Climate Risk Management 9 (2015) 41–49

Contents lists available at ScienceDirect

Climate Risk Management

journal homepage: www.elsevier.com/locate/crm

Overcoming barriers during the co-production of climate information for decision-making

Laura Briley [a], Daniel Brown [a], Scott E. Kalafatis [b,*]

[a] University of Michigan Climate Center, Great Lakes Integrated Sciences + Assessments, Ann Arbor, MI, United States
[b] University of Michigan, School of Natural Resources and Environment, Great Lakes Integrated Sciences + Assessments, Ann Arbor, MI, United States

ARTICLE INFO

Article history:
Available online 5 May 2015

Keywords:
Climate change adaptation
Boundary organization
Information usability
Decision support

ABSTRACT

The Great Lakes Integrated Sciences and Assessments program (GLISA) has led the co-development of usable climate information for decision-making in several case study projects. Although each case study is with a unique partnering organization made up of different stakeholders with varying information needs and capabilities, several patterns have emerged that GLISA has identified and overcome to advance the practice of applied climate information. There are three main barriers that GLISA encounters at the onset of many of the case studies: (1) mismatched terminology used by scientists and stakeholders to describe the types of information that are available and needed for problem solving (translation); (2) unrealistic expectations regarding the development of climate information products for problem solving; and (3) disordered integration of when stakeholders want to bring climate information into decision-making processes. Although some or all of these barriers are likely to exist at the onset of any new climate information partnership, GLISA has developed methods for overcoming them more quickly so that the process of co-developing usable climate information is more efficient and effective. In this paper we describe in detail GLISA's experiences that have led to the realization of these barriers and the steps GLISA has taken to overcome them. We also relate these barriers to literature on the "usability gap" between climate science and information use in decision-making as well as uncertainty cascades in climate change adaptation. These experiences demonstrate that climate scientists performing outreach experience similar struggles as the stakeholders they interact with. However, they also reveal the potential for climate-centered boundary organizations to cultivate their own capacities to overcome these challenges in their partnerships.

Introduction

Decision makers from a wide variety of professional backgrounds increasingly find that their work intersects with the subject of climate change. The level of scientific expertise required to work on complex climate change adaptation problems is quite high, and most decision makers – such as city planners, resource managers, health officials, and farmers – do not have any background with climate science. When tasked with integrating climate information into their planning processes, decision makers face two main challenges: (1) they find it difficult to know what climate information and data are best

* Corresponding author.
E-mail address: scottkal@umich.edu (S.E. Kalafatis).

http://dx.doi.org/10.1016/j.crm.2015.04.004
2212-0963/

suited for a particular problem (Tillmann and Siemann, 2012; Barsugli et al., 2013) and (2) they often perceive that climate information and data coming out of the scientific community is not usable in decisions (Lemos and Rood, 2010).

One approach for decision-makers to overcome these challenges is to form direct partnerships with climate scientists to co-produce usable information for decision-making (Lemos and Morehouse, 2005; Dilling and Lemos, 2011). Collaboration between decision makers and climate scientists offers an opportunity to leverage expertise from both parties to better serve problem solving. Highly iterative interactions between decision makers and scientists contribute to greater societal outcomes (Lemos and Morehouse, 2005). However, this type of relationship requires a large investment of time, and the number of decision makers working on climate problems is much greater than the number of available partnering climate scientists (Bidwell et al., 2012).

We argue an equally valid approach to climate change problem solving is the use of boundary organizations to facilitate and extend decision maker-scientist partnerships. Boundary organizations assist interactions (Kirchhoff et al., 2013) and bridge and broker knowledge (Lemos et al., 2014) between science producers and users (decision makers). The Great Lakes Integrated Sciences and Assessments Program (GLISA) is a boundary organization specializing in producing and providing climate information for decision-making in the Great Lakes region. The types of decisions most stakeholders working with GLISA face relate to climate variability and change over the next few decades. The data sources on which climate information is generally built are from historical weather station-based observations (from the past 50 to 100 years depending on the quality of data available) and derivatives of that data as well as model-based projections of future climate conditions. The actual information stakeholders find usable in their problems is a product of working through each of the barriers and is discussed in further detail in their respective sections, but typically some form of synthesis and narrative is required.

To meet these needs, GLISA employs three faculty members and three research associates trained as climate scientists who do direct outreach with other boundary organizations and their stakeholders to support efforts to use climate science in decision-making. When GLISA was formed in 2010 it took on a boundary organization strategy in order to build on the capacities that already existed in the region, enhance the number and diversity of stakeholders (decision makers) GLISA could work with, and reduce the cost of outreach (Lemos et al., 2014; Bidwell et al., 2012).

This paper offers GLISA's climate scientists' reflections on their experiences partnering with other boundary organizations and their stakeholders. The first goal of this paper is to identify barriers that GLISA has encountered while working with other boundary organizations to co-develop usable climate information for decision-making. We position each of these barriers in relation to the existing literature on the "usability gap" between the production of climate science and its application in decision-making (Lemos et al., 2012). What this glimpse reveals is the extent to which information providers experience challenges similar to those stakeholders face. The barriers are (1) mismatched terminology used by scientists and stakeholders to describe the types of information that are available and needed for problem solving (translation); (2) unrealistic expectations that stakeholders have regarding the development of climate information products for their problems (interplay); and (3) disordered integration of when stakeholders want to bring climate information into decision-making processes—stakeholders often assume climate information will reveal their vulnerabilities, but it is more effective to localize climate information around existing known vulnerabilities (information fit). The second goal is to bring attention to these barriers and what GLISA is doing to overcome them so that future boundary organization partnerships can be more effective and efficient in their co-production of climate information.

