Focus Article

Resilience implications of policy responses to climate change

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This article examines whether some response strategies to climate variability and change have the potential to undermine long-term resilience of social–ecological systems. We define the parameters of a resilience approach, suggesting that resilience is characterized by the ability to absorb perturbations without changing overall system function, the ability to adapt within the resources of the system itself, and the ability to learn, innovate, and change. We evaluate nine current regional climate change policy responses and examine governance, sensitivity to feedbacks, and problem framing to evaluate impacts on characteristics of a resilient system. We find that some responses, such as the increase in harvest rates to deal with pine beetle infestations in Canada and expansion of biofuels globally, have the potential to undermine long-term resilience of resource systems. Other responses, such as decentralized water planning in Brazil and tropical storm disaster management in Caribbean islands, have the potential to increase long-term resilience. We argue that there are multiple sources of resilience in most systems and hence policy should identify such sources and strengthen capacities to adapt and learn. *WIREs Clim Change* 2011 2 757–766 DOI: 10.1002/wcc.133

RESPONSES TO THE CLIMATE CHANGE CHALLENGES

The impacts of global climate change are already manifest and are being experienced in diverse ways in many different parts of the world. Ongoing research shows that communities are responding by adjusting economic activities, changing land use practices, introducing public health initiatives to combat heat hazards, and changing the design and implementation of infrastructure.[1] The array of responses to climate change may be spontaneous or the result of deliberate policy processes. Nonetheless, adaptive responses are not equal in terms of the sustainability of resource use, energy intensity, reduction of vulnerability, or in the distribution of their benefits.[2,3] Similarly, responses to reduce greenhouse gas emissions potentially have negative as well as positive outcomes beyond the carbon balance. Indeed, Turner and colleagues' review evidence on the impact of climate policy responses on the integrity of biodiversity conservation and conclude that, in the extreme, adaptation and mitigation activities 'could

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DOI: 10.1002/wcc.133

have impacts that match—and even exceed—the direct effects of climate change (p. 304)'.[4]

There is growing evidence that current policy approaches to climate risk which stress short-term benefits and seek simple technological fixes to complex problems fail to significantly address multiple and interacting factors which affect system resilience and the needs of vulnerable populations. Here we review examples of policies, focusing primarily on adaptation to observed climate change and variability, which are responses to anticipated future climate changes. We examine their impact on the resilience of the social–ecological systems in which they are embedded. Resilience is the capacity of a system to absorb disturbance and reorganize while undergoing change so as to retain essentially the same function, structure, identity, and feedbacks.[5,6]

One challenge to enhancing resilience of desired system states is to identify how responses to any single stressor influence the larger, interconnected social–ecological system. Clearly all climate change related risks interact with multiple other stressors. Many analyses have shown that both unsustainable resource use and maldistribution of resources amplify the risks to vulnerable populations.[7] For the impact on resilience, policy responses can be judged by their impact on the system's ability to absorb perturbations or shocks, its ability to adapt to current and future changes, and their ability to learn and create new types or directions of change. Responses to one risk alone may inadvertently undermine the capacity to address other stressors, both in the present and future. For example coastal towns in eastern England, experiencing worsening coastal erosion exacerbated by sea level rise, are taking their own action to secure against immediate erosion in order to protect livelihoods and homes, affecting sedimentation and erosion rates down the coast.[8] While such actions to protect the coast are effective in the short term, in the long run, the investments to 'hold-the-line' may have diminished capital resources for other adaptations and hence reduced adaptive capacity to future sea level rise.

There are now hundreds of major public sector initiatives in all regions in response to climate change.[9] Tompkins et al.,[10] for example, document over 300 examples of adaptive responses from the UK and Berrang-Ford et al.[11] assess peer-reviewed documentation of adaptation actions that have already been implemented across the world. We argue that dealing with specific risks without full accounting of the nature of system resilience leads to responses that can potentially undermine long–term resilience. Pielke et al.[12] have highlighted that locating adaptation policy in a narrow risk framework through concentrating only on what are identifiable anthropogenic risks, in their words, 'creates bizarre distortions in public policy'[12] because vulnerabilities are created through multiple stresses. Here we argue that, because of the impact of responses within social–ecological systems, the imperative for maintaining system resilience gives clear indicators of appropriate response strategies for public policy. We examine a set of regional responses with reference to the characteristics of problem framing, governance structures, and sensitivity to feedbacks.

