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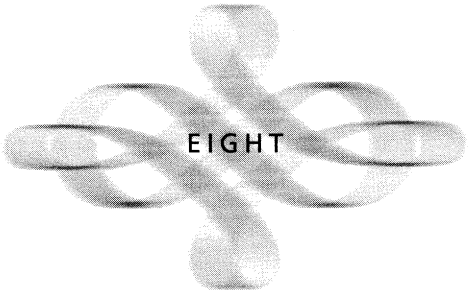

Maintaining Resilience in the Face of Climate Change

ALEJANDRO E. CAMACHO AND T. DOUGLAS BEARD

Climate change, when combined with more conventional stress from human exploitation, calls into question the capacity of both existing ecological communities and resource management institutions to experience disturbances while substantially retaining their same functions and identities (Zellmer and Gunderson 2009; Ruhl 2011). In other words, the physical and biological effects of climate change raise fundamental challenges to the resilience of natural ecosystems (Gunderson and Holling 2002). Perhaps more importantly, the projected scope of ecological shifts from global climate change—and uncertainty about such changes—significantly stresses the capacity of legal institutions to manage ecosystem change (Camacho 2009). Existing governmental institutions lack the adaptive capacity to manage such substantial changes to ecological and legal systems. In particular, regulators and managers lack information about ecological effects and alternative management strategies for managing the effects of climate change (Karkkainen 2008; Camacho 2009), as well as the institutional infrastructure for obtaining such information (Peters 2008).

A number of recent initiatives have been proposed to address the effects of climate change on ecological systems. However, these nascent programs do not fully meet the needs for developing adaptive capacity. A federal, publicly accessible, and system-wide portal and clearinghouse

will help regulators at all levels of government manage the effects and uncertainty from climate change (DiMento and Ingram 2005; Farber 2007). Such an information infrastructure, combined with a range of incentives that encourage regulators to engage in adaptive management and programmatic adjustment over time (Baron et al. 2009), will help governmental and private institutions become more resilient and capable of managing the physical and human institutional effects of changing climate (Camacho 2009).

The Projected Effects of Climate Change

Substantial and mounting evidence exists supporting the conclusion that anthropogenic climate change has already had significant adverse effects on ecological and human environments throughout the world (Parmesan 2006; Worm et al. 2006; Intergovernmental Panel on Climate Change [IPCC] 2007; Staudinger et al. 2012). Such climatic shifts will increasingly raise fundamental challenges to the resilience of both ecological and human systems (Rahel et al. 2008). Perhaps more significantly, considerable uncertainty about the projected scope of ecological shifts from global climate change raises an unprecedented challenge to the existing natural resource governance system (Ruhl 2008; Camacho 2011b).

The Physical and Biological Effects

Climate-related changes have already had impacts on wildlife and ecological resources (IPCC 2007; Staudinger et al. 2012). For example, biodiversity losses in many ecosystems have been driven by climate change (Millennium Ecosystem Assessment [MEA] 2005; Malcolm et al. 2006; IPCC 2007; Staudinger et al. 2012). Further, we know that timing of many of the natural events (phenology) has been affected by changes in climate (Davis et al. 2010), with often unknown consequences to the future resilience of the affected populations or species. The increased risk of extinction of plants and animals due to climate-driven events (IPCC 2007; Staudinger et al. 2012) will change the underlying biodiversity of

the ecosystems and their subsequent resilience. Among its many benefits, biodiversity typically brings redundancy in ecosystem function, while loss of biodiversity and subsequent loss of redundancy as a result of climate change will likely have significant effects on the resilience of systems (Gunderson and Holling 2002).

Perhaps as importantly, climate drivers are expected to have major impacts on the health and function of habitat necessary for resilient ecosystems. The warming atmosphere alters precipitation patterns and soil moisture, leading to longer, prolonged droughts; increases the destructive nature of hurricanes; and increases mean sea level (IPCC 2007; Staudinger et al. 2012). Perhaps the biggest changes in ecosystems will be as a result of changes in the hydrologic cycle and the availability of water, further exacerbating already water-stressed regions.

Increased Uncertainty

In addition to its considerable ecological effects, climate change also magnifies the uncertainty that exists for addressing environmental problems due to the many complex and confounding variables inherent in climate (Ruhl 2008). Projections of future climate-driven changes on ecosystems have high levels of uncertainty, because the underlying dynamics of global climate modeling systems are uncertain, and the dynamics of ecosystem responses are still highly variable and uncertain. Perhaps the biggest uncertainty in projecting climate-driven changes is how humans will react to changes in their environment, changes in policies and procedures, and changes to underlying norms. In many ways, uncertainty is the greatest challenge raised by climate change (Camacho 2009).

Given the highly uncertain nature of projected changes in ecosystems as a result of climate change, scenarios provide one tool for understanding projected climate-driven change and the impacts to ecosystems (MEA 2005). The use of scenarios for communicating uncertainty allows managers and policy makers the opportunity to compare and contrast alternative views of the future and craft management strategies that build resilience into the system. Given the ability of scenarios to identify common tipping points, the results of scenarios should allow decision

makers to define management strategies around key drivers of change. Effective management into the future of climate-driven changes will require full adoption of an adaptive framework (Gunderson and Holling 2002; Camacho 2009) that allows policy makers to adapt to change via a systematic, learning approach incorporating rapidly changing knowledge of climate-driven impacts.

