

Moving Climate Information off the Shelf: Boundary Chains and the Role of RISAs as Adaptive Organizations

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ABSTRACT

While research focusing on how boundary organizations influence the use of climate information has expanded substantially in the past few decades, there has been relatively less attention to how these organizations innovate and adapt to different environments and users. This paper investigates how one boundary organization, the Great Lakes Integrated Sciences and Assessments Center (GLISA), has adapted by creating “boundary chains” to diversify its client base while minimizing transaction costs, increasing scientific knowledge usability, and better meeting client climate information needs. In this approach, boundary organizations connect like links in a chain and together these links span the range between the production of knowledge and its use. Three main chain configurations are identified. In the *key chain approach*, GLISA has partnered with other organizations in a number of separate projects simultaneously, diversifying its client base without sacrificing customization. In the *linked chain approach*, GLISA is one of several linked boundary organizations that successively deepen the level of customization to meet particular users’ needs. Finally, by partnering with multiple organizations and stakeholder groups in both configurations, GLISA may be laying the groundwork for enhancing their partners’ own capacity to make climate-related decisions through a *networked chain approach* that facilitates cooperation among organizations and groups. Each of these approaches represents an adaptive strategy that both enhances the efficiency and effectiveness of participating boundary organizations’ work and improves the provision of climate information that meets users’ needs.

1. Introduction

Boundary organizations play an important role in the effort to increase use of scientific knowledge by decision

makers. Defined as organizations that stabilize the science–policy interface while assisting the interaction between science producers and users (Kirchhoff et al. 2013a), boundary organizations not only protect the boundary between science and policy, but also bridge and broker knowledge between scientists and decision makers. While research on boundary organizations’ role in increasing use of climate information has expanded substantially in the past few decades, there has been

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relatively less attention on understanding how boundary organizations themselves innovate and adapt to different environments and users (but see McNie 2008).

This article focuses on the role of one specific kind of boundary organization, the National Oceanic and Atmospheric Administration (NOAA)-funded Regional Integrated Sciences and Assessments (RISA) program. Created in the late 1990s to both produce and broker climate information, the RISA program has been hailed as one of the most successful climate science boundary organizations in the United States (Dilling and Lemos 2011; Feldman and Ingram 2009; McNie 2013; NRC 2010). At present, 11 RISAs serve a diverse range of climate information users (e.g., water managers, farmers, city managers and planners, forest managers, energy producers, public health managers) by supporting better planning for and in response to climate-driven impacts (Anderson et al. 2010; Pulwarty et al. 2009). In practice, this means that RISA research teams simultaneously carry out research relevant to their regions and actively organize users and events to increase the usability of climate information.

As both producers and brokers of climate knowledge, RISAs have faced many challenges, including those related to knowledge salience and legitimacy (Bales et al. 2004; McNie 2013); how knowledge produced by RISAs and others fits and interplays with users' decision-making processes (Corringham et al. 2008; Furman et al. 2011; Lemos et al. 2012); the level of resources available on both sides of the boundary (Kirchhoff 2013; Lemos et al. 2012; McNie et al. 2007); institutional barriers to knowledge production (Lemos and Morehouse 2005); complexity of knowledge production and use across scales (Kirchhoff et al. 2013a); and a lack of understanding and awareness of information availability (Bolson et al. 2013).

To overcome these challenges, RISAs have been innovative in "adapting" their activities and creating different models of knowledge production and user interaction to bridge the science–policy divide. In this process, they have produced customized knowledge for regional users, have bridged and brokered knowledge produced by others, and have translated and tailored climate science to local contexts (Feldman and Ingram 2009; Guido et al. 2013; Hansen 2002; Hartmann et al. 2002; Jacobs et al. 2005; Lemos et al. 2012; McNie 2008, 2013; Pagano et al. 2002; Rice et al. 2009).

In this article we explore a new approach pursued by one RISA program created in 2010, the Great Lakes Integrated Sciences and Assessments Center (GLISA), organized jointly between the University of Michigan and Michigan State University. We call it the *boundary chains* approach. In this model, GLISA has sought to improve usability of climate information and to minimize

transaction costs by connecting a series of boundary organizations like links in a chain. Together, these links span the range between the production of knowledge and its use. Each link of the chain complements the others, both in terms of resources (e.g., technical, human, and financial) and other less tangible capacities (e.g., trust and legitimacy). They build on each other's strengths, share costs, and pool resources while maintaining accountability to each other.

