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Unpacking the 'information barrier': Comparing perspectives on information as a barrier to climate change adaptation in the interior mountain West

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ABSTRACT

Inadequate information has been repeatedly identified as a barrier to climate change adaptation planning and implementation. However less is known about how information functions as a barrier, and to what degree it prevents adaptation compared to other perceived barriers. In addition, the role of institutional context in mediating the demand for information in the context of adaptation has been less well studied. This paper helps to clarify the role that information plays in adaptation planning for two sectors of public employees working at similar scales, in similar locations, with similar challenges. We conducted surveys and semi-structured interviews to investigate the demand for information in support of adaptation implementation and planning from US federal public lands managers and municipal officials in the US interior West. We found that federal managers and municipal officials both consulted information frequently for decision making, and while both groups indicated that lack of information at relevant scales was a barrier to adaptation planning, this was seen as a much stronger barrier for federal managers than for communities. Uncertainty of information was raised as an issue, but results were mixed on whether or not this acted as a strong barrier. While peer-reviewed publications were seen as the "best available science," and correlated with adaptation planning, they were not accessed directly as frequently as other sources of information, including colleagues, the internet and reports. The strong connection between communities and adjacent federal lands may provide an opportunity for networking that could facilitate the flow of information relevant for adaptation.

1. Introduction

Gaps in information have been repeatedly identified as barriers to climate change adaptation planning and implementation (Crabbé and Robin, 2006; Mukheibir and Ziervogel, 2007; Tribbia and Moser, 2008; GAO, 2009; Lowe et al., 2009; Metz and Below, 2009; Carter and Culp, 2010; ICCATF, 2010; NRC, 2010; Foster et al., 2011; Measham et al., 2011; Archie et al., 2012). Recent studies of US federal agencies by the Government Accountability Office (GAO) and the Interagency Climate Change Adaptation Task Force (ICCATF) identify lack of relevant data as one of the major challenges associated with adaptation (GAO, 2007; GAO, 2009; ICCATF, 2010). In addition, California coastal managers participating in surveys and interviews have identified multiple types of information that would be useful to them in planning for adaptation (Tribbia and Moser, 2008). Relevant information is an extremely valuable resource and institutions that have access to site-specific information have reportedly been successful in both planning for adaptation and implementing such plans (Cruce, 2007; GAO, 2009). In fact, a 2009 report by the Center for Clean Air Policy identified leadership, organizational structure, collaboration and networking, stakeholder engagement and access to scale relevant information as common characteristics of places that have been successful in planning for adaptation (Lowe et al., 2009).

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In addition, the 2011 Progress Report of the ICCATF, listed "improving accessibility and coordination of science for decision making" as one of the five key areas where federal adaptation progress has been made (ICCATF, 2011). Given all of these reports of success in the area of providing information, we can infer that at least some useful information is available.

2. Supply and demand of information

In instances where lack of information is identified as a barrier to adaptation planning it is not always obvious whether the necessary information does not exist or is just not easily accessible (Archie et al., 2012). Furthermore, even if ostensibly relevant information is available, the question arises of whether that information is usable for decision making, and if not, why not. One recent critique has suggested there is a disconnect between the supply and demand of scientific information where supply consists of knowledge and information provided by scientists and demand is determined by use of this information in achieving societal goals (Sarewitz and Pielke, 2007; Dilling, 2007; Dilling and Lemos, 2011). Effectively addressing opportunities to reconcile supply and demand could result in science that is "more likely to advance desired societal outcomes" (Sarewitz and Pielke, 2007, p.6). Often the response to the disconnect between supply and demand has been to merely increase the supply of science before confirming that what is produced is usable to decision makers, leading to a glut of information that is not necessarily usable (Lahsen and Nobre, 2007; Sarewitz and Pielke, 2007; McNie, 2007). We consider usable science to be that which "contributes directly to the design of policy or the solution of a problem" (Dilling and Lemos, 2011, p.681). The US Global Change Research Program (USGCRP) and other major scientific programs have prioritized production of adaptation science, but whether that information will be usable for decision makers remains to be seen (USGCRP, 2009).

Numerous papers analyze the information disconnect from the supply side, evaluating research agendas and science policy, but less research has been done on the demand side (McNie, 2007). Here we consider demand for climate change adaptation information from the perspective of federal land managers and municipal officials in the interior US West, a region of potentially rapid climate change and where we have limited knowledge about the role of information in adapting to climate change. We consider adaptation in the same manner as the Intergovernmental Panel on Climate Change (IPCC), which defines climate change adaptation as "adjustment in natural or human systems to a new or changing environment that exploits beneficial opportunities or moderates negative effects (IPCC, 2007)."

There are a number of documented issues related to the dissemination of climate related information. For example, literature suggests there is a lack of cross-disciplinary interaction and understanding by scientists, which leads to a constricted flow of information and makes "decision support" and communication difficult (Ingram and Bradley, 2006; Feldman and Ingram, 2009). The term "decision support" has been used to describe research activities that center around the needs of decision makers rather than those that stem from the pursuit of scientific knowledge alone (Dilling and Romsdahl, 2013). Of utmost importance are issues relating to the transmission and relevance of climate information such as the non-linear pathways that information must travel from scientist to practitioner and the differences between the "decision space" of a researcher and a decision maker (Feldman and Ingram, 2009). Issues of trust, accessibility, relevance, and timeliness are additional reasons why certain information may not be included in the decision process (Dilling and Lemos, 2011). Of similar importance when considering the effective use of science in decision making are the "tightly coupled" issues of salience, credibility, and legitimacy (Cash et al., 2003; Cash et al. 2006). Cash et al. (2003) make the case that effective information needs to be not only relevant to the needs of users but also scientifically adequate, and unbiased in relation to the potentially divergent views of stakeholders. Cash and others also point out four functions characteristic of institutions that work effectively at the science–policy interface to better link scientific knowledge to decision making (2006). These functions include convening, translation, collaboration and mediation. The translational function can be understood as both literal translation across different languages or sets of terminology, and metaphorical translation where boundary organizations must work to reconcile different sets of assumptions, causal explanations, or expectations of knowledge across the boundary between knowledge providers and users (Cash, 2001). While examining how boundary organizations can improve the linkage between science and decision making is beyond the scope of this paper, we aim to illuminate the perceived information gaps and how they function as barriers to adaptation in two types of governmental organizations as a first step toward understanding how such gaps can be remedied.

In response to Executive Order 13,514 issued by President Obama in 2009, federal agencies are required to begin the process of adaptation to climate change. Though research has shown that federal public lands agencies have indeed begun to incorporate adaptation into decision making (Cruce and Holsinger, 2010; Archie et al., 2012), few efforts have made it to the implementation stage (Amundsen et al., 2010; Moser and Eckstrom, 2010; Berrang-Ford et al., 2011; Archie et al., 2012; Dilling and Failey, 2013). Similarly, adaptation planning has begun to take place in many municipalities across the US, but research on the state of adaptation planning and implementation in Colorado mountain communities shows only a small degree of progress in implementation of such plans (Archie, 2013).