RESILIENCE AND THE NATURE OF ADAPTIVE CAPACITY

The speed, severity, and complexity of known and unknown changes in climate and ecosystems will challenge the ability of society to generate fitting responses. The appearance of novel new risks at different levels will test the ability of societies to adapt and continue to develop. Resilience theory was developed in response to observed surprising behavior in ecosystems. A resilience framework focuses on understanding processes of change. Within human managed and influenced systems the contribution of this framework is that it allows assessment of long-term sustainability within social–ecological systems. Forces that threaten sustainability may be outside the control of a system, but may also result from deliberate actions, including adaptive action to global environmental change.[13]

The ability to adapt is predicated on three fundamental characteristics: the degree to which the system is susceptible to change while still retaining structure and function, the degree to which it is capable of self-organization, and adaptive capacity.[14] These factors contribute to the overall resilience of a system. The complexity of social–ecological systems and the existence of potential thresholds and tipping points make it difficult to use past trends as predictions of future patterns.[15,16] However, adaptations can push systems closer or farther from thresholds and potential transformative change. Hence adaptation actions could potentially affect system resilience through downstream indirect effects; through loss of diversity of different elements of adaptive capacity and through specialization that locks adaptation into particular technologies or pathways.[13] Modeling approaches of complex adaptive social–ecological systems illustrate the tight feedbacks or integrated nature of the systems including economic and ecological dimensions.[17]

Adaptive capacity refers to the preconditions necessary to enable adaptation and the ability to mobilize these elements. It is represented by the set of available resources and the ability of the system to respond to disturbances and includes the capacity to design and implement effective adaptation strategies to cope with current or future events. Resources include physical capital, technology and infrastructure, information, knowledge, institutions, the capacity to learn, and social capital.[18] The determinants of adaptive capacity to cope with climate change in society have been assessed at the scale of nations, of communities, and of sectors of the economy. Adaptive capacity is, in general, influenced not only by economic development and technology but also by social factors such as human capital and governance structures. In addition, there is emerging evidence that societies with approriate governance stuctures have the capacity to respond effectively to both climate change-related risks and to the need for decarbonization. In others words, many of the determinants of the capacity to respond are common in both mitigation and adaptation.

Hence adaptive capacity is a key characteric of social–ecological systems. There is evidence of how such capacity leads to appropriate responses and its implications for overall system resilience.[19] For example, institutions that allow responsive and flexible solutions at an appropriate spatial scale represent an important element of adaptive capacity. Such institutions encourage diverse knowledge sharing of ecosystem dynamics across a variety of levels of stakeholders.[20] In some cases, co-management arrnagements mean sharing responsibility and authority for decision-making, devolving it to be more senstive to specific geographical and cultural contexts.[21] Newman and Dale argue that the ability of a community to foster bridging social capital cross diverse communities fosters 'proactive resilience building'.[22] However Putnam[23] argues that in rapidly diversifying communities, groups tend to 'hunker down' and become less adaptable, less willing and less able to share or exchange information. Ostrom[24] addresses institutional diversity as redundancy, or insurance, to cope with sudden change.

Diversity in ecological systems or in institutions for decision-making is not sufficient to manage resilience. Rather there is also the need to be able to make use of the diversity. McIntosh et al.[25] argue that such sources of resilience are part of social memory. Here social memory is defined as the arena in which past experience with change and successful adaptations, embedded in a deeper level of values is actualized, through community debate and decision-making processes, into appropriate strategies for dealing with ongoing change. Folke et al.[19] identified groups of actors, like knowledge carriers, stewards, innovators, leaders, as essential in mobilizing adaptive capacity, and have found the role of emergent bridging organizations of multilevel institutions as central in this context.