To combat the fragmented regulatory structure for most ecological systems in the United States, incorporate resilience into management approaches, and adapt to the long-term and highly uncertain climate-driven changes, it will be necessary to adopt more adaptive approaches. Adaptive capacity should reside not only in the traditional ecological resources management agencies, but adaptive approaches should work in an integrated fashion with the legal and administrative institutions responsible for ecological systems. The challenge will be, as with most adaptive management systems (Camacho 2009), to develop robust monitoring systems that integrate not only ecological monitoring, but monitoring of legal, management, and administrative approaches. Development of robust monitoring systems should allow the adaptive systems to be accountable for changes and should provide a mechanism to integrate monitoring results into management planning.

Existing Federal Learning Infrastructure for Climate Change Adaptation

Despite the growing evidence for climate change–related harm and the considerable uncertainty about the precise manifestation of such effects (Salzman and Thompson 2010), the existing regulatory infrastructure in the United States does not effectively deal with the effects and uncertainty that are expected to arise due to global climate changes (Camacho 2009). Most governmental programs do not sufficiently promote learning by government officials (Gregory et al. 2006; Camacho 2009) or incentivize such managers to be more effective at achieving regulatory goals (Baron et al. 2009). Natural resources governance in the United States is also largely fragmented (Buzbee 2005; Camacho 2009), which hinders the capacity for interjurisdictional information sharing and

collaboration directed toward reducing uncertainty about the effects of climate change and effectiveness of management strategies.

More specifically in the context of climate change adaptation, few resource management or regulatory agencies at the federal, state, or local level adopted any strategies for adapting to climate change or for managing the uncertainty climate change adaptation produces until recently (Stutz 2009). The U.S. Congress still has not established any programs expressly directed at climate change adaptation, although the U.S. Global Change Research Program has some limited ability to work on adaptation measures. Moreover, many regulatory authorities continue to rely on strategies premised on historically customary conditions (i.e., assuming stationarity in climate) that even agency officials concede are not likely to apply under projected climate change scenarios (Camacho 2009).

However, as detailed below, a small but growing number of adaptation planning initiatives are being developed that are attempting to address the effects of climate change on ecological systems. Though modest in scope and funding (U.S. Government Accountability Office 2009; Smith et al. 2010), several of these programs do make limited progress toward the development of processes for monitoring ambient conditions, fostering information sharing and cooperation, or encouraging adaptive management. These nascent programs are certainly improvements on preceding resource governance; nonetheless, they are unlilkely to completely provide a comprehensive learning infrastructure that cultivates interjurisdictional information sharing and agency learning.

The Limitations of Existing Institutions for Adapting to Climate Change

Because natural resource governance in the United States is fairly static and fragmented, it is poorly equipped to foster agency learning, to tap the potential experimentation benefits of largely dispersed regulatory authority, or to otherwise manage the uncertainties of climate change (Buzbee 2005; Camacho 2009). Though a number of mostly federal programs have recently been created to at least in part address these

shortcomings, American resource governance still lacks a more fundamental learning framework for managing the strain and uncertainty accompanying climate change.

ADAPTIVE LEARNING

Evidence from the literature suggests that most natural resource programs in the United States are not designed to foster programmatic learning within an agency; they lack the mechanisms to adjust and improve management decisions over time, fix management missteps born from limited information and uncertainty, and promote consideration of such lessons in future management decisions (Gregory et al. 2006; Camacho 2009). Evidence now exists that climate systems are not acting in a stationary manner (Coumou and Rahmstorf 2012). However, many agencies often adopt measures that subsequent experience reveals are deficient or imperfectly tailored to current conditions. One reason for this is because environmental regulators characteristically have limited information about ambient conditions and the effects of potential strategies (Karkkainen 2004; Camacho 2007), and ambient conditions inevitably change.

Yet few agencies have developed a systematic, rigorous approach to reducing such uncertainty over time and learning from the past performance of adopted strategies. Most programs are subject to requirements to monitor agency actions or approvals, but agencies commonly neglect such obligations (Camacho 2009); and ambient monitoring is typically underfunded (Biber 2011). Perhaps most importantly, agencies are not required to assess the effectiveness of prior decisions or adjust those decisions over time (Williams et al. 2007) and as a result, it is very difficult to promote such adaptive learning institutionally. Unsurprisingly, assessments of the accuracy of prior assumptions or the efficacy of adopted decisions are rare. Similarly, adjustments of decisions to incorporate new information or changed conditions are uncommon (Walters 1997; Gregory et al. 2006). By not encouraging managers to systematically learn from prior decisions, natural resource governance remains too static (Biber 2011), rendering its capacity to reduce and manage uncertainty unnecessarily weak.

Though a number of encouraging adaptive management experiments have proliferated in an attempt to address uncertainty in the regulatory process, these approaches have left substantial room for improvement. Adaptive management was developed to help resource managers deal with uncertainty in the regulatory process through periodic monitoring and adjustment of management decisions (Walters 1986; Dorf and Sabel 1998; Freeman and Farber 2005). Such an approach can increase the regulatory process's adaptive capacity by allowing for decisions to regularly account for new information or changes in circumstances. Yet recent adaptive management experiments have not *required* periodic adjustment of agency actions (Freeman 1997) and have not sufficiently provided incentives and resources for managers to monitor and adaptively manage (Biber 2011). Most attempts at adaptive management also do not apply adaptive management principles at the program level; that is, they fail to systematically monitor and adjust the program to more effectively achieve the program's goals (Camacho 2007).