The next section provides necessary background about research on climate information usability and climate change adaptation. It is followed by another background section that introduces GLISA's approach to addressing these challenges. These two sections provide perspective for the fourth section that describes the barriers of mismatched terms, unrealistic expectations and disordered integration in more detail. We present two case studies in the fifth section in order to show the emergence of these barriers in context and discuss how GLISA has learned to overcome them more quickly over time. Lastly, we conclude with a summary of strategies for overcoming the barriers.

The usability gap, uncertainty, and climate adaptation

Despite extensive work to further develop climate science, the challenge of moving from the production of information to its use in actual decision-making persists (Bierbaum et al., 2013). This gap has been referred to as a matter of a mismatch between supply and demand (Sarewitz and Pielke, 2007; McNie, 2007), as reliant on the cultivation of certain information characteristics such as salience, credibility and legitimacy (Cash et al., 2006), and as a challenge of using uncertain science that has also become highly politicized (Meyer, 2011; Mearns, 2010).

In an effort to explain the process of moving information towards being usable in stakeholder's decisions, Lemos et al. (2012) developed a model of the process of transitioning information from the production of "useful" information to the realization of "usable" information. This model built off of previous work (Lemos and Rood, 2010) that defined the distinction between these two states as information's potential functionality and desirability for a wide variety of uses (useful) versus being well-suited to a particular application (usable). In an extensive review, Lemos et al. (2012) identified three major factors underlying the usability of information: perception of fit, interplay and interactions. Limitations in any one of these factors represent well-established barriers to the use of information (Lemos et al., 2012).

Information fit encompasses a number of different information characteristics identified in the literature that make people perceive that information adequately applies to a needed purpose. Not surprisingly, people are more likely to use information when they believe that it actually matches their current decision-making needs (Lowrey et al., 2009; Pagano et al., 2002; Changnon and Kunkel, 1999). One important factor underlying this matching is the extent to which information is available at the right place at the right time (Lemos and Morehouse, 2005; Orlove et al., 2004; Stern and Easterling, 1999). Other important factors behind fit are the perception of information accuracy (Pagano et al., 2002; Changnon and Kunkel, 1999) and its credibility (Rice et al., 2009; Yarnal et al., 2006; Pulwarty and Redmond, 1997). The process of translating information between producer and stakeholder communities is an important means of enhancing fit (Lemos et al., 2012), especially when it comes to overcoming the use of discipline or sector-specific jargon (e.g., Clark et al., 2011; Tribbia and Moser, 2008; Cash et al., 2003).

Issues around interplay focus attention on factors within the context of usage itself. When new knowledge is introduced, conflicts can arise with existing knowledge (Rayner et al., 2005; Snover et al., 2003). Contextual politics, organizational culture, and institutions play a significant role in mediating these conflicts and determining their outcome (Meinke et al., 2008; Morss et al., 2005; Patt and Gwata, 2002). So do a number of existing stakeholder capacities such as the presence of relevant expertise (Pagano et al., 2001; Callahan et al., 1999), previous positive experiences with innovation (Lemos, 2008), flexibility in decision-making (Beller-Simms, 2008), and knowledge-seeking efforts and incentives (Engle, 2010).

Interactions between scientists and stakeholders around the production of climate information help overcome critical gaps in perception that block the use of climate science. They build trust in the science provided (Hedger et al., 2006; Carbone and Dow, 2005; Rayner et al., 2005), and increase the perception that information is credible and relevant in a particular context (Cash et al., 2006). Over time, interactions can produce a deeper level of understanding between scientists and stakeholders which increases awareness of context, needs, and limitations (Lemos and Morehouse, 2005; Pagano et al., 2002). On the stakeholder side, this understanding includes what climate science can and cannot offer (Changnon, 2004; Cobon et al., 2008), which can facilitate discussion about aligning decisions with informational capabilities.

Diagnosing uncertainties about both the science and the system being managed is a key aspect of developing tailored, context-appropriate information (Brugnach et al., 2008). Brugnach et al. (2008) have conceptualized uncertainty from a relational perspective, defining it as a situation in which actors do not possess a single and complete understanding of the system being managed (see also van den Hoek et al., 2014). Uncertainty in this formulation is the effect of epistemic conditions (the potentially resolvable imperfection of current knowledge), ontological conditions (the unresolvable inherent variability of the system), and ambiguity (the existence of multiple underlying interpretations of the system) (Brugnach et al., 2008). Many have argued that efforts to assess the impacts of climate change and adapt face an "uncertainty cascade" (e.g., Schneider, 1983; Jones, 2000; Wilby and Dessai, 2010). Uncertainties underlying global and more localized models of physical climate change along with uncertainties surrounding both natural and human responses propagate quickly as more and more factors are considered (Wilby and Dessai, 2010). Epistemic, ontological, and ambiguity forms of uncertainty become intertwined within this kind of uncertainty cascade (van den Hoek et al., 2014).

