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Strengthening socio-ecological resilience through disaster risk reduction and climate change adaptation: Identifying gaps in an uncertain world

WILLIAM M. COLLIER[1,*], KASEY R. JACOBS[1], ALARK SAXENA[1], JULIANNE BAKER-GALLEGOS[1], MATTHEW CARROLL[1] AND GARY W. YOHE[2]

[1]School of Forestry and Environmental Studies, Yale University, 195 Prospect Street, New Haven, CT 06511, USA
[2]Department of Economics, Wesleyan University, 238 Church Street, Middletown, CT 06459, USA

Global environmental change and climate change are rapidly altering the world's socio-ecological systems and affecting human populations at multiple scales. Important manifestations of these changes are hazard and disaster events. The emerging fields of climate change adaptation and disaster risk reduction provide significant opportunities to avoid and/or reduce many of the negative consequences associated with such events. Reviewing current attempts to link these two fields, we suggest an urgent need for a holistic and dynamic systems approach, focusing on socio-ecological resilience as a primary objective for adaptation and risk reduction. Furthermore, we propose two mechanisms for transformative change in these fields: (1) the use of iterative risk management as a primary instrument for adaptive decision making, and (2) the establishment of 'boundary organizations' and institutional changes that increase the transfer of knowledge between not only science and policy, but also science, policy and practice. There is immediate demand for participatory scholarly research to address the needs and concerns of practitioners on the ground. As a framework for these concepts, we see a dynamic systems approach to socio-ecological resilience as a means to deal with the inherent uncertainty associated with climate change and hazard events.

Keywords: adaptive management; boundary organizations; dynamic systems theory; knowledge networks; uncertainty; vulnerability

1. Introduction

Global environmental change is occurring at rates unprecedented in human history, challenging the resilience and adaptability of communities worldwide. This change can largely be attributed to environmental degradation from the exploitation of natural resources (e.g. Meyer and Turner, 1992; Dobson et al., 1997; Coleman and Williams, 2002) and the alteration of the earth's climate system through unnatural amounts of greenhouse gas (GHG) emissions into the atmosphere (e.g. IPCC, 2001; 2007). Focus on global climate change and its attributed environmental and socio-economic consequences over past decades, particularly over the last several years, has led to a growing body of literature and increasing concern about climate change impacts on human populations (e.g. Adger et al., 2003; IPCC, 2007; van Aalst et al., 2008).

Highly uncertain risks are expected to affect many dimensions of societies (i.e. agriculture, fisheries, energy, tourism, forestry, water resources, etc.) that are essential to the livelihoods of human populations, particularly in developing countries. For societies already vulnerable and sensitive to external stresses, climate change risks may exacerbate the social and economic conditions

■ *Corresponding author. *E-mail:* **william.collier@yale.edu**

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they face (Adger et al., 2003; Suárez et al., 2005). However, both contemporary and historical case studies, especially those in Africa and Asia-Pacific, have demonstrated that resilience is strong. Yet populations and communities have a new challenge to face that will certainly test this resilience.

The rate of change driven by increased anthropogenic GHG emissions continues to accelerate faster than previously anticipated (IPCC 2007; Rahmstorf et al., 2007; Smith et al., 2009). This is illustrated by one of the manifestations of climate change, the increasing intensity and frequency of natural disasters and extreme weather events (Srinivas and Nakagawa, 2008; Smith et al., 2009). The rate of increase of disasters as well as the numbers of people affected by these hazard events has been dramatic over the past decade (IFRC, 2003). Thus, the urgency to respond to these changes, even in the face of uncertainty, has become much more pressing and presents the need for assisted adaptation.

These recent trends have placed disasters at the centre of human–environment debates and have linked them with issues of development, technology and economic resiliency (Schipper and Pelling, 2006). As a response to this concern, international governance bodies, national governments, development agencies and organizations, non-governmental and non-profit organizations and private enterprise are creating mitigative and adaptive responses to these issues (Smit and Wandel, 2006). Special attention has been given to developing nations, which are considered to be the most vulnerable to the risks and pressures exerted by environmental change. In order to confront this, research endeavours, policies and practices that enhance resilience must be considered as a way to respond to a world that is in constant change (Pelling and Uitto, 2001).

In this article, we review the current understanding of natural and social disasters, the paradigm shifts in disaster management, the emergence of climate change adaptation (CCA) and the linkages between CCA and disaster risk reduction (DRR). Current scholarly and practitioner attempts to link the two fields are described, and we propose an urgent need for a holistic and dynamic systems approach, focusing on socio-ecological resilience as an opportunity to increase collaboration between the fields. We suggest two mechanisms to achieve this: (1) the use of iterative risk management as a primary instrument for adaptive decision making and (2) the establishment of boundary organizations and institutional changes to increase the transfer of knowledge between science, policy and practice.

The thoughts presented throughout this review are informed by a recent Forum held on 23–24 April 2009 at the Yale School of Forestry and Environmental Studies, entitled 'A Dynamic Systems Approach to Socio-ecological Resilience and Disaster Risk Reduction: Prioritizing the Gaps in a Changing World'. The two-day event covered many aspects of CCA, DRR and socio-ecological resilience. The participants, who are researchers, practitioners and policy makers, were charged with crossing traditional disciplines and boundaries to indentify and prioritize gaps and ways forward to link the fields of CCA and DRR for a holistic systems approach to deal with the inherent uncertainty associated with climate change and hazard events.

