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Synthesis

Does Adaptive Management of Natural Resources Enhance Resilience to Climate Change?

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ABSTRACT. Emerging insights from adaptive and community-based resource management suggest that building resilience into both human and ecological systems is an effective way to cope with environmental change characterized by future surprises or unknowable risks. We argue that these emerging insights have implications for policies and strategies for responding to climate change. We review perspectives on collective action for natural resource management to inform understanding of climate response capacity. We demonstrate the importance of social learning, specifically in relation to the acceptance of strategies that build social and ecological resilience. Societies and communities dependent on natural resources need to enhance their capacity to adapt to the impacts of future climate change, particularly when such impacts could lie outside their experienced coping range. This argument is illustrated by an example of present-day collective action for community-based coastal management in Trinidad and Tobago. The case demonstrates that community-based management enhances adaptive capacity in two ways: by building networks that are important for coping with extreme events and by retaining the resilience of the underpinning resources and ecological systems.

INTRODUCTION

The full weight of scientific evidence suggests that the climate is changing, that human activities are exacerbating natural changes in the climate (Intergovernmental Panel on Climate Change 2001), and that observed and projected future changes will have significant impacts on ecosystems, physical systems, and linked human actions (Hughes et al. 2003, Parmesan and Yohe 2003, Root et al. 2003). The likely geographical distribution of impacts and the probabilities of particular future scenarios are much less clear (Schneider 2001). Climate changes are likely to manifest in four main ways: slow changes in mean climate conditions, increased interannual and seasonal variability, increased frequency of extreme events, and rapid climate changes causing catastrophic shifts in ecosystems. Within societies, different types of climate change will bring opportunities to some and increased vulnerability to others, especially those who are already marginalized. This general pattern of adaptability and differentiated impact is confirmed in historical and contemporary records of coping with the consequences of climatic changes (McIntosh et al. 2000, Mortimore and Adams 2001).

A decade of research on vulnerability to climate change shows that inevitably it is the marginalized who suffer the impacts of changing environmental conditions (Ribot et al. 1996, Adger et al. 2001, Smit and Pilifosova 2001, Downing 2003). Thus, adaptation to climate change requires a broader conceptualization of equitable, legitimate, and sustainable development in effective and resilient response. The Intergovernmental Panel on Climate Change, for example, recognized the importance of sustainability in its Third Assessment Report in 2001 and provided guidelines for all its component scientific assessments on how to incorporate the concepts of development, equity, and sustainability (Munasinghe 2000). We argue that a system's capacity for resilience, which involves its ability to absorb perturbations without being undermined or becoming unable to adapt and learn, is an important element of any sustainable response to climate change. Some natural and social systems have inbuilt abilities to bounce back from adverse circumstances, whereas others have to learn how to become resilient. We focus on the role of

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networks and institutions in building resilience in both social and ecological systems.

There is well established evidence for significant future warming in this century on a scale unprecedented in the era of modern human history. Observed climate changes in the past century are causing changes in species ranges and ecosystems and forcing adaptations in resource-dependent economic activities such as farming and fishing. The expectation of the risk of future changes is affecting insurance markets, land use planning, and conservation efforts. Novel and largely unknown risks include, for example, those associated with the expansion of the ranges of pathogens, diseases, and pests that affect human and nonhuman populations (e.g., Harvell et al. 2002). Increasingly, adaptation to present and future risks is understood as a process precipitated by the necessity of coping with extremes within gradual changes in mean climate parameters (see Kelly and Adger 2000, Jones 2001).

Managing natural resource systems with the added stresses associated with climate change poses a challenge for socio-ecological systems. Although not a panacea, community engagement may offer a means of reducing vulnerability to the natural hazards associated with climate change (see, for example, Abramovitz et al. 2001). Critiques of how participatory planning is applied have highlighted its frequent lack of consideration for ecosystem heterogeneity and intracommunity dynamics (see, for example, Agrawal and Gibson 1999, Leach, et al. 1999) as well as the differential access to resources inherent in some community-based management (Ribot and Peluso 2003). We suggest that adaptive management processes, informed by iterative learning about the ecosystem and earlier management successes and failures, increase present-day resilience, which can in turn increase the ability to respond to the threats of long-term climate change. This type of adaptive management, as described by Lee (1999), can be used to pursue the dual goals of greater ecological stability and more flexible institutions for resource management.

This paper explores the potential benefits of present-day co-management in building resilience to cope with climate change through a case study of a coastal community in Trinidad and Tobago that relies on coastal resources. Co-management is one form of collective action whereby resource stakeholders work together with a government agency to undertake some aspect of resource management. Collective action in this context is the coordination of efforts among groups of individuals to achieve a common goal when individual self-interest would be inadequate to achieve the desired outcome (Ostrom 1990). This paper focuses specifically on the role of co-management in building community resilience. The case study shows that social networks set up to enable co-management are also available for dealing with climate-related hazards. Further, the potential outcomes of co-management, i.e., resilient ecosystems, are likely to be more adaptable in future uncertain climates. Further research would be needed to determine whether these findings apply to more complex social and ecological situations that may not be mapped onto defined ecosystems. We expect a priori that the determinants of resilience and vulnerability to external perturbations are common to many resource situations (e.g., Peluso et al. 1994, Adger 2000, and examples in Noss 2001, Adger et al. 2002, Folke et al. 2002, Pelling 2003).

We conclude that the reduction of social vulnerability through the extension and consolidation of social networks, both locally and at national, regional, or international scales, can contribute to increases in ecosystem resilience. This could be an innovative and practical strategy to deal with the threats posed by future climate change. Social acceptance of any response strategy to environmental change of any form is critical. Response strategies themselves need to be flexible enough to be able to adjust to ongoing environmental and social change. Hence, when faced with some degree of uncertainty, management approaches need to be iterative, flexible, and inclusionary; they must also take into account the technological, institutional, and management options that are available to individuals and communities.

CO-MANAGEMENT IN CLIMATE RESPONSE STRATEGIES

Action to adapt and maintain resilience in the face of climate change requires adjustment by governments, by individuals acting as citizens and through market exchange, and by civil society through collective action. Present and future vulnerabilities have strong social elements because both are a function of adaptive capacity, which is in turn dependent on social capital, institutions, and resources and their distribution. Adaptive capacity is akin to a capital asset but can only be put into play through appropriate institutions.