In the following sections, we discuss the boundary chain approach in more detail, using empirical data collected in the context of GLISA's work. Section 2 focuses on the boundary organizations' scholarly literature that informs and supports our analysis (especially that addressing the RISA program). Section 3 reviews the RISA program and briefly describes GLISA and its operating context. Section 4 explores the boundary chain model, focusing on the experience of GLISA. We conclude in section 5 and suggest how these models might evolve in the future.

2. Boundary organizations: Narrowing the gap between science production and use

In the midtwentieth century, philosophers and scholars in the social studies of science struggled to demarcate science from other intellectual activities [e.g., Popper's (1965) "falsifiability criterion" and Merton's (1973) institutionalization of the social norms of science]. Ultimately, these analytical efforts fell short, as they failed to reflect the broader social context and practical ways in which science is routinely parsed from nonscience (Gieryn 1983). In the 1980s, Gieryn (1983, 181–182) argued persuasively that the problem of demarcation was not about defining the characteristics of science; rather, it was about efforts by scientists to set their work apart from nonscientific activities. Gieryn defined these efforts as "boundary work." In addition to distinguishing science from "nonscience," boundary work also established a social boundary for science. It was not long until the boundary idea was extended beyond differentiating science from nonscience to dividing scientific activities from politics or policy. For example, work by Jasanoff (1990) explored how blurring the boundary between scientific advisors and regulatory agencies can lead to productive policy making.

In an idealized model, boundary organizations play two main roles: they bridge across the science–policy divide while protecting each side from potential negative effects, such as the politicization of science or "scientization" of politics (Ehrlich and Ehrlich 1996; Sarewitz 2004). They accomplish these goals not only by acting as an impartial player/broker between science producers

and users and being accountable to both sides but also by allowing each side to maintain their separate identities (Guston 1999; Lynch et al. 2008). In general, boundary organizations have at least three characteristics: 1) they involve information producers, users, and mediators; 2) they create and sustain a legitimate space for interaction and stimulate the creation of products and strategies that encourage dialogue and engagement between scientists and decision makers; and, 3) they reside between the worlds of producer and user with “lines of responsibility and accountability to each” (Guston 1999, p. 93).

Empirical research focusing on boundary organizations related to climate science—especially work centered on RISAs—has shown that interaction across the production–use divide (e.g., participatory dissemination, iterative models of production, and use) critically affects knowledge usability (Bales et al. 2004; Feldman and Ingram 2009; Hansen 2002; Hartmann et al. 2002; Kirchhoff 2013; McNie 2013). For example, interaction between scientists and users increases use and dissemination of forecasts among networks (Roncoli et al. 2009), may encourage scientific outreach (Frank et al. 2012), and builds trust (Lemos and Morehouse 2005), legitimacy (Carbone and Dow 2005; Lemos and Morehouse 2005; Pagano et al. 2002), and capacity for using the information in decision making (Kirchhoff 2013; McNie 2013) while simultaneously enabling the production of information tailored to a user’s needs and operational contexts (Cash et al. 2006). In the context of these interactions, understanding how knowledge fits users’ decision needs (*knowledge fit*) and how it connects (or not) to other kinds of knowledge users already employ (*knowledge interplay*) is important to increasing usability (Lemos et al. 2012). In fact, better understanding of how decision environments shape the usability of scientific knowledge remains a wide gap in this literature (Bolson et al. 2013; Furman et al. 2011; Vogel and O’Brien 2006). Finally, interactions that both facilitate convening, translating, and mediating, as well as collaborative processes increase the salience, legitimacy, and credibility of information (Cash et al. 2006).