1.1. Understanding natural and social disasters

There is a significant body of literature regarding conceptualizations and definitions of disasters in the social science literature (e.g. Quarantelli and Dynes, 1977; Turner and Pidgeon, 1978; Quarantelli, 1988; 1998; Oliver-Smith, 1996). One such example is Oliver-Smith (1996, p. 303) who defines disasters as 'a process or event involving a combination of a potentially destructive agent(s) from the natural and/or technological environment and a population in a socially and technologically produced state of vulnerability'. Thus, natural disasters are the result of the interaction between a vulnerable population and a hazard event. Consequently, climate change will have a twofold effect on disaster risk: (1) through the increase in weather and climate hazards, and (2) through an increase in social vulnerability to these hazards. By exacerbating

ecosystem degradation and affecting livelihoods at the local level, climate change will become an additional stressor as well as an inhibitor for communities' coping capacity (ISDR, 2002).

High vulnerability and low adaptive capacity have been associated with societies with a high dependence on natural resources (World Bank, 2000). This echoes the concern of the Intergovernmental Panel on Climate Change (IPCC) for low-lying coastal and island regions whose populations are highly reliant on natural resources; current adaptation for these communities is unbalanced and 'readiness for increased exposure is low' (IPCC, 2007, p. 15). Many of these regions are the most disaster-prone in the world and have experienced disaster relief and development interventions for decades. Yet resilience is still considered low in these countries. The lingering question, therefore, is 'why?' We will return to this question in detail later, but will first supply a background of the emergence of several important paradigm shifts.

1.2. From disaster response to disaster risk reduction

Since the 1970s, the disaster relief and humanitarian community has gone through several important paradigm shifts. The community, over the years, has refined its understanding and management of disasters, from identifying and responding to hazard events to determining and targeting the underlying drivers of vulnerability that turn hazards into disasters. Although the shifts are more recent, Carr (1932) proposed the conceptual model for many of these ideas much earlier. An important shift in the practitioner community came in the early 1980s, when the US Federal Emergency Management Agency (FEMA) proposed an approach to disaster management that distinguished between mitigation, preparedness, response and recovery. Similarly, following the International Decade for Natural Disaster Reduction (IDNDR) (1990–1999), the United Nations International Strategy for Disaster Reduction (ISDR) was mandated to focus on the paradigm shift from disaster mitigation to disaster prevention, also known as DRR. At the interim of the IDNDR, the Yokohama Strategy and Plan of Action for a Safer World led to a change in thinking about disaster mitigation (Schipper and Pelling, 2006). Movement in thinking and practice continued during the United Nations World Conference on Disaster Reduction (WCDR) in 2005 (Schipper and Pelling, 2006). As a result, the Hyogo Framework for Action (HFA) (2005–2015) was established as an international commitment providing technical and political agreement on issues necessary to reduce disaster risk. Ultimately, these shifts led to the newly recognized DRR framework. ISDR promoted this framework to development and humanitarian organizations worldwide. The combined efforts of various stakeholders produced an increasing desire to identify actions that promote reducing vulnerability before hazards can result in undesirable impacts, particularly within the context of climate change (Klein et al., 2003). This interest continues to date. In fact, the forthcoming IPCC Assessment Report (AR5) will have a distinct chapter on DRR as an adaptation strategy, and the IPCC is also developing a Special Report on managing the risks of extreme events and hazards, focusing largely on DRR (IISD, 2009).

Despite the efforts of the past several decades, including preventative measures that have been demonstrated to be more economically efficient than reactive ones, disaster relief, response and recovery still predominate. This is also discouraging because a growing body of literature suggests that post-disaster response can actually increase vulnerabilities in the long term (Anderson and Woodrow, 1998; Schipper and Pelling, 2006).

Nonetheless, as the emphasis continues to shift from disaster response to DRR, greater and sustained efforts are needed to make these changes within research institutions as well as development and humanitarian agencies and organizations (Linnerooth-Bayer et al., 2005). In such efforts, many institutions, agencies and organizations are developing analytical tools for disaster management, to identify indicators for effective disaster preparedness in the hopes of helping

communities to reduce their risk from disasters. Likewise, Schipper and Pelling (2006) suggest that such risk appraisal and assessment methodologies could prove significant in designing development strategies in the future.

1.3. The emergence of climate change adaptation

CCA emerged from the international treaty of the UN Framework Convention on Climate Change (UNFCCC) in 1992, especially for developing country parties through Article 4. CCA has been given second priority to climate change mitigation (CCM) since its inception, however, because of a perceived sense of greater urgency to slow the pace of emissions in response to Article 2 obligations about avoiding dangerous anthropogenic interference to the climate system (Pielke, 1998; Schipper and Pelling, 2006). For example, the Kyoto Protocol (2008–2012), an international agreement linked to the UNFCCC, sets legally binding targets for the reduction of GHG emissions but has only little emphasis on CCA. Many parties have disagreed on this prioritization, notably developing countries.