Understanding the specific information demands for these groups could help to bridge the gap between adaptation science and adaptation planning and implementation on federal public lands and in municipalities. This is the first step in reconciling the demand for adaptation information with the supply of adaptation science. Literature suggests a variety of strategies that could assist in adaptation planning (Measham et al., 2011; Romsdahl, 2011), but we focus here on the role of information. This paper helps to clarify the role that information plays in adaptation planning for two different types of public employees working at the in the same region, with similar challenges. Our approach is novel in its ability to compare the responses of these two sectors and in its inclusion of questions related to both adaptation planning and implementation. Prior work in this area has suggested that decision makers often desire additional information, but that information barriers were not necessarily as important as other barriers in preventing adaptation progress (Jantarasami et al., 2010). Furthermore, we were interested in differences in information demand for those having both a mandate to use information and directives to pursue adaptation, and for those who had neither.

To address these issues, we conducted separate surveys of western federal public lands managers and municipal government employees in Colorado mountain communities, which were supplemented with several interviews. Here we analyze the results, and discuss the reported barriers to adaptation planning, the types of information decision makers currently use, and where they get this information. We present interesting similarities and differences among the types of climate related information that federal land managers and mountain community municipal employees find useful, the scale of information that is considered most useful,

and whether a lack of information at that scale prevents managers from planning for adaptation. We also address the use of "best available science" by federal public lands managers. Finally, we discuss how peer-reviewed information relates to adaptation planning for these groups and how networking plays a role in facilitating adaptation.

3. Methods

3.1. Survey design and distribution

To obtain data about adaptation planning in Colorado mountain communities and on federal public lands, we conducted two online surveys. Though similar to prior surveys on adaptation planning (Tribbia and Moser, 2008; Theoharides et al., 2009; Amundson et al., 2010), our research provides a unique opportunity to compare the responses of federal and municipal employees. Most of the questions asked in the two surveys were identical, but some responses were adjusted in order to make them relevant to the different populations. A list of the survey questions analyzed for this paper is available in the Appendix.

Both surveys were pre-tested on a group of qualified respondents to ensure questions were worded clearly and were relevant to the proper audience. We used an online survey tool to collect the survey data and to manage the respondent lists, maintaining confidentiality and allowing potential respondents the option to opt out permanently. Online surveys do have some potential drawbacks and limitations such as a lack of human contact to provide instruction and explanation, low response rates and perception as junk mail (Evans and Mathur, 2005). However, electronically administering surveys decreases the average response time (Sheehan and McMillan, 1999), increases the researchers' ability to track responses (Sheehan, 2001), has been shown to elicit more candid responses from participants compared to phone surveys (Bachmann et al., 1999), and elicits longer responses to open ended questions than surveys delivered in other formats (Paolo et al., 2000).

3.1.1. Federal public lands survey

The first survey was sent to 3100 federal land managers employed by the Bureau of Land Management (BLM), the US Forest Service (USFS), the National Park Service (NPS), and the US Fish and Wildlife Service (FWS) in CO, UT, and WY. The names and email addresses of land managers were obtained from publicly available phone and email lists on agency websites. Qualified participants included: directors, planners, engineers, water resources managers, environmental specialists, field managers, staff scientists and others as deemed appropriate during the survey test. The term "land manager" is thus loosely defined as those both making decisions about federal public lands as well as those providing advice and information in support of decision making. To preserve anonymity respondents were not asked specifically about which office they worked in.

3.1.2. Colorado mountain communities survey

The second survey was administered to 603 local and county government employees in the mountainous region of Colorado. Communities included in this research share common environmental, economic and demographic characteristics and are located near federal public lands (Archie, 2013) (see Fig. 1). These municipalities have economies that rely heavily on tourism and outdoor recreation, which often takes place on proximate federal public lands. Potential effects of climate change will span municipal boundaries, thus the survey includes employees from both town

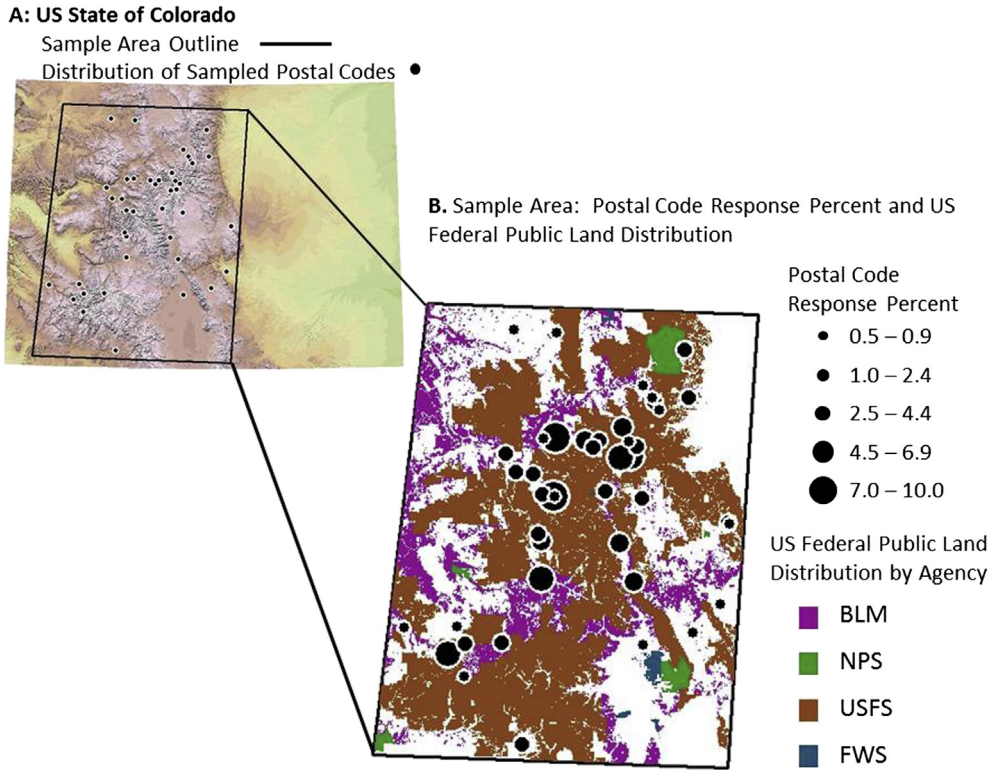

Fig. 1. Municipal response distribution. Distribution of municipal responses across the sampling region using postal codes provided by respondents.

and county governments, which traditionally work together in this region. Some county governments were not included because they either contained large areas of non-mountainous terrain (e.g. Garfield County) or housed much larger population centers that were not consistent with the rest of the sample (e.g. Boulder and Larimer Counties). The sample was limited to only those municipalities for which an extensive websearch provided publicly available contact information for employees that met the study criteria. Thus, the sample is not necessarily representative of the entire region. Municipalities that would otherwise have met the study selection criteria were not included due to a lack of available contact information. In these cases official websites did not provide employee email addresses and this information was not provided when requested.

Because municipal climate change adaptation has been shown to require an integrated approach across multiple areas of responsibility (Measham et al., 2011), we targeted a wide range of participants for this survey. Qualified participants included: directors, planners, engineers, water resources managers, environmental specialists, town council members, and others involved in environmental protection, resource allocation, development or public infrastructure. Prior research on municipal adaptation has suggested that these types of employees are those most likely to be involved in activities or decision making that could be affected by potential consequences of climate change (Moser and Tribbia 2006/2007, Tribbia and Moser, 2008; Amundson et al., 2010; Flugman et al., 2012). Thus, the sample of municipal employees includes a wide range of both those making municipal decisions as well as those providing material in support of municipal decision making.