Yet, despite the positive role boundary organizations play at producing usable information, they face a number of fundamental challenges, such as the mismatch between the size of the producer and user communities, constraints and disincentives that limit the ability of scientists at universities and research organizations to engage with user communities, and constraints users face to engaging with scientists (Dilling and Lemos 2011). In addition, within a given boundary organization’s “jurisdiction,” the increase in the number of producers and users of climate information may pose an extra burden on climate researchers tasked with providing users with specific products or with evaluating the quality of different sources of

information. First, as the demand for information increases, sustaining or expanding intensive producer–user relationships critical to usability can overwhelm the availability of a limited group of producers/brokers to meet the informational demands of an ever-expanding pool of potential users (Bidwell et al. 2013; Kirchhoff et al. 2013a). Part of the challenge in serving user needs is the inherent difficulty of knowing what constitutes the “right measure” of bridging versus boundary-protecting activity that both preserves boundary stability and increases science’s usability by society (Gieryn 1995; Guston 2001). Second, the tenure and promotion system at many research-focused organizations more often rewards disciplinary-specific basic research over the more interdisciplinary use-inspired basic or applied research produced or brokered by boundary organizations (Dilling and Lemos 2011). Third, these intensive producer–user relationships are not easily sustained by users or producers unless both are willing participants and have the commitment and capacity to do so (Kirchhoff 2013). Overcoming these obstacles requires creativity and leveraging resources that minimize the workload and risks for both organizations and individuals.

3. RISAs as boundary organizations

The RISA program, established by NOAA, facilitates integrated and interdisciplinary, place-based research and assessment (Pulwarty et al. 2009; Simpson 2009). The RISAs are experiments in novel approaches to address the paucity of climate information use in decision making despite the rapid advancement in climate information products and models. Specifically, RISAs have four main goals: 1) advance the understanding of policy, planning, and management contexts; 2) develop regionally relevant knowledge on impacts, vulnerabilities, and response options through interdisciplinary research and participatory processes; 3) innovate products and tools to enhance the use of science in decision making; and 4) test diverse governance structures for managing scientific research (for more information see <http://cpo.noaa.gov/ClimatePrograms/ClimateandSocietalInteractions/RISAProgram.aspx>). RISAs bring together natural, physical, and social scientists to work alongside regional, state, and/or local clients to identify critical issues, decision-making needs, and information gaps, and to ultimately coproduce usable climate information to meet identified needs (Pulwarty et al. 2009).

Empirical research on RISAs as boundary organizations suggests that there are three main reasons why they are relatively successful: 1) they facilitate effective two-way communication and coproduce user-driven knowledge (Bales et al. 2004; Feldman and Ingram 2009; Lemos

and Morehouse 2005; Rice et al. 2009); 2) they produce credible, salient, and legitimate information (Hansen 2002; McNie 2013); and 3) they are stable and long-term (Kirchhoff et al. 2013b; McNie 2013). In particular, RISAs benefit from NOAA's long-term commitment, as each RISA's initial 4–5-yr awards are often extended through periodic competition-based renewals. While there is no guarantee of success (proposals for continuation can be denied or moved to a different home organization), the RISA programs have been remarkably stable for the past 15 years. The longevity of RISAs supports the creation of decision-relevant research programs and the formation and maintenance of dedicated user networks (Anderson et al. 2010; Feldman and Ingram 2009; Pulwarty et al. 2009). In turn, these long-standing client networks help the RISAs identify, develop, and continue to refine information to meet client needs (Anderson et al. 2010; Corringham et al. 2008; Guido et al. 2013; Hansen 2002; McNie 2013) and overcome barriers to information use (Kirchhoff 2013; Rice et al. 2009). But RISAs are also resource intensive and limited in the range of users they can serve, especially considering the potential for a growing demand at the regional level.

GLISA as an adaptive boundary organization

In 2009/10, NOAA launched a competition for two new RISA regions alongside recompeting awards for some of its existing programs. One of the new awards was for GLISA. Drawing on resources based at the University of Michigan and Michigan State University, GLISA serves potential users of climate information in a region that spans eight U.S. states (Minnesota, Wisconsin, Illinois, Indiana, Michigan, Ohio, Pennsylvania, and New York) and the province of Ontario in Canada. GLISA's climate science efforts involve both developing tailored, locally scaled climate science for potential users and engaging in dialogue with them.