Dessai and others have emphasized an important policy implication of the uncertainty cascade: adaptation should not be delayed or restrained by the desire for an elusive, "optimal" level of prediction accuracy (Dessai et al., 2005; Wilby and Dessai, 2010; Lemos and Rood, 2010). Rather than strive for "predict and provide" science accompanied by a strictly "evidence-based" approach to policy (Dessai et al., 2005), much more may be accomplished if attention is paid to how adaptation can broadly address sources of current and potential future stress (Wilby and Dessai, 2010; Lemos and Rood, 2010). This does not mean, however, that climate projections do not have a role in adaptation work (Millner, 2012). Sustained engagements between scientists and policymakers can produce a shared understanding of differing perspectives on uncertainty that can help accurately and productively fold projections into policy (Lemos and Rood, 2010; Dilling and Lemos, 2011).

GLISA's approach

Direct, iterative relationships between science and decision-making stakeholder communities remain a key ingredient for the development of effective policies for addressing climate-related problems (Lemos and Morehouse, 2005), and boundary organizations like GLISA can scale up the development of usable climate information. GLISA believes that partnerships between boundary organizations can further enhance the impact of available resources through networks of climate information users and stakeholders (Bidwell et al., 2012; Lemos et al., 2014). Larger networks can enhance the potential for usable information to reach stakeholders without requiring the high up-front cost of iterative one-on-one relationships with everyone in the network. Lemos et al. (2014, see also Kirchhoff et al., 2015b) describe three basic structures for these relationships to take (i.e., traditional, key chain, linked chain, and networked chain arrangement). GLISA has the most experience using the key chain approach to bridge the climate science community with other boundary organizations that serve stakeholders interested in using climate information. In the key-chain approach, GLISA pursues partnerships with several boundary organizations at the same time that have the experience and expertise to help GLISA meet the decision-making needs of a variety of stakeholders (Lemos et al., 2014). By leveraging these partnerships concurrently, GLISA has been able to enhance the diversity of its outreach while also being able to identify distinctions between stakeholder communities as well as productive parallels between them (Lemos et al., 2014).[1]

[1] For more information about the experience of being a partnering boundary organization in these processes and how these experiences build their capacities see Kirchhoff et al. (2015a), Bode and Beyea (this issue), and Kalafatis et al. (2015).

Barriers to the co-production of climate information

Although each partnership is unique, GLISA has observed common barriers that emerge particularly at the onset of the relationship. These barriers slow the process of identifying and addressing specific climate information needs. Through recognizing barriers and establishing methods for overcoming them in the engagement process, the partnership becomes more efficient and less costly.

Barrier 1: mismatched terminology: translation

The first barrier that is frequently encountered is a mismatch in terminology used to describe the kinds of information available. The terms stakeholders refer to have different implications than expected from the scientific perspective. A form of translation is required in many partnerships to bridge the terminology divide between different definitions for the same term used by scientists and stakeholders. Early on this divide was a consistent challenge, but GLISA has gained a clearer perspective of the terminology used and implied definitions among partners after several repetitions.

One of the most common phrases requiring translation is a request for "downscaled climate projections." By the typical climate scientist's definition, downscaled climate projections are the output from numerical climate models that have either been dynamically simulated at very high spatial resolution or statistically adjusted to provide information at the regional scale. GLISA has found that the phrase "downscaled climate projections" often means something very different to our partners and their stakeholders, or it indicates a misconception of data accessibility and availability (see Section "Barrier #2: mismatched expectations"). In most cases, stakeholders seeking "downscaled climate projections" are actually asking for locally-relevant, narrative climate information about specific climate change impacts.

The process of moving from the scientific definition of "downscaled climate projections" to the types of information stakeholders actually found usable was lengthy and time consuming before GLISA recognized it as a reoccurring barrier with a common outcome. GLISA had to facilitate several iterations of discussions to better understand what stakeholders really meant by "downscaled" and "projections," since those terms were used in place of more descriptive means of communicating information needs. Most stakeholders GLISA encounters equate "downscaled" with high spatial resolution information, likely due to having seen climate data depicted by high-resolution maps. In addition, since most stakeholders are concerned about relatively small geographic regions, they only want locally-relevant information.

"Projections" was the second half of the information request that required translation. Variations in the stakeholder-implied definition of projections included different time frames (past or future), subject matters (physical climate versus climate impacts), and information types (quantitative versus qualitative). Historical information has been sought out in almost all of GLISA's partnerships, and in some cases it has been sufficient for making decisions about the future. The benefit of using historical information is that the data are physically observed and there is significantly less uncertainty than there is with future projections. The repeated importance of historical information led GLISA to develop historical climatologies for multi-county areas (http://glisa.umich.edu/resources/great-lakes-climate-divisions) and point-based locations (http://glisa.umich.edu/resources/great-lakes-climate-stations) within the Great Lakes region.

Regarding the subject matter of projections, many stakeholders want to start discussions around climate parameters and how they might change in the future. Unless a stakeholder knows exactly what parameters and thresholds are of value to their problem, there is a risk of getting stuck in an infinite loop discussing more climate parameters than what is meaningful to the problem. More commonly, stakeholders want to know how projected future climate changes will *impact* their decision. For example, information about lake-levels on the Great Lakes may be more meaningful than information about future precipitation patterns.