INTERJURISDICTIONAL LEARNING

The fragmentation and limited coordination of regulatory authority over natural resources exacerbates the problem by making interjurisdictional learning very difficult. Authority over natural resources in the United States is allocated typically based on the environmental component to be regulated (e.g., species, air quality, water quality) and the level of government (e.g., local, state, federal) (Buzbee 2005). Most of the authority for management of ecological systems and water resources resides with state governments. Each state has its own approach to managing these systems, and there are few incentives to work across borders, which is especially problematic when climate-driven impacts to ecosystems occur at a scale that will almost always be larger than individual states. Even issues that are the responsibility of federal agencies, such as the management of threatened and endangered species under the federal Endangered Species Act of 1973, often suffer from fragmented jurisdictional authority. For example, management of endangered anadromous salmonids is split between the National Oceanic Atmospheric Administration (NOAA) when the salmon reside in marine waters and the U.S.

Fish and Wildlife Service (USFWS) when they reside in freshwater. This fragmentation makes management of long-term climate-driven impacts difficult.

On the other hand, there are considerable advantages to relying on decentralized and overlapping authority to manage ecological resources. Such decentralized regulatory authority is in part premised on allowing for a diversity of focused, localized strategies, thus promoting regulatory experimentation and allowing the opportunity for interjurisdictional learning about the relative efficacy of different strategies (Camacho 2011b). In fact, the need for dispersed but overlapping governance of natural resources may be even stronger with the onset of climate change. Though climate change may provide some impetus for more centralized authority due to the likely increase in interjurisdictional spillovers (Adler 2005), the considerable uncertainty raised by climate change adaptation also heightens the need for regulatory experimentation and innovation that decentralized governance is designed to provide (Adelman and Engel 2009; Ruhl and Salzman 2010). In addition, given the local variation in how climate change is likely to affect resources, the substantial tailoring benefits of more local or specialized decision making are likely to persist. Key to maximizing the diversity and experimentation benefits of decentralized and overlapping governance, however, is an infrastructure that collects the disparate information about ambient conditions and management strategies, disseminates it broadly, and otherwise encourages regulators to learn from the data and experiences of other authorities (Karkkainen 2008).

However, to date this capacity to promote interagency learning and thus help reduce uncertainty is largely untapped, because there is insufficient emphasis on coordination and information sharing between jurisdictions (Karkkainen 2004; Adler 2005). Other than through ad hoc or anecdotal opportunities, resource managers and regulators have little ability or incentive to learn from the lessons of other agencies. Even when a manager collects information about ambient conditions or the performance of adopted strategies, such information is too often not broadly accessible, because there is no comprehensive infrastructure collecting and disseminating it.

To be sure, increasing agency collaboration has been a goal of a host of regional federal regulatory initiatives (Council on Environmental

Quality [CEQ] 2010). Such ecosystem- or landscape-based networks typically are established to provide some opportunity for communication and synchronization of decision-making authority. Though such venues may provide some coordination benefits, unfortunately many of these largely focus on developing regional institutions and too often pay insufficient attention to reducing uncertainty through interjurisdictional information sharing (Camacho 2011b). Most do not adopt any shared infrastructure for managing information or reducing uncertainty and continue to leave managers with limited capacity or tools for developing or accessing data about ambient conditions and the past performance of potential management strategies used by their own agencies or other authorities. Unfortunately, too often, such initiatives simply serve as yet another level of regulation that exacerbates existing regulatory fragmentation.

Recent Initiatives for Climate Change Adaptation

Though a number of initiatives have recently been established that help improve the adaptive capacity of the existing natural resource governance system, a more comprehensive commitment to promoting adaptive management and information sharing is needed in the face of climate change.

ENVIRONMENTAL PROTECTION AGENCY

In 2011, the U.S. Environmental Protection Agency (EPA) issued a policy statement committing to complete an agency-wide adaptation plan by June 2012 (U.S. EPA 2011), and as of February 2013, a draft plan has been issued for public comment. However, the EPA adopted a National Water Program Strategy in 2008 that identifies impacts of concern from climate change to water programs in the United States, defines goals for responding to such impacts, and provides specific proposed adaptation actions for drinking water systems, water quality, and effluent standards; watershed protection; the National Pollutant Discharge Elimination System program; water infrastructure; and wetlands

protection (Cruce and Holsinger 2010). In 2012, the EPA published a new, longer-term National Water Program Strategy that "describes an array of important actions that should be taken to be a 'climate ready' national water program," though the strategy "does not outline commitments to act within a specific time frame" (U.S. EPA 2012). Among other initiatives, the National Water Program Strategy helped formulate the Climate Ready Estuaries (CRE) and Climate Ready Water Utilities (CRWU) programs.