A description of the respective study including a link to the survey was emailed to the sample of federal public lands managers five times during four months and to the municipal employees four times over two months. Multiple reminders were sent as prior work has emphasized their importance in increasing response rates (Murphy et al., 1991; Mehta and Sivadas, 1995; Taylor and Lynn, 1998; Sheehan and Hoy, 1999; Sheehan and McMillan, 1999; Dillman, 2000). The federal public lands survey was administered from March 2011–June 2011 and the Colorado mountain community survey was administered from late October 2011–January 1, 2012.

The surveys, which were of similar length and contained many of the same questions, included open-ended, Likert scale, check-all and forced-choice questions. All responses were voluntary; therefore some questions have more responses than others. We received 676 responses from federal public lands employees and 238 responses from municipal employees. Responses from municipal officials were obtained from 43 different zip codes in the targeted region and no one zip code accounted for more than 10% of the responses (see Fig. 1). The overall response rates of 21.8% and 39.5% respectively are equal to or higher than what can be expected of an online survey of this size launched after the year 2000 (Sheehan, 2001). Respondents were specifically targeted based on their job title, thus the results are not necessarily representative of the views of all agency employees or all community officials in these areas.

3.2. Interview methods

Between June and September of 2011 we conducted 12 followup interviews with federal public land managers from the survey population. Using a purposive sampling technique (Tongco, 2007) allowed us to target a range of respondents with varying degrees of management responsibilities across each of the four agencies. Interviewees included scientists, resource managers, and administrators, and conversations were recorded with the respondents' consent. The relatively small number of interviews that were conducted limits our ability to attribute responses to the entire sample of public lands respondents. However, because the qualitative data collected was from such a broad range of respondents it can certainly lend more nuanced understanding to our more extensive survey data. After receiving a general explanation of how we define adaptation and a summary of our research goals, interviewees were asked about the role that information plays in their decision making; whether additional information is needed in order to plan for adaptation; what scale of information is most useful to them in planning for adaptation; whether a lack of information at this scale prevents them from planning for adaptation; and whether uncertainty in scientific information is a barrier to adaptation planning. Interviews were transcribed and coded based on conceptual categories to obtain a more detailed understanding of the public lands survey results.

Much of the data we collected was descriptive in nature and thus lent itself to simple statistical analysis. We used ordinary least squares regression, cross-tabs, chi-square tests and Pearson correlations to establish statistical differences between segments of our samples. Results from the quantitative survey data were compared with insights gained through content analysis of the qualitative interview data.

4. Results

4.1. Barriers to adaptation planning

Because limited progress on adaptation had been previously reported (Jantarasami et al., 2010) and barriers to adaptation had already been identified as potential reason for lack of progress on adaptation (Moser and Ekstrom, 2010), we asked survey respondents to rank the top three most important factors preventing them from planning for adaptation. Respondents could choose from a list of potential barriers or provide their own answers. For federal public lands managers, lack of information at relevant scales and budget constraints were the two most common answers followed by uncertainty in available information and lack of specific agency direction (Fig. 2). For municipal respondents, budget constraints and political will were the two most common answers, followed by lack of locally specific information. Overall, responses that contained the word "information" comprised 41% of the federal public lands responses and 35% of the municipal responses to this question (see Fig. 2).

4.2. Types of information used and sources consulted

To understand the general information usage of these samples we asked respondents about the types of information they consult regularly and where they obtain this information. Choosing from a list of 18 types of information (see Fig. 3), the most common response for both federal public lands managers (64%) and Colorado mountain community officials (74%) was land use plans and surveys. More than half of the federal public lands managers surveyed also consult habitat maps or studies (61%), vegetation inventory information (56%), climate and weather information (51%), and soil or geological maps (51%). More than half of the mountain community respondents consult water supply/quality data or models (59%), information on the use of recreational areas (55%), and visitor information (54%) on a regular basis. Forty eight percent of community respondents consult climate and weather information on a regular basis.

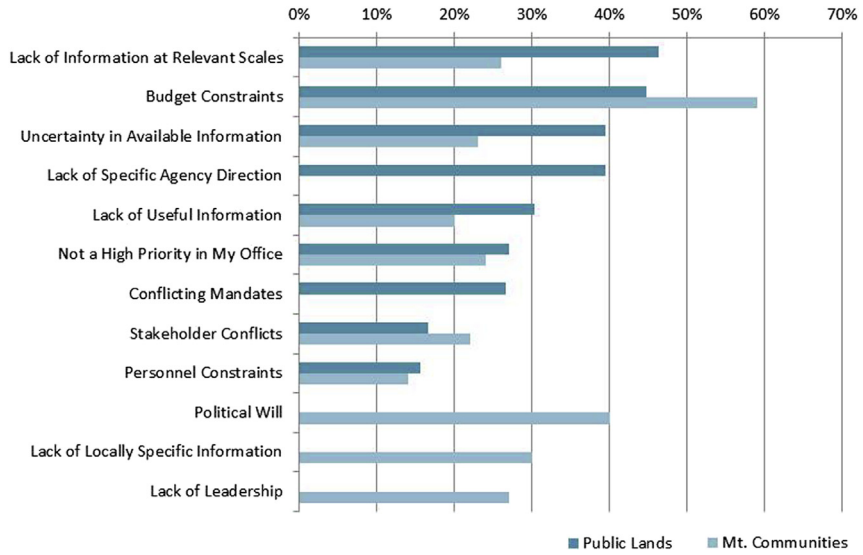

Fig. 2. Barriers to Adaptation. Respondents were asked "From your perspective, what are the most important factors preventing you from planning for adaptation to climate change? (Please rank your top three choices with 1 being the most important)" The graph shows the Percent of federal public lands and municipal respondents ranking options as one of the top 3 barriers to adaptation planning.

We also asked respondents about the sources they typically consult to obtain the data and information they use in their work. Respondents were given the option to choose: do not use in my work (0), rarely (1), occasionally (2), frequently (3), or all the time (4), for 11 different sources (Fig. 4). Though all of the sources offered were consulted by at least some respondents from both surveys, some sources are used more widely than others. Federal public lands managers report in-house colleagues as the most commonly accessed source of information followed by the internet and federal agency reports. Eighty five percent of federal public lands respondents report using in-house colleagues either frequently or all the time, 71% report using the internet either frequently or all the time, and 60% obtain data or information via federal agency reports either frequently or all the time. On average, professional listserves were the only sources offered that federal public lands managers report accessing only rarely. All other sources offered were reportedly consulted by federal public lands managers at least occasionally. The most commonly consulted source of information for community respondents was the internet followed by in-house colleagues and colleagues in other communities. Seventy percent of municipal respondents reported using the internet to obtain data or information either frequently or all the time, 64% reported using in-house colleagues either frequently or all the time, and 44% reported consulting colleagues in another community either frequently or all the time. On average, municipal respondents consult professional listserves, scientific journals, federal agency