These institutions need legitimacy and harmony with wider social goals if adaptation is to be sustainable. In effect, sustainable resource management requires government structures that are empowered to make collective decisions (Brown et al. 2002). Ostrom et al. (1999) argue that, although the scale of many environmental problems is now global and that global action is required, simply replicating local institutions of collective action at the global scale is not feasible. Indeed, the imposed impacts of climate change are manifest at particular localities. In some political systems, although the appropriate institutional scale for adaptation is often that of municipal or local resource management institutions, the interaction between institutions across scales is constrained by the power relationships among these bodies (O'Brien et al. 2004, Naess et al. 2005). In effect, the diversity of impacts of climate change means that the most appropriate adaptation responses will often be on multiple levels.

This discussion of the appropriate scale of institutions to promote adaptation suggests that broader principles of sustainable development are required to promote equality in the opportunity to adapt. However, not all ways of adapting to climate change are in harmony with existing social norms, institutions, and structures. Table 1 outlines a number of adaptation options for a range of potential impacts of climate change and illustrates dilemmas related to planning and implementation. For example, although urban planning and land use zoning generally take place within local government structures, the enforcement and effectiveness of planning and zoning are dependent on the inclusionary and consensual nature of the processes. Often, key vulnerable groups are excluded. Poorer households are forced to live in riskier areas in urban settlements, making them more vulnerable to risks such as flooding. These groups are frequently largely ignored when infrastructures are being designed to alleviate such vulnerabilities (see Cutter et al. 2000, Pelling 2003). Groups marginalized within societies, including older people and women, are often excluded from decision-making structures. When collaborative planning is ignored, the sustainability of plans and their implementation come into question.

Table 1. Adaptation pathways and their related governance issues. Adapted from Adger (2003*a*).

Adaptation strategy	Social dimensions necessary for implementation
Urban planning and zoning to avoid climate-related hazards	Community governance and participatory structures Effective means of dealing with social exclusion and urban underclasses
Planning for long-term demographic and consumption transition	Social mobility, coherent regional identity, social tolerance, and mixing
Large-scale infrastructure development for adaptation (e.g., dams, irrigation, and water management facilities)	Social acceptance of development technological solutions that have had detrimental environmental or social impacts to excluded groups in the past
New technologies in agriculture and natural resource use	Social acceptance of technologies that are potentially risky and socially disempowering Recognition of existing lay and indigenous knowledge and technologies
Policies and plans for natural areas and ecosystem conservation	New institutional structures for conservation that overturn past models of exclusive protected areas and exclusion of people-centered conservation Social acceptance of shared resilience goals

These observations on the social dimensions of adaptation strategies in urban planning in Table 1 also hold true for proposed new technologies in agriculture and other areas. In agriculture, for example, new technologies associated with the genetic modification of crops are often hailed for their potential to cope with climate stresses and consequently as an adaptation to climate change (see Lipton 1999). However, there are strong and vociferous social and environmental movements that express the public's mistrust of and uneasiness about genetically modified crops and the market structures that promote them. For this reason, these technologies cannot automatically be assumed to be potential adaptation strategies for drought resistance or food security. Similarly, in the face of potential threats to the integrity of natural ecosystems because of climate change, there have been various calls for the expansion of exclusive protected areas or marine reserves (e.g., Hughes et al. 2003). However, there is little point in planning for new protected areas in the face of new climatic conditions without confronting social concerns about the exclusion of users from traditional exclusive conservation (see, for example, Noss 2001, Brown 2002). Societies therefore adapt to climate change through collective action, mediating and trading off the elements of effectiveness and legitimacy through negotiated outcomes.

Because the traditional resources that form part of the public good are regulated by the government, co-management most often involves vertical linkages and shifts in rights and responsibilities from government to local resource users (Berkes 2002). Forms of co-management have been attempted with varying degrees of success, for example, in fisheries management (Lim et al. 1995, Berkes et al. 2001), in coastal zone management (Sandersen and Koester 2000), and in watershed management (Ravnborg and Guerrero 1999).

In principle, the concept of collective action seems to offer one solution to resource management. By working together and consolidating spaces of dependence such as social support networks and local bonding relationships, as well as by working with the government to expand spaces of engagement or outward-reaching networks, users of primary resources may be generating secondary benefits by building community resilience to better cope with the impacts of climate change. In practice, there are several necessary preconditions to the successful implementation of collective action associated with the design of institutions, the nature of the group, and the nature of the resource (Ostrom 1990, Agrawal 2001, Brown et al. 2002), as well as individual strategic behavior that can lead to free-riding behavior and the possible overuse of the resources.

Empirical evidence of successful collective actions for natural resource management, reviewed in Dietz et al. (2003), has contributed to the development of a set of general preconditions for successful collective action (Ostrom 1990, Sandler 1992, Steins and Edwards 1999). The functioning of social networks and response capacity are closely linked: much adaptation to climate change occurs through collective action to mediate collective risk (Adger 2003*b*). Thus, the preconditions for collective action may increase community resilience to climate changes. There are three principles for collective action on which there is broad agreement: (1) smaller groups tend to be more successful than larger groups; (2) the more equitable the distribution of endowments among members, the greater the chance of success; and (3) failures of collective action can be overcome by the introduction of selective benefits and alternative institutional designs (Ostrom 1990). Underpinning these principles is the concept of integration of the interests of diverse stakeholder into collective decisions (Davos 1998). The literature on inclusionary and participatory planning for resource management supports these lessons (see, for example, Owens 2000), recognizing that the barriers to community or individual action do not lie primarily in a lack of information or understanding alone, but in social, cultural, and institutional factors.

Making decisions about what to do about climate change is complicated by uncertainties related to the size and distribution of the possible impacts, and consequently to the risks attached to making maladaptive responses. Decision making in fisheries management, pollution control, coastal zone management, and flood control is characterized by uncertainty as to the outcome of decisions (Ludwig et al. 2001). Further, there is recognition of the importance of learning from past management errors.