Limited success to date in CCM and increased clarity in climate change signals have made parties realize the importance and parallel urgency of adaptive measures and policies. Indeed, IPCC (2007) concludes that observed impacts from climate change to which the planet is already committed would continue throughout the next century even if GHG emissions were cut to zero. So, while CCM has traditionally been the pivotal issue for many climate change experts, CCA is now widely acknowledged as necessary for responding effectively and equitably to the impacts of climate change. In recent years, CCA has become a key focus of the scientific and policy-making communities and is now a major area of discussion under the UNFCCC. The Seventh Conference of the Parties (COP7) in 2001 addressed the special concerns of the world's 38 Least Developed Countries (LDCs), which were given an opportunity to develop National Adaptation Programmes of Action (NAPAs). Similarly, at the Eleventh Conference of the Parties (COP11) in 2005 the Nairobi Work Programme (NWP) (2005–2010) was established to focus exclusively on impacts, vulnerabilities and adaptation. CCA gained further recognition at the Thirteenth Conference of the Parties (COP13) in 2007 when the Bali Road Map (BRM) and Bali Action Plan (BAP), which chart a path to move forward post-Kyoto Protocol, gave equal priority to both CCM and CCA. The BAP also identified risk management and DRR as important elements for CCA moving forward.

Governments, institutions, researchers, practitioners and populations are all preparing for the CCA challenge posed to societies. In such efforts, Klein and Tol (1997) and Huq and Klein (2003) have developed approaches to anticipatory adaptation. Increased importance of CCA and identification of DRR has led to numerous initiatives that address both DRR and CCA (e.g. UNISDR Working Group on Climate Change and the Red Cross/Red Crescent Climate Change Center), suggesting that DRR has much to contribute to CCA policy and research (Handmer, 2003).

Community-based adaptation (CBA) is one innovative approach to CCA that focuses on enabling communities to enhance their own adaptive capacity, thereby empowering vulnerable communities to increase their own resilience to the impacts of climate change. CBA identifies, assists and implements community-based activities, research and policy in regions where adaptive capacity is as dependent on livelihoods as climatic changes. While CBA has strong merits for strengthening the resilience of communities, it cannot, however, be viewed as a panacea. We propose, as have others (e.g. O'Brien et al., 2006; Schipper and Pelling 2006; Thomalla et al., 2006), that CCA and DRR must to be integrated together into a larger, holistic and systems-based approach, and that CBA techniques could play an important role in achieving many of the desired goals towards increasing socio-ecological resilience and reducing disaster risk.

2. Linking disaster risk reduction and climate change adaptation

It has become apparent that climate change will not only be expressed through slow-onset changes in trends and average conditions over a long period, but also through non-linear and stochastic shifts in the frequency, intensity and severity of extreme events. The disaster relief community has great experience with droughts, floods, heat waves and cyclones, but only recently have disaster scholars and practitioners engaged in climate change debates (Helmer and Hilhorst, 2006). One of the most evident distinctions between DRR and CCA is that, while CCA focuses solely on the disturbances attributed to the dynamic climate system, DRR deals with all types of hazards, which include geophysical hazards as well (Schipper and Pelling, 2006). Both stress recent emphasis of working with communities, either by addressing risk aspects of climate change (in the case of DRR) or increasing resilience through CBA (in the case of CCA) (Næss et al., 2005; Tompkins, 2005; Penning-Rowsell, 2006). In attempts to link the two fields, it is noted that the 'core insight disaster studies can bring to climate-related research is that vulnerability is critical to discerning the nature of disasters' (Helmer and Hilhorst, 2006, p. 2). Thus, as the intensity and frequency of disasters increases, it becomes a requirement for DRR and CCA also to increase resilience (Helmer and Hilhorst, 2006, p. 3).

The IPCC Fourth Assessment Report (AR4) (2007) identifies the usefulness of taking a risk perspective in order to identify synergies to 'promote sustainable development, reduce the risk of climate-related damage, and take advantage of climate-related opportunities'. For years, the UNISDR was internally attempting to link CCA and DRR and until recently was largely unsuccessful. On 29 September 2008, the UN Secretary General Ban Ki-Moon made the following statement at a ministerial meeting he specially convened in New York:

> If we are too slow to adapt to climate change, we risk making disasters even more catastrophic than they need to be. We must draw on the Hyogo Framework for Action and disaster risk reduction knowledge to protect the world's most vulnerable populations against climate change (Ban Ki-Moon, 2008).

This meeting officially linked the UN programme areas of CCA and DRR at the international level. Furthermore, at this meeting the Secretary General called on ministers to lead the way at the UNFCCC negotiations by championing DRR as a core element of CCA. This was a critical step for developing countries and has opened the door for collaboration between the two disciplines to share much-needed resources, ultimately leading towards more effective protection of the most vulnerable populations. While DRR is relatively new and constantly developing new methods, CCA is even younger. At this early stage of development, the integration of these two fields holds significant potential to address the impacts of climate change and reduce vulnerable populations' risk from disaster.

Most importantly though, while there have been some notable exceptions, few research initiatives are actually aimed at answering practitioner questions (Helmer and Hilhorst, 2006). We defer to Kellenberg and Mobarak (2008) to illustrate an exception that addresses an important practitioner concern. The authors show that previous literature and understanding on the negative relationship between income per capita and measures of risk from natural disasters missed an important point: behavioural changes at the microlevel in response to increasing income may lead to a nonlinear relationship between aggregating incomes and disaster damages, where risks increase with income before they decrease. This suggests that the dual goals of DRR and economic development cannot be assumed to be complementary for all forms of natural disasters, specifically flooding, landslides and windstorms. Extreme temperature events and earthquakes seem to follow the traditional thought more closely. This has significant policy and practical implications for

developing, and particularly least developed, countries. To again elucidate the link to CCA, those divergent disasters (i.e. flooding, landslides and windstorms) are all hazards that projections show will increase with climate change (IPCC, 2007).