CLIMATE CHANGE RESPONSES AND IMPLICATIONS FOR SYSTEM RESILIENCE

To test ideas concerning the role of sensitivity, governance and framing of policy responses, we examine a number of case studies of regional scale policy response to the climate challenge. We evaluate examples of responses to environmental stress and change that are predominantly adaptations to changing weather-related risks on natural resource and social systems. We also include the example of biofuels as a response to the imperative to reduce fossil fuel use with multiple implications for ecological systems and land use. The nine examples, highlighted in Table 1 are not a representative sample, but chosen to illustrate the range of problem framing and timescale of the policy responses. All policy responses are subject to multiple stresses and multiple reasons for implementation at the time. As Leichenko and O'Brien[7] argue, there is no analytical benefit in seeking to isolate the climate change rationale for policy responses: all policies are constrained by global economic structures and by the path dependency of prior decisions.

Although there are multiple stressors in each case, the magnitude of current change and the projected speed and scope of projected change make climate a significant concern for each of these decision arenas. The examples capture a range of scales for evaluating resilience. Several of the examples focus on the national and international socio-ecological implications of national public policy. Other examples place an analytical focus on how local responses and resilience are shaped by larger scale policies. Regardless of the form or scale of response, the adaptive actions described have specific implications for the resilience of social–ecological systems.

Table 1 provides a description of the principal system stress, a summary of the responses, and the sources of social–ecological resilience, derived from the already published peer-reviewed work in those cases. The final columns in the table summarize how the elements of response influence system resilience. The table shows that the balance of many responses, particularly those focused on a single parameter of risk, is to reduce overall system resilience, insofar as this can be deduced on the basis of both ecological and social process change. Below follows an analysis of the cases presented in the table which draws general conclusions about the ways in which responses to changing climates affect system resilience

TABLE 1 | The Sources of Resilience and Observed Adaptive Actions to Various Resource Stresses in Social–Ecological Systems

			Effects on resilience	
System Stresses	Sources of Resilience	Active Responses	Enhancing	Reducing
Expansion of biofuel production, USA[26–28]	Existing (historical) institutions for soil and land conservation from dustbowl era; Growing concern over water availability and quality Market liberalization: access to Brazilian ethanol from sugarcane	Public actions: Renewable Fuel Standards & Energy Policy Act; Subsidization of ethanol industry Farm-level actions: Expansion of corn acreage, increase in input use, decrease in soybean acreage		Loss of crop diversity; increased risk of erosion and aquifer depletion, decline of soil conservation practices; Infrastructure for new corn-based industry reducing flexibility for alternative fuel development; Increased food insecurity and price volatility with trading partners; Increased global risk of covariate climate shocks in energy and grain sectors
Drought, Northeast Brazil[29]	Lessons learned from past drought events; social networks; social security payments, local and international NGOs	Public actions: humanitarian relief; crop insurance; seed distribution; irrigation schemes Private actions: livelihood diversification; agricultural risk management; patron-client relationships		Reliant on outside assistance; increasing financial costs competing with other public priorities; emergency investment rather than development and continued vulnerability to other disturbances
Variable rainfall, Canadian Prairie agro-ecosystems[30,31]	Experience with drought from the 1930s; experience with minimum or no-tillage and with drainage practices; learning from a wide variety of farm-level responses to weather variability; use of local associations and support networks	Public actions: crop insurance; income stabilization programs; drainage regulations; environmental farm plans Farm-level actions: coping responses; increasing options; decreasing costs; turning to government assistance		Loss of landscape diversity and crop diversity; reliance on technology and government programs, rather than local knowledge and ecosystem services
Tropical storms, Cayman Islands[32]	Recurrent exposure to hazards within living memories; Experiences of neighboring countries reveal importance of preparedness; Annual learning exercise in reviewing the last years hurricane plan and its implementation; Recognition of the importance of key utilities and services in enabling the society to function—these are prioritized in recovery process; Preparedness support for all members of society provided - avoids social exclusion and ensures wider participation in recovery	Public and private actions: Formal government institutions supported collective action by government, private sector and NGOs to motivate individual preparedness action Resulted in a semi-formal committee that now manages hurricane response and broader risk management	Increasing awareness among population of weather-related risks and the importance if individual as well as collective responsibility in preparedness	Growing dependence on multi-national corporations (esp. banks) to support recovery could reduce economic diversification and hence longer term adaptive capacity
Pine beetle infestation, Western Canadian[33,34]	Past industry experience with market volatility; government (uncorrelated) income diversity; labor mobility	Public actions: increased harvest rates; income compensation programs; burning to create a buffer; awareness and monitoring programs		Loss of landscape diversity; increased flooding; disturbance of commercial salmon habitat; decreased labor mobility