SOCIAL RESILIENCE FOR ADAPTING TO CLIMATE CHANGE

Integrated learning and adaptive management are based on three related principles (for a review, see

Brown 2002). Resource stakeholders must (1) be fully engaged in developing management strategies as a means of building a constituency for the resource management problem, (2) agree upon and fully understand the consequences of making decisions, and (3) agree upon the processes for making decisions in a context of deliberative democracy. These approaches offer pathways for vulnerable communities to engage in developing response policies and ensure that there is room for change in those policies. These principles are relevant to climate change in situations in which there is much uncertainty and disagreement about how best to manage the potential consequences of climate change, yet there is a need to take anticipatory adaptive action. Adaptation refers to the actions that people take in response to, or in anticipation of, projected or actual changes in climate, to reduce adverse impacts or take advantage of the opportunities posed by climate change. Adaptation is not about returning to some prior state, because all social and natural systems evolve and, in some senses, co-evolve with each other over time.

Social resilience is often used to describe the capacity for positive adaptation despite adversity (Luthar and Cicchetti 2000). In the context of climate change, social resilience is the ability of groups or communities to adapt in the face of external social, political, or environmental stresses and disturbances (Adger 2000). To be resilient, societies must generally demonstrate the ability to (1) buffer disturbance, (2) self-organize, and (3) learn and adapt (e.g., Trosper 2002). Adaptive capacity, which is often used to refer to the set of preconditions that enables individuals or groups to respond to climate change (Olsson and Folke 2001, Brooks 2003, Berkhout et al. 2004), is a synonym for many characteristics of resilience.

So are social systems resilient in the face of climate change over time? Clearly, individuals and communities are presently responding to climate change in the same way that they have dealt with climate variability throughout history (Adger and Brooks 2003). The capacity to respond to changes in environmental conditions exists within communities to different degrees. Not all responses are sustainable, and there is recent historical evidence that large-scale, systematic changes in global climate have had profoundly negative consequences for many societies in the past (Keys 1999, Cullen, et al. 2000, de Menocal 2001).

There are a growing number of documented contemporary examples of social responses to climatic perturbations. For example, the Inuvialuit people of Sachs Harbour in the Canadian Artic have been making short-term adjustments in the face of slow changes in mean climate conditions over several decades (Berkes and Jolly 2002). Social responses have focused almost exclusively on managing the consequences of the change and have included changing the species hunted and the timing and methods of the hunt. Flexibility within cultural traditions and networks make other forms of response possible for this community, such as food-sharing networks and intercommunity trade. The Berkes and Jolly study also found that newly evolving co-management institutions are creating linkages across scales ranging from local to international, thus transmitting local concerns to a wider audience. This wider community is being drawn on for assistance and advice.

The importance of social resilience can also be seen in responses to other rapid changes in environmental conditions, as revealed in observations of response to natural hazards (Berke et al. 1993, Berke and Beatley 1997). In New Zealand, for example, after the volcanic eruption of Mt. Ruapehu, it was found that self-efficacy and a sense of community were good predictors of community resilience and increased community capacity to respond to sudden changes (Paton et al. 2001). Most importantly, Paton and colleagues recognize the importance of the nature of social relationships as a factor that can enhance resilience. Although the lessons from these studies are context-specific, they do establish some broad criteria by which to assess the adaptive capacity of communities. The nature of the relationships between community members is critical, as are access to and participation in the wider decision-making processes (Adger 2003*b*).

In communities in which there is less cohesion or more centralized planning of community life, the structure of government institutions may be another important factor. In other areas, such as coastal zone management, the expansion of social networks has been noted as an important element in developing more robust management institutions (Tompkins et al. 2002). More specifically, drawing on Cox (1998), networks can be explored in terms of the access to power and representation that they provide to participants, i.e., networks of engagement, and the

support they offer to participants in vulnerable positions, i.e., networks of dependence. The expansion of networks of engagement appears to be critical to the enhancement of resilience in communities affected or likely to be affected by climate change.

How then can communities enhance their social networks and thus expand and consolidate their spaces of engagement? Local groups and individuals often feel their powerlessness in many ways, although none so much as in the lack of access to decision makers (Brown et al. 2001*c*). Building successful community-based resource management in the form of, e.g., co-management arrangements can potentially enhance the resilience of communities as well as maintain ecosystem services and ecosystem resilience. We turn now to examine the mechanisms through which this can occur in one case.

How co-management promotes resilience for climate change adaptation in Trinidad and Tobago

This section outlines an experience in new forms of governance that affect social and ecological resilience in Trinidad and Tobago. Small islands are particularly vulnerable to climate change and are at the forefront of the challenges of sustainable adaptation. This vulnerability has a number of facets. First, tropical island nations are highly dependent on coastal ecosystems and the ecosystem services that flow from them. However, these ecosystems and services are threatened by both climate change and other stressors. Evidence from the past two decades suggests that coral reefs are in decline globally as well as in the Caribbean (Gardner et al. 2003, Pandolfi et al. 2003). Coral reefs under chronic stress effectively have lower resilience and are less likely to recover from stress events associated with climate change, such as higher mean temperatures at the sea surface, a higher frequency of hurricane impacts in some regions, and novel pathogens (Nyström et al. 2000). Although there is evidence that reef systems are resilient to individual stressors, such as the widespread loss of corals associated with the 1997–1998 El Niño/Southern Oscillation event, their resilience in the future may be dependent on some areas being managed for resilience and acting as refugia for species dependent on them (McClanahan et al. 2002).

Second, small island states in the tropics and subtropics face periodic major impacts from hurricanes. Although societies have coped with such impacts throughout history, recovery from hurricane impacts does not necessarily build resilience. Post-disaster recovery frequently reinforces vulnerabilities and excludes sections of society in a way that undermines resilience (Pelling 2003). Communities in which the economy is based on commodity-oriented agriculture often suffer greater impacts from disasters than do the more diverse traditional farming systems typical of tropical small islands (Paulson and Rogers 1997, Holt-Giminez 2002). Third, issues such as the underlying economic openness of small island economies in the presently globalizing world make them susceptible to global political and economic changes (Pelling and Uitto 2002). In historical settings, human populations in island societies have coped with climate change and maintained their resilience through human movement to alleviate resource constraints (e.g., Haberle and Lusty 2000), and these remain important in contemporary island societies. Nevertheless, projected climate changes could potentially undermine the resource base, particularly for freshwater resources, and hence the sustainability of the present populations of the most vulnerable island states, such as those made up exclusively of atoll islands (Barnett and Adger 2003). Thus, the resilience afforded by adaptive management is brought sharply into focus in tropical coastal ecosystems and their related human systems.