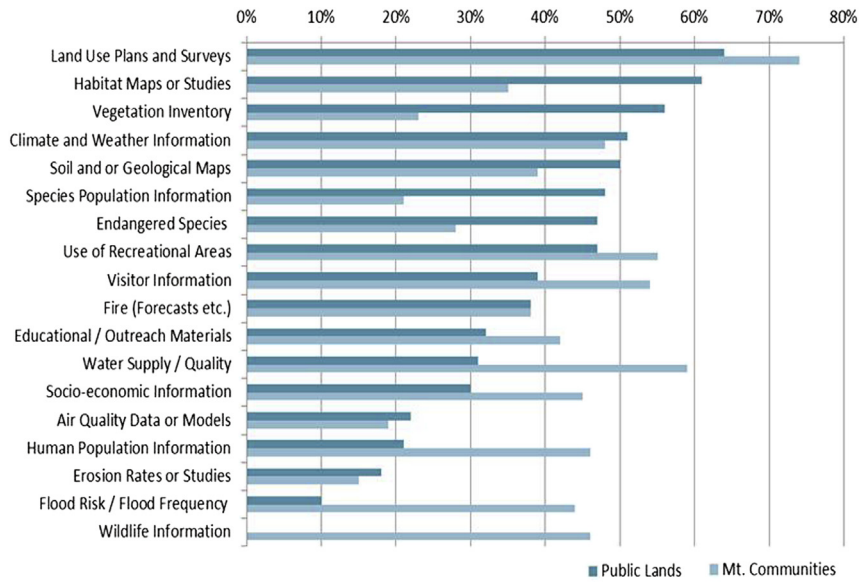

Fig. 3. Information Types. Respondents were asked "In order for you to carry out your daily job responsibilities, what data and information do you consult regularly? (Please check all that apply)." The graph shows the percent of federal public lands and municipal respondents using specific types of information.

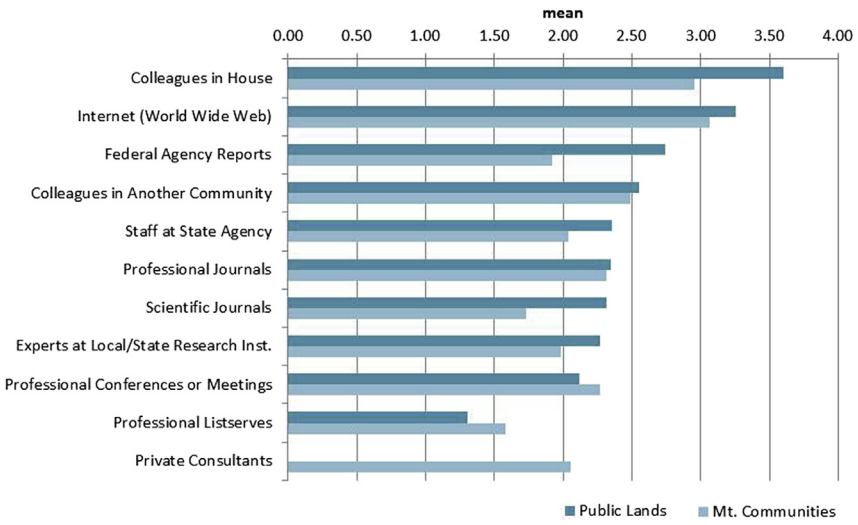

Fig. 4. Sources of Information. Respondents were asked "What sources do you typically consult to obtain the data and information you need for your work?" The graphs shows information sources consulted by federal public lands and municipal respondents (by mean usage where: Do not use in my work = 0, Rarely = 1, Occasionally = 2, Frequently = 3, and All the Time = 4).

reports, and experts at local or state research institutions only rarely.

Peer reviewed scientific information was not one of the more popularly consulted sources of information for either group of respondents. However, 40% of federal public lands respondents and 20% of municipal respondents consult scientific journals either frequently or all the time (Table 1). We were interested in which segments of these samples were accessing this type of information most often. The results of an ordinary least squares regression of the public lands data showed that respondents with higher levels of education and those considered scientists were significantly more likely to consult peer-reviewed scientific information in their work (education $B = 0.310$, $p \leq 0.001$; scientist $B = 0.508$, $p \leq 0.001$). Beliefs and attitudes about climate change did not have a significant impact on federal public land manager use of this type of information ($B = 0.080$, $p = 0.117$). As shown in Table 1, 56% of scientists consult peer-reviewed information either frequently or all the time compared to 25% of technicians, 36% of managers, and 24% of those in the "other" category.

In contrast, there was no significant difference in the use of peer-reviewed information for community respondents with higher levels of education, or for elected officials compared to bureaucratic employees ($B = 0.023$, $p = 0.712$; $B = 0.124$, $p = 0.367$). Beliefs and attitudes about climate change also did not have an effect on reported use of peer-reviewed scientific information for this sample ($B = -0.043$, $p = 0.593$).

We hypothesized that use of peer-reviewed science would be associated with increases in reported adaptation planning for both groups of respondents. As expected, use of this type of information was positively correlated with reported adaptation planning (federal public lands: $r(337) = 0.125$, $p = 0.021$; mountain communities: $r(183) = 0.235$, $p = 0.001$). Some federal agencies have a requirement for management decisions to be made using "best available science" (Clark, 2009). To better understand how land managers interpret this requirement we asked them to tell us in what format information should be available to be considered "best available science." Eighty seven percent of the federal public lands respondents consider peer-reviewed scientific publications to be "best available science."

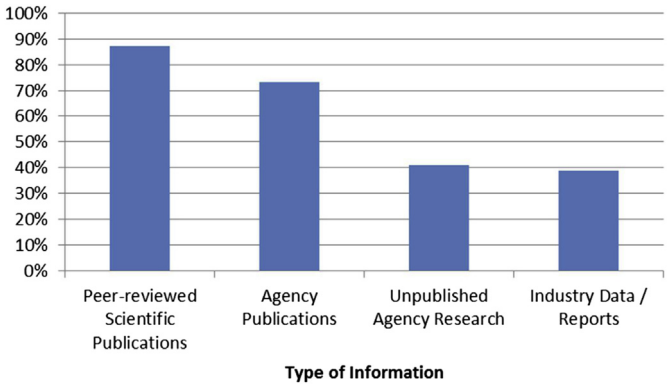

Figure 5. "Best available science." Respondents were asked "Some agencies have a requirement for management decisions to be made using "Best Available Science." In what format should information be available to be considered "Best Available Science"? (please check all that apply)" The graph shows sources considered "best available science" by federal public lands managers.

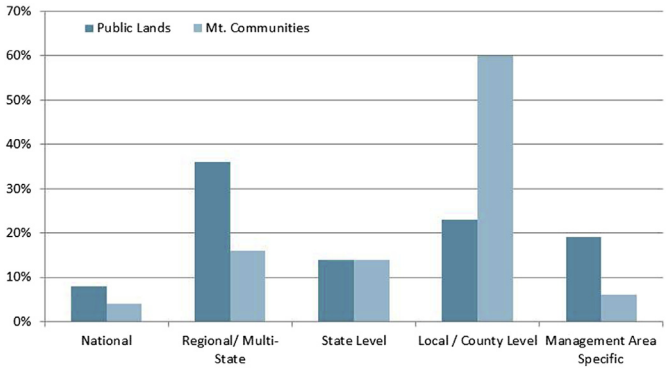

Figure 6. Scale of Information. Respondents were asked "At what scale is information most useful to you in planning for adaptation to climate change?" The graph shows respondent reports of the most useful scale of information for adaptation planning (by percentage).

