Climate-Sensitive Decisions and Time Frames: A Cross-Sectoral Analysis of Information Pathways in the Carolinas

KIRSTEN LACKSTROM

Department of Geography, University of South Carolina, Carolinas Integrated Sciences and Assessments, Columbia, South Carolina

NATHAN P. KETTLE

Alaska Center for Climate Assessment and Policy, Alaska Climate Science Center, Fairbanks, Alaska

BENJAMIN HAYWOOD AND KIRSTIN DOW

Department of Geography, University of South Carolina, Carolinas Integrated Sciences and Assessments, Columbia, South Carolina

(Manuscript received 16 April 2013, in final form 11 September 2013)

ABSTRACT

This paper analyzes the information dissemination pathways that support climate-sensitive decisions in North and South Carolina. The study draws from over 100 online questionnaires and follow-up interviews with leaders in the forestry, natural resources management, planning and preparedness, tourism and recreation, and water supply management sectors. Participants represented subregions within each state, different types of organizations, and organizations working at different geographic scales. The cross-sector comparison demonstrates diverse information uses across multiple time horizons and a wide range of sector-specific needs and factors that influence how and where decision makers obtain climate information. It builds upon previous research regarding climate decision making by providing a comprehensive view of the patterns of information exchange within a given region. Although all sectors draw from a common pool of federal agencies for historical and current climate data, participants consider sector-specific and local sources to be their key climate information providers. Information obtained through these sources is more likely to be trusted, accessible, and relevant for decision making. Furthermore, information sharing is largely facilitated via subregional networks, and accessing relationships with colleagues and local agency personnel is a critical component of this process. This study provides a more nuanced understanding of how climate information use varies across sectors and time frames and the decentralized nature of existing networks. These findings have important implications for future efforts to provide climate decision support to state- and local-level decision makers and highlight the need for networks and processes that meet diverse regional and sector concerns and contexts.

1. Introduction

Climate variability and change threaten human and ecological systems worldwide; however, the specific character of variability and potential climatological shifts, impacts, and adaptation responses is likely to vary considerably among and within local and regional communities (Adger 2006; Field et al. 2012; Meehl et al. 2007; NRC 2010a; Parry et al. 2007). As such, examining regional and local adaptation contexts and capacities is essential for improving climate-related decision support (NRC 2009). Here, decision support refers to the suite of products, services, and systems designed to inform climate-sensitive decisions, including activities such as the provision of historical climatologies, forecasts, or climate model projections; vulnerability assessments; and the development of technical or process-oriented tools. Deepening knowledge of decision-making contexts, information networks, factors influencing information use, and how these factors vary across different climate-sensitive sectors is important to understanding

Corresponding author address: Kirsten Lackstrom, Department of Geography, University of South Carolina, Carolinas Integrated Sciences and Assessments, Columbia, SC 29208.
E-mail: lackstro@mailbox.sc.edu

DOI: 10.1175/WCAS-D-13-00030.1

how science and technology can most effectively be developed and deployed to enhance local adaptive capacities (Bowen et al. 2012; Virji et al. 2012).

A host of government agencies and nongovernmental organizations (NGOs) currently engage in climate decision support through the provision of data, information, and products. An ongoing challenge is to ensure that scientific knowledge is meaningful for decision makers and that diverse efforts to produce information are integrated (USGCRP 2012). For example, several federal agencies (e.g., the U.S. Department of the Interior, U.S. Department of Agriculture) and the U.S. Global Change Research Program (USGCRP) are considering or have established ''regional hubs'' to improve the delivery and management of climate information. Such hubs will ''engage with existing federal or nonfederal partners through each region to coordinate global change science and information, connect decision makers and climate experts, and engage a broad range of stakeholders'' (USGCRP 2012, p. 70). A regional framework has the potential to support several key ''best practices'' with regard to integrating science and public policy. These include promoting two-way communication between federal leaders and scientists and regional experts and opinion leaders, cultivating context-relevant and use-inspired research, and focusing on problem-oriented decision support (Kasperson and Berberian 2011). However, the specific mechanisms or approach for engagement are still in the preliminary stages, and there is also the opportunity to build on existing infrastructures, networks, and resources.

Research on and for decision support has enhanced understanding of the factors that shape information use, information pathways, and decision contexts. However, much of this research has been conducted at national or regional levels (Frumhoff et al. 2007; Karl et al. 2009) for individual sectors (Corringham et al. 2008; Kim and Jain 2010; Mote et al. 2003), or at the local decision-making level (Carbone and Dow 2005; Roncoli 2006). These studies identify a wide range of factors that influence the use of climate information, yet there remains a limited understanding of how decision contexts and information networks vary across sectors and levels of governance. This lack of a system-level analysis fails to capture the extent to which bridging activities occur across sectors and scales. As a result, we also lack knowledge of the array of needs that exist and how to serve multiple sectors and interests. We propose that enhanced knowledge about subregional climate information networks might aid in the development of more interactive and collaborative federal adaptation policy and planning processes. This proposition is guided by the premise that effective adaptation efforts involve intentional linkages between science experts and local practitioners that rely on small-scale dynamic networks for information dissemination and communication, rather than traditional large-scale, one-way linear processes (Kasperson and Berberian 2011).

To better understand climate decision-making processes and information sharing networks within a subregional context, this research examines five sectors in North and South Carolina, including their climate-relevant decisions, use of climate information, and factors that influence information use. We focus on climate information networks specifically because a lack of information sharing and communication between scientists and decision makers often contributes to a ''science–practice'' gap (Vogel et al. 2007). The following section briefly reviews the existing literature on decision-making contexts, climate information use, and factors influencing information use. The methods used to understand decision-making contexts, existing patterns of information exchange, and factors affecting information use in the Carolinas are then introduced. Research findings are presented and discussed in the larger context of how a deeper understanding of decision contexts and information networks can inform ongoing efforts to improve decision makers' access to decision support and opportunities to engage in the development of useful climate information.

2. The use of climate information for decision support

a. *Decision-making context*

Theoretical and empirical research suggest that climate-related decision-support activities, including risk-based management approaches, are more likely to be effective when they are attentive to broader decision-making contexts (French and Geldermann 2005; Jacobs et al. 2005; Kasperson and Berberian 2011; NRC 2008, 2009, 2010b; Willows and Connell 2003). Understanding the decision-making context entails not only identifying the decision maker(s), the range of available options, and temporal and spatial scales at which decisions are made, but also examining the diverse social, political, institutional factors that influence how an organization or sector pursues its goals and objectives (Jacobs et al. 2005; Ray et al. 2007). Internal factors and characteristics—such as the prevailing management paradigm, available resources, leadership capacities, perceptions and framings of risk, and ability to learn and adapt—interact with external conditions and processes to shape how an organization responds to climate risks and impacts (Berkhout 2012).

Climate-sensitive decisions are management choices that are likely to affect, or be affected by, climate conditions (NRC 2009). For example, agricultural management strategies are sensitive to changes in temperature and precipitation because these factors influence irrigation, planting, and harvesting schedules (Breuer et al. 2008). Climate-sensitive decisions occur within and across multiple sectors, including agriculture, tourism, government, fire, water, and wildlife management (Pulwarty and Melis 2001; Ray et al. 2007; Scott and Lemieux 2010) and occur at multiple time horizons, ranging from day-to-day to longer-term decisions (Corringham et al. 2008; Lowrey et al. 2009). Pulwarty and Melis (2001) illustrated this point by developing a ''hydro-climatic calendar'' of operational, monthly, seasonal, and annual decisions for dam operators in order to identify entry points for climate information into planning and management. Other research has developed annual decision calendars for specific climate stressors across multiple sectors (Ray et al. 2007). What is considered ''long-term'' may vary by sector. For example, fire management plans extend 3 to 5 years (Corringham et al. 2008), while water utilities develop plans to address capital needs for 30- to 50-yr periods (Lowrey et al. 2009). Findings from this type of inquiry have advanced our understanding of the broader decision-making context in which climate choices are made and when climate information may be most relevant to specific management duties and responsibilities (NRC 2010b).

b. Climate information use

Decision makers use a wide range of information on climate variability and change to address existing and potential management concerns, including historical climatologies and normals, current weather and climate conditions, vulnerability and impact assessments, seasonal forecasts, and longer-term projections of change (Changnon and Kunkel 1999; Corringham et al. 2008; Dilling and Lemos 2011; Hartmann et al. 2002; Lowrey et al. 2009; Owen et al. 2012; Roncoli et al. 2012; Tribbia and Moser 2008). Lowrey et al. (2009) found that water managers sometimes use paleo-reconstructions of streamflow for long-term supply projection and current streamflows for annual water availability. Owen et al. (2012) identified five categories of information used in fire management: fire climate, fire weather, fuels/fire danger, intelligence, and significant fire potential and found that fire managers are more interested in fuels/fire danger and fire climate during prefire seasons and fire weather during the peak fire season. Tribbia and Moser (2008) assessed information needs among coastal managers in California and found that weather, climate, and hydrologic information were the most frequent sources of information used; long-term projections of climate change, sea level rise, or changes in coastal erosion rates were generally not used. Findings from these case studies suggest that information use varies across individual sectors, regions, and time frames.