Although Trinidad and Tobago may not appear to be among the most vulnerable of island nations according to traditional indicators of vulnerability (Gowrie 2003), the country is nevertheless subject to major sustainability challenges. The struggle to find a balance between development and conservation has made coastal management in Tobago in particular controversial and contested for more than 30 yr. Development pressures to create job opportunities and improvements in the quality of life have involved major investments in physical infrastructure for the tourism industry. At the same time, the government is expected to manage fish stocks, conserve the “natural” heritage for future generations, maintain the quality of the environment for both residents and tourists, manage waste disposal, and maintain the natural coastal defences provided by the coral reefs and mangroves to protect the island from storm and wave damage (e.g., Goreau 1967, Laydoo et al. 1987, Institute for Marine Affairs 1995, Tobago House of Assembly 1999). The contested objectives for one popular part of the coast, the Buccoo Reef area, have

proven difficult to resolve, and over the years environmental conditions have deteriorated (Institute for Marine Affairs 1995, Institute for Marine Affairs 1996).

Resilience has, therefore, not been central to resource management in Trinidad and Tobago. First, experience suggests that there is an incompatibility of current government structures with those suggested as necessary for promoting social and ecological resilience. Inclusive institutions and the sharing of responsibility for natural resources go against the dominant hierarchical institutional forms of most governments throughout the world. Second, adaptive ecosystem management overturns some major tenets of traditional management styles that have in many cases operated through the exclusion of users and the top-down application of scientific knowledge in rigid programs.

In response to declining conditions, action research during the period 1997–2000 (Brown et al. 2001*b*) proposed that social and ecological resilience could be enhanced by including stakeholders for the Buccoo Reef area in an inclusive and sectorally and vertically integrated decision-making process. This process involved identifying and engaging key stakeholders; defining their interests and objectives for the resource; managing conflicts; engaging them in a process of information dissemination and dialog to explore their preferences for managing the area; collecting and analyzing economic, social, and ecological data to understand the impacts of different future scenarios on important criteria; analyzing data; resolving existing conflicts; and finding areas of agreement among the stakeholders (see Brown et al. 2001*c*).

The process brought together a mix of community stakeholders from different spatial areas, socioeconomic backgrounds, and areas of employment. This cross-sectoral, multiscale stakeholder engagement ensured that those who influence or are affected by coastal change had the opportunity to participate in deciding how to tackle both the causes and the consequences of the change. The process itself was learning-driven and iterative, with stakeholder preferences being elicited and fed into a multicriteria analysis model. The results were reported back to the stakeholders, who then took part in group discussions to explore their own preferences and learn about the preferences of others. These processes ensured that the decision-making system was flexible enough to include new information about changing environmental conditions as well as changing preferences about coastal management and local capacity to respond.

Bringing together projections of change in the vulnerable physical and biological systems with potential human actions and responses through stakeholder engagement and conflict resolution was an important part of the adaptive ecosystem management approach. These findings converge with those of both Berkes and Jolly (2002) and Paton et al. (2001) in demonstrating the evolution of social learning. Social learning refers to sustained, i.e., decade-long, processes of attitudinal and behavioral change by individuals in social environments through interaction and deliberation (see Social Learning Group 2001). In the Tobago context, social learning was partly facilitated by providing a forum for deliberation (cf. Roling 1994), sharing information, and providing feedback that served as positive reinforcement. The immediate benefits of this included the removal of barriers to communication and a reduction in the transaction costs of communication (Glasbergen 1996). Out of this process came a consolidation of local spaces of dependence and an expansion of the spaces of engagement. The self-created group immediately solidified the informal interactions between individual agents, and on this base grew the possibility of developing a more formalized co-management arrangement with the government decision makers. In effect, this outcome made it possible to apply integrated ecosystem management that facilitated social learning by government agencies and resource users (see also McCay and Jentoft 1998, Berkes and Jolly 2002).

The evolution of co-management arrangements brought about two critical changes at both the community and the government level. First, the various groups of stakeholders who had previously been in confict were mobilized to take both conservation and development actions together, because they recognized that they had more power as a group than as individuals. Prior to the establishment of the group, few of the group members communicated with each other. The group's cohesion introduced the potential for more flexible localized adaptive responses to the threat posed by climate change to reef systems and the threat of changes in the Caribbean hurricane regime. Open lines of communication meant that small modifications in behavioral norms at the

community level could be instigated through group processes rather than through more formalized institutional change.

One example of this type of collective action was the decision of local boat users to be more careful with oil and gas in the marine area to reduce spillage (Brown et al. 1999). This decision was taken in response to a discussion within the wider group about the ways in which oil and gas spills in the marine area contributed to chronic stress on reef systems. The Brown et al. (1999) study also reports that the group committed itself to community outreach notably through visits to schools, an information and education campaign, and the solicitation of funds to pay for new information signs for users of the Buccoo Reef Marine Park area.

The second critical change arose as the multistakeholder group realized that, by acting collectively and agreeing on a single coherent message, they had greater influence with government agencies. The group decided to write an open letter, published in the local newspaper, to the local government to offer its support for practical management actions that the government could undertake, such as the placing of marker buoys in the marine park and a voluntary warden system (Brown et al. 2001*a*). At the same time, the government decision makers found that active support from the multistakeholder group enabled them to initiate changes in the management process without fear of making unsupported and hence unsuccessful resource management decisions. The integration of the stakeholders into the decision-making process expanded their space of engagement, which in itself provided them with the incentive to continue to work together. Thus the integration of the different stakeholder groups, coupled with learning by the different agents involved in co-management, contributed to a general sense of enhanced capacity to manage the problem, both its causes and consequences. It was generally perceived that this would over time translate into greater ecosystem resilience.

However, does such action and the emergence of these institutions constitute response capacity in the context of climate change? From the example in Tobago, it appears that inclusionary and integrated learning-based coastal management contributes to response capacity in two ways. First, empirical evidence from other case studies in the Caribbean suggests that expanded networks of engagement act as a resource in coping with weather extremes. Preliminary findings from work on government responses to hurricane risk in the Cayman Islands has similarly identified the importance of co-management and dense networks of actors to ensure that a wider range of factors are taken into account in decision making (Tompkins and Hurlston 2003). Similarly, in Grenada, Jessamy and Turner (2003) found that community-based organizations and networks are an important component of present-day disaster management that is often overlooked. In both cases, the expansion of the networks of engagement enhanced the adaptive capacity of the community groups as more resources become available that they could draw on.