TABLE 1 | Continued

System Stresses	Sources of Resilience	Active Responses	Effects on resilience	
			Enhancing	Reducing
		Industry actions: selective salvage coupled to market demand; reconfiguration of mills; market development for 'beetlewood'		
Drought, flood, disease incidence, Kenya[35–37]	Long experience with drought; social networks and new ways to access social capital both locally and beyond	Public actions: water development; infrastructure development; increasing privatization of land; group ranches Private actions: move livestock in new ways and to new places; diversity livelihoods; sell land, livestock; move to urban areas		Reduced ability to move; loss of landscape complexity; increases in socioeconomic differentiation; poor have less ability to adapt; increased poverty; responses dependent on outside assistance
Water quality and supply, Brazil[38,39]	National networks of local committees; local buy-in; local participation and knowledge; technical assistance	Public actions: Decentralization of water management to watershed level	More equitable, transparent and informed decision making; management and resources are local; continuity in membership; expanded management focus to include all development issues	Political control leading to changing water management objectives; focus on economics of water use at expense of the environment and equitable development
Coastal changes UK[40,41]	High adaptive capacity; long-standing planning laws and experience with observed incremental changes and extreme events	Community and regional and national government responses in advance of much anticipated change	Shoreline management planning has enhanced community resilience in areas where community coherence is already high and where communities desire to retain autonomy and decision-making	Lack of control by many communities reduces the perception of efficacy and fairness. Long-term policies and strategy for compensation and other mechanisms still to be finalized
Fluctuating lake levels, Uganda[42,43]	Ecological diversity of lake and wetland system offers a diverse range of livelihood options Social capital of lake-shore populations, especially links to people away from the lake region	Public actions: Introduction of co-management institutions and enforcement of fishing regulations. Private actions: changing fishing practices; land-based livelihood diversification		Active fishing methods lead to overfishing; Livelihood diversification is vulnerable to long-term variability, for example, extreme rainfall and flooding events; Tensions between survival and maintaining livelihood resilience and the differing goals of lakes-shore dwellers and government agencies threaten the effectiveness of co-management

through time. The three classes of characteristics analyzed include the governance structures involved and the sensitivity of the response to changes in future conditions, and the way the problem is framed.

Governance

The cases represent a range of governance arrangements from highly vertical, top down approaches, to situations with highly decentralized implementation. The governance structures have direct implications for the level of flexibility in responding to future change as well as variation in local contexts. In the examples, vertical integration is correlated with the way in which problems are framed. Problems that are defined in narrow risk and technological terms are addressed through top-down approaches. Drought management in Northeast Brazil is an example of a highly vertical approach and the centralized control of emergency resources during 140 years has been detrimental to the emergence of more local and expansive institutions. More broadly considered responses, such as coastal management in the UK, tend to be less vertically driven and more open to participation and local contributions. All of the responses, however, have some level of hierarchical control. Hurricane response in the Cayman Islands is coordinated at the national level, and the decentralization of water management in Brazil is structured through federal legislation and the national water agency.

