10 Promoting adaptation success in natural resource management through decision support

Lessons from the Great Plains and Rocky Mountain regions

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Introduction

Governments at all levels in the United States are beginning to grapple with the question of how to incorporate climate change into decision-making; examples include the federal government updating management plans for vast tracts of public land and local municipalities considering the longevity of infrastructure improvements (NRC 2010b). Natural resource management is one of the areas of particular concern, as change and uncertainty become the "new normal" for many locations (Baron *et al.* 2009). There is a pressing need to understand how managers can adjust strategies to support the continued use and conservation values of natural resources, and to help the communities who depend on those resources to adapt to a changing environment.

Managing natural resources in the US is a balancing act between extractive and consumptive uses of the resource, preservation of natural habitat for wildlife and wilderness values, and accessibility of the resource for non-consumptive uses such as recreation (e.g. Loomis 1993). Finding the right balance and priority among these values depends on the mission of the organization, the resource itself, the interest from constituencies, and a host of other factors, all of which are integrated into the final decisions made by land managers after months or even years of deliberative processes involving the public and agencies from a variety of governance levels (Loomis 1993; Martin and Steelman 2004).

Scientific information is often critical to these decision processes. In the context of federal lands, managers are required to use "best available science" to support decisions, and science is often a key input in decision-making at local governmental scales (Dilling and Failey 2013). For these resource managers, past climate experience is now less reliable as a decision guide to future conditions. Additionally, new developments in the understanding of climate variability and change may provide opportunities to improve management of given resources and help constituencies build resilience and successfully adapt to future conditions. The question for the scientific community then is how to best support these

managers in making well-informed decisions as they move forward in managing resources under climate change.

We suggest there is an ever-increasing opportunity to provide decision support for more effective resource management. However, reviews of the capacity of the scientific enterprise suggest that the US climate science community is not well organized, nor conceptually well grounded, to deliver effective decision support (NRC 2009b). Decision support has become a popular concept in the climate change research community as adaptation to a changing climate takes center stage, and it is clear that the "loading-dock" models of delivering information (i.e. scientists publish new knowledge and believe decision-makers will seek and find it) are inadequate for meeting the challenge (Cash *et al.* 2006; NRC 2007, 2009a, 2009b; Romsdahl and Pyke 2009; Dilling and Lemos 2011). Romsdahl (2011) and Moser (2009) note that, while the science policy landscape is awash with the term "decision support," there is a wide range of perspectives on exactly what is meant by the term.

For the purposes of this chapter, we define the concept of decision support as knowledge-related activities that are decision-centric – that is, science aimed at supporting decision-makers on the ground who are involved with actual decisions in real-world contexts. In practice, this means that decision support often involves some common approaches, including assessing available science and stakeholder needs, provision of tools or resources, and stakeholder engagement. Further, to be of optimal use to the decision process, decision support activities must follow the principles of being salient, credible, and legitimate in the eyes of the stakeholders and decision-makers involved (Cash *et al.* 2003).

As the decision environment for resource managers becomes more challenging under a continually changing climate, the mandate for effective decision support becomes even more compelling. Because the mission of an agency or individual resource manager emphasizes resource use or preservation (Martin and Steelman 2004), no manager wants to purposefully degrade or waste a resource. Instead, their charge is to make the best decision they can with the available science.

Given this context, what might successful adaptation look like for resource managers? While there are divergent values within resource management organizations, there are some overriding commonalities we can infer from the existing literature (Martin and Steelman 2004; Baron *et al.* 2009). We suggest that, for natural resource managers, adaptation success would mean preserving as much as possible of the values of the resources they manage under a changing climate, even as the landscape itself may undergo transformative change. We argue that effective decision support is an integral part of adaptation success, as using information effectively is necessarily a part of the decision process for many resource managers, and, ultimately, incorporating credible, relevant, and legitimate science into decisions should improve decision outcomes (see also Chapter 13).

In this chapter, we present data on the current status of adaptation efforts in the US Great Plains and the Rocky Mountain region in natural resource agencies at the federal and local level. We highlight the role of information in supporting

adaptation in these contexts, and infer from survey results how decision support efforts might be improved. While these results represent only two regions of the country, there are some strong consistencies suggesting that similar results might be found elsewhere. We offer several process and outcome-level indicators for adaptation success as they relate to decision support in this context. We draw on the existing literature to conclude with suggestions for how adaptation success might be fostered through improved decision support in the future.