The CRE program was created in 2008 to provide estuary communities that participate in the National Estuaries Program (NEP) various tools and financial and technical assistance for assessing climate change vulnerabilities, engaging and educating stakeholders, developing and implementing adaptation strategies, and, encouragingly, sharing lessons learned with other coastal managers (Cruce and Holsinger 2010). Estuaries are among the locations most vulnerable to the effects of climate change. Most prominently, the CRE program includes a "coastal toolkit," a portal of collected data, tools, and databases on climate change, coastal vulnerability, smart growth options, adaptation planning, and financing opportunities. In addition, EPA holds occasional workshops that bring together similarly situated officials to discuss adaptation planning (CRE 2010). The goal is for this infrastructure to improve the adaptive capacity of NEP communities to more effectively identify risks and adapt to the effects of climate change.

Likewise, the CRWU program was established to provide technical resources and tools for water utilities to engage in adaptation planning (Cruce and Holsinger 2010). Promisingly, a CRWU working group developed a report recommending a framework for increasing the adaptive capacity of water utilities through increased information generation and dissemination and agency coordination (National Drinking Water Advisory Council Report 2010). The EPA has begun to implement many of the report's recommendations, seeking to promote the application of emergency management principles and sustainable infrastructure practices by utilities for assessing risk, determining vulnerability, evaluating consequences, and developing effective adaptation strategies (Cruce and Holsinger 2010). Akin to the CRE program, is an EPA-created, searchable "toolbox" containing water sector climate change information on government and utility activities, workshops,

publications, funding, and tools. It also has developed a risk assessment and scenario-based tool it calls Climate Resilience Evaluation and Awareness Tool, as well as a Tabletop Exercise Tool for Water Systems to help utilities assess their vulnerability to climate change and consider potential adaptation options.

In addition to these programs, through its Office of Research and Development's Global Change Impacts and Adaptation Program and its Water Resources Adaptation Program, the EPA is conducting studies and developing various decision-support tools for resource managers about the effects of climate change and adaptation options pertaining to air and water quality, aquatic ecosystems, human health, and socioeconomic systems in the United States (Cruce and Holsinger 2010).

COUNCIL ON ENVIRONMENTAL QUALITY

Under Presidential Executive Order 13514, the CEQ has been charged with co-chairing (along with the Office of Science and Technology Policy and NOAA) a federal interagency task force and coordinating adaptation planning across all federal agencies (CEQ 2011a). The CEQ and the participating federal agencies have adopted an approach that seeks to ensure that adaptation is integrated throughout all agency planning efforts. The CEQ has issued guidance requiring federal agencies to submit information to CEQ demonstrating that the agency is engaging in adaptation planning by a series of deadlines (CEQ 2011c). Further, CEQ is working broadly with all state, local, and other partners to promote resilience thinking in community-level planning activities (CEQ 2010). These efforts are meant to lead and support international efforts in climate change adaptation.

A cornerstone of these efforts is improving accessibility and coordination of science for decision making, and assuring that the "best available" science is available. According to CEQ, a science-based approach to adaptation planning should use integrated approaches and vulnerability assessments to identify the most vulnerable ecosystems, and then risk management approaches to prioritize adaptation responses (CEQ 2011a). The CEQ has already produced a national action plan for freshwater resources and is working closely with the USFWS, NOAA, and

state and tribal agencies to develop an adaptation strategy for fish and wildlife resources (CEQ 2011b).

In addition, CEQ has led the federal agencies in creation of regional-based interagency coordination efforts on climate information, focused initially on ecological systems. The regional coordination efforts are meant to create consistency in the use of climate information across the federal government, reduce redundancy in management and science efforts, and provide state and local authorities access to information helpful for climate change adaptation planning.

DEPARTMENT OF THE INTERIOR

The U.S. Department of the Interior (DOI) is tasked with managing one-fifth of the land in the United States, handling trust responsibilities for 562 Indian tribes, managing water supplies for 30 million people, and conserving fish and wildlife and their habitats (U.S. DOI 2011). The DOI developed an adaptive management guidebook (Williams et al. 2007) and adopted an adaptive management implementation policy in 2008 that focused on applying adaptive approaches on a landscape-wide level. The DOI is often only one of many management agencies responsible for ecological systems on any given landscape, so the application of adaptive management requires a full partnership with multiple agencies and jurisdictions. The DOI recognized early on that climate-driven management issues are far more complex and occur at a scale much larger than any one agency could handle on its own.

Therefore, DOI's approach to implementing adaptive management in response to climate change is intended to engage the entire science and management community by working with science and management partners to form twenty-two landscape conservation cooperatives (LCCs) and eight regional climate science centers (CSCs). The CSCs are operated through the U.S. Geological Survey's (USGS) National Climate Change and Wildlife Science Center (NCCWSC), established by Secretarial Order 3289 (Secretary of the Interior 2009). The CSCs are partnership-driven science centers focused on providing science in support of the various DOI resource management programs. Science support can range from development of models

and better understanding of ecological processes, to development of monitoring frameworks and protocols that allow tracking of climate-driven changes. The LCCs are public–private partnerships focused on bringing applied science approaches to the management of ecological systems. LCCs, working closely with CSCs, primarily work on development of syntheses and assessments of the ecological systems, and development of decision-support tools for active resource managers. The LCCs work closely with the various partners to actually develop strategic approaches, implement consistent regulations and policies, and monitor progress toward goals.