Lastly, most of GLISA's partners and stakeholders have realized that quantitative projections are not in a usable or readily accessible format, and they prefer summaries and simple ways to display the data (i.e., maps, plots, tables, etc.). There are only a few instances when raw downscaled climate data are required: (1) a numerical climate impact model (i.e., hydrological or ecological model) is being used and it requires quantitative inputs for climate parameters. (2) A stakeholder's decision relies on a quantitative number or range of values. And (3) the stakeholder is looking to develop quantitative climate change scenarios. Outside of these uses, most stakeholders ultimately need locally-relevant narrative climate information about specific climate change impacts, and it has been one of GLISA's roles to guide them to specifically define the impacts that they are interested in knowing more about.

GLISA's recognition of the different uses of the phrase "downscaled climate projections" has allowed them to more effectively communicate with partners and their stakeholders early on during iterations. By knowing the different meanings implied, GLISA has learned to ask stakeholders to describe their climate question or problem up front to more quickly identify the types of information that they may be interested in pursuing. This has helped GLISA guide project structure and more effectively engage with partners and stakeholders at the onset.

Barrier 2: unrealistic expectations: interplay

The challenge posed by interest in "downscaled projections" also stems from the difficulty of producing the form of information that those requesting it think that they want. Typically, stakeholders or partners requesting "downscaled climate projections'' have been exposed to displays of climate data that include visible local details in a map format for a location outside of their own region. Increasingly, processed and downscaled climate data are being presented in an aesthetically pleasing means through online utilities, on webpages, and in presentations made publicly available. Such displays inspire interest and connection to the information being presented. The stakeholder or partner often expects that (1) there is greater value in the downscaled data because there is more spatial detail, (2) the data are easily accessible and can be used readily without significant processing and analysis, and (3) the approach and display of data they have experienced elsewhere will be appropriate for their problem. These expectations are often untrue. Many downscaled data sets provide high-resolution climate data for the Great Lakes region, but typically unknown to stakeholders, the data are missing important information about the role the Great Lakes play in determining the future climate for the region. After discussing limitations and deficiencies of the data for our region, stakeholders often realign their expectations of the types of information the data can provide. To some extent, these gaps in expectations are simply an issue of interplay, where the perceived demand for information does not match up with climate scientists' existing knowledge and other resources available to produce or make sense of it.

Fortunately, there are other means of localizing data and information that GLISA has relied on to provide stakeholders with valuable information upon which they can act. One of the most widely used products is GLISA's climate division and weather station climatologies (links listed above). These products set the historical context for thinking about how climate has already changed at the most feasible local scale. When information about future climate change is needed for problem solving, downscaled climate data can serve to compliment local knowledge, which is of great value. In the case that downscaled data do not capture important local weather processes (i.e., lake-effects), the data are less reliable and narrative information plays a larger role. GLISA has relied on climate models for information about large-scale changes (i.e., warming wintertime temperatures over the Midwest) for a particular region and then tailored information with local knowledge (i.e., declines in Lake Superior ice cover and suitable ice bridges) to build climate projection narratives for specific locations (see Isle Royale case study, Section ''Isle Royale National Park'').

Barrier 3: disordered integration: information fit

The translation work outlined in 4.1 is not the only barrier that emerges to having climate information ''fit'' the decision-making needs of stakeholders. In general, discerning exactly how existing knowledge might be integrated into their decision-making process requires some direct engagement and negotiation. This is typically not straightforward or simple, because each problem is different. Stakeholders who have not identified local climate parameters or impacts that are important to their problem tend to approach the process assuming climate data will inform their vulnerabilities. In GLISA's experience, presenting information about how climate parameters are projected to change in hopes that it will reveal information about local vulnerabilities is inefficient and does not provide the most applicable information for the problem. There is the risk that existing vulnerabilities could be overlooked, or emphasis on certain parameters could bias the assessment.

As a result, GLISA has made an effort to work with boundary organization partners to pre-emptively engage stakeholders around their specific key climate impacts of concern. Typically, stakeholders or partners have knowledge about the vulnerabilities stakeholders currently face, which is a good starting place for thinking about future vulnerabilities and how climate change may increase or reduce stresses on their systems. In addition, the goals of their project can inform other areas of concern that climate information can be tailored to address. First, the stakeholder must identify the most important components and thresholds in their problem, and then climate information can be localized to their individual needs.

GLISA's approach is similar to the ''bottom-up'' method described by Wilby and Dessai (2010), where climate adaptation is initially founded on past or current vulnerabilities to climate variability and change. Using a ''bottom-up'' method helps constrain the amount of uncertainty inherent to the problem, because there is significantly less uncertainty in observations from the past compared to projections for the future. Determining whether or not stakeholders are prepared to adapt to the climate variability and change already experienced is a necessary step prior to planning for the future, which has much greater uncertainty.

The next section provides two case studies from GLISA's partnerships to give examples of these barriers and how GLISA overcame them.

Case studies

Huron River Watershed Council

The Huron River Watershed Council (HRWC) is a well-established boundary organization in Southeast Michigan that interacts with a comprehensive network of stakeholders focused on watershed management. GLISA has partnered with HRWC since 2011, which has allowed GLISA staff to observe how climate information propagates, echoes, and is translated among boundary organizations that share a common interest. The Huron River Watershed itself occupies area in seven counties, includes sixteen cities and villages, and spans heavily urban, agricultural, and natural forest land cover types. While this scope presents numerous challenges for an organization that focuses on natural resource conservation, it also provides a diverse geography for observing decision-making processes relating to land use policy, environmental concerns, and climate change.