A survey of adaptation progress in the US Great Plains and Rocky Mountain regions

Within the US federal government, the discussion and priority of climate-related decision support are rapidly evolving. For example, prior to 2010, adaptation was only just emerging as a national discussion (NRC 2010a), whereas, in 2011, there was a task force on adaptation planning across the federal government led by the White House Council on Environmental Quality. Recent reviews, however, find that, while there may be a surge in planning efforts, there are not many adaptation-related actions being taken on the ground (Arnell 2010; Berrang-Ford *et al.* 2011). Because the landscape is rapidly changing, Berrang-Ford *et al.* (2011) may not reflect the current situation, but evidence from other studies suggests there may be hesitation or barriers to taking action that make it difficult to move forward (Amundsen *et al.* 2010; Moser and Ekstrom 2010; Dilling and Failey 2013).

We therefore have attempted to understand the landscape of climate adaptation in our respective regions and the conditions under which new efforts might be taken in providing decision support for adaptation success. We focus on the challenges and context for adaptation success and decision support. The case examples in this section are drawn from experiences in the US Great Plains and Rocky Mountain regions. The two studies – conducted in 2009 and 2011, respectively – examined whether the adaptation focus within the US federal agencies is translating into action on the ground, at the state/local decision-maker levels in the Great Plains study and to local offices of federal agencies in the Rocky Mountain study; and, if not, why not. Overall, we find that adaptation planning is minimal among state/local decision-makers, but more active in local offices of federal agencies. One of our highlighted areas of inquiry was to understand the barriers that might be preventing adaptation from moving forward.[1]

Great Plains case study

Great Plains survey respondents included state and local government officials who had either manager or planning roles related to public lands or natural resources; the survey also included elected officials, county commissioners, and tribal leaders, because of their roles in land-use decision-making. The 939 respondents across 12 states[2] indicated that, within natural resource management, very little adaptation planning is taking place. When asked if their jurisdiction had developed any plans to deal with potential impacts from climate change, only

Table 10.1 Decision-making context for Great Plains respondents

	Per cent
Natural resource management challenges	
Drought (n=519)	55
Soil erosion (n=519)	55
Invasive species (n=462)	49
Water quality in lakes, rivers, and wetlands (n=446)	48
Pollution, non-point sources (e.g. agric. runoff) (n=366)	39
Types of information consulted regularly	
Agriculture statistics (n=538)	57
Land-use plans and surveys (n=533)	57
Climate and weather info. (temp., rainfall, etc.) (n=513)	55
Water quality info. (n=454)	48
Drought prediction info. (n=433)	46

4 per cent of respondents indicated yes (n=724), while 8 per cent indicated plans are currently being developed, 76 per cent indicated no planning, and 12 per cent did not know (Romsdahl *et al.* 2013). Although 81 per cent of respondents indicated they feel moderately well informed about climate change, 52 per cent claimed little or no personal level of concern about climate change. Despite this apparent disconnect, respondents did indicate concern for natural resource issues relative to water management. Table 10.1 provides a snapshot of the decision-making context facing the Great Plains survey respondents.

As Table 10.1 shows, drought and soil erosion are significant concerns for Great Plains decision-makers and the majority indicated that the most frequently used strategies to address these challenges are education/information for the public (54.1 per cent, n=508) and land-use planning (40.7 per cent, n=382). In addition to highlighting concerns about water management issues, the survey also identified types of decision support resources that are utilized most often and those that may be most effective for Great Plains decision-makers. In this region, agriculture is the dominant land use, so it is not surprising that the types of information regularly consulted, even for public lands decisions, relate to agricultural issues, e.g. agriculture statistics, weather, water quality, and drought information.

Rocky Mountain case study

A similar survey was conducted of 676 respondents in local offices of four US federal land management agencies, the National Park Service, Bureau of Land Management, the Fish and Wildlife Service, and Forest Service in the Rocky Mountain states of Colorado, Utah, and Wyoming (Archie *et al.* 2012). In response to the question of whether their local office had developed any