An example of the approach being pursued by DOI is the management of western native trout. Working through the NCCWSC, and ultimately through the Northwest CSC, the agency has provided initial projections of climate-driven risk to future persistence of trout in the Rocky Mountains (Muhlfeld et al. 2011) to management partners within the Great Northern LCC. Partners in the Great Northern LCC are now working to integrate this information into applied approaches, strategic plans, and development of management strategies that will allow adaptation to forecasted changes in trout persistence.

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

The National Oceanic and Atmospheric Administration's (NOAA) main climate responsibility resides with the physical climate system and its impacts on marine ecosystems. NOAA has extensive climate activity ongoing, ranging from the National Climatic Data Center (NOAA n.d.) to the Climate Prediction Center (NOAA 2013) and NOAA's Regional Integrated Sciences and Assessments (RISA). NOAA has focused on providing information, science, and data that broadly characterize the physical climate system, and other aspects, generally in marine systems, that help NOAA meet its missions. NOAA's broad science mission in support of climate activities includes development of global-level climate models; assessment of natural climate variability, anthropogenic change, and the global carbon cycle; research in support of policy; and other decisions in managing for and adapting to climate impacts (NOAA 2011). For example, RISAs will contribute information and

work collaboratively with LCCs and CSCs organized by the DOI by performing interdisciplinary research for local private and public decision makers (CEQ 2011b).

NOAA has made a push to consolidate its various climate activities into a series of regional climate service centers (NOAA, "Proposed Climate Service in NOAA," n.d.). This budget-neutral approach would have allowed NOAA to provide access to a number of climate science products and data through a singular interface. However, during the Fiscal Year 2011 Congressional budget debates, language was inserted into the adopted budget bill that forbade NOAA from using any resources to establish the climate services (Strain 2011). If ultimately started, NOAA's climate services are intended as "one-stop shopping" for authoritative science and data about climate and climate impacts across the nation.

UNITED STATES FOREST SERVICE

The U.S. Forest Service (USFS) is among the other large federal land management agencies, having land management responsibility for 193 million acres within the United States. The USFS is located in the U.S. Department of Agriculture and has a mission directed at sustaining the health, diversity, and productivity of its lands for a wide range of ecosystem services (USFS 2010). The USFS has management and research components focused on better understanding the impact of climate-driven changes on forests and actively working to incorporate them into forest management planning, using an adaptive management framework (USFS 2010). The USFS developed a strategic framework for responding to climate change in 2008, which led to the development of a national approach for responding to climate change across all USFS-managed lands (USFS 2010). Currently, each individual management unit of the USFS is adapting strategic plans to incorporate the long-term implications of climate on forest management strategies. Each USFS national forest and grassland will monitor progress toward climate change goals through a standard Climate Change Performance Scorecard (http://www.fs.fed.us/climatechange/advisor/scorecard.html). The USFS 2012 budget requests additional resources to support the climate-driven planning and development

of adaptation strategies in response to regulations changes across the USFS (USFS 2012).

The USFS research and development program has developed a research plan that focuses on enhancing ecosystem sustainability and carbon sequestration, developing decision-support tools, and working collaboratively across the entire research infrastructure of the federal government (USFS 2009). The USFS research components contributed to the overall long-term goals of the U.S. Global Change Research Program (USGCRP) and work collaboratively, especially with the land management bureaus located in the DOI. As part of the USFS activities for integrating climate change activities into their planning activities, a climate change resource center has been developed (USFS 2013) that addresses managers' questions about what they can do about climate change (USFS 2010). The Fiscal Year 2012 omnibus budget, however, eliminates a direct line item focused on climate change activities in the USFS budget and redistributes the funding to other programs, with an implicit assumption that there will still be a focus on climate activities.

UNITED STATES GLOBAL CHANGE RESEARCH PROGRAM

The USGCRP program was created by Congress with the passage of the Global Change Research Act of 1990 (http://www.globalchange.gov/about). The USGCRP is tasked with developing a coordinated research plan that includes development of shared information management and public participation strategies among fourteen federal agencies. Among the chief responsibilities of the USGCRP is to produce a national assessment of the effects of climate change on a number of natural, agricultural, and other resources. Pursuant to the Global Change Research Act, these assessments are to be completed at least every four years; however, only two assessments have been produced to date, and there is no ongoing sustained process for completing this legal requirement.

The federal agencies named as part of the Global Change Research Act are required to coordinate their annual budget requests through USGCRP, along with their research activities. Additionally, under the statute, all agencies are expected to make their research results available to EPA for promulgation of any rules or policies regarding climate

change impacts. Further, the USGCRP and its member agencies are expected to participate in international activities focused on climate, such as the IPCC.

Given the lack of an ongoing process for producing the national assessment in a timely fashion, USGCRP, as part of its third assessment, is attempting to create an ongoing commitment and process among federal agencies to simplify the assessment process. Working closely with the NOAA RISAs, DOI CSCs, and other federal agencies, USCRP has teamed with CEQ to create regional coordinating bodies among federal agencies that would, among other tasks, create a long-term commitment to completing the national climate assessment. Whether this approach will succeed is unknown, but clearly completing a series of one-off assessments that do not build upon previous work has not been an effective approach to meeting the mandates of the Global Change Research Act. Nor does the random approach provide timely vital information about the effects of and adaptation options for addressing climate change.