Governance is also intricately related to questions of scale and the incorporation of appropriate actors at each level. Ideally, there is overlap between actors who define problems and responses and those who are affected by the response. Coastal management in the UK is based on the devolution of responsibility for climate change planning to the local level. There is however, a disconnect between the levels and scales of the problem (long-term and strategic) and the extent of decision-making power (short-term and local). In some instances this has led to ineffective governance and disempowerment of the participants because they are unable to affect change at a level that is appropriate to addressing the problem.

Sensitivity to Feedbacks

Adaptation is a continuous process which influences the location of a system in relation to thresholds. In order to evaluate the influence of adaptation activities there must be sensitivity to changes, or feedbacks, in the system. Sensitivity to feedbacks relates both to the timing as well as where these feedbacks occur. Learning is more likely if feedbacks occur soon relative to action and if those most affected by feedbacks are those responsible for the action. Slow feedbacks, those that are spatially distant, or those that are masked by short-term gains in economic or productivity measures are less likely to result in changes in the response. The biofuels example represents a case in which ecological impacts are masked by short-term economic gain and are dislocated through space with international ramifications for land use and land cover. Drought responses in Brazil and Canada mask ecological impacts through government programs and transfers.

In both the Cayman Islands and Ugandan examples, there is sensitivity to the impacts of policy responses. However, sensitivity to feedbacks is valuable only in relation to the ability of an actor to respond to those feedbacks. Without this ability there is no capacity for learning and for changing actions in the future. In the Cayman Islands there is a high level of flexibility in future responses, which are continually evolving. In Uganda, however, the fishermen are limited in their ability to act on the perceived changes.

Problem Framing

The way in which a problem is conceptually framed determines the way in which responses are identified and evaluated and therefore influences the range of response characteristics. In the examples presented problem framing ranges from very narrow, technological perspectives, to broader and more encompassing frames, more focused on the management of issues rather than specific actions. A technological perspective considers the possibilities of specific responses to identified threats while a more inclusive approach recognizes the importance of other system drivers and the maintenance of response flexibility, which is dependent on local contextual factors.

The examples of pine bark beetle infestation, declining fish stocks, and the development of biofuels are all concerned with narrow, technological approaches. In Western Canada, activities are designed to maximize short-term economic output of forest resources; in Uganda government policy is directed at controlling fishing technologies, and in the US, biofuel expansion is driven by a perceived need reduce foreign oil dependence and reduce greenhouse gas emissions. Water resources management in Brazil moves beyond a supply and demand based approach to incorporate the multitude of development and economic perspectives that drive water use and value in basins. The example from the Cayman Islands focuses on tropical storm preparedness, but expands beyond questions of infrastructure and response logistics, to include governance issues and the incorporation of an active learning cycle.