Table 10.2 Decision-making context for Rocky Mountain respondents

	Per cent
Physical and biological management challenges (n=542)	
Species and habitat management	78
Erosion	56
Climate change	56
Fire management	56
Restoration from fire or other disturbance	54
Types of information consulted regularly (n=501)	
Land-use plans and surveys	64
Vegetation inventory	56
Climate and weather information	51
Soil and/or geological maps	51
Species population information	48
Use of recreation areas	47
Endangered species maps or studies	47

plans/strategies to deal with climate change impacts, 5 per cent of respondents indicated that a plan was being implemented, 24 per cent indicated plans were being developed, 45 per cent indicated no planning, and another 24 per cent did not know. In addition, 85 per cent of respondents indicated they feel moderately well informed about climate change. Table 10.2 provides a brief summary of the decision-making context for these Rocky Mountain respondents. Soil erosion is an area of common concern between the two regions, and notable differences include the role of species management, which, with the exception of invasive species, seems to be more emphasized in the Rocky Mountain area compared with the Great Plains region.

The types of regularly consulted information that are similar between the two studies include land-use plans and climate/weather information. The information sources that respondents in both surveys used most frequently include colleagues within and without their office, staff at state agencies, and the Internet. This is in stark contrast to their relative non-use of scientific journals, which is the most popular method used by scientists for disseminating new knowledge (Table 10.3). As we discuss in the next section, this disconnect between the development and distribution of new information from the science community to public lands/natural resources decision-makers highlights an area where decision support could become more engaged.

About 40 per cent or more of respondents in both studies perceived the following types of information as very useful: weather and seasonal climate forecasts, information on how to assess the vulnerability of natural resources under their jurisdiction, and historical climate data, while long-term climate projections (such as changes in rainfall, temperature, or drought risk) and climate projections for the next few years were seen as very useful by fewer than 40 per cent (Table 10.4).

Table 10.3 Responses to the question: "What sources do you typically consult to obtain the data and information you need for your work?" Per cent reporting consulted sources. (These are listed in order from high to low in terms of overall consultation of source.)

	All the time		*Frequently*		*Do not use*	
	Rocky Mts	*Great Plains*	*Rocky Mts*	*Great Plains*	*Rocky Mts*	*Great Plains*
In-house colleagues	41	20	44	37	1	12
Internet	30	13	40	27	1	13
Colleagues in another community (with similar job responsibilities)	12	15	37	38	4	4
Staff at state agency	10	19	30	39	5	4
Professional journals	10	6	31	20	7	22
Scientific journals	11	4	28	12	8	31

Table 10.4 Responses to: "Rate the usefulness of the following types of information (whether or not you currently use them) for determining the risks to public lands/natural resources from climate change." Per cent reporting consulted sources.

	Very useful		*Not at all useful*	
	Rocky Mts	*Great Plains*	*Rocky Mts*	*Great Plains*
Weather and/or seasonal climate forecasts	43	39	6	5
Information on how to assess vulnerability of specific areas	46	26	4	7
Historical climate data	46	NA	4	NA
Long-term climate projections	37	NA	7	NA
Climate projections for the next few years	31	18	8	12

NA = Not asked

In addition, 50 per cent (n=753) of respondents in the Great Plains survey indicated that hands-on training in how to use information and/or tools in real-life settings would be very useful for their decision-making; while 40 per cent (n=741) felt that an Internet-based clearinghouse of case studies illustrating decision support resources would be equally useful.

Survey respondents in both the Great Plains and Rocky Mountain regions indicated that a variety of issues limit their office's ability to take action on climate adaptation planning. Table 10.5 provides a summary of some of the most common constraints (out of 13–16 possible selections).

These constraints highlight that climate change is not a high-priority issue at this time for decision-makers in these broad regions; and any attempts at adaptation

Table 10.5 Perceived hurdles by survey respondents

	Great Plains	*Rocky Mts*
	(per cent)	*(per cent)*
Top hurdles to adaptation planning for climate impacts		
Monetary/budget constraints	68	66
Lack of public awareness/demand for action	55	63
Lack of staff resources	39	56
Current issues are all consuming	50	59
Lack of perceived solution options	39	55
No legal mandate to address climate change	43	48

planning will face trade-offs with higher-priority issues unless there is a legal mandate and/or funding to move it higher on the agenda. A decision-maker in the Great Plains provided an example:

> There is little or no information available at or to my county level of government which would reasonably facilitate county government responses. We have county zoning with a limited ability to apply conditions to the permits we issue, with those conditions having to be limited to legitimate health and welfare concerns of county residents. Our state Department of Environmental Quality is largely occupied granting livestock feeding operation permits which keep the state in compliance with federal water quality requirements. Few resources are devoted to other issues. When federal water law does not prescribe standards, there are none.
>
> (Great Plains respondent)

Interviews with federal managers across Colorado from the US Bureau of Land Management and US Forest Service echo that there is a lot of uncertainty about how to incorporate climate information into decision-making. In some cases, a lack of information is cited, but, in others, the problem is not having a clear idea of how to incorporate climate into decision-making (Dilling and Failey 2013; Ellenwood *et al.* 2012).