Decision makers obtain needed climate information from a diverse network of individuals, organizations, agencies, collaborations, and climate service providers (Lowrey et al. 2009; Pagano et al. 2002; Vogel and O'Brien 2006). These entities include state and federal agencies and nongovernmental and nonprofit organizations (NPOs), as well as friends, in-house colleagues, and local experts. Decision makers also rely on several types of documents, such as professional journals, peer-reviewed literature, and local- to national-level reports. Findings by Tribbia and Moser (2008) suggest that professional journals, publications directed toward practitioners in the field of interest, are frequently consulted by coastal managers (80% use them occasionally); scientific journals, primarily peer-reviewed publications directed toward scientists, are used infrequently (70% rarely or never use them). Other research suggests that the media and Internet are among the most frequently cited sources of information on climate (Demeritt and Landgon 2004; Tribbia and Moser 2008). Although these findings provide insight into preferences for specific information sources, there remains a limited understanding of the full range of needs and preferences across multiple sectors and the implications for providing climate information and decision support.

Understanding where individuals access information and how specific information needs vary throughout the year, across space, and within organizations helps identify optimal points for improving decision processes through the use of climate information. However, some decision makers are reluctant to use climate information in their operational to long-term planning processes (Rayner et al. 2005). The following section discusses factors affecting use of climate information.

c. Factors influencing climate information use

Diverse factors influence the use of climate information in decision making [for reviews, see Kirchhoff et al. (2012) and Moser and Ekstrom (2010)]. Some scholars focus on social and psychological factors, including trust, perceptions of risk, and uncertainty. O'Connor et al. (2005) found that water managers were more likely to use weather and climate forecasts when they perceived a higher level of risk. Research in U.S. coastal communities suggests that higher levels of uncertainty about, and inability to agree on, the magnitude and impacts of climate change are negatively correlated with coastal planners' support for adaptation planning

(Kettle 2012a). Other research emphasizes the importance of trust in mediating and building social relations, thereby increasing the use and reliability of climate information (Callahan et al. 1999; Cash et al. 2003, 2006; Nowotny et al. 2001). Institutional factors are also a notable barrier to the use of climate information (Jones et al. 1999; Pagano et al. 2001). Rayner et al. (2005) highlight how existing routines, codes, structures, and practices impede opportunities for innovation and the use of weather and climate forecasts. Other barriers to information use include lack of human and technical capacity, the timing of the availability of the forecast, reliability, and scale mismatches in the resolution of the data (Callahan et al. 1999; Hanson et al. 2006; Pulwarty and Melis 2001; Rayner et al. 2005; Snover et al. 2003).

Several approaches have been advocated to address the above barriers to information processing and use, such as building opportunities for the coproduction of knowledge, enhancing the ''usability of knowledge,'' reconciling the supply and demand of information, and utilizing boundary organizations (Dilling and Lemos 2011; Lemos and Morehouse 2005; Lemos et al. 2012; McNie 2007). The coproduction of knowledge model suggests that iterative interactions between users and producers of climate information create conditions for shaping knowledge production and enhancing the value of such knowledge (Lemos and Morehouse 2005). Efforts that promote reconciling the supply and demand of information suggest that science portfolios will be better equipped to address societal needs when climate science policy decisions reflect a better understanding of the supply of, and demand for, climate information (Sarewitz and Pielke 2007). Other models propose that the usability of climate information may be improved by overcoming barriers associated with fit, interplay, and interaction (Lemos et al. 2012). These approaches emphasize the importance of understanding the local decision-making contexts, as well as processes of learning and building trust, through iterative and deliberative dialogues, and the role and functions of diverse networks and institutional arrangements.

While the different areas of inquiry highlighted in this section have contributed many insights regarding the factors that affect the use of climate information in decision making, they examine these issues somewhat narrowly, that is from the perspective of individual decision makers or sectors. These studies provide limited information to the existing, but only loosely connected, set of climate information and decision support providers in terms of the entire landscape of climate information use and exchange, within and across geographic scales and levels of governance. These disparate studies are unable to provide this comprehensive view, a perspective that can provide valuable insights regarding patterns of information exchange within a given region and the most appropriate and effective strategies to target and disseminate climate information to different audiences and decision makers.

3. Methods

This study was part of a larger research effort to identify and assess climate concerns and information use, responses to climate change, the factors that facilitate and constrain activities, and needs to enhance adaptive capacity in North Carolina and South Carolina (Lackstrom et al. 2012). The project focused on five climate-sensitive sectors—forestry, natural resources management (hereafter natural resources), planning and preparedness, tourism and recreation, and water supply management (hereafter water). These sectors were selected because they have existing or potential sensitivity to climate variability and change and are important to regional and local economies. Furthermore, decision makers engaged in these sectors are beginning to document management issues and concerns related to climate change and engage in adaptation activities (see Bardon et al. 2010; Curtis et al. 2011; Deaton et al. 2010; SCFC 2010; SCSGC 2009).

Analysis for this article focused on understanding the existing patterns of climate-related decision making and knowledge exchange in the Carolinas. Multiple methods were used to assess decision-making contexts, the use of climate information, and the factors influencing information use. The study began with an extensive web-based search to compile a database of key decision makers and organizations involved in climate change adaptation in the Carolinas. We focused on finding participants engaged in climate issues and activities in applied settings, who were not necessarily climate scientists or climate service providers. An initial group of 130 individuals were contacted via telephone calls and e-mails. Additional participants were identified by requesting recommendations from the initial pool. Nonrespondents received two supplemental reminders at 1-week intervals. Individuals willing to participate were e-mailed further information regarding the project and a link to an online questionnaire. The questionnaire consisted of 23 questions, including inquiries regarding the types of climate information used and methods of access, current activities related to climate variability and change, and information needs.

Semistructured interviews were used to follow up on responses provided in the questionnaires and collect more in-depth information about the organizational decision-making contexts and management concerns.

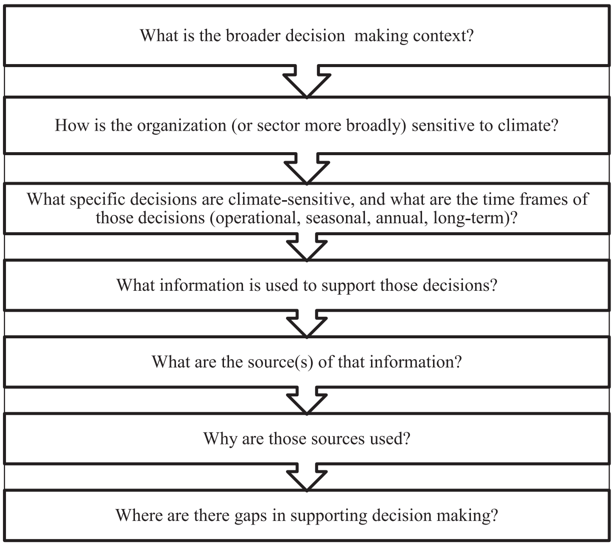

FIG. 1. Questions used to guide the analysis.

Additionally, participants were asked why particular information sources were useful or relevant, needs for additional climate information or tools, climate-related activities currently planned or in progress, and any constraints that affect their sector's capacity to respond to and manage climate perturbations. Interviews were conducted from June to September 2011. Interviews were recorded, if the interviewee granted permission, and typically lasted between 45 and 60 min. Interview audio files were then transcribed using Dragon Naturally Speaking software and reviewed by project staff to validate the transcription process. NVivo content analysis software was used to code and analyze the qualitative data obtained through interviews through a sequence of interconnected questions (Fig. 1).