Second, the learning that occurs in groups can more easily be incorporated into management processes in flexible informal institutions, as evidenced by the boat users in Tobago and their decision to reduce effluents into the reef systems. It is clear that high sea-surface temperatures such as those experienced in El Niño/Southern Oscillation years, which may become more frequent over time with climate change, pose a threat to the continued widespread existence of coral reef ecosystems in tropical coastal waters (Reaser et al. 2000, Hughes et al. 2003). Flexible management systems that can be modified on the basis of new information are important elements in building resilience. Such learning-based processes are antithetical to the traditional forms of governance that follow more rigid decision-making processes.

Community participation in decision making about natural resources can be beset by a myriad of problems and may not always be in the best interests of either the targeted community or the natural resource being managed (Cooke and Kothari 2001). Indeed, the creation of strong spaces of dependence, empowered communities, and high self-reliance does not automatically promote sustainable management or lead to the inclusion of the most vulnerable (Tacconi and Tisdell 1992, Pelling 2003). This lesson from experience in co-management may be particularly relevant in the case of climate changes in which those experiencing the impacts will not necessarily be causing the impacts, although the findings of Berkes and Jolly (2002) add credence to the idea that it is important to build resilient communities so that they are able to respond to any environmental change.

CONCLUSIONS

The mechanisms for enhancing social and ecological resilience are often inherent in the communities and co-management institutions coping with environmental change. In other cases, mechanisms need to evolve through new institutions for resource management through collective action. Building community resilience through the expansion of the networks of dependence and engagement facilitates this type of learning-based management. The review and evidence from the case presented here suggests a number of ways to build resilience to climate threats. These are to cement localized spaces of dependence, to expand spaces of engagement, and to avoid being tied to specific response paths by implementing flexible learning-based management.

Those societies dependent on resources that are vulnerable to climate change have, in the past, adapted to change through strengthening their spaces of dependence to spread the risks associated with individual events. In parallel, they have expanded their spaces of engagement to enable them to find a wider support network, for example, in the form of interaction with regional or national government or international agencies. Social resilience in this context appears to be promoted through at least two distinct forms of cross-scale interaction:

- networks and community relations of individuals and groups operating to cope with variability and change in everyday decision making, and
- wider networks of individuals or groups who may be able to influence the decisions that are being made at the local scale.

Adaptive co-management may promote the expansion of networks and thus enhance social resilience. In the area of responding to climate change, clearly the nature of the relationships between resource users at the community level, their access to new technology, and their willingness to change will determine their immediate response to climate change risks. However, it is their networks that enable individuals to engage in the wider decision environment that will affect their longer-term resilience. The existence and the usefulness of these networks are determined by institutional as well as social factors.

At the community level, reducing the barriers to communication through sharing information and feedback that provides positive reinforcement are important elements in consolidating networks of dependence. At the institutional level, integrated institutional structures may be better able to support the inclusion of climate stakeholders in decision-making processes and to ensure that their needs can be addressed by as wide an audience as possible. Providing spaces for deliberation within co-management decision-making processes can facilitate this, as can opening up channels of communication and ensuring that important stakeholders are engaged.

The generic conclusion from this review is that resilience in social-ecological systems is important to their ability to adapt to uncertain future climate change. However, this is not a blueprint for adaptation for a number of reasons that form the limitations of this study. First, the past is not always a good guide to the future. Although many risks associated with climate change are well known, adaptation to climate change will be manifest in the first instance through adjustments in experienced variability and extremes, and the landscape of risk is likely to be altered. As discussed in Scheffer et al. (2001) and others, chronic stress on natural resource systems from human disturbance and pollution means that ecosystems may face irreversible change. The cumulated impacts of more frequent or intense weather extremes further threaten the recovery of these systems. Although there is much evidence of chronic stress to Caribbean and other coral reefs, there is more contested evidence for this region on projected changes in hurricane intensity or frequency (Intergovernmental Panel on Climate Change 2001). There are other resource systems, for example in the high latitudes, that face greater absolute changes in temperature, precipitation, and, ultimately, resource availability.

Thus, although there are limits to spatial or temporal analogs of climate change adaptation, the present-day capacity to adapt and to be resilient is a crucial starting point for that adaptation. Vulnerability among certain social groups is prevalent in virtually all resource circumstances (see Luers et al. 2003, Turner et al. 2003 for examples from Mexico, the Arctic, and elsewhere). The capacity to adapt is clearly uneven in both spatial and social terms, partly because of the role of access to the underlying resource base in determining this adaptive capacity and the nature of successful adaptation (Yohe and Tol 2002, Kahn 2003).

Although much adaptation to climate change is anticipatory, some also takes place in response to the impacts of single extreme events. Further, some climate change impacts, such as a significant and rapid rise in sea level, are likely to significantly alter the resource systems and their ecosystem services. The processes needed to adapt to catastrophic system changes would involve a major restructuring of the economy and society. Clearly, these are dangerous thresholds in the climate system that need to be avoided. There is, in effect, no substitute for the significant mitigation of emissions at the present time. Adaptation to both gradual and significant changes should involve encouraging the evolution of new institutions that are sensitive to the resilience of the ecosystems they are managing and knowledgeable about the specific nature of the risks of climate change.

Responses to this article can be read online at: http://www.ecologyandsociety.org/vol9/iss2/art10/responses/index.html

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LITERATURE CITED

Abramovitz, J., T. Banuri, P. O. Girot, B. Orlando, N. Schneider, E. Spanger-Siegfried, J. Switzer, and A. Hammill. 2001. *Adapting to climate change: natural resource management and vulnerability reduction.* International Union for Conservation of Nature and Natural Resources, Gland, Switzerland.

Adger, W. N. 2000. Social and ecological resilience: are they related? *Progress in Human Geography* **24**(3):347-364.

Adger, W. N. 2003*a.* Social aspects of adaptive capacity. Pages 29-49 *in* J. Smith, R. Klein, and S. Huq, editors. *Climate change, adaptive capacity and development.* Imperial College Press, London, UK.