A stark contrast between the two studies was seen in the question of whether climate change is real and happening now. Among Great Plains respondents, only 37 per cent agreed with this sentiment, while 73 per cent of Rocky Mountain respondents agreed. This substantial disagreement in personal opinions may be influenced by the different types of respondents, indicating that more federal employees (Rocky Mountain respondents) are aware of or exposed to data about current climate change impacts; or it may highlight differences in observable experience, with Great Plains respondents more accustomed to extreme climate variability and seasonal changes which can mask impacts from global climate change (Weber 2006). As climate impacts become more observable, Great Plains respondents may notice an increase in frequency and severity of weather and climate extremes, such as thunderstorms, heat waves, and droughts; while

Rocky Mountain respondents may see changes in ecosystems along elevation gradients, increasing temperatures, less snowfall and water availability, more wildfire, and declines in forest health (Karl *et al.* 2009).

Despite the emphasis on adaptation planning at the US federal level in Washington, DC, the translation to state/local offices within and outside the government agencies is proving slow and is constrained by day-to-day management and high-priority issues such as drought, floods, wildfire containment, etc. Added challenges appear in the form of shortages in funding and staff resources, and a lack of legal mandates to address climate change, among others (Table 10.5). To effectively begin planning for climate change adaptation, decision support resources will also need to bridge the divide between traditional science information distribution and those on-the-ground decision-makers who do not regularly utilize scientific journals but who could be implementing the new knowledge.

Indicators for adaptation success

Before we focus on the decision support component of successful adaptation, we will first discuss some of our overall findings, from our surveys and the literature, on what successful adaptation might mean for resource managers. As there is no common definition of adaptation success, we have suggested a general definition for resource managers might be to preserve as much as possible the values of the natural resources they manage under a changing climate. Adaptation success can be thought of in two dimensions: one that relates to the process of adaptation and one that relates to the outcomes. Our data and a brief review of the literature suggest at least four measures for the process of adaptation and how it might be judged successful for resource managers in the Great Plains and Rocky Mountains.

Process indicators

Incorporate climate considerations into the existing values and options available to resource managers

As Tables 10.1 and 10.2 demonstrate, managers are already grappling with numerous challenges in their management of natural resources before contemplating climate change; additionally, funding and staff resources for new tasks are a perennial concern (Table 10.5). Adaptation in this context will likely be an incremental process, needing to weigh trade-offs and co-benefits of these other values and factors as decisions are considered.

Guidance offered to resource managers must relate to their scale and needs for immediate decision-making on the ground

The information presented as decision support must consider the challenges and existing decision context of a given manager; in addition, it must be

relevant, timely, and available at the appropriate scale (Dilling and Lemos 2011). Rocky Mountain region managers saw lack of information, uncertain information, and lack of useful information as three of the top-five barriers preventing them from carrying out planning for climate change adaptation (Archie *et al.* 2012).

Build a shared sense of constituent interest

After budget constraints, the most important hurdle to moving forward with adaptation in resource management was a perceived lack of public awareness or demand for action (Table 10.5). Because resource management often involves multiple constituencies and, indeed, multiple-use mandates, a shared sense of buy-in to adaptation planning and implementation is critical to success.

Instill creative and adaptive management expectations

The high percentages of respondents who indicate that existing issues are all-consuming and that there is a lack of perceived solutions to climate change (Table 10.5) suggest an overall disempowering environment for developing novel and effective climate adaptation actions. With increasing uncertainty in what to expect from the climate, decision-makers may need to develop an increased sense of experimentation with management actions, and even a "willingness to fail." To do so, however, agencies will need to increase trust with their public and a different set of expectations than might have been present under "optimization" or traditional management approaches (Lempert and Collins 2007).

Outcome indicators

There are similarly no agreed-upon indicators for what the outcomes of a successful adaptation process might look like. However, given the future uncertainty that climate change currently represents, and the multiple constituencies that are involved in the decision process, we can suggest some general guidelines based on the existing literature.