From the outset, the GLISA core team (project codirectors and co-principal investigators) actively considered interactive approaches for producing and disseminating information, building upon what could be learned from the experience of other RISAs. Taking advantage of both published empirical research on RISAs and knowledge from the tight network of RISA scientists and stakeholders, GLISA sought to innovate on two fronts. First, it developed an adaptive approach organized around a flexible research program that is committed to solicit, review, and select research proposals through a small grants competition (up to \$50,000, 1-yr duration) held annually. The competition sought proposals from other organizations that involved both creating usable science and bridging/brokering it to

regional users (for more information, see section 4).¹ This approach recognized that research needs and emphases evolve over time in response to both science advancements and changing input from stakeholders.

Second, GLISA chose to add value to existing climate knowledge (e.g., tailoring and customizing) to meet regional stakeholders' needs, rather than developing its own in-house climate research. Accordingly, GLISA's climate science team: 1) identified best practices for the use of climate information in decision making in the Great Lakes region; 2) created an archive of climate projections for the Great Lakes region from multiple sources, organized metadata to facilitate their use by scientists and stakeholders, and created an avenue for their uptake through ongoing interaction with users (e.g., meetings, phone conversations, e-mails, coproduction); and 3) developed a web portal to facilitate the delivery of these resources. Meanwhile, GLISA's social science team assessed stakeholders' contexts and networks and the development and application of climate science in the region. They also initiated a series of comparative assessments for the different stakeholder groups served by GLISA. As a part of this approach, GLISA's online presence includes a compilation of available resources and a collaboration space for project teams (www.glisa.umich.edu). Next, we discuss the work being carried out in the context of these relationships and how they can represent a viable path not only for other RISAs but also for other boundary organizations.

4. Boundary chains: Pooling resources and spreading costs

GLISA's first grant competition in 2011 focused on funding climate-related research projects, requiring each of them to include a stakeholder-driven component to their core activities. In this competition, GLISA funded four small grants in the Great Lakes region, ranging from assessing the impacts of climate change on Great Lakes evaporation and lake levels to a modeling framework for informing the decision makers' response to extreme heat events. GLISA also collaborated in a fifth project funded by the Charles Stewart Mott Foundation to a local non-governmental organization (NGO), the Huron River Watershed Council, to create a stakeholder group around water management challenges in the Huron River watershed. GLISA's portion of the project specifically

¹To the best of our knowledge, the only other RISA that implemented a small grants competition is the Alaska Center for Climate Assessment and Policy, but in that case the competition was focused on in-house applied research projects.

focused on adding climate impacts to the range of problems the water management group targeted. While the results in terms of stakeholders' involvement in the four more traditional scientific projects were mixed (see <http://www.glisa.umich.edu/> for more details), the interaction with the Huron River Watershed Council offered the best promise of close and sustained iteration with stakeholders.

Following GLISA's adaptive management approach, the core team evaluated the effectiveness of the first competition in terms of actively fostering the usability of climate information. Originally, the goal of funding these projects was to leverage GLISA's limited resources to add value to existing climate-related research (by funding a stakeholder-driven component) in the Great Lakes region, rather than developing in-house applied research projects. However, one significant limitation of partnering with ongoing research-driven projects was the relatively limited opportunity it afforded for building long-term iterative relationships between producers and users of scientific knowledge. Such relationships often depend on factors such as trust and ongoing communication between producers and users as well as a willingness of all involved to interact and invest in the coproduction of usable science. The experience with the first competition showed that while the small grants competition succeeded in leveraging GLISA resources to include stakeholders, it fell short from critically increasing knowledge usability, especially when compared with the outcome of the Huron River Watershed Council partnership.

Learning from this experience and after considering different ways to overcome the transaction costs involved in building long-term relationships in the context of limited human, technical, and financial resources, the idea of partnering with other boundary organizations that already have ties to stakeholders emerged as a testable approach. In this model, rather than serving as a central boundary organization for all producers and users of climate information in the Great Lakes region, GLISA supports and partners with other boundary organizations to leverage their long-term relationships with stakeholders. The rationale was that such partnerships would reduce the transaction costs of increasing climate change usability by spreading costs, pooling resources, and fine-tuning roles over time to provide the level of fit and support necessary for meeting stakeholder information needs.