Adger, W. N. 2003*b.* Social capital, collective action and adaptation to climate change. *Economic Geography* **79**(4):387-404.

Adger, W. N., and N. Brooks. 2003. Does global environmental change cause vulnerability to disaster? Pages 19-42 *in* M. Pelling, editor. *Natural disaster and development in a globalising world.* Routledge, London, UK.

Adger, W. N., P. M. Kelly, and N. H. Ninh, editors. 2001. *Living with environmental change: social resilience, adaptation and vulnerability in Vietnam.* Routledge, London, UK.

Adger, W. N., P. M. Kelly, A. Winkels, L. Q. Huy, and C. Locke. 2002. Migration, remittances, livelihood trajectories and social resilience. *Ambio* **31**:358-366.

Agrawal, A. 2001. Common property institutions and sustainable governance of resources. *World Development* **29**(10):1649-1672.

Agrawal, A., and Gibson, C. C. 1999. Enchantment and disenchantment: the role of community in natural resource conservation. *World Development* **27**(4):629-649.

Barnett, J., and W. N. Adger. 2003. Climate dangers and atoll countries. *Climatic Change* **61**:321-337.

Berke, P. R., and T. Beatley. 1997. *After the hurricane: linking recovery to sustainable development in the Caribbean.* Johns Hopkins University Press, Baltimore, Maryland, USA.

Berke, P. R., J. Kartez, and D. Wenger. 1993. Recovery after disaster: achieving sustainable development, mitigation and equity. *Disasters* **17**(2):93-109.

Berkes, F. 2002. Cross-scale institutional linkages for commons management: perspectives from the bottom up. Pages 293-321 *in* E. Ostrom, T. Dietz, N. Dolsak, P. C. Stern, S. Stonich, and E. U. Weber, editors. *The drama of the commons.* National Academy Press, Washington, D.C., USA.

Berkes, F., and D. Jolly. 2002. Adapting to climate change: social-ecological resilience in a Canadian Western Arctic

community. *Conservation Ecology* **5**(2):18. [online] URL: http://www.consecol.org/vol5/iss2/art18.

Berkes, F., R. Mahon, P. McConney, R. C. Pollnac, and R. S. Pomeroy. 2001. *Managing small-scale fisheries: alternative directions and methods.* International Development Research Centre, Ottawa, Canada.

Berkhout, F., J. Hertin, and D. M. Gann. 2004. *Learning to adapt: organisational adaptation to climate change impacts.* Tyndall Centre Working Paper 47. Tyndall Centre for Climate Change Research, University of East Anglia, Norwich, UK.

Brooks, N. 2003. *Vulnerability, risk and adaptation: a conceptual framework.* Tyndall Centre Working Paper 38. Tyndall Centre for Climate Change Research, University of East Anglia, Norwich, UK.

Brown, K. 2002. Innovations for conservation and development. *Geographical Journal* **168**(1):6-17.

Brown, K., W. N. Adger, and E. L. Tompkins. 2001*a*. *Building consensus amongst stakeholders for management of natural resources at the land water interface: final technical report to DFID Natural Resources Systems Programme.* Overseas Development Group, University of East Anglia, Norwich, UK.

Brown, K., W. N. Adger, E. L. Tompkins, P. Bacon, D. Shim, and K. Young. 1999. *Evaluating trade-offs between users of marine protected areas in the Caribbean: final technical report to DFID Natural Resources Systems Programme.* Overseas Development Group, University of East Anglia, Norwich, UK.

Brown, K., W. N. Adger, E. Tompkins, P. Bacon, D. Shim, and K. Young. 2001*b*. Trade-off analysis for marine protected area management. *Ecological Economics* **37**(3):417-434.

Brown, K., E. L. Tompkins, and W. N. Adger. 2001*c*. *Trade-off analysis for participatory coastal zone decision-making.* Overseas Development Group, University of East Anglia, Norwich, UK.

Brown, K., E. L. Tompkins, and W. N. Adger. 2002. *Making waves: integrating coastal conservation and development.* Earthscan, London, UK.

Cooke, B., and U. Kothari, editors. 2001. *Participation: the new tyranny?* Zed Books, London, UK.

Cox, K. R. 1998. Spaces of dependence, spaces of engagement and the politics of scale, or: looking for local politics. *Political Geography* **17**(1):1-23.

Cullen, H. M., P. B. de Menocal, S. Hemming, F. H. Brown, T. Guilderson, and F. Sirocko. 2000. Climate change and the collapse of the Akkadian empire. *Geology* **28**(4):379-382.

Cutter, S. L., J. T. Mitchell, and M. S. Scott. 2000. Revealing the vulnerability of people and places: a case study of Georgetown County, South Carolina. *Annals of the Association of American Geographers* **90**:713-737.

Davos, C. A. 1998. Sustaining co-operation for coastal sustainability. *Journal of Environmental Management* **52**:379-387.

de Menocal, P. B. 2001. Cultural responses to climate change during the late Holocene. *Science* **292**:667-673.

Dietz, T., E. Ostrom, and P. C. Stern. 2003. The struggle to govern the commons. *Science* **302**:1907-1912.

Downing, T. 2003. Toward a vulnerability/adaptation science: lessons from famine early warning and food security. Pages 77-100 *in* J. Smith, R. Klein, and S. Huq, editors. *Climate change adaptive capacity and development.* Imperial College Press, London, UK.

Folke, C., S. Carpenter, T. Elmqvist, L. Gunderson, C. Holling, B. Walker, J. Bengtsson, F. Berkes, J. Colding, K. Danell, M. Falkenmark, L. Gordon, R. Kasperson, N. Kautsky, A. Kinzig, S. Levin, K.-G. Mäler, F. Moberg, L. Ohlsson, P. Olsson, E. Ostrom, W. Reid, J. Rockström, H. Savenij, and U. Svedin. 2002. *Resilience and sustainable development: building adaptive capacity in a world of transformations.* Report 2002:1. Swedish Environmental Advisory Council, Stockholm, Sweden.

Gardner, T. A., I. M. Côté, J. A. Gill, A. Grant, and A. R. Watkinson. 2003. Long-term region-wide declines in Caribbean corals. *Science* **301**:958-960.