3. Resilience as a dynamic systems concept

A detailed body of literature over previous decades has shown that many of the world's ecological problems originate from social problems, especially under dominant and hierarchal socio-political regimes. Consequently, in order to understand and deal with ecological problems, societal problems must be addressed. In considering socio-ecological systems, socio-economic resilience may be considered to have a higher impact than biophysical resilience (Young et al., 2006).

Traditionally, research on adaptation to environmental change has been centred on the *responses* of different social entities to environmental stimuli. Alternatively, the resilience approach is based on a holistic perspective that *anticipates* dynamic change and views adaptive capacity as an essential characteristic of socio-ecological systems. The resilience approach also provides a framework through which CCA processes can be analysed and policies can be identified. The approach allows for greater flexibility in CCA, since it envisions the possibility of change in the state of systems itself. Thus, the approach fosters the prevalence of those characteristics that allow the system to assimilate perturbations without losing their autonomy (i.e. function, networks, social capital, etc.) in a dynamic environment (Nelson et al., 2007). Folke states:

> The implication for policy is profound and requires a shift in mental models toward human-in-the-environment perspectives, acceptance of the limitation of policies based on steady-state thinking and design of incentives that stimulate the emergence of adaptive governance for social-ecological resilience of landscapes and seascapes (Folke, 2006, p. 263).

The term resilience has been used metaphorically in a socio-ecological context since the 1970s. Almost four decades later, there seems to have been little clarity attained in regard to what makes a system resilient or how resilience can be enhanced (Klein et al., 2003). Some theorists use this term to refer to the ability of certain societies to adapt and cope with external shocks. In fact, in development practice it is widely assumed that a more resilient system is less vulnerable to hazards (Klein et al., 2003).

Holling (1973) first introduced the concept of a resilient ecosystem by defining it as a measure of the ability of ecosystems to absorb change and persist beyond that change. This work is highly valuable in that it contrasts the concept of resilience with that of stability. A stable ecosystem is one considered to return to a state of equilibrium after a temporary disturbance (Holling, 1973). Accordingly, a stable ecosystem would return to equilibrium quickly without major fluctuations, whereas a resilient system may reach high points of instability and fluctuation in a path towards dynamic change. This conceptualization is essential for applicability purposes, given the fact that systems, as we define them today, are dynamic and in constant change as they respond to both external and internal influences (Klein et al., 2003).

Carpenter et al. (2001) define resilience as the magnitude of disturbance that can be tolerated before a socio-ecological system moves into a different region of state-space controlled by a different set of processes. Accordingly, resilience may be considered in multiple contexts: in relation to sustainability, as a property of dynamic models and as a quantifiable variable that can be assessed through location-specific field studies. In order to accomplish this last point, there must be a general understanding of the socio-ecological system and disturbances must be identified (Carpenter et al., 2001).

As these ideas developed from an ecosystem perspective, resilience became a concept of value for economic and social studies as well. Certain ecological economists who considered resilience to be key to sustainability addressed

the issues of a resilient society to climate change, hence linking resilience to vulnerability (Common, 1995; Klein et al., 2003).

The resilience concept was convergently developed in the context of disaster management. In this context, resilience is defined as the ability of a system (or one of its parts) to absorb and recover from the occurrence of a hazard event. Given the interest in the field of DRR to identify the qualities that minimize fatalities, Dovers and Handmer (1992) work within the conceptualization that resilience is critical. The authors distinguish between reactive and proactive resilience. In the former, a society aims to strengthen its status quo by promoting and enforcing the system's present characteristics. In the latter, change is integrated as an inevitable and intrinsic characteristic of systems, henceforth aiming efforts at creating a system that will be able to withstand change by adapting to the new conditions (Klein et al., 2003). As a result of these studies, Dovers and Handmer (1992) similarly identify the importance of resilience to the field of DRR in planning for and coping with disasters.

4. Linking resilience, vulnerability and adaptation

We have previously discussed synergies between CCA and DRR. Here, we attempt to further link the two fields through the complementary concepts of resilience and vulnerability. Resilience, vulnerability and adaptive capacity are mutually linked. As described by Smit and Wandel (2006), vulnerability of the system to a particular hazard is reflective of the system's exposure, sensitivity to the hazard and its resilience to the hazard. Adaptive capacity, or the ability of a system to adapt, defines the nature and state of adaptation towards a particular hazard. Thus, adaptive capacity of a system is closely dependent upon the resilience of the system.

Significant discussions on these concepts exist in the literature. While Turner et al. (2003) attribute coping capacity and adaptive capacity as separate dimensions of resilience, Smit and Wandel (2006) lump them together. To Smit and Wandel (2006), adaptive capacity is equivalent to resilience. Similarly, Dovers and Handmer (1992) suggest that proactive resilience is what should be termed as adaptive capacity, and Gallopín (2006) concludes that resilience is related to the capacity to respond. Despite important differences, in all these examples resilience is non-trivially related to adaptive capacity. Since, ultimately, CCA is a resultant of adaptive capacity, then the resilience of a system will certainly influence the CCA outcome.