These topics are discussed in the findings section. Insights from the cross-sector analysis are presented in the discussion section.

A total of 252 individuals were invited to participate in this research. The response rates for the questionnaires and semistructured interviews were 46% (n = 117) and 38% (n = 96), respectively.[1] Participants represented the target sectors, both North Carolina and South Carolina and subregions within each state, different types of organizations (academic, public, private, nonprofit, and nongovernmental organizations), and organizations working at different geographical scales (local, state, Carolinas, Southeast) (Table 1). The forestry and water sectors focus more narrowly on the management of timber and forest resources, and water supply, respectively. The natural resources sector includes a wide range of environmental agencies and organizations tasked with managing wildlife, habitat, and ecosystem services. The planning and preparedness sector includes local sustainability and green building coordinators, energy offices, city and county planners, and hazard management departments. The tourism and recreation sector is represented by industry and business (e.g., visitors' bureaus, travel associations), as well as outdoor recreation interests.

4. Findings

a. Decision-making context and information use

North Carolina and South Carolina share similar climates, resources, and economies and face parallel challenges related to land use, coastal development, and population growth, which together influence natural resources industries, municipal services, and the health of ecological communities (Napton et al. 2010). The region experiences considerable interseasonal and interannual climate variability as well as a range of extreme events. For example, there have been two record-breaking droughts across the Carolinas in the past 15 years, which have reduced reservoir storage and streamflow and contributed to saltwater intrusion in coastal areas. These droughts have led to economic losses in forestry, tourism, hydropower generation, and agriculture, and have contributed to social controversies in land development and planning (Dow 2010). The southeastern United States also experiences frequent periods of heavy rainfall. These events are often associated with slow-moving extratropical cyclones in the winter and spring and with tropical cyclones in the late summer and fall (Konrad and Fuhrmann 2012). The South Atlantic coast is particularly vulnerable to tropical cyclones, which bring flooding, damaging wind, and storm surge. Impacts are felt in coastal as well as inland regions of the Carolinas (Blake et al. 2011; Konrad and Perry 2010).

Changes in temperature and precipitation are likely to exacerbate existing management challenges and stressors in the Carolinas. Interannual variability of precipitation has increased over the past several decades, with more exceptionally wet and dry summers, compared to the mid-twentieth century (Groisman and Knight 2008; Wang et al. 2010). Although an overall warming trend is not evident in the southeast United States during the entire twentieth-century period, temperatures have risen steadily since the 1960s and the most recent decade (2001–10)

[1] 113 participants fully completed the questionnaire and 4 were incomplete, so n ranges from 113 to 117 depending on the survey question.

TABLE 1. Study participation by sector, organization type, and geographic scale.

	Forestry (n = 21)	Planning and Preparedness (n = 36)	Tourism and Recreation (n = 22)	Water (n = 14)	Natural Resources (n = 24)	Total (n = 117)
Organization type						
Academic	2	5	5	0	1	13 (11%)
NGO/NPO	8	4	9	2	12	35 (30%)
Private	1	2	2	7	0	12 (10%)
Public	10	25	6	5	11	57 (49%)
Geographic scale						
Local–NC	0	14	13	1	0	28 (24%)
Local–SC	1	2	3	1	0	7 (6%)
State–NC	6	9	2	1	9	27 (23%)
State–SC	6	3	3	3	5	20 (17%)
Carolinas	0	5	1	4	3	13 (11%)
Southeast	8	3	0	4	7	22 (19%)

was the warmest on record (Konrad and Fuhrmann 2012). Sea level rise also poses significant coastal management challenges for government operations, wildlife habitat management, and the tourism industry in the Carolinas (Burkett and Davidson 2012; Karl et al. 2009; Kettle 2012b; Lackstrom et al. 2012). Together, these circumstances contribute to conditions that create climate sensitivities and concerns across the Carolinas.

Participants indicated that their management decisions incorporate climate- and nonclimate factors across multiple time frames, including those that are *operational* (daily to weekly), *seasonal* (several months), *annual* (calendar or fiscal year), and *long term* (3–30 years). Figure 2 provides specific examples of some of these decisions, categorized by decision time frame and sector. The following section presents many of these climate-sensitive decisions for each of the five sectors and the types of information used to address these concerns. Our findings illustrate sector-specific needs for information in terms of format, temporal and spatial scale, and fit with other types of information (e.g., environmental, social, economic, or regulatory) that are required for decision making. These findings also demonstrate that sectors engage with many different climate information providers, depending on the time frame of the decision.

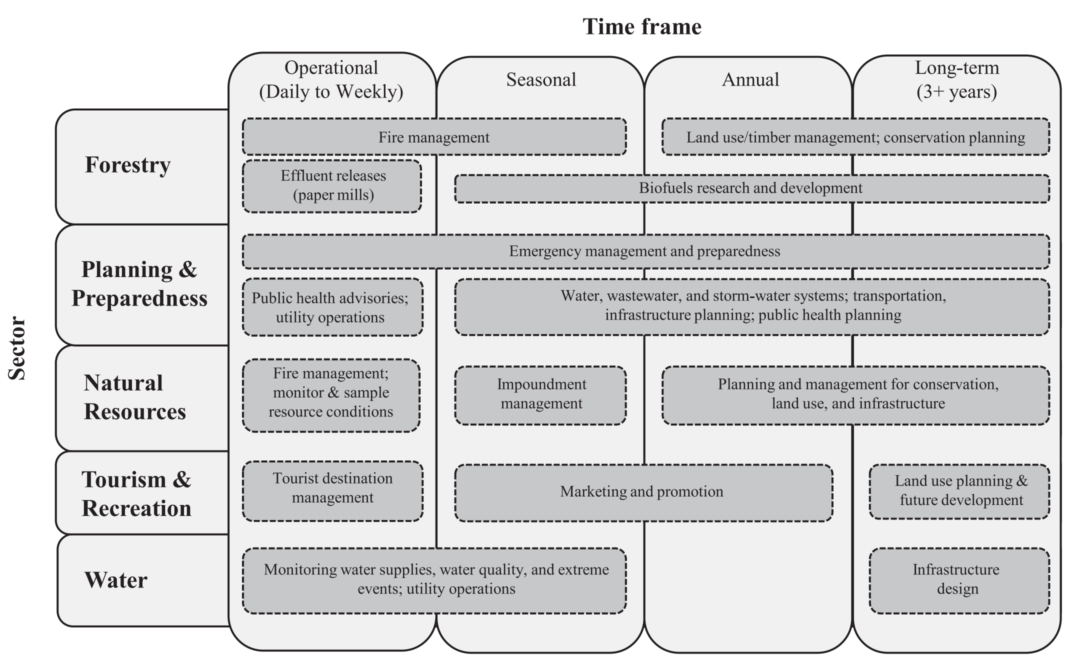

FIG. 2. Examples of climate-sensitive decisions identified by participants (by time frame and sector).

1) Forestry

Forestry sector participants identified a wide range of climate-sensitive decisions, including fire management, conservation planning and timber management, biofuel research and development, and paper milling operations. Operational decisions, such as the magnitude of effluent that may be released from a paper mill, are sensitive to temperature and precipitation because these climate variables influence streamflow, water level, river inflow, and water quality—all of which may be addressed in permitting processes. In the context of fire management, the frequency and intensity of extreme weather events affects operational staffing requirements, thus affecting seasonal and annual budgets. To address these concerns, fire managers use hourly forecasts (e.g., humidity, temperature, precipitation, wind direction) to monitor wildfire conditions and seasonal and annual outlooks to schedule seasonal prescribed burns. Long-term decisions, such as timber management, conservation, and planning for biofuel production are sensitive to temperature and precipitation changes, which impact species selection, hardiness criteria, biological threats such as invasive species, and the prevalence of extreme events such as flooding, tornadoes, and winter storms. Forestry sector participants primarily use historical climatology records for timber management, conservation, and research, although decision-support tools that incorporate future climate projections are being developed [e.g., the Template for Assessing Climate Change Impacts and Management Options (TACCIMO); SGCP 2013].