Glasbergen, P. 1996. Learning to manage the environment. Pages 175-193 *in* J. Meadowcroft, editor. *Democracy and the environment: problems and prospects.* Edward Elgar, Cheltenham, UK.

Goreau, T. F. 1967. *Buccoo Reef and Bon Accord Lagoon, Tobago; observations and recommendations concerning the preservation of the reef and its lagoon in relation to urbanisation of the neighbouring coastal land.* Tobago House of Assembly, Carenage, Tobago.

Gowrie, M. N. 2003. Environmental vulnerability index for the island of Tobago, West Indies. *Conservation Ecology Conservation Ecology* **7**(2):11. [online] URL: http://www.consecol.org/vol7/iss2/art11.

Haberle, S. G., and A. C. Lusty. 2000. Can climate influence cultural development? A view through time. *Environment and History* **6**:349-369.

Harvell, C. D., C. E. Mitchell, J. R. Ward, S. Altizer, A. P. Dobson, R. S. Ostfeld, and M. D. Samuel. 2002. Climate warming and disease risks for terrestrial and marine biota. *Science* **296**:2158-2162.

Holt-Gimenez, E. 2002. Measuring farmers' agroecological resistance after Hurricane Mitch in Nicaragua: a case study in participatory, sustainable land management and impact monitoring. *Agriculture, Ecosystems and Environment* **93**:87-105.

Hughes, T. P., A. H. Baird, D. R. Bellwood, M. Card, S. R. Connolly, C. Folke, R. Grosberg, O. Hoegh-Guldberg, J. B. C. Jackson, J. Kleypas, J. M. Lough, P. Marshall, M. Nyström, S. R. Palumbi, J. M. Pandolfi, B. Rosen, and J. Roughgarden. 2003. Climate change, human impacts, and the resilience of coral reefs. *Science* **301**:929-933.

Institute for Marine Affairs (IMA). 1995. *The formulation of a management plan for the Buccoo Reef Marine Park.* IMA, Carenage, Trinidad and Tobago.

Institute for Marine Affairs (IMA). 1996. *Report of phase 2 and phase 3: an ecological assessment of the proposed alternative development strategies for S. W. Tobago.* Technical Advisory Services, IMA, Carenage, Trinidad and Tobago.

Intergovernmental Panel on Climate Change (IPCC). 2001. *Climate change 2001: synthesis report; a contribution of Working Groups I, II, and III to the third assessment report of the Intergovernmental Panel on Climate Change.* Cambridge University Press, Cambridge, UK.

Jessamy, V. R., and R. K. Turner. 2003. *Modelling community response and perception to natural hazards: lessons learnt from Hurricane Lenny 1999.* CSERGE Working Paper EDM 03-06. University of East Anglia, Norwich, UK.

Jones, R. N. 2001. An environmental risk assessment/management framework for climate change impact assessments. *Natural Hazards* **23**(2/3):197-230.

Kahn, M. E. 2003. Two measures of progress in adapting to climate change. *Global Environmental Change* **13**:307-312.

Kelly, P. M., and W. N. Adger. 2000. Theory and practice in assessing vulnerability to climate change and facilitating adaptation. *Climatic Change* **47**:325-352.

Keys, D. 1999. *Catastrophe: an investigation into the origins of the modern world.* Arrow Books, London, UK.

Laydoo, R., L. Heileman, and C. R. Society. 1987. *Environmental impacts of the Buccoo and Bon Accord sewage treatment plants, south-west Tobago.* Tobago House of Assembly, Carenage, Tobago.

Leach, M., R. Mearns, and I. Scoones. 1999. Environmental entitlements: dynamics and institutions in community-based natural resource management. *World Development* **27**(2):225-247.

Lee, K. N. 1999. Appraising adaptive management. *Conservation Ecology* **3**(2):3 (online) http://www.consecol.org/Journal/vol3/iss2/art3/.

Lim, C. P., Y. Matsuda, and Y. Shigemi. 1995. Co-management in marine fisheries: the Japanese experience. *Coastal Management* **23**:195-221.

Lipton, M. 1999. *Reviving global poverty reduction: what role for genetically modified plants?* Crawford Memorial Lecture, October 1999. Consultative Group on International Agricultural Research, Washington, D.C., USA.

Ludwig, D., M. Mangel, and B. Haddad. 2001. Ecology, conservation, and public policy. *Annual Review of Ecology and Systematics* **32**:481-517.

Luers, A. L., D. B. Lobell, L. S. Sklar, C. L. Addams, and P. A. Matson. 2003. A method for quantifying vulnerability, applied to the agricultural system of the Yaqui Valley, Mexico. *Global Environmental Change* **13**:255-267.

Luthar, S. S., and D. Cicchetti. 2000. The construct of resilience: implications for interventions and social policies. *Development and Psychopathology* **12**(4):857-885.

McCay, B. J., and S. Jentoft. 1998. Market or community failure? Critical perspectives on common property research. *Human Organization* **57**(1): 21-29.

McClanahan, T. R., N. V. C. Polunin, and T. J. Done. 2002. Resilience of coral reefs. Pages 111-163 in L. H. Gunderson and L. Pritchard Jr., editors. *Resilience and the behaviour of large-scale systems.* SCOPE Volume 60. Island Press, Washington, D.C., USA.

McIntosh, R. J., J. A. Tainter, and S. K. McIntosh, editors. 2000. *The way the wind blows: climate, history, and human action.* Columbia University Press, New York, New York, USA.

Mortimore, M., and W. M. Adams. 2001. *Working the Sahel.* Routledge, London, UK.

Munasinghe, M. 2000. Development, equity and sustainability. Pages 69-110 *in* R. Pachauri, T. Taniguchi, and K. Tanaka, editors. *Guidance papers on the cross-cutting issues of the third assessment report of the IPCC.* International Panel on Climate Change, Geneva, Switzerland.

Næss, L. O., G. Bang, S. Eriksen and J. Vevatne. 2005. Institutional adaptation to climate change: flood responses at the municipal level in Norway. *Global Environmental Change* **15**(2), *in press.*

Noss, R. F. 2001. Beyond Kyoto: forest management in a time of rapid climate change. *Conservation Biology* **15**:578-590.

Nyström, M., C. Folke, and F. Moberg. 2000. Coral reef disturbance and resilience in a human-dominated environment. *Trends in Ecology and Evolution* **15**(10):413-417.