a. Three models of boundary chains

Conceptually, the GLISA experience advances three configurations of boundary chains beyond the more conventional relationship in which boundary organizations directly connect with each information user (Fig. 1). In the

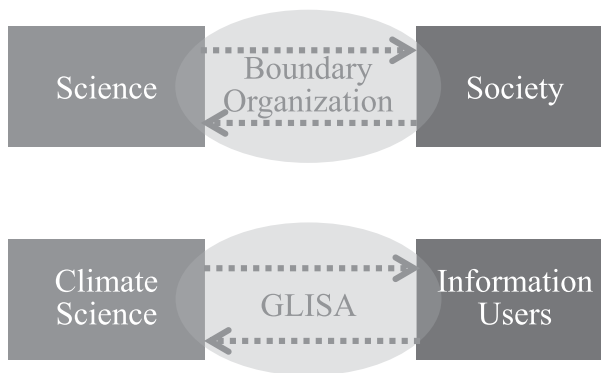


FIG. 1. Traditional boundary organization arrangement.

key chain arrangement (Fig. 2), boundary organizations maximize their limited resources by collaborating with a range of other boundary organizations that increase the potential diversity of users served (e.g., water and forest managers, urban planners). In each of these links, knowledge use can range from building awareness of potential information products to the actual creation of specific products customized for specific users and uses. However, in the context of these relationships, it might be necessary to engage more than one link to efficiently close the gap between producers and users, leading to the second configuration: a *linked chain* arrangement (Fig. 3). In it, some end users may require several steps of customization or filtering through different boundary organizations (links) before information can be applied (e.g., to their decision support tools). In these instances, each link (boundary organization) gets one step closer from the two bookend functions of science production and science use. Ultimately, the links forming each of these individual chains may benefit from interactions with each other, leading to the development of our third configuration, the *networked chain* arrangement (Fig. 4). This arrangement maximizes each boundary organization's potential role as a true bridging organization, connecting the needs of an organization down one chain with the resources of an organization down another chain. Over time, it may even be possible to imagine cultivating such a relationship network as a means of maximizing regional institutional capacity to apply climate information. In all three conceptualizations, the way the links are arranged can add flexibility and reach to boundary organizations, allowing them to become more adaptive to changing conditions (e.g., evolution of information needs, emergence of new information needs, nonlinearity in climate impact and response). In other words, boundary chains offer the potential for a high level of customization of information without sacrificing diversity (of users or their information needs, or of the kinds of interactive approaches used to address those needs).

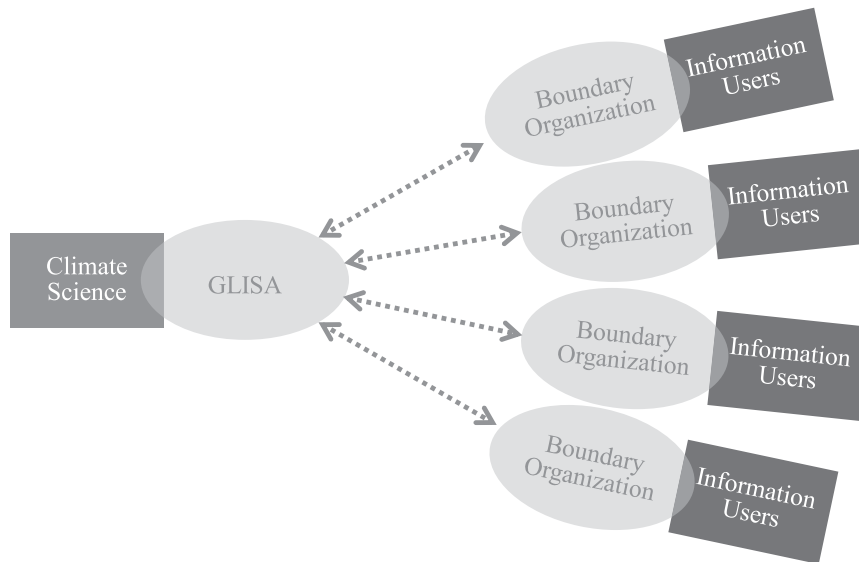


FIG. 2. Key chain arrangement.