In the context of DRR, conceptualizations of risks and disasters, including the pressure and release (PAR) model (Blaikie et al., 1994; Wisner et al., 2004), identify the environmental stresses of hazards and the progression of social forces that contribute to vulnerability, including those that relate to adaptive capacity. This view of socio-ecological coupled systems that specify the role of human adaptive responses is further developed in the vulnerability framework of Turner et al. (2003) and the access model of Wisner et al. (2004).

When addressing resilience, however, there are important questions to be addressed. For example, what is kept and what is lost when adapting? What is it, specifically, that should be resilient? Other questions in the literature emerge in respect to governance in socio-ecological systems. In particular, for whom is resilience to be managed, and for what purpose? (Lebel et al., 2006, p. 1). We refer to Lebel et al. (2006, p. 33), as they suggest that 'In our roles as analysts, facilitators, change agents, or stakeholders, we must ask not only: the resilience of what, to what? We must also ask: for whom?'

5. Uncertainty and iterative risk management

One of the greatest obstructions in understanding and combating climate change is the multitude of uncertainty surrounding climate change issues. From indentifying underlying drivers of vulnerability, to understanding the biophysical dynamics of the complex climate systems, to predicting and

anticipating a variety of climate futures, one thing that is certain is that nothing will be certain when research agendas must be set, practical action must be applied and policy decisions must be made.

It is also important to recognize that systems consist of nested dynamics operating at multiple organizational scales. Thus, sub-systems exist within a given system and can have significant influence on overall resilience or vulnerability. This idea stresses the notion that socio-ecological systems are highly interconnected, forming networks of interaction at multiple scales.

In an attempt to understand such networks, Armitage et al. (2007) link the concepts of co-management and adaptive management to present a framework for both research and practice with a new term called 'adaptive co-management'. The authors state:

> The co-management narrative has been primarily concerned with user participation in decision making and with linking communities and government managers ... [while] the adaptive management narrative has been primarily about learning-by-doing in a scientific way to deal with uncertainty (Armitage et al., 2007).

Dynamic approaches to adaptive systems and complexity have catalysed insights in resource management and socio-ecological systems (Capra, 1996; Levin, 1999). Although adaptive co-management was primarily designed for natural resource management, we see it of equal importance to CCA and DRR, complementary at its roots to ideas of iterative risk management. Armitage et al. (2007) further assert of the breakdown of past assumptions in natural resource management that they:

> Are yielding to new developments and trends, including: (1) the imperative of broad-based participation when devising management strategies that respond to change; (2) the need to emphasize knowledge, learning and the social sources of adaptability, renewal and transformation; and (3) and understanding of change and uncertainty as inherent in social-ecological systems.

This statement strongly reflects the convergent aspects of CCA and DRR. We see significant intersections in these fields, providing substantial opportunity to develop holistic, dynamic systems approaches to socio-ecological resilience.

The above supports the need for resilience approaches for institutional diversity. Iterative risk management is neither exclusively top-down nor bottom-up, but requires participatory approaches at all levels to gain a better understanding of a system. Specifically, iterative risk management should include both assessed risk *and* subjective risk. Furthermore, risk perception from local communities is essential for developing appropriate resilience-building strategies and participatory approaches that ensure local inclusion.

However, Ostrom et al. (2007) stress the importance of avoiding panaceas in community-based management, or any institution for that matter, to address issues of resilience. Allen (2006) similarly urges that community-based disaster preparedness (CBDP), which can be included in iterative risk management, cannot be treated as a panacea for disaster management. Both Ostrom et al. (2007) and Allen (2006), however, provide insightful works that highlight the merits and challenges of governance and community-based approaches to natural resource management and disaster preparedness. We suggest that these lessons can also be applied to iterative risk management and the resilience approaches to CCA and DRR.

Focusing on institutions while developing resilience strategies through iterative risk management raises an important complication. In particular, while institutional diversity and effectiveness can strengthen resilience, practitioners should be wary of and scientists should look for institutional forms that, although they may increase institutional performance, actually hinder resilience (Janssen and Anderies, 2007).

We propose that iterative risk management, and risk in general, is the appropriate lens through which to view uncertainty. IPCC (2007), similarly, concludes that iterative risk management is an appropriate approach to address climate change. However, there is still little information about what this means practically. Here, we attempt to elucidate what this means, and more importantly, how it might be implemented.

5.1. Risk and economic resilience

In a world where climate variability, extreme hazard events, robust ecosystem services and global financial markets are more and more uncertain, protecting financial assets in countries and communities becomes an imperative to ensure resilient societies. Economic and/or financial vulnerability can be reduced through a variety of mechanisms in terms of preparing for climate change. Some examples include promoting alternative livelihood awareness, developing income-generating adaptation efforts, conducting countrywide risk assessments that include financial vulnerability models, strengthening poverty reduction strategies, encouraging dual economies for local resource users and utilizing insurance schemes. By no means is this list exhaustive or are these concepts mutually exclusive. Below, we highlight how two of these approaches can strengthen economic resilience through iterative risk management.