2) Natural Resources

Climate-sensitive decisions for participants in the natural resources sector center on conservation planning and management. These decisions include maintaining the ecological integrity of existing landholdings through monitoring, prioritizing the acquisition of new holdings, managing invasive species, controlling water distribution and allocation, implementing prescribed burns, and addressing coastal erosion. Operational decisions, such as staffing requirements for fire management, resource sampling and monitoring, and the selection of invasive species control techniques are sensitive to highly variable parameters including relative humidity, soil moisture, and wind speed. Short-term weather data (hourly to daily data on temperature, precipitation, wind, etc.) are therefore used to address the above operational decisions. Seasonal decisions, such as the release of water from various impoundments, are sensitive to climate variables because management must consider streamflows and control for salinity conditions (ratio of brackish and freshwater). As such, seasonal forecasts and outlooks guide activities to maintain the appropriate streamflows and ratios of brackish water to freshwater. Finally, long-term planning decisions on conservation and management are sensitive to sea level rise, the frequency of flooding, saltwater intrusion rates, and shoreline erosion. These long-term decisions are informed by projections and models of sea level rise, coastal erosion, and saltwater intrusion.

3) Planning and Preparedness

Climate-sensitive decisions in the planning and preparedness sector span a wide range of contexts, including hazard and emergency management, transportation planning, provision of public utilities, and economic development. Short-term operational decisions, such as public health advisories, public utility operations, and emergency management activities, are all sensitive to variability in precipitation, temperature, and extreme storms. Study participants also reported a seasonal orientation toward emergency management planning and preparedness, which is driven by hurricanes, tropical storms, nor'easters, and winter weather. Long-term decisions, such as stormwater and wastewater infrastructure planning are sensitive to climate factors such as sea level rise, saltwater intrusion, and precipitation extremes.

Planning and preparedness sector participants rely predominantly on information on climate extremes, daily-to-seasonal weather forecasts, and societal response (e.g., vulnerability assessments, emissions, adaptation) to inform these decisions. For example, weather data and seasonal forecasts are used to make operational decisions on water and wastewater treatment, severe weather alerts, and public health intervention services. For seasonal to long-term decisions, a variety of information types are used for hazard mitigation, planning, infrastructure design, zoning, resource management, and environmental protection. These include historical data, climatologies, and resource use records as well as climate change models and projections. Such information is often utilized in tandem with geographical mapping software to identify potential vulnerable ''hot spots'' in regards to precipitation change (flooding), sea level rise (coastal development), and saltwater intrusion (wastewater infrastructure management).

4) Tourism and Recreation

Decisions made by the tourism and recreation sector with regard to climate information reflect the concerns of two distinct subsectors, one focused on hospitality and the other on outdoor recreation. Decisions are not necessarily focused specifically on climate but are related to climate in ancillary ways. While all decision makers exhibit a shared interest in protecting and promoting tourism in the Carolinas, interviews revealed differences in terms of the scope of their climate-sensitive decisions and information use. Participants in the hospitality subsector focus on business and economic considerations. Operational and seasonal decisions center on personnel management, event and visitor planning, and maintenance of tourist-related infrastructure. Weather data were the most often cited type of information used for these shorter-term activities. Longer-term decisions focus on initiating sustainable business practices (e.g., constructing energy efficient buildings, using alternative fuel vehicles, reducing waste, and recycling) and planning for future growth and development. Interviews revealed that climate change was not an immediate concern for longer-term decisions in the hospitality subsector in 2011.

The outdoor recreation subsector indicated interest in specific activities that are affected by weather and climate, such as camping, kayaking, hiking, and fishing. Many decisions involve planning for such activities, as well as managing staff and resources. Operational decisions for selecting the routes for kayaking and boating excursions, for example, require streamflow and tide data. Seasonal and annual decisions on scheduling tourist activities are influenced by climate extremes, such as high temperatures that make many outdoor activities unsafe for visitors because of the risk of heat exhaustion. Decisions related to staffing, monitoring, and planning prescribed burning in state parks and national forests also affect tourism-related activities and require a range of wind, precipitation, temperature, and drought information. Long-term decisions center on land-use planning and future development. This group indicated a higher level of engagement with climate change issues and demonstrated concerns about the potential impacts of ecosystem alterations, increased frequency of climate extremes, and sea level rise on natural resources, as tourism activities throughout the Carolinas depend on them. To inform the above concerns, decision makers in the tourism and recreation sector rely primarily on short-term weather data and forecasts for operational to annual decisions, and historical climatologies and climate change information for long-term land use planning.

5) WATER

Providing safe, reliable, and affordable water supplies and increasing buffering capacity for extreme events are the primary climate-sensitive decisions for participants in the water sector. Operational to seasonal decisions, such as when to advise water use restrictions and transfer water among systems and how much water to release downstream, are sensitive to existing environmental conditions and near-term expectations in climatic conditions. As such, participants rely on hydrological data (including hourly, daily, monthly, and peak streamflow) and drought indices to inform these climate-sensitive decisions and ensure the reliability of water supplies. Long-term planning decisions, such as the development of engineering design parameters of water systems to maintain reliable water supplies, are informed predominantly by historical climatologies, rather than projections of climate change.

b. *Information pathways and processes*

The findings in the previous section highlight several examples of how climate information is used to inform climate-sensitive decisions across five sectors and four time frames in the Carolinas. This section discusses the information pathways and processes used to obtain climate information, including particular documents, agencies, and other sources.

1) WHERE DO DECISION MAKERS OBTAIN CLIMATE INFORMATION?

Study participants obtain climate information from a wide variety of sources, rather than using a single go-to source, to address their climate-related concerns. Table 2 shows results from the online questionnaire that demonstrate the use and relative importance of key documents, federal and state agencies, and additional sources of climate information to address climate-sensitive decisions.

Overall, the most frequently reported sources of climate information are 1) conferences and workshops and 2) colleagues and organizations within individual sectors. Over 80% of all participants obtained climate information from these sources at the time of the survey. Interviewees stated that conferences are especially important because they provide access to climate information and opportunities to network and generate new ideas (Dow et al. 2013). One conference of particular importance was the "Planning for North Carolina's Future: Ask the Climate Question" workshop, conducted in March 2010 (NC DENR 2010). This conference convened local, state, and nationally known scientists and decision makers in order to discuss how resource managers can incorporate climate information into long-term planning decisions. A participant from the tourism and recreation sector (participant 079) stated that the conference was especially important because it provided "an opportunity for us to talk to emergency response organizations, transportation organizations, regional planners, local planners, and kind of learn what they are doing. Those are organizations that do not typically interact with the tourism industry." Colleagues

TABLE 2. Sources of climate information used by study participants (%).

		Forestry (n = 21)	Planning and preparedness (n = 36)	Tourism and recreation (n = 22)	Water (n = 14)	Natural resources (n = 24)	Total (n = 117)
Documents[a]							
Survey question: "Do you obtain climate information from the following documents?"							
Professional journals		90	74	55	92	75	76
International documents		67	74	55	62	92	71
National documents		86	69	45	77	83	71
Scientific literature		62	71	41	85	92	70
State-level documents		67	74	45	46	83	66
State and federal agencies							
Survey question: "Do you obtain climate information from the following [federal or state] sources at least once a year?"							
State	NC Dept. of Environment and Natural Resources	24	46	41	23	54	40
	NC State Climate Office	29	43	27	38	25	33
	SC Dept. of Health and Environmental Control	14	3	5	23	13	10
	SC Dept. of Natural Resources	14	3	18	38	25	17
	SC State Climate Office	24	3	14	54	21	18
Federal–NOAA	NOAA	57	63	59	46	79	63
	NOAA–Climate Services[b]	24	29	23	46	63	36
	NOAA–National Climatic Data Center	38	43	32	54	38	40
	NOAA/NWS–Climate Prediction Center	19	11	18	54	25	22
	NWS–Climate Services Division	24	11	9	46	21	19
	NWS–Local/regional offices[c]	48	37	55	62	46	47
	Southeast Regional Climate Center[d]	19	29	18	46	38	29
Federal–Other	Environmental Protection Agency (EPA)	29	51	18	31	46	37
	National Aeronautics and Space Administration (NASA)	14	17	23	23	33	22
	National Integrated Drought Information System (NIDIS)	29	31	9	38	17	24
	U.S. Army Corps of Engineers	5	9	18	23	13	12
	U.S. Fish and Wildlife Service	14	6	14	15	42	17
	U.S. Geological Survey	19	29	18	69	67	37
Additional sources of climate information							
Survey question: "Do you obtain climate information from the following sources?"							
Conferences/workshops		81	89	73	92	91	85
Listservs		33	43	32	33	39	37
Colleagues/organizations within sector		81	80	64	75	96	80
Friends		38	37	36	25	35	35

[a] The authors recognize that there may be some overlap across the five types of documents. For clarification, the following examples were provided on the questionnaire: Scientific literature (written by scientists); professional journals (written by experts in your field); international documents (Intergovernmental Panel on Climate Change); national documents (Global Climate Change Impacts in the U.S.; America's Climate Choices); and state-level documents (Final reports of the NC Climate Action Plan Advisory Group; SC Climate, Energy & Commerce Advisory Committee).