Human systems exhibit robust decision-making

Lempert and colleagues have suggested that in situations when the future is highly uncertain and values are contested, an approach should be followed that aims for decision outcomes that are robust to a wide range of futures, rather than attempting to be optimized around a particular set of outcomes (Lempert *et al.* 2004). Natural resource decision-making in the context of climate change is both contested and uncertain, and thus re-envisioning decision processes in resource management to emphasize outcomes that are less sensitive to assumptions and "satisfice" in the face of change will likely represent successful adaptation.

Natural systems maintain resilience

Given that one of the measures of success in natural resource decision-making is to preserve the value of the resource, whether for extraction, recreation, wilderness, and/or species habitat, a focus on the natural system and its function is important. Joyce *et al.* (2009) suggest management should focus on reducing already identified stresses to the ecosystem, building resistance to threats, and managing for resilience and maintenance of ecosystem function. Together, these strategies would seek to "work with natural processes" to help ecosystems adapt in an uncertain and changing climate (*ibid.*) (see also Chapter 3).

Evaluation and ability to adjust

Another outcome of successful adaptation is the ability of managers to achieve a flexible, learning environment in which they can change management strategies as needed. Also known as adaptive management (Holling 1978), it is increasingly important as we continue to observe climate impacts on natural resources that are outside the realm of most managers' experience with the system (Joyce *et al.* 2009; West *et al.* 2009). Evaluating outcomes and creating a flexible management paradigm will be another outcome of successful adaptation.

Decision support for successful adaptation

So, what do these indicators of successful adaptation for resource management say about how we envision decision support moving forward? Some of the essential features in achieving effective decision support (Jones *et al.* 1999; Dilling and Lemos 2011) can be reemphasized in the driving need for adaptation planning:

- Awareness of the context of the decision to be supported
- Appropriate spatial and temporal scale of information and well-characterized uncertainty
- Trust between those receiving and producing decision support
- Accessibility (in many senses of the word) of information and decision-making processes
- Setting common goals that are clearly defined.

Moser (2009) finds that there are generally three types of goals that are often articulated for decision support: establishment or improvement in the process of interaction, delivery of specific outputs, and accomplishment of wider or longer-term outcomes. Because "beauty is often in the eye of the beholder," it is important to recognize, as Moser (2009) points out, that individuals in the process can have differing views on these goals. There is often disagreement as well on what a "good" decision is and what "useful" information is (Romsdahl 2011). From our studies, we offer five suggestions of how decision support might contribute to successful adaptation in light of the indicators outlined above.

Invest in people, not only in tools

As Table 10.3 demonstrates, the top information sources that managers turn to are people, whether colleagues in-house or at other agencies. Natural resource managers, and many other decision-makers, do not generally read scientific journals, which are the primary vehicle for scientists to communicate new information (Tribbia and Moser 2008). Decision support efforts can be better promoted through training of and support for knowledge brokers, i.e. people who work at the boundary between scientific information and management decisions. Knowledge brokers are trained to bridge this gap between science and society and can work interactively with knowledge seekers, i.e. decision-makers, to understand needs and provide decision support. A significant limitation is that knowledge brokers are not easily identified; outside of agriculture extension agents, there is no job title for this role in most organizations. The availability of knowledge brokers needs to be increased and advertised because managers often do not know where to find information on climate adaptation specifically. Other work from the Rocky Mountain region examining stakeholder needs over the past decade (from workshop reports, technical reports, etc.) supports this by showing that stakeholders desire much more coordination and a clear place to go for information, such as a "1-800-SCIENCE" number (Berggren and Dilling in preparation).

Foster collaborations between knowledge providers and decision-makers

One key finding from the literature is that, in order for information to be usable in decision-making, it must be created with an awareness of the decision context in which the information will be used (e.g. Lemos and Morehouse 2005; Romsdahl 2011; Dilling and Lemos 2011; Dilling and Failey 2013). An essential difference between effective decision support activities to facilitate adaptation success and more traditional types of scientific research and dissemination efforts is that decision support often involves an active, ongoing collaboration between users of knowledge (i.e. decision-makers) and those producing the knowledge (i.e. scientists) (Lemos and Morehouse 2005). Without this collaboration, well-meaning efforts to generate effective decision support can fail to be relevant, timely, or of the right quality, and decision-makers may not find it trustworthy (see also Chapter 11). Whether assessments, tools, or a process, an ongoing, iterative dialogue can help to ensure that whatever is being created under the banner of decision support is actually what is needed to aid in adaptation decision-making. There are many mechanisms that can be created to facilitate this dialogue, including boundary organizations, information brokers, "embedded" participants, collaborative processes, and knowledge networks (McNie 2007; Dilling and Lemos 2011; Romsdahl 2011). Additionally, in order for a "decision-centric" process to be effective at creating decision support for adaptation success, it must be acknowledged and "owned" that one of the goals is indeed

to create decision support. If not, the actual decision support function may fall through the cracks as both the knowledge providers and resource managers may assume it is the other's responsibility to apply the new knowledge to the decision situation.