ISDR (2009) recently released a report entitled *Risk and Poverty in a Changing Climate* that identifies three primary drivers of risk: (1) deficient urban and local governance, (2) vulnerable rural livelihoods, and (3) declining ecosystem services. Thus, to return to our earlier stated question, 'Why, with all the efforts of disaster relief, development intervention and local resource management, are communities still so vulnerable?' The ISDR (2009) report stressed that while disaster preparedness and response are reducing mortality, progress in tackling these three drivers of risk is insufficient.

We suggest that one approach to addressing these drivers is to link CCA and DRR with insurance mechanisms and other financial tools. There is a significant body of literature exploring insurance for CCA and DRR (e.g. Kunreuther, 1996; Kunreuther and Michel-Kerjan, 2007) and insurance under uncertainty (e.g. Kunreuther, 1976; Schoemaker and Kunreuther, 1979; Hogarth and Kunreuther, 1985). However, there are also many challenges to effectively implementing insurance mechanisms for CCA and DRR, which Warner et al. (2009) identify as low awareness levels, lack of reliable information on risk pricing, accessibility, affordability and the potential for insurance to incentivize maladaptation. In many cases, direct investment (e.g. restoring mangroves) may be cheaper than insurance payouts. To overcome many of these challenges, we propose that countries, regions and insurers could make risk reduction activities a prerequisite to accessing insurance.

Insurance is largely based on the 'risk transfer principle', a fundamental tool for risk insurance schemes, especially for CCA in developing countries. Insurance companies spread consequences of a hazard event more evenly across an insured community. This explains why having large insured pools can make insurance more affordable and more effective. However, if losses resulting from climatic events become too frequent, intense, or severe, and all members of a community suffer damage, then there are no non-victims to share the burden. Insurance then becomes insolvent. For this reason, one goal of insurance companies is to ensure that damage does not become the norm. Therefore, CCA and DRR merged with insurance schemes could play an important role when discussing financial vulnerability and managing risks for governments and communities.

Understanding resilience and vulnerability is more complex than looking at risk, and there are strengths and weaknesses to this approach. As such, another challenge inherent to insurance is that of the 'moral hazard'. This occurs when the insured partake in risky behaviours instead of less risky behaviours because they feel protected by insurance. When intervening in communities that are hazard-prone, experience from insurance schemes shows that mechanisms should be put in

place to avoid moral hazards. In the case of CCA and DRR insurance, one such mechanism, as suggested previously, is to make risk reduction a prerequisite for access to insurance. For resilience and vulnerability approaches, other mechanisms might include community empowerment, capacity building and awareness building.

After perturbations to a system, some communities have been forced to change their livelihood strategies, which are usually connected to an increase in risk. This was evident after the 1994 eruption of Mt Merapi in Central Java, Indonesia. A number of factors, including demographics, politics and the global economy, contributed to the village of Turgo shifting from a system wherein livestock supported subsistence agriculture to a system where agriculture supported market-oriented livestock husbandry (Dove and Hudayana, 2008). While this usually would increase risk because households become more dependent on external factors, in the case of the village of Turgo, risk was mitigated because market participation was limited to the sale of commodities and not the purchase of the inputs used in their production. As Dove and Hudayana (2008, p. 742) note, 'To continue reliance on local resources for agricultural production (viz. land, labor, livestock, vegetation) represents a significant buffer against market uncertainty and volatility'. By keeping one foot in traditional local subsistence living and one in global markets, the community created a dual economy that was able to mitigate risks associated with changing livelihoods after the eruption of Mt Merapi and subsequent government interventions. Thus, this duel economy increased the resilience of the socio-ecological system.

Yet, on a larger scale, there is the lack of a link to policy-relevant work with the inherent complexity of resilience and vulnerability. While there are relatively straightforward processes of doing risk planning, this is not the case for resilience planning. Therefore, we propose a nested approach at multiple scales, integrating iterative risk management within a resilience framework.

6. Information transfer and knowledge networks

A need has arisen to effectively utilize policies, programmes and institutional structures which are presently available, or which could be transferred from one sector to another, to strengthen the ability of societies to link CCA and DRR. This strongly relies on effective communication of information to be transferred and knowledge networks to be formed, both formally and informally. This can be accomplished through processes of social learning. According to Pelling et al. (2008), social learning has been interpreted within the literature to mean both individual learning that is conditioned by its social environment, and learning in the sense that social collectives such as organizations and institutions can 'learn' in their own right. These are distinct but complementary aspects of learning within organizations. The authors discern that since collaborative learning among peers facilitates learning, there is a possibility that informal 'communities of practice' can allow for knowledge to be diffused more efficiently and be more open (or in some cases, more constrained), thus impacting on the collective adaptive capacity of institutions, organizations and communities (Pelling et al., 2008).

An important component of social learning is facilitating useful knowledge networks and, moreover, identifying existing networks in order to support them through capacity building. Experience has shown that by making existing local networks more robust, a community, instead of outside 'experts', can sustain a project or programme more easily than a new network created by outside knowledge and expertise. Many communities have both formal institutions and networks such as government bodies, community organizations and customary laws, as well as informal networks that prove to be very effective during a disaster.