Table 1
Use of peer-reviewed science. Use of peer-reviewed science for federal public lands respondents (by position) and municipal respondents.

	Public lands					Mt.Comm
	Scientist	Technician	Manager	Other	Total	Total
Do not use in my work	5%	12%	7%	17%	8%	9%
Rarely	7%	23%	8%	13%	12%	32%
Occasionally	33%	41%	50%	46%	40%	39%
Frequently	36%	22%	25%	20%	28%	19%
All the time	20%	3%	10%	4%	11%	1%

Pearson chi^2 (12) = 56.69, $p \leq 0.000$.

Agency publications ranked second, chosen by 73% of respondents, and unpublished agency research and industry data/reports were considered to be "best available science" by 41% and 39% of respondents respectively (Fig. 5).

Interview responses from federal public lands managers assist in interpretation of the survey results. Interviewees report that most of the local scale information used by federal public lands mangers is generated on site through monitoring and inventorying. However, managers explained that limited staff resources simply do not allow for internal generation of everything they would find useful. One federal public lands interviewee explained that his agency is not set up to "build science about which to make decisions." From his perspective they are particularly good at bringing interested parties to the table and presenting options based on good information, but that creating information is not part of their mission. Regional and national federal lands offices supply most of the more general information used by the interviewees, often in the form of webinars or trainings. Peer reviewed literature is consulted on a limited basis. According to interviewees, the use of science in federal public lands management often varies by agency.

4.3. Relevant scales of information

Prior work has shown lack of information at relevant scales to be perceived as a major barrier to adaptation (Broad and Agrawala, 2000; Letson et al., 2001; Broad et al., 2002; Jagtap et al., 2002; Patt and Gwata, 2002; Leetmaa, 2003; Rayner et al., 2005; Archie et al., 2012). Thus, we asked respondents to choose the scale of information most useful to them in planning for adaptation to climate change. Overall information at the regional/multi-state scale was reported to be the most useful for federal public lands managers and local/county level information was considered to be the most useful for municipal employees. As expected, information at the national scale was reported to be the least useful for both samples (Fig. 6).

Following the survey question about which scale of information respondents would find most useful in planning for adaptation, we asked respondents whether a lack of information at this scale prevented them from planning for adaptation. Responses from federal public lands managers overall were split with 31% answering yes, 35% answering no, and 34% answering that they don't know. Responses to this question varied significantly depending on the category of employee ($chi^2 = 8.35$, $p = 0.039$). Scientists tend to report that a lack of information at the most relevant scale prevents them from planning for adaptation more than managers, technicians or other types of federal public lands employees. Thirty six percent of Colorado mountain community respondents report that lack of information at relevant scales prevents them from planning for adaptation while 43% report that it does not and the remaining 21% report that they don't know (see Fig. 7). Responses from elected officials and bureaucratic employees from Colorado mountain communities did not differ significantly ($chi^2 = 1.85$, $p = 0.397$).

Across the four federal land agencies the responses to this question varied significantly ($chi^2 = 29.39$, $p \leq 0.001$). Fifty seven percent of FWS respondents reported that lack of information at the specified scale prevents them from planning for adaptation while only 22% of USFS respondents reported the same. BLM and NPS responses were more equally distributed among the three potential responses (see Fig. 7).

To better understand this question of scale, interviewees from federal public lands offices in the region were asked to clarify exactly what scale of information is most useful to them in planning for adaptation. Interviewees confirmed that regional information was indeed the most useful, but exactly what defines a "region" depends on where you are located and what you are managing for. In fact, though most interviewees initially classify the information that they are looking for as "regional," further discussion makes it clear that they really prefer local or sub-regional scale information. Interviewees from federal public lands offices in the Gunnison area of Colorado explained that the unique climate situation of the Gunnison Basin makes broader regional models of the Rocky Mountains not as useful for them as they would be for other areas in the state. For these managers sub-regional scale information, specifically for the Gunnison Basin, would be the most useful. The need for more locally specific data was echoed by other interviewees who deal directly with threatened or endangered species. They explained that managing to maintain critical habitat typically requires more targeted information than is usually provided in what they consider to be regional information. One of the main challenges expressed repeatedly by interviewees is an apparent lack of climate change science and modeling at these smaller scales. One interviewee explains that even for managers who want to be proactive in adaptation planning and who understand the potential risks associated with climate change, decision making based on imprecise models can be difficult. Unfortunately, local scale climate models are not only difficult to come by but also carry more uncertainty than larger scale projections (Tribbia and Moser, 2008).

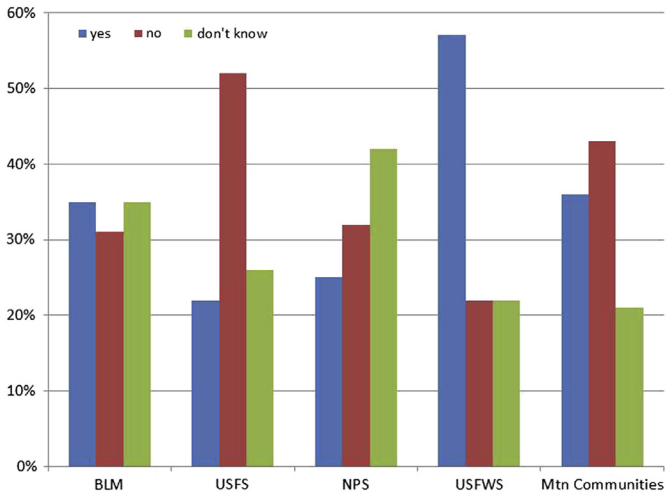

Fig. 7. Planning and the Scale of Information. Respondents were asked "Does a lack of information at the scale you specified in question #10 prevent you from planning for adaptation to climate change?" The graph shows Responses about whether a lack of information at the scale considered most relevant prevents planning for adaptation (by percent).