Understand that climate-related decision support occurs in a multiple-use context

Our surveys emphasize that resource managers work with multiple values and outcomes and face several challenges in doing so even before they contemplate climate change impacts. To improve the likelihood that decision support will help facilitate climate adaptation planning, it needs to be integrated into this multiple-use reality of natural resource management. In other words, climate information (i.e. weather and seasonal forecasts, climate projections, etc.) can be more useful if placed within the context of existing high-priority agenda items, such as drought/water management. This can reframe adaptation planning away from controversies surrounding climate change and help decision-makers overcome perceptions of political bias. In this way, decision-makers can also improve the likelihood of adaptation success by moving adaptation planning higher on their management agendas; and by integrating it into existing agenda items, it may benefit from funding already available to those current management issues.

Much is said about the concept of "win–win" strategies for climate change. Finding those decisions that can indeed produce positive outcomes for short-term goals as well as long-term climate resilience is important but may sometimes be elusive. Options that can produce a more adaptive and resilient decision-making landscape may often require trade-offs with other, high-priority goals that may or may not mesh well with building adaptive capacity for climate change. For example, many land managers in the American West are grappling with (timber) fuels management to mitigate the risk of high-intensity, large-scale fire, especially near human settlements. Simultaneously, there is a need to manage for enhancing carbon storage to assist with mitigation of carbon dioxide in the atmosphere. However, there is a lot of uncertainty about how different options for fuels management, such as prescribed burning, large-scale thinning, and doing nothing, affect the carbon balance on the landscape in the long term (Ellenwood *et al.* 2012). Because so many resource managers are making decisions in an already complicated, politically charged, and time- and resource-stressed environment at present, climate change is likely to be just one more consideration they must take into account rather than a prominent driver of decision-making. On the positive side, there are several examples of decisions that do have benefits in the short term, as well as building adaptive capacity, such as preventing soil erosion through low- or no-till methods which also help to store carbon, retain water, and improve soil productivity (Dilling and Failey 2013).

Create flexible and learning-oriented decision support systems and evaluate

In the move toward more adaptive and flexible management under climate change, decision support systems themselves must become more adaptive. Successful decision support projects exemplify several characteristics: they involve decision-makers, bridge the boundary between science and decision-making, and develop end-to-end knowledge networks (Eden 2011). In addition, a key success factor in a decision support enterprise is adaptive learning within the research organization, such as self-evaluations to prompt organizational adjustments and resource allocations. A caution, however: if the decision support goals are not stated at the outset, Moser (2009) argues, the evaluation of results is nearly impossible. Moreover, not all stakeholders benefit from the results of decision support in the same way, and, in some cases, decisions based on scientific information can and do create winners and losers, resulting in a potential conflict over the information itself that is not necessarily alleviated by the process of decision support (Eden 2011). In addition, measuring the impact that decision support has on outcomes is notoriously difficult.

As decision support experiments continue to develop around the US and the world, strategies and best practices could be shared through an Internet-based network. A national network, managed by a federal agency or office, could be promoted through state and local government institutions, and contributed to at all levels of decision-making. This type of national network could provide a variety of benefits to decision support efforts, including reducing reinvention of methods by encouraging communication and serving as an information resource and/or database; and encouraging decision-makers to integrate adaptation planning in their established management decision processes (Romsdahl 2011). Despite the fact that adaptation activities will take place mostly at local levels, this type of decision support network could provide opportunities for managers to connect upward to state and national efforts and outward to other local communities.