Special attention should also be given to the 'shadow systems' within organizations and communities, which allow individuals to affect organizational dynamics in an informal manner. Shadow systems, also referred to as 'informal institutions', are informal systems that are not

regulated, do not represent formal roles, but often are dominant drivers of systems. These informal networks may imply that an organization could almost dissolve and still retain the original function of the organization. By enhancing the understanding of how these shadow systems and other institutional factors promote resilience, institutions and organizations could be reorganized and/or adjusted to accomplish our goals of strengthening systems resilience. Stacey (1996) and Shaw (1997) argue shadow systems significantly contribute to learning and innovation in organizations. A challenge is for organizations to support, without managing, these informal systems (Stacey, 1996; Shaw, 1997). This can also apply to shadow systems outside institutions and organizations, such as the shadow systems in local communities.

Few researchers have investigated the relationships between learning, communication and adaptive capacity. Yet, those that have argue that:

> Relational attributes of organizations and policy regimes allow individuals or sub-groups within organizations to experiment, imitate, communicate, learn and reflect on their actions in ways that can surpass formal processes within policy and organizational settings ... offering a potential method for measuring adaptive capacity that focuses on process rather than output, enabling proactive adaptation (Pelling et al., 2008).

Studies further identify components of these concepts as (1) learning by doing, (2) integrating knowledge systems, (3) increasing collaboration and equity among community, regional and national levels, and (4) creating greater flexibility in management techniques (Olsson et al., 2004; Armitage et al., 2007). Again we see these proposals as complementary to the influence of social learning, knowledge networks and iterative risk management in linking CCA and DRR. Furthermore, we propose institutional changes, namely the creation of 'boundary organizations' as an important component of such efforts. Likewise, we suggest the development of innovative and layered institutions that facilitate learning through change and complexity (as do Dietz et al., 2003).

We now return to the earlier question of 'why are communities still so vulnerable?' We propose another possible response, linked to our previous discussion. The use of iterative risk management, the efficient transfer of knowledge and development of knowledge networks described in the preceding sections, as well as the development of boundary organizations and institutional changes described in the following sections, all foster growth in underlying determinants of adaptive capacity. These range from governance issues, to recognizing and using human social capital, to understanding causal links and spreading risk to promote resilience, just to name a few. If the weakest link hypothesis proposed by Tol and Yohe (2007) holds true, then all these components are necessary to strengthen socio-ecological resilience. Up to now, disaster relief and development interventions have focused on one episode or one component at a time, ameliorating effects and events but not building support to lower vulnerability to future events. In short, weaknesses elsewhere have prevented increases in resilience because capacities have not increased.

7. Developing boundary organizations

The world has faced huge disasters over the last few decades and concerns have been expressed by nearly all international agencies involved that there is a scarcity of managerial skills to deal with the mitigation and management of disasters (Silva, 2001; APA, 2005; IRC, 2005; WHO, 2005; MacFarlane et al., 2006; UN Commissioner for Refugees, 2006). These skills are needed in both science and practice. We suggest that boundary organizations can fulfil this niche and are essential to achieve many objectives necessary to link CCA and DRR, such as utilizing iterative risk management and adaptive co-management, using a dynamic systems approach to socio-ecological resilience, and considering multiple scales when designing CCA and DRR strategies.

Yet, to date there is a lack of fluidity between research, policy and practice.

The term 'boundary organization' is not a new one. It has previously been used in the social sciences and environmental sciences, most often referred to as 'intermediate organizations' (Guston, 1995; 2001; Cash et al., 2002; 2006; Hellstrom and Jacob, 2003; Brooke, 2008). The Harvard University Global Environmental Assessment (GEA) Project defines such organizations as 'institutions that straddle the shifting divide between politics and science ... It is hypothesized that the presence of boundary organizations facilitates the transfer of usable knowledge between science and policy' (Guston, 2001). Several examples of such institutions include the Sea Grant Program in the US, the Subsidiary Body for Scientific and Technological Advice (SBSTA) of the UNFCCC, the Stockholm Environment Institute, and ProVention Consortium of the World Bank.

Pointing out that science was traditionally kept separate to protect its legitimacy, Jasanoff's (1990) work on the advisory relationship between scientists and regulatory agencies demonstrated that blurring the boundaries between science and politics could lead to more productive policy making than could be achieved by maintaining intentional separation. While boundary organizations have not been extensively researched for CCA or DRR, there are some emerging exceptions. Brooke (2008) argues that 'boundary organizations – organizations or institutions that bridge different scales or mediate the relationship between science and policy – could prove useful for managing the transdisciplinary nature of adaptation to climate change, providing communication and brokerage services and helping to build adaptive capacity' in regards to biodiversity conservation and CCA. Another notable exception is Ludwig et al. (2009), who assert that 'climate-proofing requires, like other environmental problems, clearly (re)defined and negotiated boundaries between science and policy ... problem-defining, policies and research agendas need to be mutually constructed in boundary organizations, which may also lie outside the traditional domain of water resources management' (Ludwig et al., 2009, p. 119). While related to CCA and DRR, these views of boundary organizations still seem to focus on science and policy, not science and practice. Thus, we argue, while human capital is improving, 'applicable' human capital lags behind.