[b] At the time of the study, a proposal to establish a NOAA Climate Service had been submitted to Congress, although ultimately the creation of such a service was not approved. The term "NOAA–Climate Services" was used to encompass the wide range of NOAA entities and offices that provide climate information and decision support. Climate.gov now provides access to information about climate data and services.

[c] Weather Forecast Offices.

[d] Located in Chapel Hill, North Carolina.

and organizations within individual sectors are also important providers of climate information across all sectors. This is especially the case for the natural resources sector, where over 96% of participants obtained information from colleagues and organizations within their sector at the time of the survey.

Study participants also reported using a wide range of printed documents. Reports and publications from sector-specific sources are the most frequently used documents. Water (92%) and forestry (90%) sector participants, in particular, indicated that professional journals (publications that target sector-specific audiences; e.g., American Water Works Association publications and *Forest Science*) were especially relevant. Governmental, intergovernmental, and agency reports are also broadly used. Interviews indicated that such documents are viewed as general references, as they provide synthesis and are often written in a nontechnical way.

Participants also indicated that they obtain climate information from many different state and federal agencies. Several significant themes emerged from analysis of the sources of climate information used across and within the sectors. First, while a broad range of government agencies are utilized, questionnaire results indicate that National Oceanic and Atmospheric Administration (NOAA)-affiliated offices are key sources of climate information for nearly two-thirds of all participants. Second, specific agencies appear to be preferred sources for certain types of information. This is especially the case for NOAA-affiliated offices, which provide key sources of climate information on sea level, climatology, and other climate variables. Decision makers generally use state agencies and the National Integrated Drought Information System (NIDIS) for drought data, the Environmental Protection Agency (EPA) for information about societal response, the National Weather Service (NWS) for forecasts and precipitation information, and the U.S. Geological Survey (USGS) for hydrological data. Participants requiring multiple types of climate information therefore rely on a wide variety of agencies to meet their diverse information needs. For example, a participant in the water sector (participant 099), whose job responsibilities spanned the Carolinas, stated that state-level agencies in North and South Carolina each provide ''pieces of information that we use to run our utility and to make especially long-range water planning decisions.'' Third, some sectors exhibit strong linkages with particular state and federal agencies. We found connections between the forestry sector and the U.S. Forest Service, the planning and preparedness sector and the EPA, the tourism and recreation sector and the NWS, the natural resources sector and both USGS and the U.S. Fish and Wildlife Service, and the water sector and USGS. The factors influencing these linkages are discussed in the following section.

2) FACTORS INFLUENCING INFORMATION USE

Although climate-sensitive decisions and information use often vary across sectors, analysis of the semistructured interviews revealed several factors that shape information use, including relevance to decision making and job responsibilities, credibility and trust, and familiarity and accessibility. Relevance to job responsibilities and decision-making needs was one of the most commonly identified factors influencing information use. Decisions, activities, and needs often vary by sector and time scales and thereby shape the types of information used. Study participants indicated that suitability to decisions and job responsibilities is the primary driver in using certain climate information sources. In particular, participants in the water, forestry, and natural resources sectors indicated that sector-specific sources are valued because they provide information most relevant to their particular management contexts. The scale of information provided, and the availability of locally or regionally specific information, is also critical. For example, while federal sources are perceived as good sources of longer-term and larger-scale climate patterns, trends, and predictions [e.g., El Niño–Southern Oscillation (ENSO), hurricanes], state, regional, and local sources are viewed as more pertinent to decisions, planning, and policy making because of the higher level of detail about local contexts. The use of multiple scales of information is well illustrated by a planning and preparedness sector participant, employed by a local municipality:

> [W]hen a hurricane is out in the Atlantic...we focus pretty much entirely on the National Hurricane Center's work. But as the storm approaches and gets much closer to us, we switch our attention to the local weather service office as our primary source of information because those are the guys who are more acutely aware of any climatic abnormalities here or anything that is unique to this community that the hurricane center might not be so much focused on (participant 037).

The extent to which an information source is viewed as credible and trustworthy strongly influences which sources are consulted. Across all sectors, participants viewed federal and state government agencies and information from scientific journals and professional documents as more trustworthy than private sector or advocacy groups because the former have higher levels of competence and lower levels of bias and conflict of interest. Particular agencies may be valued for certain types of information because they are viewed as having long-standing expertise and authority. A participant in the water sector (participant 097) reported that the USGS is perceived as the ''gold standard, the results are accepted by everybody [water resource engineers].'' Natural resources sector interviewees stated:

> We try to go to what we perceive to be the most credible sources...[where] there is not necessarily a perceived

> bias from a particular private sector interest like renewable energy interest or coal or nuclear interests. . . . I think everybody has problems with government data in some ways but it tends to be viewed as more credible than what comes out of the private sector. (participant 103)

> I would say that certainly those entities [North Carolina Department of Environment and Natural Resources (NC DENR), NOAA, USGS, Fish and Wildlife Service (FWS)] are respected sources of credible knowledge. They are not likely to be organizations that are sort of pushing particular agendas. . . They have governance structures that are designed to ensure that the information that they are sharing is credible and therefore can be useful in helping us shape our approach to learning about and dealing with climate change. (participant 112)

Multiple interviewees stated that they held higher levels of trust in climate information developed at the local and state level, including the local and regional offices of federal agencies, than information coming directly from the national level. Trust in local and state agencies is built through participating and networking in workshops, conferences, and sector-specific professional meetings. Personal relationships between decision makers and individuals in State Climate Offices, The Regional Climate Center, NWS regional and local offices, USGS Water Science Centers, and other resource agencies in the Carolinas contribute to the credibility of the information provided. A participant in the water sector (participant 099) stated that "local decision makers know how their [state agency] processes work and we understand their processes for gathering information."

The convenience provided by familiar and accessible sources also influences which information sources are used. The terms "familiarity" and "accessibility" were used in three primary contexts, referring to 1) the source of the information (e.g., professional associations, personal relationships with colleagues, previously used agency or organization), 2) the type of information or data provided (e.g., has the decision maker previously used this information), and 3) the format in which information is provided (e.g., through a web interface, translations or summary reports). Interviewees also used "accessibility" to describe the ease of accessing (e.g., online sources) and understanding information (e.g., is a report written in a nontechnical manner).

5. Discussion

Study findings demonstrate how decision makers in the Carolinas have multifaceted needs for climate information and rely on diverse sources to access that information. Further examination reveals additional insights about climate information use and implications for future efforts to provide useful decision support to regional decision makers.

a. *Use of climate information*

Comparison of sectoral differences in climate information use illustrates the range of information use and needs throughout the Carolinas. Each of the study sectors exhibits a particular decision-making context that shapes what information is used to address climate-sensitive concerns and the timeframes in which that information is deemed appropriate. Information linked to historical temperature and precipitation data is the main type of climate information used across sectors. However, specialized information that aligns closely to specific management decisions and associated time frames is also valued highly. The temporal diversity of climate-sensitive decisions and information use has major implications for the way in which information is developed, provided, and accessed. This will require interactions between information providers and users to determine and monitor how, when, and how often specific types of information are used and what formats and accompanying information are appropriate for different temporal scales. This could pose a challenge for information providers, who may also need to build their capacity to engage with a wide range of information users who need support for putting climate information in context.