HRWC was among the first boundary organizations in the region to explicitly incorporate climate adaptation into watershed conservation efforts. Following initial efforts to convene stakeholders, HRWC and GLISA built three stakeholder workgroups in three sectors: (1) natural infrastructure, (2) water infrastructure, and (3) in-stream flows. Vulnerabilities to climate change and adaptation opportunities were identified in each workgroup. Each group faced their own specific barriers related to data availability and accessibility, and all three groups faced the fundamental barriers listed above, but in the end, each developed applicable informational resources. We will describe the barriers faced by each of these three workgroups below.

(1) The natural infrastructure workgroup was comprised primarily of ecosystem managers. This workgroup primarily faced barriers in expectations of climate data (barrier 2) and in how to integrate the existing information with what was already known about ecosystems within the watershed (barrier 3). Stakeholders from multiple municipalities initially hoped to see climate data specifically referencing their key locations, but this data does not exist. GLISA and HRWC worked with the participants to describe the spatial scale of climate information available and the inherent uncertainty in applying historical trends and projections to specific species. With this awareness of limitations and data-processing capacity in mind, the participants focused on developing deliverable products useful to the region. Specifically, these products were a suite of fact sheets describing the projected changes in tree species critical to the watershed that made conclusions on the favorability of planting each species.
(2) The water infrastructure workgroup primarily faced disordered integration of climate data (barrier 3), though many stormwater managers participating were aware of the limitations of climate projections. After evaluating historical precipitation changes, the workgroup realized that the precipitation data used in most county and municipal level stormwater management plans, NOAA Bulletin 71, was outdated by more than 30 years. As heavy precipitation events have become more frequent and total precipitation has increased significantly since then, the values most stormwater managers in the region were using to inform decisions were inaccurate. Federal Emergency Management Agency (FEMA) and Michigan Department of Environmental Quality (MDEQ) guidelines relied on these same obsolete values to generate floodplain maps local governments are required to use. Furthermore, FEMA and MDEQ regulations do not allow the consideration of future precipitation changes, which are projected to be significant in much of the region. The workgroup brought these issues to the attention of local and state officials and continues to press for inclusion of precipitation projections in stormwater management plans. Some of the communities engaged with HRWC are also planning to take unilateral steps to adapt to future changes.
(3) The in-stream flows workgroup, comprised primarily of dam operators and stormwater managers, provides an example of how the integration of climate information can inform adaptation planning by identifying that some environmental management factors are not affected by climate change. Previously available scientific information focused on downscaled climate data that led dam operators to anticipate that climate models could accurately forecast high volume flows. In this way, mismatched terminology around climate projections and weather forecasts (barrier 1), unrealistic expectations around the limitations of climate projections (barrier 2), and disordered integration of precipitation and river flow data (barrier 3) without a vulnerability assessment allowed practitioners and decision makers to effectively argue that adaptation efforts should be postponed until better data became available.

After reviewing the observed and projected changes in precipitation, the consensus was that major dams on the Huron River are adequate to withstand probable extreme flows following intense precipitation. Other than a greater frequency of storms leading to more frequent flow management challenges, the available climate information did not reveal new problems for dam operators. The vulnerabilities instead resided in managing rapid flows in real-time. There are seventeen significant dams along the main stem of the Huron River under eleven different jurisdictions. With a few exceptions, there was no communication between dams under different jurisdictions. During periods of intense precipitation and flow, operators worked entirely in reaction to observed flows at their own locations. To help work through the barrier of disordered integration, the HRWC convened a regular meeting of dam operators to discuss operational practices and concerns to alleviate the urgency experienced during high flows. While the primary challenge identified had little dependence on climate change, it was the broad, region-wide discussion of climate and precipitation patterns that revealed the systemic problems could not be solved within the limitations of climate data. Other adaptation actions had to be taken.

By identifying and addressing the common barriers encountered in each of the workgroups, GLISA has learned valuable lessons that it has subsequently applied across other projects. While the traditional approach to education and outreach is often to provide information on climate changes and impacts as completely as possible at the onset of a project, GLISA has found this is often inefficient, as workgroup members need to be reminded of the climate information throughout the engagement process anyway. Instead, it has been better to allow workgroups to identify vulnerabilities to potential impacts first and then directly apply the climate information to address the severity and likelihood of the potential impacts identified.

Isle Royale National Park

In 2012, the National Park Service approached GLISA as a regional climate expert to co-develop climate information for climate change scenario planning at Isle Royale National Park (Fisichelli et al., 2013). Aside from a national effort for the parks to incorporate climate change into their future management plans, Isle Royale faced a specific and urgent concern that immediately required climate change information. The well-known wolf population on Isle Royale was at risk for extirpation. Since the 1940s when three wolves first inhabited the island, the total wolf population has fluctuated in response to several control variables. The only mechanism historically for new wolves to naturally migrate to the island is the formation of an ice bridge between Isle Royale and the mainland during winter. One of the primary wolf population controls on the island is the availability of prey (moose), which is tied to the existence of balsam fir. Isle Royal park administrators and staff recognized the role climate plays in governing the conditions suitable for wolves to thrive or fail, so they sought to better understand those relationships. This pinpointed issue was the entryway for the park to engage in climate change scenario planning where the wolves were one of many components considered.