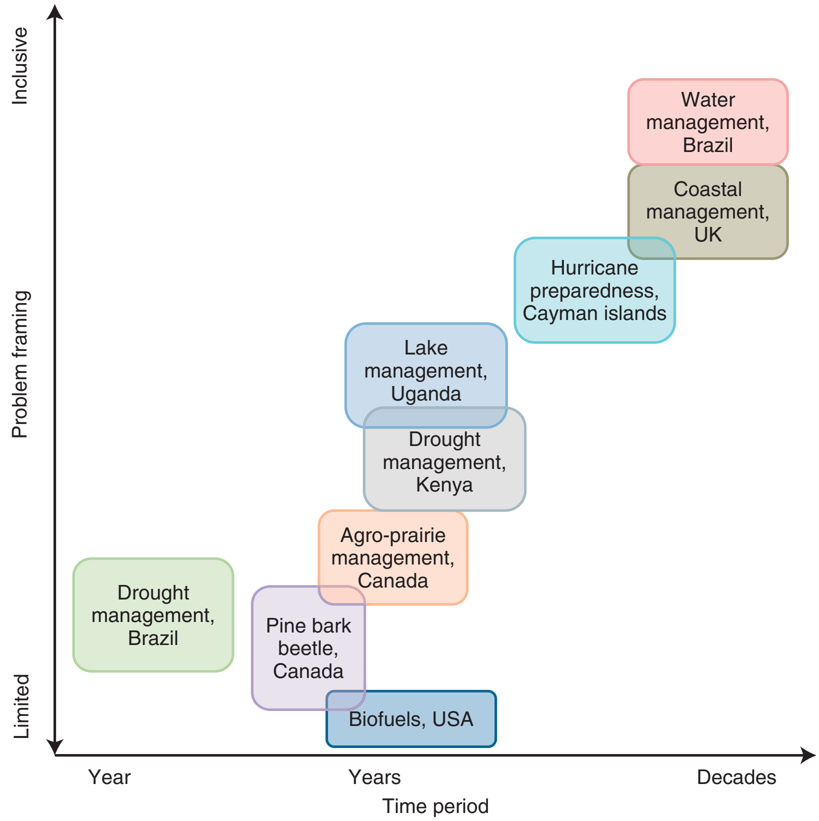

FIGURE 1 | Time horizon and inclusiveness of nine of regional climate change response strategies.

Problem framing and the urgency of the perceived threat influence planning and implementation horizons. The implicit time horizon of the response strategies are shown in Figure 1 indicating that there is not a simple negative correlation between the narrowness of the scope of analysis and the length of time horizon. Some integrative planning responses can have short time horizons while some single parameter responses, such as biofuel promotion for energy security can be planned and implemented over decades. On balance, however, narrow technological responses are associated with near term time response horizons.

In the case of forestry management in Western Canada government and industry responses address the economic and social impacts of pine beetle infestation. The immediate economic needs are privileged over the long-term state of the ecosystem. There are significant negative downstream effects, and the forest ecosystem appears to be moving toward a threshold change. Government responses to variable rainfall in the Canadian prairie agro-ecosystem are targeted at specific weather events. Thus, rather than a long-term focus on reducing exposure to the impacts of rainfall variation, the government has responded to the negative outcomes of drought events by implementing crop insurance and income stabilization programs. These programs have reduced the need for farmers to adopt long-term practices such as conservation tillage, proper drainage measures, and the maintenance of landscape heterogeneity.

Sources of Resilience

Responses to climate and environmental stresses affect the system state to social and ecological thresholds. In a majority of the examples, local and linked ecosystems are being actively undermined through efforts to address perceived climate risk. Nonsustainable agricultural practices continue in the Canadian prairie agro-ecosystem and in Northeast Brazil as a result of the government practices that counter any incentive for ecologically sound agricultural practices. Biofuel production in the US has resulted in the expansion of cultivated area and a corresponding reduction in soil conservation technologies. Pine bark beetle containment in Canada has fundamentally changed the ecosystem in ways that are potentially irreversible.

The physical and social elements of adaptive capacity are found at all organizational scales, from individuals to nations. However, adaptive capacity also requires the ability to mobilize these elements. The nine cases point to the issue of mobilizing adaptive capacity at different scales. Responses developed at larger scales may actively limit or undermine the range of responses at the local level, effectively inhibiting the sources of resilience that are available. Several of the studies, including fisheries management in Uganda and drought responses in Kenya highlight local sources of resilience that include knowledge of local ecosystems, social networks, and mobility. In both cases these local sources are being diminished by larger scale forces that include legislation and institutional changes, which circumscribe the local response options. The coastal management in the UK and the water management in Brazil examples highlight efforts to be responsive to local knowledge and capacities by building recognition of their importance into national legislation and by bridging communication across diverse communities.

Nearly all of the examples cite past experience as primary sources used to engage in response to climate change. Thus, some degree of learning has taken place in the past. However, the learning may not be applicable to new challenges that are outside the realm of experience. A key difference in the cases, therefore, is not that learning has occurred. Rather, it is in the willingness to continue learning and to experiment. Past experiences with tropical storms contributed to the initial structuring of the institutional responses in the Cayman Islands. However, there is active learning that occurs through annual evaluations of performance and plans and practices are reformulated as necessary. Water resources management in Brazil is a national level experiment in designing management systems that are more responsive to the local needs and demands.