Use of historical climatologies and climate normals involves an implicit assumption of stationarity. These findings are consistent with other research suggesting that water managers, for example, make decisions based on climate stationarity (Milly et al. 2008). Although some decision makers in the Carolinas are beginning to collect information about possible climate change impacts to the region and conduct preliminary planning for climate change, study participants seldom reported using climate change data and projections (Lackstrom et al. 2012). Other research has shown that the limited use of climate change information may be the result of uncertainty, lack of consensus regarding future climate trends, or lack of capacity within existing decision-making structures to integrate uncertain climate information into planning and management (Kujala et al. 2013; Refsgaard et al. 2013; Sarewitz and Pielke 2007; Thompson and Calkin 2011). In the Carolinas an increasingly unsupportive political environment has constrained efforts to actively plan for climate change in the region (Dow et al. 2013). In this study, only natural resources sector participants consistently indicated use of climate projections for planning and decision-making purposes in interviews. This may be due to increasing attention in the broader environmental community (governmental agencies and nongovernmental actors) to the potential impacts of climate change on environmental resources and the development of strategies and plans to adapt (see, e.g., CCSP 2008; Glick et al. 2011; Mawdsley et al. 2009). With state and local decision makers emerging as important actors in climate change adaptation processes (Poyar and Beller-Simms 2010), future work should continue to 1) assess which climate change information is useable, relevant, and credible and 2) develop ways to support integration of that information into regional and local decision-making processes.

b. Sources of climate information

Participants across all five sectors in the Carolinas use a variety of climate information sources to address climate-sensitive decisions, and often select specific pathways to gather information that is relevant to job responsibilities, trusted, and accessible. These findings are consistent with other research across the United States that highlights a diversity of climate-sensitive decisions, information needs, and contexts (Cash et al. 2006; Kirchhoff et al. 2012; McNie 2007; NRC 2009). These distinctions exist in part because climate change adaptation and response are being addressed from local actors, in the context of other state, sector, or municipal-specific stressors such as population growth and distribution, development trends, infrastructure needs, and economic drivers (Berkhout 2012).

Climate information dissemination pathways across the Carolinas are characterized by diverse, sector-specific networks rather than by one centralized or regional information hub. For example, professional associations and networks within the forestry and water sectors are particularly important for the exchange of technical and sector-specific information. Participants in the planning and preparedness, tourism and recreation, and natural resources sectors highlighted the importance of opportunities for sharing information about best management practices for adaptation and mitigation with colleagues, technical experts, and scientists at the local level. These local-scale, trusted, and sector-specific networks mediate where climate information comes from, what type of information is needed and used, whether it is trusted or perceived as credible, and for what purposes it is used. It is also apparent that most sectors rely on federal, and to some degree state, sources for climate information that relates to longer-term or broad-scale impacts (e.g., potential threat of new worldwide disease epidemics, regional impacts of shifting ENSO patterns). This complex web of multi-governance information pathways and players exemplifies the multiple channels involved in the diffusion of science to practice (Ernstson et al. 2010; Kasperson and Berberian 2011; Vogel et al. 2007).

The heterogeneity of subregional climate-sensitive decisions and information pathways in the Carolinas suggests that a ‘‘regional hub’’ strategy may benefit by leveraging and strengthening existing sector-specific channels of information dissemination. Within the USGCRP’s regional hub strategy, the United States would be divided into eight regions (USGCRP 2012). In the third National Climate Assessment (NCADAC 2013) the ‘‘southeast region’’ encompasses 11 states, Puerto Rico, and the U.S. Virgin Islands, a broad geographical area that exhibits tremendous diversity and variability in both physical geography and climate and socioecological systems. Necessarily, questions remain regarding the most appropriate scope and scale at which to build effective and efficient adaptation networks within the United States and the structures needed to facilitate cross-scalar coordination and integration. What this and similar studies in other regions highlight is that decision makers require not only a wide range of information, but information that is accompanied by a variety of tools and support from agencies and information providers acting at a variety of scales and with in-depth knowledge and expertise related to the regional context (Bolson et al. 2013; Guido et al. 2013; Rice et al. 2009).

Furthermore, this study demonstrates that many existing and emerging adaptation activities in the Carolinas are enhanced by both formal and ad hoc networks. These networks have facilitated partnerships within and across sectors, leading to collaborative adaptation efforts that pool regional expertise and resources (Dow et al. 2013). Federal-level efforts to improve climate information delivery and use will therefore likely benefit from investing in efforts aimed at fostering working relationships and knowledge networks built on trust and credibility among scientists, policy experts, and decision makers (Feldman and Ingram 2009). Multiple, complementary, and interconnected information channels can enhance the development of networks to meet the diversity of decision makers, challenges, and local contexts. Efforts to facilitate ‘‘bridges’’ across information channels, levels of governance, and sector-specific networks are more likely to improve connections between providers and users of climate information, and enhance decision making at the subregional, state, or local levels given the specialized nature of adaptation response (Bidwell et al. 2013).

6. Conclusions: Topics for future research

Decision-making contexts, patterns of information exchange, and factors influencing information use are important elements in the development of more effective tools and processes for supporting climate adaptation (NRC 2001, 2010a). This investigation provides insight into the climate-sensitive decisions and pathways through which climate information is accessed within five sectors in the Carolinas. As such, the analysis provides useful knowledge regarding the ways in which science and services can most effectively support climate adaptation.

Moving forward, we suggest that climate decision support—and ultimately the decision makers with climate-sensitive management concerns—will benefit from the reexamination of several basic questions about climate information use, access, and delivery networks when examined in the context of subregional and local scales. Basic decision support principles such as ‘‘begin with users’ needs’’ (NRC 2009) will benefit from greater recognition of the diversity of users, including their sector-specific decision contexts and geographic management scope and the diversity of needs. This and other studies demonstrate that having access to climate data and information is useful, but not sufficient, to meet all decision makers’ needs related to climate adaptation. They also request and value connections with scientists and outreach specialists and both formal and informal opportunities to exchange information and best practices with colleagues (Dow et al. 2013; Flugman et al. 2012; Kocher et al. 2012; Roncoli et al. 2012). Providers of climate information should also consider the time frame in which the information is being used, rather than just what decisions are being informed with climate information. These questions are important because they affect the scale, frequency, and parameters of information used and emphasize that information may need to be provided in multiple formats for diverse audiences.

Efforts to enhance the delivery of relevant climate information will benefit from identifying the role of existing formal and ad hoc networks in creating, sharing, and enhancing climate information use at multiple scales; the trusted sources in these networks; and the best method to supplement information development and dissemination within existing networks. Engaging with such questions has the potential to advance our understanding of the complexity of subregional, local, and sectoral networks, enhance climate information delivery and use, and build trust among individuals involved in climate services and applications, and thus enhance the adaptive capacities of locales to climate-sensitive concerns.

Acknowledgments. This research was funded by NOAA’s Climate Program Office (NA060AR4310007). This study represents one component of a larger research project, which served as a technical input for the 2013 National Climate Assessment (Lackstrom et al. 2012). The authors thank all the individuals who volunteered to participate in the web-based questionnaires and interviews. The authors also thank research team members Amanda Brennan, Ashley Brosius, Sam Ferguson, Dylan Foster, Julie Lam, Chris Rappold, Daniel Tompkins, Erin Weeks, and Henrik Westerkam for their assistance.

REFERENCES

Adger, W. N., 2006: Vulnerability. *Global Environ. Change,* **16,** 268–281.

Bardon, R., M. A. Megalos, B. New, and S. Brogan, 2010: North Carolina’s forest resources assessment: A statewide analysis of the past, current and projected future conditions of North Carolina’s forest resources. North Carolina Division of Forest Resources, 510 pp.

Berkhout, F., 2012: Adaptation to climate change by organizations. *Wiley Interdiscip. Rev.: Climate Change,* **3,** 91–106.

Bidwell, D., T. Dietz, and D. Scavia, 2013: Fostering knowledge networks for climate adaptation. *Nat. Climate Change,* **3,** 610–611.

Blake, E. S., C. E. Landsea, and E. J. Gibney, 2011: The deadliest, costliest, and most intense United States tropical cyclones from 1851–2010. National Weather Service, National Hurricane Center, 47 pp.