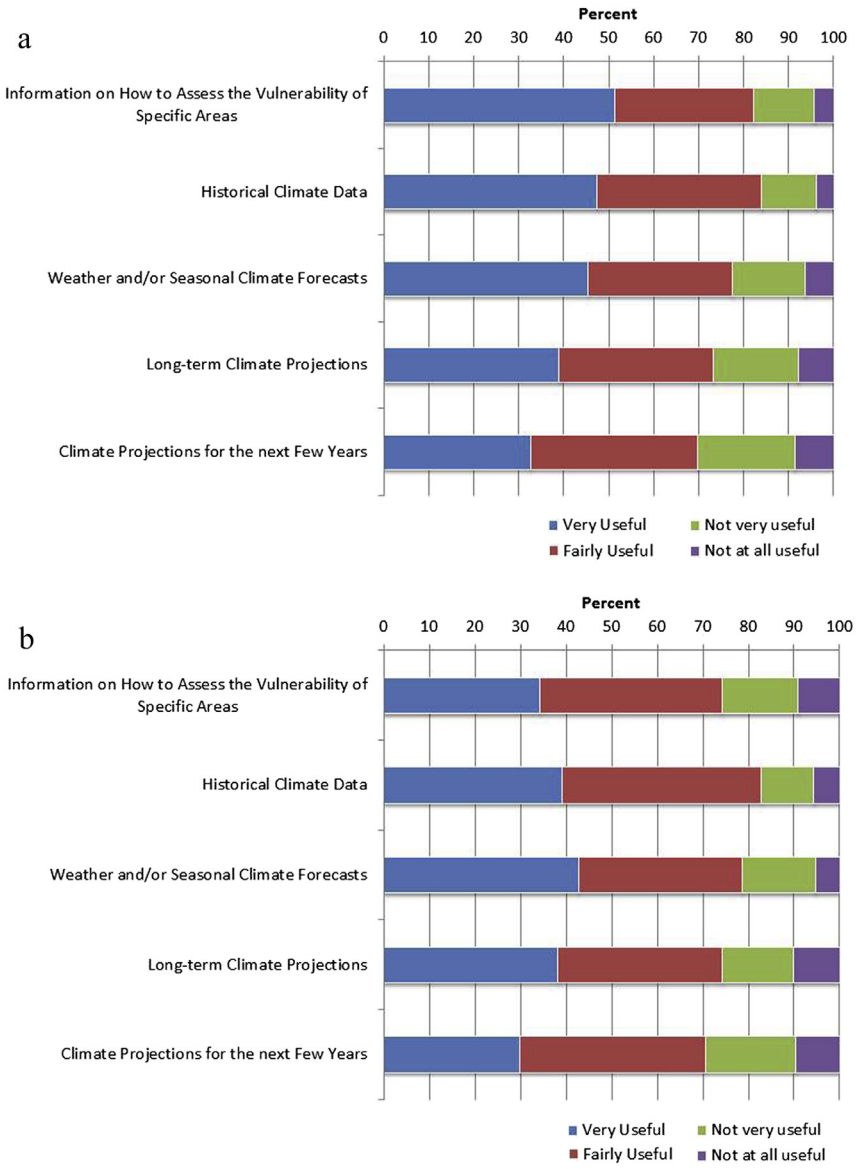

Fig. 8. a. Useful information: Public Lands. Respondents were asked to "Please rate the usefulness of the following types of information (whether or not you currently use them) for determining the risks to public lands from climate change." The graph shows perceived usefulness of climate related information by federal public lands respondents. b. Useful information: Colorado mountain communities. Respondents were asked to "Please rate the usefulness of the following types of information (whether or not you currently use them) for determining the risks to public lands from climate change." The graph shows perceived usefulness of climate related information by municipal respondents.

For example, in mountainous regions such as the Rockies changes in snow pack and runoff timing are some of the most widely anticipated impacts of climate change. However, without more specific understanding of how those changes will manifest locally on a year to year basis it is nearly impossible to predict how they will affect related issues such as seasonal vegetation. One interviewee expressed his concern with amending grazing permits based on predictions made at a scale that does not necessarily take into account local variability. From his perspective, policies that err on the side of caution can make adaptation planning increasingly unpopular if the predictions appear to be inaccurate in the short-term. Some interviewees did acknowledge efforts in their respective regions by outside entities (research institutes, academic institutes, non- profits) to provide climate information in a more usable format. In these cases interviewees explained that the collaborative effort allowed a synthesis of available resources that would otherwise not be possible with limited staff and resources. The general consensus from public lands interviewees was that more specific local scale information could indeed help them to make more informed decisions about adaptation, especially when management actions based on the climate information do not require additional time or money to implement.

4.4. Usefulness of climate related information

We asked both sets of survey respondents to rate the usefulness of five types of climate related information for determining the risks to their area. They were given the option to rate the information as "not useful at all," "not very useful," "fairly useful," "very useful," or "don't know." The five types of information were: information on how to assess the vulnerability of specific areas,

historical climate data, weather and/or seasonal climate forecasts, long-term climate projections and climate projections for the next few years.

The results suggest that information on how to assess the vulnerability of specific areas to climate change is the most useful for federal public lands managers (51.4% rate this type of information as very useful and another 30.9% as fairly useful). On average, all types of climate related information were seen by federal public land managers as being at least fairly useful, with the exception of climate projections for the next few years. For community officials, weather and/or seasonal climate forecasts are reportedly the most useful type of climate related information (42.7% rate this type of information as very useful and another 35.9% as fairly useful). However, just like the federal land managers the community respondents found all types of proffered climate information except for climate projections for the next few years at least fairly useful. Though climate projections for the next few years was seen by both sets of respondents as the least useful type of information, 32.7% of federal public lands managers and 29.8% of community officials still find these projections to be very useful. Both samples appear to be generally interested in weather and climate information, but particularly interested in locally specific projections. This result highlights what Tribbia and Moser consider an "irresolvable time lag between science's ability to generate considerable concern about this global problem and its slower-to-mature ability to deliver credible, reliable, and locally specific information that could inform local action (2008 p 322)(Fig. 8a and b)."

4.5. Uncertainty and decision making

When downscaled to the local level, climate change projections can carry a significant amount of uncertainty (Tribbia and Moser, 2008). Therefore one of the potential responses for questions about barriers to adaptation planning and hurdles to adaptation implementation was uncertainty in available scientific information. Thirty nine percent of federal public lands managers ranked uncertainty in the available information as one of the top three barriers to adaptation planning while 81% of federal land managers report that uncertainty in science is at least a small hurdle to adaptation implementation. Twenty three percent of community officials ranked uncertainty in available information as one of the top three barriers to planning for adaptation and 57% of community respondents report uncertainty in science to be at least a small hurdle to implementation of adaptation plans.

Because the survey results showed uncertainty in available science to be a sizable challenge for federal public lands managers, we asked the interviewees to shed some light on how uncertainty plays a role in their decision making. In general, managers explained that they make decisions under uncertainty all the time, so some degree of uncertainty in the information was not only acceptable but also expected. Some of the interviewees did confirm that scientific uncertainty can be a problem from a management perspective, but none of the interviewees expressed views that climate information needs to be completely free of uncertainty. One interviewee explained that federal public lands are often criticized for acting without the best available information but that not acting is also not an option. In the experience of some managers, even relative confidence in data is typically sufficient to assuage public concern about informed decision making. Others explained that in their experience uncertainty is a bigger concern for the public than it is for the managers making the decisions. Managers expect a degree of uncertainty in the information while the public, especially those who may be affected by changes in management, demand more certainty. Adaptive management was one of the strategies mentioned by interviewees as a tool currently used to combat uncertainty. Under an adaptive management paradigm decisions made without perfect knowledge can be adjusted when better information becomes available. This strategy was seen as particularly effective when dealing with stakeholders demanding certainty that just wasn't available. According to interviewees, uncertainty in available science did not necessarily prevent planning for adaptation, but it made it less of a priority when compared to other more pressing issues. Managers explained that it can be difficult to pull resources away from existing problems and allocate them to a task that requires planning based on considerable uncertainty.