O'Brien, K., L. Sygna, and J. E. Haugen. 2004. Vulnerable or resilient? A multi-scale assessment of climate impacts and vulnerability in Norway. *Climatic Change* **64**:193-225.

Olsson, P., and C. Folke. 2001. Local ecological knowledge and institutional dynamics for ecosystem management: a study of Lake Racken Watershed, Sweden. *Ecosystems* **4**(2):85-104.

Ostrom, E. 1990. *Governing the commons: the evolution of institutions for collective action.* Cambridge University Press, Cambridge, UK.

Ostrom, E., J. Burger, C. B. Field, R. B. Norgaard, and D. Policansky. 1999. Revisitng the commons: local lessons, global challenges. *Science* **284:**278-282.

Owens, S. 2000. "Engaging the public": information and deliberation in environmental policy. *Environment and Planning A* **32**:1141-1148.

Pandolfi, J. M., R. H. Bradbury, E. Sala, T. P. Hughes, K. A. Bjorndal, R. G. Cooke, D. McArdle, L. McClenachan, J. H. Newman, G. Paredas, R. R. Warner, and J. B. C. Jackson. 2003. Global trajectories of the long-term decline of coral reef ecosystems. *Science* **301**:955-958.

Parmesan, C., and G. Yohe. 2003. A globally coherent fingerprint of climate impacts across natural systems. *Nature* **421**:37-42.

Paton, D., M. Millar, and D. Johnston. 2001. Community resilience to volcanic hazard consequences. *Natural Hazards* **24**(2):157-169.

Paulson, D. D., and S. Rogers. 1997. Maintaining subsistence security in Western Samoa. *Geoforum* **28**:173-187.

Pelling, M. 2003. *The vulnerability of cities: natural disasters and social resilience.* Earthscan, London, UK.

Pelling, M., and J. I. Uitto. 2001. Small island developing states: natural disaster vulnerability and global change. *Environmental Hazards* **3**:49-62.

Peluso, N. L., C. R. Humphrey, and L. P. Fortmann. 1994. The rock, the beach and the tidal pool: people and poverty in natural resource dependent areas. *Society and Natural Resources* **7**:23-38.

Ravnborg, H. M., and M. P. Guerrero. 1999. Collective action in watershed management: experiences from the Andean hillsides. *Agriculture and Human Values* **16**:257-266.

Reaser, J. K., R. Pomerance, and P. O. Thomas. 2000.

Coral bleaching and global climate change: scientific findings and policy recommendations. *Conservation Biology* **14**(5):1500-1511.

Ribot, J. C., A. R. Magalhães, and S. S. Panagides, editors. 1996. *Climate variability, climate change and social vulnerability in the semi-arid tropics.* Cambridge University Press, Cambridge, UK.

Ribot, J. C., and N. L. Peluso. 2003. A theory of access. *Rural Sociology* **68**:153-181.

Roling, N. G. 1994. Communication support for sustainable natural resource management. *IDS Bulletin* **25**:125-133.

Root, T. L, J. T. Price, K. R. Hall, S. H. Schneider, C. Rosenzweig, and J. A. Pounds. 2003. Fingerprints of global warming on wild animals and plants. *Nature* **421**:57-60.

Sandersen, H. T., and S. Koester. 2000. Co-management of tropical coastal zones: the case of the Soufriere Marine Management Area, St Lucia, WI. *Coastal Management* **28**:87-97.

Sandler, T. 1992. *Collective action: theory and applications.* Harvester Wheatsheaf, London, UK.

Scheffer, M., S. Carpenter, J. A. Foley, C. Folke, and B. Walker. 2001. Catastrophic shifts in ecosystems. *Nature* **413**:591-596.

Schneider, S. H. 2001. What is "dangerous" climate change? *Nature* **411**:17-19.

Smit, B., and O. Pilifosova. 2001. Adaptation to climate change in the context of sustainable development and equity. Pages 877-912 *in* J. J. McCarthy, O. Canziani, N. A. Leary, D. J. Dokken, and K. S. White, editors. *Climate change 2001: impacts, adaptation and vulnerability.* Cambridge University Press, Cambridge, UK.

Social Learning Group. 2001. *Learning to manage global environmental risks. Volume 1. A comparative history of social responses to climate change, ozone depletion, and acid rain.* MIT Press, Cambridge, Massachusetts, USA.

Steins, N. A., and V. M. Edwards. 1999. Collective action in common pool resource management: the contribution of social constructivist perspective to existing theory. *Society and Natural Resources* **12**:539-557.

Tacconi, L., and C. Tisdell. 1992. Rural development projects in LDC's: appraisal, participation and sustainability. *Public Administration and Development* **12**(3):267-278.

Tobago House of Assembly. 1999. *The integrated plan for the development of the people of Tobago in the 21st Century.* Policy Research and Development Institute, Tobago House of Assembly, Carenage, Tobago.

Tompkins, E., W. N. Adger, and K. Brown. 2002. Institutional networks for inclusive coastal management in Trinidad and Tobago. *Environment and Planning A* **34**:1095-1111.

Tompkins, E. L., and L.-A. Hurlston. 2003. *Report to the Cayman Islands' Government: adaptation lessons learned from responding to tropical cyclones by the Cayman Islands' Government, 1988 - 2002.* Tyndall Centre Working Paper 35. Tyndall Centre for Climate Change Research, University of East Anglia, Norwich, UK.

Trosper, R. L. 2002. Northwest coast indigenous institutions that supported resilience and sustainability. *Ecological Economics* **41**:329-344.

Turner, B. L., P. A. Matson, J. J. McCarthy, R. W. Corell, L. Christensen, N. Eckley, G. K. Hovelsrud-Broda, J. X. Kasperson, R. E. Kasperson, A. Luers, M. L. Martello, S. Mathiesen, R. Naylor, C. Polsky, A. Pulsipher, A. Schiller, H. Selin, and N. Tyler. 2003. Illustrating the coupled human-environment system for vulnerability analysis: three case studies. *Proceedings of the National Academy of Sciences* **100**:8080-8085.

Yohe, G., and R. S. J. Tol. 2002. Indicators for social and economic coping capacity: moving toward a working definition of adaptive capacity. *Global Environmental Change* **12**:25-40.