Prior to GLISA's involvement in the Isle Royale scenario planning process, the project team went down the typical path of wanting downscaled climate data to inform their problem. A mean and standard deviation for specific climate parameters (i.e., temperature and precipitation) were reported for the climate model grid cell encompassing Isle Royale. This simple means of reporting change was not sufficient for understanding the underlying mechanisms for change, which is one reason why the team reached out to GLISA.

The team had unrealistic expectations (barrier 2) about the downscaled climate data, and quickly learned that reporting a number alone was not sufficient. In addition, many of the climate parameters they were interested in were not directly simulated (i.e., lake ice, weather-blocking patterns, and the arctic oscillation). Another unmet expectation was that the downscaled data captured important information about Isle Royale. The particular data set the team was using lacked the necessary information about the Great Lakes and other factors to truly represent the impact of Lake Superior on Isle Royale weather.

Instead, GLISA used observed data and knowledge of local weather processes in combination with large-scale predicted changes in the models to formulate narratives around their climate parameters of interest. Fortunately, downscaled data are not necessary to be able to say, for example, that future lake-ice will continue to decline as winter temperatures rise (especially given that Lake Superior water temperatures have already warmed faster than local air temperatures (Austin and Colman, 2007)), and that there will be fewer opportunities for ice bridges to form. This statement combined with additional local knowledge that wolves require a *suitable* ice bridge for passage, concludes that there is even less projected opportunity for new wolves to migrate to Isle Royale in the future. This finding implies human intervention will be required to sustain a wolf population if no reproducing females exist on the island.

The narrative climate information for Isle Royale was integrated with local climate impacts knowledge (i.e., ecosystem changes cascading down to impacts on the wolves) prior to the formulation of narrative-based scenarios for the park. Since specific climate parameters were prioritized for the park (i.e., lake-ice, snowfall, extreme temperature/precipitation events, etc), there was a manageable number to consider when thinking about the climate impacts that would be most devastating or beneficial to the park. The process of first identifying what was important to the park and then building a knowledge base around those issues prevented this group from encountering barrier 3 (disordered integration).

Conclusion

The number and diversity of potential uses for climate information is growing quickly (Kirchhoff et al., 2013). In order to keep up with this expanding demand, GLISA has pursued flexible partnerships with other boundary organizations that have enhanced its ability to tailor information to the particular needs of groups of stakeholders (Lemos et al., 2014). Over the course of these projects, common themes have emerged regarding barriers that slow down the process of coproducing knowledge that is usable in decisions. The first barrier is mismatched terminology, where terms have different implications for climate scientists as they do for stakeholders. One method for overcoming barrier 1, especially when there is a request for downscaled data, is to generate discussion around what types of information stakeholders want by describing the inputs that are necessary for their problem. The second barrier is when stakeholders have already developed unrealistic expectations about the kinds of information that can be developed. The quickest way to overcome barrier 2 is to have an existing knowledge of the limitations for data and information in the stakeholder's geographic location of interest. Limitations in climate model data leave opportunities for local knowledge to play a larger role in problem solving, which ultimately produces a more tailored information product. The last barrier is disordered integration, or when the order of climate information comes prematurely in the decision making process. Stakeholders often want to rely on climate information to tell them about their vulnerabilities, when in reality stakeholders are already familiar with local problems that could benefit from more detailed climate information for planning. This barrier presents itself early, but can be overcome by having the stakeholder describe a particular concern or describe existing vulnerabilities that they face.

These observations mirror those from studies of barriers that decision makers experience as well. The process of translating information between producer and user communities is an important means of enhancing stakeholders' perception that information is relevant and usable (Lemos et al., 2012). It is also important that new information interplays well with other conditions in the stakeholders' context (Lemos et al., 2012). The struggle GLISA's scientists had with reconciling stakeholders' information expectations with their own existing resources was its own interplay issue. GLISA's efforts to find the right process to discern the specific nature and possible means to address stakeholders' information requirements reflects the need to establish that information "fits" the specific decisions they need to make. GLISA has been able to successfully overcome these barriers through interactions, and the shared understanding that emerges from them (Lemos et al., 2012).

GLISA's climate change adaptation experiences also call attention to the role that scientists who are experienced information brokers play in addressing the uncertainty cascade that underlies adaptation. Van den Hoek et al. (2014) argue that because the various epistemic, ontological, and ambiguity components of existing uncertainty are interrelated in uncertainty cascades, addressing any one aspect can actually address the others tied to it. When GLISA scientists address unrealistic expectations, they are aligning decision makers' understanding of the climate system with their own, thereby reducing the ambiguity caused by a gap between scientists' and decision makers' interpretation of the system. As described above, this intervention often addresses the impact of existing epistemic and ontological uncertainties associated with projections as well because decision makers avoid an overreliance on predictive tools. A similar effect emerges from the GLISA scientists' response to disordered integration. Placing the emphasis on user-generated issues of concern restricts the potential system interpretations and sources of information to only those that are most pertinent to decisions at hand. This intervention again cuts off unnecessary sources of an uncertainty cascade and focuses decision-making attention on what is known and can be done.

