk reduction outcomes?

5.4 What are the root causes and drivers of post-disaster decisions that entrench pre-event vulnerability, undermine ecosystem resilience and foster unsustainable practices?

5.5 What are the barriers and opportunities for maintaining and where necessary restoring ecosystem function and services in post-disaster recovery efforts? And what role(s) are played by 'disaster actors', including those in government, civil society, the private sector, media and the research community?

**Contributes of Research on Ecosystem Resiliency and Human Community Adaptation to a Theory of Recovery**

While an extensive body of scholarly research has developed around recovery of ecosystem resilience and the biophysical factors that influence resilience, there is a gap in knowledge about factors influencing utilization of this research and in understanding the performance of institutions and governance systems in improving ecosystem resiliency. There are calls for a new management and planning paradigms for sustaining the capacity of ecosystems to provide services that benefit society (e.g., Adger et al. 2005, Chapin et al. 2009), but the links among the capacity of institutions and governance systems to create informed recovery plans and post-disaster interventions, and actual use of knowledge on ecosystem phases and strategies are not well understood.

The few recovery studies that integrate knowledge from the social and biophysical sciences tend to be one-shot that lack comparative designs that precludes assessments of recovery in different biophysical and social settings (e.g., Berke, Chuenpagdee, Juntarashote, and Chang 2008). They also lack longitudinal research designs which preclude monitoring of change and the performance of recovery planning strategies over time. This situation constrains the systematic accumulation of knowledge from empirical studies and in the assessment of past efforts aimed at ecosystem protection and restoration in response to disasters. Without the capacity to undertake systematic, comparative research, recommendations for the design of governance arrangements and aid delivery programs, formulation of recovery plans to guide strategy selection may be based on naïve ideas about what works and what does not.

**Research Recommendations**

1. A starting point is to initiate the *development of alternative theoretical frameworks* by various research groups to help *to organize diagnostic, analytical, and prescriptive strategies*. The frameworks could serve to enhance replication of measurements, monitoring of change, and comparison of findings across multiple studies. The frameworks could evolve with the most productive ones that cumulate knowledge emerging over time while others would fade. The literature has begun to identify the major structural variables of a theoretical framework for understanding vulnerability of human communities due to a range of factors effecting ecosystem resiliency. Such variables are present to some extent in all governance arrangements, aid delivery programs, recovery plans, and ecosystem resiliency outcomes and their effects on different human populations. The values among these variables, however, would vary from one

setting (the particular biophysical characteristics, governance arrangements, plans, and population groups) to another.

2. Another recommendation is to extend the frameworks with broader problem definitions by *integrating a broad range of disciplines, knowledge systems, user groups and approaches*. Natural resource managers, for example, could move from narrow conceptions of expert-driven management of ecosystems by acknowledging the importance of ordinary knowledge of local people and the broader range of ecosystem services at risk to disaster events and possibly at risk to negative transformation after a disaster. In another example, emergency managers motivated primarily to work on traditional emergency preparedness and response activities could also become engaged in pre-disaster recovery planning and post-disaster recovery decisions by linking their traditional activities to recovery. Emergency managers could shift to ecosystem management after a disaster by leveraging resources and knowledge aligned with traditional response activities in, for example, toxic chemical cleanup to recovery of coastal ecosystems impacted by an oil spill. This shift requires recognition of the legitimacy of multiple user groups who value multiple ecosystem services.

3. A third recommendation is to place more emphasis on *comparative analysis of governance arrangements, recovery plans, and aid delivery systems* in different social/ecological settings; for example, through comparative studies of recovery of ecosystem services that generate, for example, fresh water supply, timber, and fisheries. These comparative analyses enable learning from past unplanned actions and to define conditions that minimize risks of future planned actions. Comparative studies and systematic observations require information systems at scales that are relevant for conducting assessments, generating scenarios and informing decision making. The development of theoretical frameworks discussed in recommendation #1 could serve to enhance replication, monitoring, and comparison of findings. For example, GIS-based systems can be used to monitor multiple indicators in almost real-time to enable rapid detection of the pace of changes in ecosystem resiliency, development of dialogues with diverse population groups, design effective adaptive strategies, and rapidly deploy resources and facilitate implementation, monitoring, evaluation and adaptation.

4. Knowledge of how to cope with historical conditions is often insufficient in a rapidly changing world. Thus, a fourth recommendation involves use of *scenario building and testing* as one way to formulate pre-disaster recovery plans that reflect alternative goals of different population groups and premised on the best available bio-conservation science. Scenario development and testing requires *creation of decision support tools that incorporate advanced visualization technologies* to aid stakeholders and decision makers. Scenarios facilitate exploration of plausible future conditions that cannot be readily predicted, envision potential futures and test various strategies to achieve desired goals. For instance, by exploring different futures under alternative land development and sea level rise scenarios in poor countries, the discourse about environmental impacts (e.g., protection of coastal wetlands and associated services), economic development, and impacts of coastal storms can be expanded beyond a limited range of recovery actions to embrace a wider set of plausible strategies that increase wetland ecosystem services, land productivity, income and household food security. Comparisons of scenarios often highlight the tradeoffs and facilitate the coordination of

individual initiatives to produce co-benefits among stakeholders, including present and future generations, which may be less evident if fewer options are examined.

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