Create conditions for knowledge acquisition and use

Our data show that the top management challenge and barrier to implementing adaptation actions is lack of funding in agencies at multiple scales. Thus, we must ask: what does this mean for the likelihood of decision-makers to commit to decision support processes to co-produce knowledge that may be time- and resource-intensive (Lemos and Morehouse 2005)? The appeal of less iterative and involved decision support tools, such as passive websites, is based on their relatively low cost and potential to reach large numbers of people. The limitations are that they do not provide the multiple and personal connections where resource managers can ask complex questions of a researcher in a dialogue. Creating conditions that foster the use of knowledge can be more complex, and require changes to organizations as well as personnel time. Solutions to improving decision support must navigate a context-specific, widely dispersed population of

decision-makers and knowledge providers and imply changes in how both groups operate going forward.

Conclusion

In sum, decision support for climate change adaptation is still in early conceptual stages. There are many theoretical models that provide guidance and a variety of these have been put into practice; however, rigorous assessment of the effectiveness/usefulness of these decision support efforts is still rare (although see Kirchhoff 2010 and McNie 2008 for analyses of the US Regional Integrated Sciences & Assessments (RISA) program). Rigorous evaluations include identifying decision support goals, using empirical metrics to measure achievement, and comparing results with an established baseline (Moser 2009). In addition, to achieve effective decision support strategies, we will need to: invest in people, foster trust and collaboration, create common goals, develop robust climate information at different scales that meets the context-specific needs of climate decision-making, and then create the conditions for actual use of this information. This will continue to be time- and labor-intensive because it requires changing the traditional methods of knowledge production away from a system that maintains separation between research goals, decision-makers, and scientists. This may be the greatest constraint on implementing successful decision support for climate change adaptation planning more broadly.

Notes

1 The questionnaires in these two studies were adapted from a 2006 survey conducted with California coastal managers by Susanne Moser and John Tribbia. Please see the following link for more information about the California survey: http://www.isse.ucar.edu/moser/california/ (accessed 4 April 2011).
2 The survey boundaries included three distinct ecological sections. The Northern Plains was composed of a large portion of Montana, northwestern Wyoming, all of North Dakota, the majority of South Dakota, and western Minnesota. The Central Plains included parts of New Mexico, Colorado, Nebraska, Kansas, Oklahoma, and Texas. The Southern Plains included central Oklahoma to the north and broadened to the south to include most of Texas.

Bibliography

Amundsen, H., Beglund, F. and Westskog, H. (2010) 'Overcoming barriers to climate change adaptation: a question of multilevel governance?', *Environment and Planning C: Government and Policy*, 28: 276–289.

Archie, K., Dilling, L., Milford, J. and Pampel, F. (2012) 'Climate change and Western public lands: a survey of US federal land managers on the status of adaptation efforts', *Ecology and Society*, 17(4): 7–20.

Arnell, N.W. (2010) 'Adapting to climate change: an evolving research programme', *Climatic Change*, 100(1): 107–111.

Baron, J.S., Gunderson, L., Allen, C.D., Fleishman, E., Mckenzie, D., Meyerson, L.A., Oropeza, J. and Stephenson, N. (2009) 'Options for national parks and reserves for adapting to climate change', *Environmental Management*, 44(6): 1033–1042.

Berggren, J. and Dilling, L. 'Analyzing expressed stakeholder needs in the Western Water Assessment RISA', in preparation.

Berrang-Ford, L., Ford, J.D. and Paterson, J. (2011) 'Are we adapting to climate change?', *Global Environmental Change*, 21(1): 25–33.

Cash, D.W., Clark, W.C., Alcock, F., Dickson, N.M., Eckley, N., Guston, D., Jäger, J. and Mitchell, R. (2003) 'Knowledge systems for sustainable development', *Proceedings of the National Academy of Sciences*, 100(14): 8086–8091.

Cash, D., Borck, J. and Patt, A. (2006) 'Countering the loading-dock approach to linking science and decision making', *Science, Technology and Human Values*, 31(30): 465–494.

Dilling, L. and Failey, E. (2013) 'Managing carbon in a multiple use world: implications of land use decision making for carbon sequestration', *Global Environmental Change*, 23(1): 291–300.

Dilling, L. and Lemos, M.C. (2011) 'Defining usable science: what can we learn for science policy from the seasonal climate forecasting experience?', *Global Environmental Change*, 21: 680–689.

Eden, E. (2011) 'Lessons on the generation of usable science from an assessment of decision support practices', *Environmental Science & Policy*, 14(1): 11–19.

Ellenwood, M.S., Dilling, L. and Milford, J.B. (2012) 'Managing United States public lands in response to climate change: a view from the ground up', *Environmental Management*, 49(5): 954–967.