This paper has demonstrated that climate scientists performing outreach encounter similar barriers to developing usable information and uncertainty cascades that stakeholders often face. However, this represents at least as much of an opportunity as a constraint. The reflections in this paper show that addressing these barriers can build institutional capacities within boundary organizations. Enhancing these capacities in boundary organizations and their partnerships ultimately may make overcoming these barriers easier for both producers of climate science and the decision makers working with them over time.

Acknowledgements

This research was supported by National Oceanic and Atmospheric Administration's Climate Program Office through Grant NA10OAR4310213 which supports GLISA. The authors would like to thank all of our boundary organization partners and stakeholders that we have worked with over the course of our projects with GLISA. We would also like to thank our fellow Special Issue authors who provided feedback over the course of the development of this paper. Finally, we are grateful for the feedback we have received on this paper from our anonymous reviewers.

References

Austin, J.A., Colman, S.M., 2007. Lake Superior summer water temperatures are increasing more rapidly than regional air temperatures: a positive ice-albedo feedback. Geophys. Res. Lett. 34.
Barsugli, J.J., Guentchev, G., Horton, R.M., Wood, A., Mearns, L.O., Liang, X.-Z., et al, 2013. The practitioner's dilemma: how to assess the credibility of downscaled climate projections. Eos, Trans. Am. Geophys. Union 94, 424–425.
Beller-Simms, N. et al, 2008. Decision-Support Experiments and Evaluations Using Seasonal to Interannual Forecasts and Observational Data: A Focus on Water Resources. United States Climate Change Science Program.
Bidwell, D., Dietz, T., Scavia, D., 2012. Fostering knowledge networks for climate adaptation. Nat. Clim. Change 3, 610–611.
Bierbaum, R., Smith, J.B., Lee, A., Blair, M., Carter, L., Chapin Iii, F.S., Fleming, P., et al, 2013. A Comprehensive review of climate adaptation in the United States: more than before, but less than needed. Mitig. Adapt. Strat. Glob. Change 18, 361–406.
Bode, C.N., Beyea, W. Deliberating toward regional climate adaptation plans: a process comparison of two (very different) Michigan communities. Clim. Risk Manage. (this issue).
Brugnach, M., Dewulf, A., Pahl-Wostl, C., Taillieu, T., 2008. Toward a relational concept of uncertainty: about knowing too little, knowing too differently, and accepting not to know. Ecol. Soc. 13.
Callahan, B., Miles, E., Fluharty, D., 1999. Policy implications of climate forecasts for water resources management in the Pacific Northwest. Policy Sci. 32, 269–293.
Carbone, G.J., Dow, K., 2005. Water resources and drought forecasts in South Carolina. J. Am. Water Resour. Assoc. 41, 145–155.
Cash, D.W., Clark, W.C., Alcock, F., Dickson, N.M., Eckley, N., Guston, D.H., Jäger, J., Mitchell, R.B., 2003. Knowledge systems for sustainable development. PNAS 100, 8086–8091.
Cash, D.W., Borck, J.C., Patt, A.G., 2006. Countering the loading-dock approach to linking science and decision making. Comparative analysis of El Niño/Southern Oscillation (ENSO) Forecasting systems. Sci. Technol. Hum. Val. 31, 465–494.
Clark, W.C., Tomich, T.P., van Noordwijk, M., Guston, G., Catacutan, D., Dickson, N.M., McNie, E., 2011. Boundary work for sustainable development: natural resource management at the Consultative Group on International Agricultural Research (CGIAR). PNAS.
Changnon, S.A., Kunkel, K.E., 1999. Rapidly expanding uses of climate data and information in agriculture and water resources: causes and characteristics of new applications. Bull. Am. Meteorol. Soc. 80, 821–830.
Changnon, S.A., 2004. Changing uses of climate predictions in agriculture: implications for prediction research, providers, and users. Weather Forecast 19, 606–613.
Cobon, D., Bell, K., Park, J., Keogh, D., 2008. Summative evaluation of climate application activities with pastoralists in western Queensland. Rangeland J. 30, 361–374.
Dessai, S., Lu, X., Risbey, J.S., 2005. On the role of climate scenarios for adaptation planning. Global Environ. Change 15, 87–97.
Dilling, L., Lemos, M.C., 2011. Creating usable science: opportunities and constraints for climate knowledge use and their implications for science policy. Global Environ. Change – Hum. Policy Dimensions 21, 680–689.
Engle, N.L., 2010. Adaptation to Extreme Droughts in Arizona, Georgia, and South Carolina: Evaluating Adaptive Capacity and Innovative Planning and Management Approaches for States and Their Community Water Systems (Ph.D. thesis). Univ. of Michigan.
Fisichelli, N., Hoffman C.H., Welling L., Rood R.B., Briley L.J., GLISA, 2013. Using Climate Change Scenarios to Explore Management at Isle Royale National Park. Natural Resource Report NPS/NRSS/CCRP/NRR.
Hedger, M., Connell, R., Bramwell, P., 2006. Bridging the gap: empowering decision-making for adaptation through the UK Climate Impacts Programme. Clim. Policy 6, 201–215.
Jones, R.N., 2000. Managing uncertainty in climate change projections: issues for impact assessment. Clim. Change 45, 403–419.
Kalafatis, S.E., Grace, A., Gibbons, E., 2015. Making climate science accessible in toledo: the linked boundary chain approach. Clim. Risk Manage. 9, 30–40.
Kirchhoff, C.J., Lemos, M.C., Dessai, S., 2013. Actionable knowledge for environmental decision making: broadening the usability of climate science. Annu. Rev. Environ. Resour. 38, 393–414.
Kirchhoff, C.J., Esselman, R., Brown, D., 2015a. Climate science through chains of boundaries. Clim. Risk Manage. 9, 20–29.