Assessment of Recent Initiatives for Climate Change Adaptation

Though a number of the recent federal agency climate change adaptation programs have promising features that are likely to help reduce uncertainty and increase agency coordination, they nonetheless fail to sufficiently incorporate a comprehensive adaptive learning infrastructure that requires, encourages, and maximizes the capacity for managers to learn from their own endeavors and those of others. A few federal initiatives do propose integrating adaptive management more fully into decision processes as an important component of climate adaptation. For example, the Federal Interagency Climate Change Adaptation Task Force's recently proposed strategy requiring adaptation planning by all federal agencies, recommending the incorporation of adaptive management and interagency cooperation and information sharing, should help emphasize the importance of agency monitoring, assessment, and adjustment for managing the effects of climate change (CEQ 2010).

Other initiatives, such as the DOI's LCCs, do aim to increase coordination between agencies that share jurisdictional authority over particular

landscapes (Secretary of the Interior 2009). As climate change causes ecological shifts, it will likely increase resource scarcity and conflict and the interaction of regulatory authorities, as actions by one authority will increasingly have effects on resources regulated by others (Camacho 2011b). Endeavors such as the LCCs should help reduce interjurisdictional spillovers from adaptation activities and allow for more harmonization of management activities or creation of coordinated climate goals that hopefully will lead to more effective climate change adaptation.

Similarly, a number of new Federal programs are working diligently to contribute vital information and decision-support tools that should help reduce the dearth of information about the effects of climate change and adaptation. Research funded and undertaken by the U.S. Global Change Research Program, regional NOAA climate service centers, the USGS's National Climate Change and Wildlife Center, and the EPA's Office of Research and Development's Global Change Impacts and Adaptation Program will certainly proliferate important data about climate change and help develop information about possible adaptation strategies, with agency websites serving as portals wherein local, state, and federal resource managers can access critical information. The authorization and creation of regional CSCs will help produce missing but fundamental scientific information for use by the DOI's LCCs. At the individual program level, EPA's CRE, and CRWU programs encouragingly have collected and developed information, tools, and clearinghouses for discrete issue areas (Cruce and Holsinger 2010). Each of these attempts to increase available information and tools should help reduce some of the uncertainty about the effects of climate change and make it easier for managers to attempt adaptation planning.

Though certainly an improvement on conventional resource management (Milly et al. 2008), these few initiatives are not sufficiently directed at requiring either a more adaptive process or developing a comprehensive apparatus across multiple jurisdictions for private parties or government officials to more effectively manage uncertainty and the effects of climate change on ecological systems. As with past adaptive management experiments, despite the fact that a few of these adaptation initiatives espouse the need for increased reliance on adaptive management, few are developing systematic protocols that rigorously require the monitoring, assessment, and adjustment of agency decisions. A more comprehensive

commitment to learning also requires scrupulous evaluation and adjustment not only of individual management decisions but of the individual programs and agencies as well (Doremus 2007). Moreover, these adaptation initiatives do not heed the lessons of prior attempts at adaptive management that point to the need to focus on providing concrete objectives and incentives for learning for managers (Walters 1997; Baron et al. 2009). Without clear goals, timelines for assessment and modification, resources, and other performance incentives, managers are not likely to strongly commit to adaptive management (Susskind et al. 2010). Though statements calling for integration of adaptive management are laudable, a commitment to learning and reducing uncertainty requires sustained emphasis on manager incentives as well.

Furthermore, various initiatives such as the LCCs, seek to promote better coordination, but they tend to focus on place-based or interagency dialogue and pay little attention to a broader commitment to information coordination. The creation of place-based forums for dialogue can be helpful for harmonization of management strategies for particular resources (Bardach 1998; Karkkainen 2008), and more such coordinating venues could be developed. Similarly, the Federal Interagency Climate Change Adaptation Task Force provides an important forum for preliminary discussion among federal natural resource agencies about climate change adaptation and could be productive in allowing for adaptation goals to be coordinated. However, as recently found by the U.S. Government Accountability Office (2011), such forums have yet to yield a shared understanding of strategic adaptation priorities or integration as "climate change programs and activities are set across the federal government" (86).

Perhaps more importantly, most managers are left to engage in fairly isolated adaptation planning in narrowly defined jurisdictional areas and with varying degrees of interaction with other managers from their regions. This, combined with the fact that most agencies do not generate and/or gather information about the effectiveness of their management strategies, leaves regulators with a limited capacity to manage for uncertainty, yet managing for uncertainty is critical for effective climate change adaptation. The massive uncertainty that accompanies climate change requires a more comprehensive infrastructure that allows and encourages private, local, state, and federal resource managers from

throughout the country to share information, communicate, and learn from one another (Camacho 2011b).