In practice, GLISA initiated two boundary chains by building partnerships across two parallel processes. The first is a dedicated small grant competition focusing on building partnerships with boundary organizations already working with stakeholders in areas that intersect with climate change impact. The second is through opportunistic relationships with other boundary organizations that sought GLISA as a partner outside of the formal funding mechanism. In the next three subsections, we discuss the boundary chains' experience and speculate on the potential evolution of the process into a broader network that is more sustainable over time.

b. Broadening the diversity of users: The key chain approach

In 2012, GLISA launched a second grants competition, this time focusing on other organizations that could support and enhance its mission of coproducing climate information and increasing information usability. As a result of that competition, GLISA awarded six 1-yr grants of financial and informational support to organizations that have experience interacting directly with policy and decision makers in the Great Lakes region, in effect creating a key chain of boundary

organizations (Fig. 2). The funded organizations and their projects in this round of competition were 1) Michigan State University Extension (MSU Extension), to provide technical support for master plan development processes in Benton Harbor and Marquette, Michigan; 2) Illinois–Indiana Sea Grant, to support the city of Chicago's efforts to incorporate changes in winter weather events into their ongoing climate adaptation work; 3) the Northwest Michigan Horticulture Research Station (NMHRS), to provide assistance to the local tart cherry industry, which was greatly affected by variable spring weather in 2012; 4) the Toronto and Region Conservation Authority, to support both farmers and those responsible for municipal shoreline management in the Region of Peel, Ontario; 5) the Nature Conservancy, to perform an expert solicitation to better understand the performance of agricultural best management practices (BMP) under climate change; and 6) the Huron River Watershed Council, to continue the work started with the Charles Stewart Mott Foundation funding. Each organization took on the role of brokering knowledge to and/or coproducing knowledge with their stakeholders. A summary of GLISA's boundary organization partnerships is provided in Table 1.



FIG. 3. Linked chain arrangement.