Kirchhoff, C.J., Lemos, M.C., Kalafatis S.E., 2015b. Creating synergy with boundary chains: can they improve usability of climate information. Clim. Risk Manage. 9, 77–85.
Lemos, M.C., 2008. What influences innovation adoption by water managers? climate information use in Brazil and the US. J. Am. Water Resour. Assoc. 44, 1388–1396.
Lemos, M.C., Kirchhoff, C.J., Kalafatis, S.E., Scavia, D., Rood, R.B., 2014. Moving climate information off the shelf: boundary chains and the role of RISAs as adaptive organizations. Weather Clim. Soc. 6, 273–285.
Lemos, M.C., Kirchhoff, C.J., Ramprasad, V., 2012. Narrowing the climate information usability gap. Nat. Clim. Change 2, 789–794.
Lemos, M.C., Morehouse, B., 2005. The co-production of science and policy in integrated climate assessments. Global Environ. Change 15, 57–68.
Lemos, M.C., Rood, R., 2010. Climate projections and their impact on policy and practice. WIREs Clim. Change 1, 670–682.
Lowrey, J., Ray, A., Webb, R., 2009. Factors influencing the use of climate information by Colorado municipal water managers. Clim. Res. 40, 103–119.
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.
Mearns, L.O., 2010. The drama of uncertainty. Clim. Change 100, 77–85.
Meinke, H. et al, 2008. Actionable climate knowledge: from analysis to synthesis. Clim. Res. 33, 101–110.
Meyer, R., 2011. The public values failures of climate science in the US. Minerva 49, 47–70.
Millner, A., 2012. Climate prediction for adaptation: who needs what? Clim. Change 110, 143–167.
Morss, R., Wilhelmi, O., Downton, M., Gruntfest, E., 2005. Flood risk, uncertainty and scientific information for decision making: lessons from an interdisciplinary project. Bull. Am. Meteorol. Soc. 86, 1593–1601.
Orlove, B.S., Broad, K., Petty, A.M., 2004. Factors that influence the use of climate forecasts — evidence from the 1997/98 El Niño event in Peru. Bull. Am. Meteorol. Soc. 85, 1735–1743.
Pagano, T.C., Hartmann, H.C., Sorooshian, S., 2002. Factors affecting seasonal forecast use in Arizona water management: a case study of the 1997–98 El Niño. Clim. Res. 21, 259–269.
Pagano, T.C., Hartmann, H.C., Sorooshian, S., 2001. Using climate forecasts for water management. J. Am. Water Resour. Assoc. 37, 1139–1153.
Patt, A., Gwata, C., 2002. Effective seasonal climate forecast applications: examining constraints for subsistence farmers in Zimbabwe. Global Environ. Change 12, 185–195.
Pulwarty, R.S., Redmond, K.T., 1997. Climate and salmon restoration in the Columbia River Basin: the role and usability of seasonal forecasts. Bull. Am. Meteorol. Soc. 78, 381–396.
Rayner, S., Lach, D., Ingram, H., 2005. Weather forecasts are for wimps: why water resource managers do not use climate forecasts. Clim. Change 69, 197–227.
Rice, J.L., Woodhouse, C.A., Lukas, J.L., 2009. Science and decision making: water management and tree-ring data in the western United States. J. Am. Water Resour. Assoc. 45, 1248–1259.
Sarewitz, D., Pielke Jr., R.A., 2007. The neglected heart of science policy: reconciling supply of and demand for science. Environ. Sci. Policy 10, 5–16.
Schneider, S.H., 1983. CO_2, climate and society: a brief overview. In: Chen, R.S., Boulding, E., Schneider, S.H. (Eds.), Social Science Research and Climate Change, Interdisciplinary Appraisal. D. Reidel, Boston, pp. 9–15.
Snover, A.K., Hamlet, A.F., November, D.P.L., 2003. Climate-change scenarios for water planning studies: pilot applications in the Pacific Northwest. Bull. Am. Meteorol. Soc. 84, 1513–1518.
Stern, P., Easterling, W.E., 1999. Making Climate Forecasts Matter. National Academy.
Tillmann, P., Siemann, D., 2012. Advancing Landscape-Scale Conservation. National Wildlife Federation.
Tribbia, J., Moser, S.C., 2008. More than information: what coastal managers need to plan for climate change. Environ. Sci. Policy 11, 315–328.
Van den Hoek, R.E., Brugnach, M., Mulder, J.P.M., Hoekstra, A.Y., 2014. Analysing the cascades of uncertainty in flood defence projects: how "not knowing enough" is related to "knowing differently". Global Environ. Change 24, 373–388.
Wilby, R.L., Dessai, S., 2010. Robust adaptation to climate change. Weather 65, 180–185.
Yarnal, B., Heasley, A.L., O'Connor, R.E., Dow, K., Jocoy, C.L., 2006. The potential use of climate forecasts by community water system managers. Land Use Water Resour. Res. 6, 1–38.