Finally, existing governmental research initiatives are limited in their capacity to link agency information gathering, translating science into management actions and providing for information exchange. The various fragmented governmental ventures seeking the production of scientific data and decision-support tools are undoubtedly useful at regional and local levels. Yet creating information is only one part of the process. Making data, reports, and tools readily and widely accessible to others is yet another step; providing opportunities for other managers or users to contribute data is yet another; and providing opportunities for managers and other users to comment and otherwise interact is still another. Though the creation of repositories of information, such as the toolkits created by EPA's CRE and CRWU programs, is a substantial improvement on conventional management's tendency to leave managers isolated, the information flow is fairly unidirectional. In both of these programs, only EPA provides the data, guidance, and models. The portals are not at all interactive; they neither allow other managers to contribute information, nor do they facilitate communication between similarly situated managers or between managers and relevant research scientists. The Interagency Task Force continues to report that the USGCRP is "exploring options for developing and maintaining an online interagency global change information portal/system to provide 'one-stop shopping' for climate-related information" and recently a beta version of an interagency portal system has been demonstrated (CEQ 2011b, 16), but it has taken several years for this limited progress. Without a more comprehensive, shared, and evolving framework for learning, agencies will continue having difficulty managing and reducing the substantial uncertainty that is becoming compounded by a rapidly changing climate.

Possible Legal and Institutional Reforms to Increase the Legal System's Resilience

Though there may be a range of potential substantive options for increasing the adaptive capacity of natural resource management in

the United States to help prepare for and respond to the effects of climate change, the most fundamental changes necessary to support the legal system's resilience are procedural. To be sure, there are perhaps many substantive adaptation strategies that could help fortify ecosystem resilience by integrating recognition of ecological change into resource management (Peterson et al. 2008). One commonly mentioned example might be the required establishment of passive wildlife migration corridors that enable movement between ecological reserves as climatic conditions change (Simberloff and Cox 1987; Simberloff et al. 1992; Williams et al. 2005). Other substantive adaptation strategies might foster ecological resilience by building flexibility into legal rights and obligations. One example is the establishment in some jurisdictions of rolling easements, publicly owned entitlements to coastal property that shift with the coastline as sea levels rise (Titus 1998; Easterling et al. 2004). Such public entitlements would establish legal arrangements that shift obligations and rights to ensure that valuable ecosystem services remain protected as ecological conditions change (Caldwell and Segall 2007).

A more fundamental, long-term, substantive change in natural resources law might be a paradigm shift in statutory goals toward a focus on minimizing ecological harm, maximizing ecological function, or building redundancy in ecosystem functions in light of climatic and other changing environmental conditions. Rather than the traditional fidelity in American natural resources law either to maintaining ecological conditions at a specific historical baseline or to ensuring minimal human management of ecological resources (Ruhl 2010), such a transformation in regulatory goals would be more compatible with an understanding of ecological dynamism and, designed properly, could help foster ecological function and resilience (Camacho 2011b). Yet strategies that accept and promote rather than resist ecological change certainly are not without risk of harm. Inevitably, the focus of management will have to be on designing standards and deciding among strategies with an eye toward safeguarding against harmful shifts and fostering shifts that promote important ecosystem services.

Perhaps the most essential reforms for increasing the legal system's capacity to manage the effects of climate change are those that seek to improve the decision-making process by integrating and incentivizing learning to manage uncertainty. Undoubtedly, as recently proposed for

federal agencies by the Federal Interagency Climate Change Adaptation Task Force (CEQ 2010), developing a process and adopting requirements for widespread adaptation planning by local, state, and federal agencies is important, as is broad assimilation in all agency actions of consideration of the effects of climate change. The myriad of individual agency actions designed to engage in climate research and adaptation planning are also significant, as are the various research programs seeking to increase information about climate change and its effects.

Yet the procedural adaptation that may be the most vital for maintaining institutional resilience is the development of a comprehensive regulatory framework for learning (Camacho 2010). Though the existence of a multitude of governmental entities with authority over natural resources provides the potential for management experimentation and consequent interjurisdictional learning, resource managers are not given sufficient incentives or opportunities to learn and adapt, and authorities are not provided opportunities to learn from one another, because there is little information gathered or shared (Camacho 2011a). As a consequence, U.S. resources management is poorly designed to promote systematic regulatory experimentation and learning. Accordingly, the two foundational elements of such a learning infrastructure would be (1) the integration of more adaptive approaches to management that require and otherwise urge officials to systematically monitor, assess, and adjust regulatory strategies over time; and (2) the creation of a collaborative and interactive information-sharing apparatus. Such an infrastructure would improve natural resource management's adaptive capacity by encouraging regulators to manage and reduce uncertainty about the regulatory programs and natural systems under their jurisdiction.

The first feature would take principles of adaptive management and lessons from its implementation and seek to apply them broadly throughout the regulatory process. Such an approach would seek opportunities not only for integrating standard adaptive management but also less formal forms of adaptive regulation that incentivize monitoring, assessment, and periodic adjustment. In the context of adaptation planning, this would include requiring science- and goal-based monitoring, assessment, and periodic adjustment of proposed and adopted adaptation strategies throughout initial planning, rule making,

implementation, and enforcement. Monitoring activities would include not only ambient monitoring but also assessment of the effects and efficacy of adopted strategies, as well as of agencies themselves, at achieving stated regulatory goals (Karkkainen 2002). Significantly, because of the strategic disincentives that managers have for engaging in systematic adaptive management, past regulatory experiments suggest the need for monitoring, assessment, and adjustment to each be mandated and not voluntary, with clear goals and concrete triggers, deadlines, and other thresholds for action based on new information or changes in conditions (Susskind et al. 2010). In addition to obliging agencies to assess and adjust over time, providing other incentives for learning such as incorporation in manager performance evaluations, and enlisting stakeholders and other regulatory authorities to reinforce monitoring could also serve to increase learning. Such initiatives would likely serve to foster learning, better-tailored resource management, and regulator accountability.