Bolson, J., C. Martinez, N. Breuer, P. Srivastava, and P. Knox, 2013: Climate information use among southeast US water managers: Beyond barriers and toward opportunities. *Reg. Environ. Change,* **13,** S141–S151.

Bowen, K. J., S. Friel, K. Ebi, C. D. Bulter, F. Miller, and A. J. McMichael, 2012: Governing for a healthy population: Towards an understanding of how decision-making will determine our global health in a changing climate. *Int. J. Environ. Res. Public Health,* **9,** 55–72.

Breuer, N., V. E. Cabrera, K. T. Ingram, K. Broad, and P. E. Hildebrand, 2008: AgClimate: A case study in participatory decision support system development. *Climatic Change,* **87,** 385–403.

Burkett, V. R., and M. A. Davidson, Eds., 2012: *Coastal Impacts, Adaptation and Vulnerability: A Technical Input to the 2012 National Climate Assessment.* Island Press, 216 pp.

Callahan, B., E. Miles, and D. Fluharty, 1999: Policy implications of climate forecasts for water resource management in the Pacific Northwest. *Policy Sci.,* **32,** 269–293.

Carbone, G. J., and K. Dow, 2005: Water resource management and drought forecasts in South Carolina. *J. Amer. Water Resour. Assoc.,* **41,** 145–155.

Cash, D. W., W. C. Clark, F. Alcock, N. M. Dickson, N. Eckley, D. H. Guston, J. Jäger, and R. B. Mitchell, 2003: Knowledge systems for sustainable development. *Proc. Natl. Acad. Sci. USA,* **100,** 8086–8091.

——, J. C. Borck, and A. G. Patt, 2006: Countering the loading-dock approach to linking science and decision making: Comparative analysis of the El Niño/Southern Oscillation (ENSO) forecasting systems. *Sci. Technol. Human Values,* **31,** 465–494.

CCSP, 2008: Preliminary review of adaptation options for climate-sensitive ecosystems and resources: A report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. U.S. Environmental Protection Agency, Climate Change Science Program, 973 pp.

Changnon, S. A., and K. E. Kunkel, 1999: Rapidly expanding uses of climate data and information in agriculture and water resources: Causes and characteristics of new applications. *Bull. Amer. Meteor. Soc.,* **80,** 821–830.

Corringham, T. W., A. L. Westerling, and B. J. Morehouse, 2008: Exploring use of climate information in wildland fire management: A decision calendar study. *J. For.,* **106,** 71–77.

Curtis, S., P. T. Long, and J. Arrigo, 2011: Climate, weather, and tourism: Issues and opportunities. *Bull. Amer. Meteor. Soc.,* **92,** 361–363.

Deaton, A. S., W. S. Chappell, K. Hart, J. O'Newal, and B. Boutin, 2010: North Carolina coastal habitat protection plan. North Carolina Department of Environment and Natural Resources, Division of Marine Fisheries, 639 pp.

Demeritt, D., and D. Landgon, 2004: The UK Climate Change Programme and communication with local authorities. *Global Environ. Change,* **14,** 325–336.

Dilling, L., and M. C. Lemos, 2011: Creating usable science: Opportunities and constraints for climate knowledge use and their implications for science policy. *Global Environ. Change,* **21,** 680–689.

Dow, K., 2010: News coverage of drought impacts and vulnerability in the US Carolinas, 1998–2007. *Nat. Hazards,* **54,** 497–518.

——, B. K. Haywood, N. P. Kettle, and K. Lackstrom, 2013: The role of ad hoc networks in supporting climate change adaptation: A case study from the southeastern United States. *Reg. Environ. Change,* **13,** 1235–1244.

Ernstson, H., S. Barthel, E. Andersson, and S. T. Borgström, 2010: Scale-crossing brokers and network governance of ecosystem services: The case of Stockholm. *Ecol. Soc.,* **15** (4), 28.

Feldman, D. L., and H. M. Ingram, 2009: Making science useful to decision makers: Climate forecasts, water management, and knowledge networks. *Wea. Climate Soc.,* **1,** 9–21.

Field, C. B., and Coauthors, 2012: *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation.* Cambridge University Press, 582 pp. [Available online at http://ipcc-wg2.gov/SREX/.]

Flugman, E., P. Mozumder, and T. Randhir, 2012: Facilitating adaptation to global climate change: Perspectives from experts and decision makers serving the Florida Keys. *Climatic Change,* **112,** 1015–1035.

French, S., and J. Geldermann, 2005: The varied contexts of environmental decision problems and their implications for decision support. *Environ. Sci. Policy,* **8,** 378–391.

Frumhoff, P. C., J. J. McCarthy, J. M. Melillo, S. C. Moser, and D. J. Wuebbles, 2007: Confronting climate change in the U.S. Northeast: Science, impacts, and solutions. Synthesis report of the Northeast Climate Impacts Assessment (NECIA). Union of Concerned Scientists, 146 pp.

Glick, P., B. A. Stein, and N. A. Edelson, 2011: Scanning the conservation horizon: A guide to climate change vulnerability assessment. National Wildlife Federation, 168 pp.

Groisman, P. Ya., and R. W. Knight, 2008: Prolonged dry episodes over the conterminous United States: New tendencies emerging during the last 40 years. *J. Climate,* **21,** 1850–1862.

Guido, Z., D. Hill, M. Crimmins, and D. Ferguson, 2013: Informing decisions with a climate synthesis product: Implications for regional climate services. *Wea. Climate Soc.,* **5,** 83–92.

Hanson, C. E., J. P. Palutikof, A. Dlugolecki, and C. Giannakopoulos, 2006: Bridging the gap between science and the stakeholder: The case of climate change research. *Climate Res.,* **31,** 121–133.

Hartmann, H. C., T. C. Pagano, S. Sorooshian, and R. Bales, 2002: Confidence builders: Evaluating seasonal climate forecasts from user perspectives. *Bull. Amer. Meteor. Soc.,* **83,** 683–698.

Jacobs, K., G. M. Garfin, and M. Lenart, 2005: More than just talk: Connecting science and decision making. *Environment,* **47,** 6–21.

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

Karl, T. R., J. M. Melillo, and T. C. Peterson, Eds., 2009: *Global Climate Change Impacts in the United States*. Cambridge University Press, 196 pp.

Kasperson, R. E., and M. Berberian, Eds., 2011: *Integrating Science and Policy: Vulnerability and Resilience in Global Environmental Change.* Earthscan, 416 pp.

Kettle, N. P., 2012a: Coastal climate change adaptation: The influence of perceived risk, uncertainty, trust, and scale. Ph.D. dissertation, Department of Geography, University of South Carolina, 181 pp.

——, 2012b: Exposing compounding uncertainties in sea level rise assessments. *J. Coast. Res.,* **28,** 161–173.

Kim, J.-S., and S. Jain, 2010: High-resolution streamflow trend analysis applicable to annual decision calendars: A western United States case study. *Climatic Change,* **102,** 699–707.

Kirchhoff, C. J., M. C. Lemos, and N. Engle, 2012: What influences climate information use in water management? The role of boundary organizations and governance regimes in the Brazil and the U.S. *Environ. Sci. Policy,* **26,** 6–18.

Kocher, S. D., and Coauthors, 2012: How can we span the boundaries between wildland fire science and management in the United States? *J. For.,* **110,** 421–428.

Konrad, C. E., and L. B. Perry, 2010: Relationships between tropical cyclones and heavy rainfall in the Carolina region of the USA. *Int. J. Climatol.,* **30,** 522–534, doi:10.1002/joc.1894.

——, and C. M. Fuhrmann, 2012: Climate of the Southeast United States: Past, present, and future. *Southeast Region Technical Report to the National Climate Assessment,* K. T. Ingram, K. Dow, and L. Carter, Eds., 9–38. [Available online at http://globalchange.gov/what-we-do/assessment/nca-activities/695.]

Kujala, H., A. Moilanen, M. B. Araújo, and M. Cabeza, 2013: Conservation planning with uncertain climate change projections. *PLoS ONE,* **8** (2), e53315, doi:10.1371/journal.pone.0053315.

Lackstrom, K., K. Dow, B. Haywood, A. Brennan, N. Kettle, and A. Brosius, 2012: Engaging climate-sensitive sectors in the Carolinas. Carolinas Integrated Sciences and Assessments, 185 pp. [Available online at http://www.cisa.sc.edu/resourcesReports.html.]