5. Discussion and conclusions

We found that the context of decision making is extremely important for determining the role of information and identifying where opportunities lie for improving the use of information in adaptation. This study revealed several patterns regarding the demand for information across mountain community officials and federal public lands managers operating in the same region and at a similar geographical scale. We discuss these patterns of similarities and differences, and discuss the role of organizational goals, legal environments, types of information used, uncertainty, and funding constraints in supporting possible actions. We then focus on the role of "best available science" for federal agencies. Finally we discuss the opportunities for improving access and dissemination to information through networks and boundary organizations in the region.

Similarities and differences across groups: Both groups of managers consult information regularly and share some overlap in the types of information frequently consulted, specifically land use surveys and climate and weather information. Both groups reported that having the appropriate scale of information was important for moving forward with adaptation planning, although public lands managers preferred regional or multi-state information, while communities preferred local or county level information.

Differences in the information consulted reflect the types of decisions made at the municipal level versus those made to manage public lands–municipalities manage water systems, respond to population growth within their town borders, enhance economic security, and prepare for hazards such as floods because they are responsible for providing basic services to their citizens at the local level. Federal managers of public lands, on the other hand, must manage habitat for species, monitor the effects of resource extraction, grazing and recreation, and track the impact of actions on endangered species.

Both groups reported budget constraints as a top barrier to progress on adaptation, but lack of information at relevant scales was ranked much more frequently as a top barrier by federal lands managers than by mountain community officials. Similarly, uncertainty in information was ranked as a top barrier more frequently by federal lands managers than by community officials. Inadequate information was therefore not seen as nearly as important of a barrier to adaptation action by mountain communities compared to budget constraints or political will, although it was still an important concern. Respondents also listed many barriers that could not be fully addressed by improving the relevancy or flow of information such as lack of political will, funding, lack of specific agency direction, and so on. Interviewees did suggest, however, that more usable information could speed the decision making process.

Uncertainty and decision making: The responses of land managers and mountain communities suggest that while they can use information at a wide range of scales, they do have preferable scales

of information that tend more toward the regional and local. Unfortunately, as has been pointed out by Dessai et al. (2009), downscaled climate models may not be particularly reliable for the foreseeable future and may have a high level of uncertainty. This suggests that a strategy of making decisions that are robust to a wide range of possible futures is of utmost importance (Dessai et al., 2009). However, for the respondents in this study, uncertainty in available information in and of itself does not appear to be a major obstacle to future adaptation planning and implementation. Land managers in particular are used to making decisions under a certain level of uncertainty, but it can become an issue for adaptation planning as it relates to limited resources. Moreover, relatively high uncertainty can mean that adaptation implementation ranks lower than other priorities for managers faced with many competing priorities.

Federal Managers and Requirements for "Best Available Science": The requirement to rely on "best available science" to support decisions is a well-established norm for federal lands managers. Public lands managers clearly distinguished peer-reviewed scientific publications as meeting this standard, while less than 50% considered unpublished research or industry data reports to be best available science. Indeed, peer-review is one of the elements defined by Sullivan et al. (2006) to be a characteristic of "best available science". Interestingly, our results showed positive correlations between use of scientific journals and planning for adaptation, which could suggest that expanding the use of this type of information might increase planning, or alternatively that those already planning are also those who prefer to use scientific journals as a source for information.

We observed mixed perceptions across federal agencies on whether or not lack of information at relevant scales was actually preventing adaptation planning. Federal agency decision context may partially explain this result. The U.S. Fish and Wildlife Service, for example, has special responsibilities in the area of wilderness and the protection of species that are threatened with extinction. In this role, the FWS is heavily involved in rule-making and policy as required by the Endangered Species Act, which requires the use of "best available science" to support decision making – although what constitutes best available science is not defined by the original law and is often a source of disagreement (Sullivan et al., 2006). This may partially explain why the FWS respondents stated by more than two to one that lack of information at relevant scales prevents adaptation planning – information may serve a critical role in their overall ability to perform their mission. Despite these perceptions, FWS respondents reported the highest levels of overall implementation of adaptation plans as compared with its sister land management agencies (Archie et al., 2012). In contrast to the FWS, the USFS strongly reported, by more than two to one, that lack of information at the relevant scale did not serve as a barrier to adaptation. Further research would be necessary at the detailed agency level to tease apart the underlying reasons for these results.

Sources and access to information across groups: Although peer-reviewed information was clearly identified as the top source of best available science, we also found that less than half of land managers and community officials consulted peer-reviewed journals on a regular basis. We did not ask specifically in our survey why this might be the case, but we might speculate that in many cases, peer-reviewed science may simply not exist for their particular management question in their particular area. Moreover, this type of science is likely both difficult to access and difficult to understand in relation to the practical needs of both groups. Many peer-reviewed publications still require either a journal subscription or academic membership in order to access full-text documents. Tribbia and Moser (2008) also suggest that other priorities prevent decision makers from spending time searching for relevant scientific sources regardless of their usefulness. Federal public lands interviewees in this study repeatedly cited a lack of time to search for and interpret this type of science and reportedly deferred instead to materials and reports provided by national and regional offices. Because scientists working for federal public lands agencies reportedly use peer-reviewed science at higher rates than other federal public lands respondents it may be that these scientists also synthesize this material and provide it to other managers in various other formats such as presentations or reports. Thus, it is possible that indirect use of peer-reviewed information is more common for federal public lands managers than these results show.

Opportunities for dissemination and regional networks: Our results suggest that in this region, informal (and even formal) networks may play an important role in the dissemination of information, especially given the reported lack of use of peer-reviewed publications. Both federal public lands managers and community officials regularly use colleagues and the internet as common sources for information. The high level of collaboration among these groups suggests that education of even a small number of decision makers in both these sectors could facilitate more abundant transfer of knowledge about adaptation. Prior work has highlighted the importance of knowledge networks in creating useful information (Feldman and Ingram, 2009; Romsdahl, 2011). These networks involve an iterative conveyance of information across organizational boundaries particularly between scientists and decision makers. Knowledge networks might be a powerful model for dissemination of information on adaptation in this region as mountain communities are particularly influenced by both decisions on nearby federal public lands and those in surrounding mountain communities, suggesting ongoing awareness and likely exchange among the different groups (Archie, 2013).

Increasing the use of networks may work to counteract the lack of time and resources to access and synthesize existing information. We heard from our interviewees that collaborative efforts in the region within established networks or between practitioners and external organizations are helpful in synthesizing and facilitating the more efficient use of available information and this could better direct future research. In a 2008 study of climate change adaptation planning, Tribbia and Moser found that along with additional information, coastal managers in California could benefit from learning opportunities and assistance from outside entities acting as intermediaries between science providers and practitioners. Our study of federal public land managers and community officials shows that they likely do already, or could in the future, benefit from boundary organizations that straddle the policy and science divide and help to mediate the flow of information (Agrawala et al., 2001; McNie, 2007; Tribbia and Moser, 2008). A number of boundary organizations already exist in this region (e.g. the Western Water Assessment, the Western Regional Climate Center, High Plains Regional Climate Center, the Department of Interior Climate Science Centers, land grant universities), and previous work has suggested a number of additional players who could fill this role and a variety of methods that they could employ to do so (McNie, 2007). Several studies that have evaluated experimental efforts at providing usable science in a university setting suggest that effective organizations need to meet the specific needs of individual stakeholders using an ongoing process of negotiation and that their activities should be periodically assessed by an outside entity (e.g. McNie, 2013; Parker and Crona, 2012). It is important to note that success in bridging this divide typically requires the process of generating usable science to be "owned" by an organization or individual (Dilling and Lemos, 2011).