The small difference between these previous definitions of boundary organizations and our current proposal is that Guston (2001) focuses on how science can guide policy making while not becoming politicized and Brooke (2008) focuses on biodiversity conservation and CCA and argues that non-governmental organizations are the appropriate actors to fill this niche because they tend to be active across the areas of science, policy and practice. Here, we propose the use of boundary organizations specifically to link CCA and DRR while arguing that a variety of existing institutions could be reorganized to fill this niche. We see boundary organizations as necessary to catalyse fluid communication and information transfer between science, policy *and* practice, not just science and policy. As Vogel et al. suggest:

> ... Where the science–practice interaction is not taken seriously or carefully designed, a number of disconnections can emerge that frustrate otherwise well-meaning measures to reduce vulnerability and enhance resilience ... thus, although there is a growing body of knowledge on vulnerability, adaptation, and resilience, and a variety of pressing application opportunities for that knowledge, all too often still silos of knowledge get produced that fail to help make systems and communities more robust to extremes and to change (Vogel et al., 2007, p. 352).

Additionally, it seems that most of the existing work on boundary organizations focuses on systematically incorporating scientific advice into the decision making of Western, democratized governing bodies and organizations. Furthermore, this body of work has focused heavily on formal institutions with multiple stakeholders in the Global North. Thus, emphasis has not been placed on the complex knowledge networks and informal institutions of communities in developing countries. We, therefore, see a need to extend these ideas to those institutions, communities and socio-ecological systems in the Global South.

8. Conclusions

Even though substantial discussion is taking place at the academic and policy levels in terms of incorporation and interaction of various concepts like CCA, DRR and socio-ecological resilience, very little has actually happened on the ground. We propose an urgent need for a dynamic systems approach to socio-ecological resilience as a primary objective for CCA and DRR. We furthermore suggest an immediate need for scholarly research to address the needs and concerns of practitioners on the ground. We have discussed two primary mechanisms to catalyse change in the fields of CCA and DRR. These include an increased use of iterative risk management for adaptive decision making and the establishment of boundary organizations and institutional changes that increase the transfer of knowledge between science, policy and practice.

As the boundaries between disciplines are linked, the traditional methods of quality control and scientific reward systems appear increasingly outdated. The conventional scientific institutional structures might require significant adjustment as researchers and practitioners attempt to cross disciplinary boundaries and the boundaries between science and practice. A dynamic systems approach to socio-ecological resilience may provide a significant opportunity to restructure institutions to fulfil this role. Embedding boundary organizations into academic institutions might be one way to deal with the institutional obstacle.

The Forum held on 23–24 April 2009 at the Yale School of Forestry and Environmental Studies, entitled 'A Dynamic Systems Approach to Socio-ecological Resilience and Disaster Risk Reduction: Prioritizing the Gaps in a Changing World', identified innovative and interdisciplinary scientific work as a key contributor to past and future resilience work. All participants in the Forum agreed that academic institutions and young scholars, respectively, provide significant opportunity to develop boundary organizations, as well as individuals who can work between disciplines and substantially increase communication between science, policy and practice.

Promoting a dynamic systems approach to socio-ecological resilience might provide the perfect opportunity to restructure the scientific institution, pave the way for a new generation of scholars, and increase collaboration between the young and the seasoned within academic institutions, development and relief organizations and government. We see this path, embedded in adaptive and iterative risk management, as the way forward for CCA and DRR.

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research article

ENVIRONMENTAL HAZARDS
Human and Policy Dimensions

United States hurricane landfalls and damages: Can one- to five-year predictions beat climatology?

ROGER A. PIELKE JR*

Center for Science and Technology Policy Research, CIRES, University of Colorado-Boulder, 1333 Grandview Avenue, UCB 488, Boulder, CO 80309-0488, USA

This paper asks whether one- to five-year predictions of United States hurricane landfalls and damages improve upon a baseline expectation derived from the climatological record. The paper argues that the large diversity of available predictions means that some predictions will improve upon climatology, but for decades if not longer it will be impossible to know whether these improvements were due to chance or actual skill. A review of efforts to predict hurricane landfalls and damage on timescales of one to five years does not lend much optimism to such efforts in any case. For decision makers, the recommendation is to use climatology as a baseline expectation and to clearly identify hedges away from this baseline, in order to clearly distinguish empirical from non-empirical justifications for judgements of risk.

Keywords: economic damage; hurricanes; insurance; prediction; uncertainty

1. Introduction

The answer to the question posed in the subtitle is, unfortunately, no. This paper explains why skilful prediction of US hurricane landfalls and damages is not possible in the short term, defined here as a time period of one to five years. A 'skilful' prediction is one that improves upon expectations derived from the statistics of the long-term historical record.

More precisely, this paper argues that the range of predictive methodologies available, and the corresponding diversity of predictions, mean that it is guaranteed that some prediction(s) will beat climatology, but it will be many decades if ever before we can know if that performance was due to chance or actual skill in the prediction methodology. On the timescales of decision making, decision makers must therefore proceed under irreducible uncertainties and fundamental ignorance. There may be many reasons for decision makers to hedge their judgements of risk in various directions, and there is ample science available to support virtually any hedging strategy. The paper concludes with a discussion of the implications of the lack of skilful prediction for decision making related to expectations of future storms and their impacts.

2. Methods and data

The methods employed in this paper are restricted to those that seek to identify strong signals using simple methods. This is for two reasons. First, strong signals identified using simple methods are most likely to have direct applications. There are countless studies that have sought to extract weak signals in messy hurricane data using complex methods, and such studies can indeed be of scientific value. However, for purposes of shaping expectations of hurricane behaviour on timescales of one to five years into the future, such studies are of little use if the signals identified

■ *E-mail: pielke@colorado.edu

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