AN ASSESSMENT OF SYSTEM RESILIENCE TO POLICY RESPONSES

While we seek to draw out the specific lessons for resilience of the policy responses, we recognize the multiple sources of stress and policy imperatives that limit such analysis. In the case of Canadian forests, for example, changes in the demand for timber domestically and internationally had a profound effect on decisions on allowable cut that coincided with the beetle infestations. Similarly in Uganda, displacement of populations associated with conflict in northern Uganda moving to southern Uganda seeking employment and security complicate the regulatory response to sustain fisheries. Resilience assessment seeks to bring such dynamics within its overall explanation and to evaluate how adaptive capacity can be generic enough to ensure integrity when systems are stressed.

Analyzing coupled social–ecological systems increases the complexity of measurement. Without knowing precise thresholds, or the way in which systems will respond to nonlinear change, a proxy for measuring system resilience is the sources of resilience. Sources of resilience help to maintain system functions through time. The way in which these sources are harnessed to support responses to climate change has implications for the long-term resilience of each of the systems.

Any evaluation of resilience requires careful consideration of the scale of analysis and the relationship between local and larger scale sources of resilience. Many of the sources of resilience are collections of past experience and associated social and institutional memories. The nonlinear and stepped changes that are associated with climate change are likely to challenge the applicability of many of these knowledge bases. Climate change will continue to have significant impacts on both ecological and social systems and responses will need to be sensitive to these changes as well as their own impacts. Responses based on past experience can lock systems into pathways that reduce future options. Experimentation and learning are no guarantee that a system will be robust to all types of shocks, but by their nature they imply a level of response diversity.

Analyses frequently evaluate the direct impact of external shocks on sources of resilience and the system state. Our analysis focuses on the indirect impacts of the perceived and future changing climate, as humans harness available capacities to respond. In this, the type of resources and sources of resilience appear to be less significant than the way in which they are mobilized and employed. On balance the sources of resilience are similar for each of the cases. These sources include past experiences with related stresses, networks of individuals, commercial markets, and formal institutions among others (Table 1). Yet the influence of adaptive actions on system resilience is quite different for each of the cases. The differences in the cases therefore, can be explained not by adaptive capacity but the way in which the capacities were applied. The governance structures, through which policy prescriptions were defined and implemented, determined the way in which capacities were mobilized. In the cases presented, highly vertical, centralized governance structures tended to either reduce local sources of resilience or rendered them unusable because the ability to effectively respond to change was removed from local areas. In the same way, these governance structures also masked system feedbacks through time, distance, or increased short-term economic returns.

The common thread in the examples that relates the governance structures to sensitivity to feedbacks, and to the maintenance of sources of resilience is the way in which the issues were framed by the decision makers. The situations in which system stresses were defined as narrow, technical problems with short-term horizons, governance structures were top-down, did little to link actors at different scales, masked system feedbacks, and did not provide incentive or structure to promote learning. In contrast, in the two examples where the issue was framed in a broader manner, policy implementation tended to enhance characteristics that supported the ability to manage resilience, including flexibility and learning.

CONCLUSIONS

Climate change will inevitably cause shocks and disruption to societies in many ways. Adaptive capacity will be needed, which will require social–ecological sources of resilience for dealing with the challenges, for recombining experiences, and to create innovation and ways forward. The analysis presented here suggests that many response strategies run the risk of reducing system resilience if not carefully conceived and implemented. Hence there are definite trade-offs between policy objectives focussed on efficient and effective adaptation, narrowly defined, and those strategies which seek to retain resilience by investing in the underlying capacity to adapt both to climate and to other stresses that affect social–ecological systems.

There are various reasons why adaptation is focussed narrowly on effectiveness. These measures include the desire for readily observable metrics, political and election structures, as well as a history and culture of dealing with social–ecological problems in this manner. The real challenge, therefore, is to make use of the issues of climate change to find opportunities to transform social–ecological systems into development pathways that may improve human conditions. It will require shared visions and a willingness to devolve influence and authority for decision-making that constitutes adaptive capacity.

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