Networks can also facilitate collaboration through organizing trainings, webinars and collaboration opportunities. One

interviewee in our study mentioned that additional training on climate change would be necessary if adaptation planning is to gain momentum. Existing pilots may serve as a useful guide – for example, a partnership between USFS and NPS units in the Pacific Northwest successfully demonstrated effective interagency science-management collaboration for climate change adaptation (Halofsky et al., 2011). Using vulnerability assessments, manager workshops and other tools, managers from Olympic National Forest and Olympic National Park were able to work together to come up with concrete ways to adapt to climate change on the Olympic Peninsula (Ibid. 2011). A similar science-management collaboration on the Tahoe National Forest in California produced concrete adaptation strategies (Littell et al., 2012). Expanding the learning opportunities for adaptation through these types of activities and partnerships could increase overall understanding of opportunities in this area.

The regional networks discussed above have also been proposed by national level working groups. A report from the National Climate Adaptation Summit Committee (NCASC, 2010) identified "initiating a regional series of ongoing climate adaptation forums" as one of the seven priorities for short-term adaptation action, and the 2010 progress report from the ICCATF identified development of regional climate change adaptation consortia as one of the immediate ways to coordinate federal capabilities in support of adaptation (ICCATF, 2010). The most recent report from the ICCATF highlights work being done to fill in the gaps in adaptation information and exploit regional opportunities for collaboration (ICCATF, 2011). In addition to these efforts, prior work has suggested that internal state or federal level reports, conferences and meetings are areas where opportunities exist for showcasing relevant research (Tribbia and Moser, 2008). Our results certainly support these findings and suggest that increased attention to the use of established information networks both within communities and agencies and across those boundaries could vastly improve the dissemination of science in support of adaptation.

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Appendix 1

From your perspective, what are the most important factors preventing you from planning for adaptation to climate change? (Please rank your top three choices with 1 being the most important)

Whether or not your office has already taken action to prepare for the possible impacts of climate change, how much of a hurdle do you perceive the following issues to be in planning for climate change? (Please check one box per possible reason)

	1	2	3
Budget constraints			
Conflicting mandates*			
Lack of information at relevant scales			
Lack of specific agency direction*			
Lack of useful information			
Not a high priority in my office			
Personnel constraints			
Stakeholder conflicts			
Uncertainty in available information			
Lack of locally specific information**			
Political will**			
Lack of leadership**			
Other (please specify)_____			

*Answer available for only PL respondents, **Answer available for only municipal respondents.

	Big hurdle	Small hurdle	Not a hurdle
Lack of public awareness or demand to take action			
Insufficient staff time to get informed about issue, gather relevant information			
Available science is at the wrong scale			
Lack of perceived importance to public			
Science is difficult to understand			
Insufficient staff resources to analyze and assess relevant information			
Legal pressures to maintain status quo			
Not a high priority in my office			
Lack of social acceptability of strategies that take global warming into account			
Lack of perceived solution options			
Science is too uncertain			
Budget constraints			
No legal mandate to take global warming impacts into account			
Currently pressing issues are all-consuming			
Opposition from stakeholder groups			
Lack of "best available science"			
Other (please specify)			

In order for you to carry out your daily job responsibilities, what data and information (yours or others) do you consult regularly? (Please check all that apply).

- ○ Vegetation Inventory
- ○ Land Use Plans and Surveys
- ○ Water Supply/Quality Data or Models
- ○ Human Population Information
- ○ Erosion Rates or Studies
- ○ Species Population Information
- ○ Wildlife Information**
- ○ Soil and or Geological Maps
- ○ Use of Recreational Areas
- ○ Air Quality Data or Models
- ○ Socioeconomic Information
- ○ Educational/Outreach Materials
- ○ Climate and Weather Information (e.g. Temperatures, Rainfall, Wind, Storm Frequency)
- ○ Habitat Maps or Studies
- ○ Endangered Species Maps or Studies
- ○ Fire (Forecasts, Historical Trends etc.)

- ○ Visitor Information
- ○ Flood Risk Maps and/or Flood Frequency Information

** answer available for only municipal respondents

What sources do you typically consult to obtain the data and information you need for your work?

Please rate the usefulness of the following types of information (whether or not you currently use them) for determining the risks to your community/county from climate change:

Source	All the time	Frequently	Occasionally	Rarely	Do not use in my work
Private consultants[a]					
Scientific journals					
Professional journals					
Colleagues in house					
Professional listserves					
Staff at state agency					
Federal agency reports					
Professional conferences or meetings					
Colleagues in another community (with similar job responsibilities)					
Experts at local/state research institution(s)					
Internet (websites not including those used to access items listed above)					
Other (please specify)					

[a] Answer available for only municipal respondents.

- ○ Regional/MultiState
- ○ National
- ○ State Level

Type of info	Not at all useful	Not very useful	Fairly useful	Very useful	Don't know
Weather and/or seasonal climate forecasts					
Climate projections for the next few years					
Information on how to assess the vulnerability of specific areas					
Historical climate data					
Longterm climate projections					

At what scale is information most useful to you in planning for adaptation to climate change?

- ○ Local/County Level
- ○ Management Area Specific

Does a lack of information at the scale you specified in question #17 prevent you from planning for adaptation to climate change?

- ○ Yes
- ○ No
- ○ Don't know

Some agencies have a requirement for management decisions to be made using "Best Available Science." In what format should information be available to be considered "Best Available Science"? (please check all that apply).

* asked to PL respondents only

- ○ Peer-reviewed Scientific Publications
- ○ Unpublished Agency Research
- ○ Agency Publications
- ○ Industry Data/Reports
- ○ Other (please specify)

Which Federal land agency do you currently work for? (choose all that apply)

* asked to PL respondents only

- ☐ BLM
- ☐ US Forest Service
- ☐ National Park Service
- ☐ US Fish and Wildlife Service
- ☐ Other (please specify)

Which of the following best describes the position you fill in your agency?

*asked to PL respondents only

- ☐ Planner
- ☐ Field Practitioner/Technician
- ☐ Executive/Director
- ☐ Park/Forest Ranger
- ☐ Office Support
- ☐ Forest Supervisor
- ☐ Wildlife Manager
- ☐ Engineer
- ☐ Water Resources Manager
- ☐ Environmental Specialist
- ☐ Field Manager
- ☐ Staff Scientist
- ☐ Public Outreach/Education
- ☐ Recreation Planner/Technician/Specialist
- ☐ Other (please specify)

Which of the following best describes the department in which you work?

** asked to municipal respondents only

- ○ Town Council
- ○ Parks and Recreation
- ○ Planning
- ○ Economic Development
- ○ Public Outreach/Education
- ○ Community Development
- ○ Water
- ○ Wildlife
- ○ Tourism
- ○ Government
- ○ Housing
- ○ Public Works/Transportation
- ○ Other (please specify)

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