To allow opportunities for regulatory experimentation and to promote collaborative learning at the national level, such an adaptive governance framework in the United States would most appropriately be led by the federal government in coordination with the states (Camacho 2011a). Federal agencies might consider identifying concrete metrics and standards against which management efforts can be measured, similar to the Office of Management and Budget's high-priority performance metrics (2010). To promote adaptive monitoring, assessment, and adjustment by state authorities, a national adaptive framework might range from federal approaches that build upon existing state information programs to federally prescribed standards for information gathering and sharing. As with other cooperative federalism measures in natural resources management, federal authorities could incentivize participation by offering funding for state adaptation efforts to state agencies engaging in continued monitoring, assessing, and reporting of information congruent with federally delineated metrics.

The second feature seeks to develop a widespread and public interjurisdictional network for information coordination, sharing, and interaction (Camacho 2010). Clearinghouses such as EPA's CRE and CRWU toolkits, which provide managers of particular resources access to data developed or gathered by a particular regulatory authority, are

undoubtedly useful in helping otherwise isolated resource managers engage in adaptation planning. Accordingly, more networks can usefully be created for other resources, and such networks should be linked to one another where overlap exists.

Yet as a conduit for information sharing and learning, existing approaches are largely one-directional; a single authority provides information to others to assist their decision making, with at best limited communication in the other direction and even less among the participating managers. Though agencies increasingly are focusing on reducing uncertainty, many generally do so by collecting readily available scientific data and providing introductory guidance about what adaptation options might make sense (Camacho 2011a). In short, most existing attempts to manage uncertainty in adaptation planning have not been fully embraced as adaptive approaches that bring together diverse stakeholders to develop adaptation plans (Walters 1997; Stankey et al. 2003). Drawing on the increased reliance on and growing literature promoting the use of "collaboratories" (Bly 1998), an interjurisdictional information network should foster adaptive multiparty communication and learning through an interactive cyber-infrastructure that provides not only access to information but also opportunities to upload data and comment on and interact with such data. In the United States, this interjurisdictional information network most appropriately would be housed in a federal authority (such as the Library of Congress or the CEQ), but would continue to allow for resource management decisions to remain with each agency delegated authority over a particular resource. In the context of climate change adaptation, relevant information would include not only ambient data and developed decision-support tools, but also information about potential management strategies gleaned from mandated monitoring and adaptive management. These collaboratories would harness information from participating authorities, academic scientists, and private stakeholders; offer genuine and numerous opportunities for interaction between such authorities; and provide a shared learning environment.

Such a federally maintained, publicly accessible, and system-wide collaboratory would facilitate information dissemination among similarly situated authorities, allowing for the full diversity of experience and information on the range of regulatory alternatives to be considered

(DiMento and Ingram 2005). Importantly, this transparent network provides opportunities to other management authorities and the public at large to review, contribute to, and challenge the efficacy of proposed and adopted adaptation strategies, facilitating deliberation and debate regarding existing uncertainty and the comparative value of alternative management strategies. Perhaps of equal importance, this learning infrastructure would create opportunities for more substantive collaboration and coordination of adaptation strategies between those with overlapping jurisdiction. As such, it would help reduce some of the undesirable effects of regulatory fragmentation that lead to regulatory inefficiencies and hinder interjurisdictional learning (Buzbee 2005). Finally, this information infrastructure would help managers at all levels of government manage the effects and uncertainty accompanying climate change and engage in adaptation planning. When combined with a process mandating sustained monitoring and correction by resource managers of adopted strategies, such a cyber-infrastructure would help promote resilience in the legal system by reducing uncertainty and allowing for more nimble adjustment of management strategies over time.

Conclusion

Global climate change brings with it not only substantial change to natural resources, but also considerable uncertainty about the precise type and magnitude of such effects on any particular location or resource. This uncertainty exacerbates existing gaps in knowledge about ambient conditions and the efficacy of strategies in managing resources and resource conflict. Maintaining the resilience and effectiveness of natural resource management in the face of climate change necessitates the development of a learning infrastructure that helps managers reduce and manage uncertainty over time.

Congress and state legislatures could provide authoritative direction in this regard. Though recently proposed and adopted federal research and regulatory initiatives are likely to help increase the adaptive capacity of natural resource agencies, they neglect key sources of uncertainty, do not provide clear prioritization or goals for resource managers, fail to consistently require (or otherwise provide incentives

for) adaptive learning and management by managers throughout the regulatory process, and do not provide opportunities for interactive information sharing among similarly situated managers. Federal and state legislatures may wish to establish clear goals and priorities for resource management and concrete benchmarks, resources, and incentives for monitoring, assessment, and periodic adjustment of strategies and programs in furtherance of such goals. In addition, legislatures or agencies could assist managers in harnessing the experience of others by establishing a cyber-infrastructure that not only collects and disseminates information on ambient conditions and potential management strategies, but also provides meaningful opportunities for managers, independent scientists, and other interested parties to interact and collaborate. A focus on developing an adaptive regulatory system that encourages interactive information sharing and tailoring of management in furtherance of identified regulatory priorities will help resource managers cope with uncertainty and work toward promoting the resilience of ecological systems as those systems are increasingly taxed by climatic change.

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