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

——, C. J. Kirchhoff, and V. Ramprasad, 2012: Narrowing the climate information usability gap. *Nat. Climate Change,* **2,** 789–794.

Lowrey, J. L., A. J. Ray, and R. S. Webb, 2009: Factors influencing the use of climate information by Colorado municipal water managers. *Climate Res.,* **40,** 103–119.

Mawdsley, J. R., R. O'Malley, and D. S. Ojima, 2009: A review of climate-change adaptation strategies for wildlife management and biodiversity conservation. *Conserv. Biol.,* **23,** 1080–1089.

McNie, E. C., 2007: Reconciling the supply of scientific information with user demands: An analysis of the problem and review of the literature. *Environ. Sci. Policy,* **10,** 17–38.

Meehl, G. A., and Coauthors, 2007: Global climate projections. *Climate Change 2007: The Physical Science Basis,* S. Solomon et al., Eds., Cambridge University Press, 747–845.

Milly, P. C. D., J. Betancourt, M. Falkenmark, R. M. Hirsch, Z. W. Kundreqicz, D. P. Lettenmaier, and R. J. Stouffer, 2008: Stationarity is dead: Whither water management? *Science,* **319,** 573–574.

Moser, S. C., and J. A. Ekstrom, 2010: A framework to diagnose barriers to climate change adaptation. *Proc. Natl. Acad. Sci. USA,* **107,** 22 026–22 031.

Mote, P. W., and Coauthors, 2003: Preparing for climatic change: The water, salmon, and forests of the Pacific Northwest. *Climatic Change,* **61,** 45–88.

Napton, D. E., R. F. Auch, R. Headley, and J. L. Taylor, 2010: Land changes and their driving forces in the southeastern United States. *Reg. Environ. Change,* **10,** 37–53.

NCADAC, cited 2013: Draft climate assessment report. National Climate Assessment and Development Advisory Committee. [Available online at http://ncadac.globalchange.gov/.]

NC DENR, 2010: *Planning for North Carolina's Future: Ask the Climate Question.* North Carolina Department of Environment and Natural Resources, 29 pp.

Nowotny, H., P. Scott, and M. Gibbons, 2001: *Re-Thinking Science: Knowledge and the Public in an Age of Uncertainty.* Polity Press, 288 pp.

NRC, 2001: *A Climate Services Vision: First Steps toward the Future.* National Academies Press, 97 pp.

——, 2008: *Public Participation in Environmental Assessment and Decision Making.* National Academies Press, 322 pp.

——, 2009: *Informing Decisions in a Changing Climate.* National Academies Press, 200 pp.

——, 2010a: *Adapting to the Impacts of Climate Change.* National Academies Press, 292 pp.

——, 2010b: *Informing an Effective Response to Climate Change.* National Academies Press, 348 pp.

O'Connor, R. E., B. Yarnal, K. Dow, C. L. Jocoy, and G. J. Carbone, 2005: Feeling at risk matters: Water managers and the decision to use forecasts. *Risk Anal.,* **25,** 1265–1275.

Owen, G., J. D. McLeod, C. A. Kolden, D. B. Ferguson, and T. J. Brown, 2012: Wildfire management and forecasting fire potential: The role of climate information and social networks in the southwest United States. *Wea. Climate Soc.,* **4,** 90–102.

Pagano, T. C., H. C. Hartmann, and S. Sorooshian, 2001: Using climate forecasts for water management: Arizona and the 1997–1998 El Niño. *J. Amer. Water Resour. Assoc.,* **37,** 1139–1153.

——, ——, and ——, 2002: Factors affecting seasonal forecast use in Arizona water management: A case study of the 1997–98 El Niño. *Climate Res.,* **21,** 259–269.

Parry, M. L., O. F. Canziani, J. P. Palutikof, P. J. van der Linden, and C. E. Hanson, Eds., 2007: *Climate Change 2007: Impacts, Adaptation and Vulnerability.* Cambridge University Press, 976 pp.

Poyar, K. A., and N. Beller-Simms, 2010: Early responses to climate change: An analysis of seven U.S. state and local climate adaptation planning initiatives. *Wea. Climate Soc.,* **2,** 237–248.

Pulwarty, R. S., and T. S. Melis, 2001: Climate extremes and adaptive management on the Colorado River: Lessons from the 1997–1998 ENSO event. *J. Environ. Manage.,* **63,** 307–324.

Ray, A. J., G. M. Garfin, M. Wilder, M. Vasques-Leon, M. Lenart, and A. C. Comrie, 2007: Applications of monsoon research: Opportunities to inform decision making and reduce regional vulnerability. *J. Climate,* **20,** 1608–1627.

Rayner, S., D. Lach, and H. M. Ingram, 2005: Weather forecasts are for wimps: Why water resource managers do not use climate forecasts. *Climatic Change,* **69,** 197–227.

Refsgaard, J. C., and Coauthors, 2013: The role of uncertainty in climate change adaptation strategies—A Danish water management example. *Mitigation Adapt. Strategies Global Change,* **18,** 337–359.

Rice, J. L., C. A. Woodhouse, and J. J. Lukas, 2009: Science and decision making: Water management and tree-ring data in the western United States. *J. Amer. Water Resour. Assoc.,* **45,** 1248–1259.

Roncoli, C., 2006: Ethnographic and participatory approaches to research on farmers' responses to climate predictions. *Climate Res.,* **33,** 81–99.

——, N. Breuer, D. Zierden, C. Fraisse, K. Broad, and G. Hoogenboom, 2012: The art of the science: Climate forecasts for wildfire management in the southeastern United States. *Climatic Change,* **113,** 1113–1121.

Sarewitz, D., and R. J. Pielke, 2007: The neglected heart of science policy: Reconciling supply of and demand for science. *Environ. Sci. Policy,* **10,** 5–16.

SCFC, 2010: *South Carolina's Forest Resource Assessment and Resource Strategy (Forest Action Plan).* South Carolina Forestry Commission, 271 pp.

Scott, D., and C. Lemieux, 2010: Weather and climate information for tourism. *Procedia Environ. Sci.,* **1,** 146–183.

SCSGC, 2009: The changing face of South Carolina, valuing resources, adapting to change: Strategic and implementation plan 2010–2013. South Carolina Sea Grant Consortium, 33 pp.

SGCP, cited 2013: Template for assessing climate change impacts and management options. The Southern Global Change Program. [Available online at http://www.sgcp.ncsu.edu:8090/.]

Snover, A. K., A. F. Hamlet, and D. P. Lettenmaier, 2003: Climate-change scenarios for water planning studies: Pilot applications in the Pacific Northwest. *Bull. Amer. Meteor. Soc.,* **84,** 1513–1518.

Thompson, M. P., and D. E. Calkin, 2011: Uncertainty and risk in wildland fire management: A review. *J. Environ. Manage.,* **92,** 1895–1909.

Tribbia, J., and S. C. Moser, 2008: More than information: What coastal managers need to plan for climate change. *Environ. Sci. Policy,* **11,** 315–328.

USGCRP, 2012: The National Global Change Research Plan 2012–2021: A strategic plan for the U.S. Global Change Research Program. U.S. Global Change Research Program, 132 pp.

Virji, J., J. Padgham, and C. Seipt, 2012: Capacity building to support knowledge systems for resilient development—Approaches, actions, and needs. *Curr. Opin. Environ. Sustainability,* **4,** 115–121.

Vogel, C., and K. O'Brien, 2006: Who can eat information? Examining the effectiveness of seasonal climate forecasts and regional climate-risk management strategies. *Climate Res.,* **33,** 111–122.

——, S. C. Moser, R. E. Kasperson, and G. D. Dabelko, 2007: Linking vulnerability, adaptation, and resilience science to practice: Pathways, players, and partnerships. *Global Environ. Change,* **17,** 349–364.

Wang, H., R. Fu, A. Kumar, and W. Li, 2010: Intensification of summer rainfall variability in the southeastern United States during recent decades. *J. Hydrometeor.,* **11,** 1007–1018.

Willows, R., and R. Connell, 2003: *Climate Adaptation: Risk, Uncertainty and Decision-Making.* UK Climate Impacts Program, 154 pp.