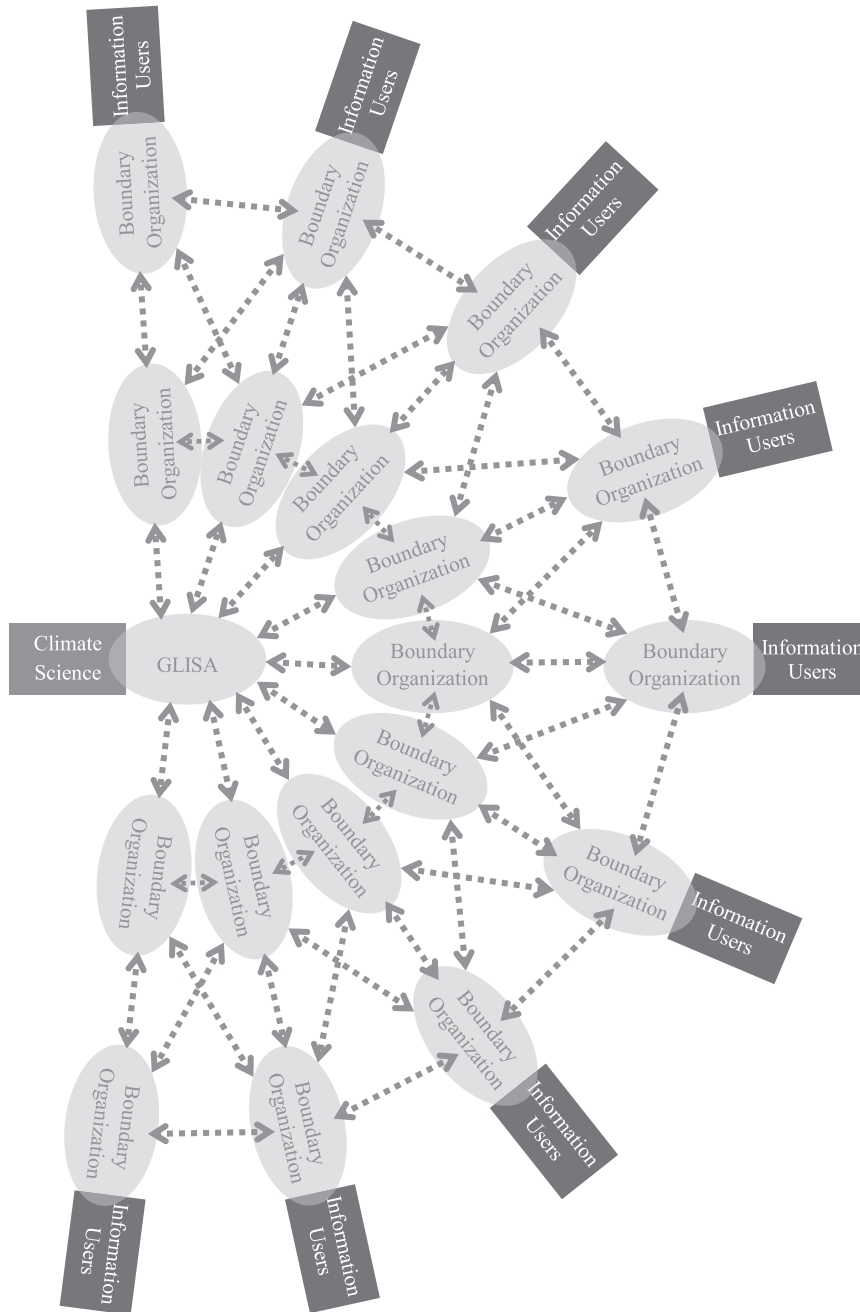


FIG. 4. Networked chain arrangement.

Whereas some of these organizations did not define themselves initially as traditional boundary organizations, by subscribing to the terms of the competition’s request for proposals, they agree to act as de facto boundary organizations in their relationship with GLISA and with the stakeholders with whom they work. Hence, as part of the second competition, awardees committed to participate in a step-by-step evaluation of the interaction between GLISA climate scientists and representatives

at each linked boundary organization as well as between each linked boundary organization and the stakeholders they target. This includes collecting information both before and after interactions with GLISA data, and allowing GLISA social scientists to observe the interactions between GLISA climate scientists, partner organization staff assisting with information brokering, and stakeholders. GLISA social scientists have been following these interactions, tracking the processes of

TABLE 1. Summary of GLISA boundary organization partnerships.

| Boundary organization partner | Project goals | Stakeholders | Bridging events and coproduced outputs |
|---|---|---|--|
| GLAA-C | Bring researchers and practitioners together to support the creation of actionable programs for climate adaptation in cities in the Great Lakes region | Ann Arbor, Dayton, Flint, Kingston, Thunder Bay, and Toledo | Workshops held throughout the region featuring GLISA climatologists; local historical and future climate projections and socioeconomic data (through Headwaters Economics) |
| Huron River Watershed Council | Bring stakeholders in the watershed together to understand how their communities can maintain quality of life under different climate change scenarios and to provide the information needed to make adaptation decisions | Managers of water, in-stream flows, and natural infrastructure in watershed communities | Six monthly meetings, presentations about local historical and future climate, Ann Arbor and southeast Michigan climatologies, and fact sheets and reports for three sector groups (water infrastructure, in-stream flows, and natural infrastructure) |
| Illinois–Indiana Sea Grant | Easily understandable wintertime climate change indicators that Chicago and other cities can use to monitor wintertime impacts and the efficacy of adaptation planning | City of Chicago | Presentation and report to city officials based on interviews and input from GLISA climatologists; freeze–thaw cycle and “wet snow” projections |
| MSU Extension | Assess community vulnerabilities and strengths and prioritize adaptation strategies through a discussion-based, deliberation-with-analysis process | City of Marquette and SWMPC | Public input sessions in both cities with GLISA presentations and reviews, historical trends on Great Lakes ice cover, precipitation, lake levels, and temperature and climate sensitivity maps |
| NPS Climate Change Response Program | Bring together park officials and other experts to develop and explore four divergent but plausible scenarios of future climate and associated ecological responses to support current and future decision making needs | Isle Royale National Park | Presentation and discussions at workshop including GLISA and other experts and park officials, local historical and future climate projections (e.g., climate summary table, least change scenario, matrix of plausible scenarios), and a NPS report about the process |
| NMHRS | Compile information to help the tart cherry industry make choices about risk mitigation and resource appropriation, foster understanding of climate variability and extreme events | Michigan tart cherry farmers | Workshops, panels, and presentations at annual industry Northwest Michigan Orchard and Vineyard Show; relevant local historical and future climate projections (e.g., date of plant “side green”) |
| Nature Conservancy | Assess the implications of climate change for agricultural BMP for conservation, use expert solicitation to recommend changes to existing models that incorporates BMP performance under changing climate | Agriculture and water quality modelers, groups working to minimize the impact of farming on water quality | Final report and recommendations for modeling based upon expert and stakeholder feedback |
| Toronto and Region Conservation Authority | Pilot a method for risk identification and analysis based on future climate ensembles, scope adaptation options for climate change impacts/hazards facing the region | Port Credit and farmers in the Region of Peel | “Keep it Growing in Peel” farmer workshop and two workshops for Port Credit risk identification; presentations, assessments, and risk assessment methodology |