Holling, C.S. (ed.) (1978) *Adaptive Environmental Assessment and Management*. New York: John Wiley.

Jones, S.B., Fischhoff, B. and Lach, D. (1999) 'Evaluating the science–policy interface for climate change research', *Climatic Change*, 43(3): 581–599.

Joyce, L.A., Blate, G.M., Mcnulty, S.G., Millar, C.I., Moser, S., Neilson, R.P. and Peterson, D.L. (2009) 'Managing for multiple resources under climate change: national forests', *Environmental Management*, 44(6): 1022–1032.

Karl, T.R., Melillo, J.M. and Peterson, T.C. (eds) (2009) *Global Climate Change Impacts in the United States*. Cambridge, UK: Cambridge University Press.

Kirchhoff, C. (2010) 'Integrating science and policy: climate change assessments and water resources management', Ph.D. Dissertation, University of Michigan.

Lemos, M.C. and Morehouse, B. (2005) 'The co-production of science and policy in integrated climate assessments', *Global Environmental Change*, 15: 57–68.

Lempert, R.J. and Collins, M.T. (2007) 'Managing the risk of uncertain threshold responses: comparison of robust, optimum, and precautionary approaches', *Risk Analysis*, 27(4): 1009–1026.

Lempert, R., Nakicenovic, N. and Sarewitz, D. (2004) 'Characterizing climate-change uncertainties for decision-makers', *Climatic Change*, 65: 1–9.

Loomis, J.B. (1993) *Integrated Public Lands Management: Principles and Applications to National Forests, Parks, Wildlife Refuges and BLM Lands*. New York: Columbia University Press.

McNie, E.C. (2007) 'Reconciling the supply of scientific information with user demands: an analysis of the problem and review of the literature', *Environmental Science & Policy*, 10: 17–38.

—(2008) 'Co-producing useful climate science for policy: lessons from the RISA program', Ph.D. Dissertation, University of Colorado.

Martin, I.M. and Steelman, T.A. (2004) 'Using multiple methods to understand agency values and objectives: lessons for public lands management', *Policy Sciences*, 37: 37–69.

Moser, S.C. (2009) 'Making a difference on the ground: the challenge of demonstrating the effectiveness of decision support', *Climatic Change*, 95: 11–21.

Moser, S.C. and Ekstrom, J.A. (2010) 'A framework to diagnose barriers to climate change adaptation', *Proceedings of the National Academy of Sciences*, 107(51): 22026–22031.

NRC (National Research Council) (2007) *Evaluating Progress of the US Climate Change Science Program: Methods and Preliminary Results*. Washington, DC: National Academies Press.

—(2009a) *Informing Decisions in a Changing Climate – Panel on Strategies and Methods for Climate-Related Decision Support*. Washington, DC: National Academies Press.

—(2009b) *Restructuring Federal Climate Research to Meet the Challenges of Climate Change*. Washington, DC: National Academies Press.

—(2010a) *America's Climate Choices: Adapting to the Impacts of Climate Change*. Washington, DC: National Academies Press.

—(2010b) *America's Climate Choices: Informing an Effective Response to Climate Change*. Washington, DC: National Academies Press.

Romsdahl, R.J. (2011) 'Decision support for climate change adaptation planning in the US: why it needs a coordinated Internet-based practitioners' network', *Climatic Change*, 106: 507–536.

Romsdahl, R.J. and Pyke, C. (2009) 'What does decision support mean to the climate change research community?', *Climatic Change*, 95: 1–10.

Romsdahl, R.J., Atkinson, L. and Schultz, J. (2013) 'Planning for climate change across the US Great Plains: concerns and insights from government decision-makers', *Journal of Environmental Studies and Sciences*, 3(1): 1–14.

Tribbia, J. and Moser, S.C. (2008) 'More than information: what coastal managers need to plan for climate change', *Environmental Science & Policy*, 11(4): 315–328.

Weber, E.U. (2006) 'Experience-based and description-based perceptions of long-term risk: why global warming does not scare us (yet)', *Climatic Change*, 77: 103–120.

West, J.M., Julius, S.H., Kareiva, P., Enquist, C., Lawler, J.J., Petersen, B., Johnson, A.E. and Shaw, M.R. (2009) 'US natural resources and climate change: concepts and approaches for management adaptation', *Environmental Management*, 44(6): 1001–1021.