information brokerage comparatively as they evolve in different contexts. This involves, first, carrying out in-depth interviews and surveys with GLISA staff, their boundary organization partners, and the potential users of climate information; and then compiling updates at 3-month intervals throughout the year and at the close

of the funded year to gauge development over time. By acting as a bridge between GLISA climate scientists and their stakeholders, these organizations are also able to maintain accountability across the chain. On the one hand, by adding value to and tailoring climate scientific knowledge in response to their partners’

requests, GLISA scientists are accountable both to other climate scientists and to the partners in the chain. On the other hand, by procuring knowledge and “customizing” it (in terms of communicating and application) to their stakeholders, partner organizations are accountable to their stakeholders while keeping the boundary protected.

Preliminary observations of these projects suggest that linking to other boundary organizations successfully leverages and bolsters GLISA’s services through the diversity of roles and support opportunities that have emerged through these links. Moreover, these initial activities are, at a minimum, fostering awareness of climate impacts and of GLISA’s products among a wider range of stakeholders than possible under the one boundary organization model, as well as improving information usability. The extent to which these activities will continue to foster and deepen climate information use by decision makers is part of an ongoing evaluation. However, even this early in the process, we already can identify two distinct paths in the interaction among GLISA, other boundary organizations, and groups of stakeholders.

In the first path, the interaction between GLISA climate scientists and stakeholders progressed relatively quickly toward a quasi-service model in which tailored information is shared with potential users. For example, MSU Extension worked closely with GLISA to explore adaptation priorities for the city of Marquette in Michigan’s Upper Peninsula and the Southwest Michigan Planning Commission (SWMPC). GLISA provided information requested by SWMPC and Marquette on temperature, precipitation, ice cover, and lake levels. MSU Extension used these data as input for SWMPC and Marquette to perform climate change self-assessments based on Sea Grant’s “A Self-Assessment to Address Climate Change Readiness in Your Community: Midwest Region” (Sea Grant 2012). The data were also used to develop vulnerability maps that the cities are using for communication and planning purposes. In addition to information, community engagement sessions were completed in Marquette and Benton Harbor to obtain feedback from residents about their vulnerability concerns and preferences about adaptation options. MSU Extension and GLISA collaborated closely not only in tailoring climate information for these events, such as developing historical climatologies and future projections to address locally relevant vulnerabilities, but also in designing the structure of the engagement process so that it was sensitive to the interests and experiences of local residents and officials. For example, following challenges with disruptive attendees of an initial public meeting in one location, MSU Extension, GLISA, and local clients adjusted the subsequent event to have a more structured format than

the first. Accordingly, GLISA changed how local climate impacts were presented as well how to frame discussion of future changes more positively, focusing more on observed changes rather than the more controversial projections of future climate. These community engagement sessions provided insights about residents’ interests that informed the next stage of adaptation strategy prioritization.

In a second example, interviews performed by the Illinois–Indiana Sea Grant program with the city of Chicago identified climate information needs that GLISA helped provide, such as the influence of climate change on the frequency and intensity of ice storms and heavy, wet snow events. Such storms can produce widespread power outages. The realization that climate models project that changing temperatures will produce more heavy, wet snow events has already stimulated conversations within the city. For example, city officials have begun discussing contingency plans for community “warming centers” that can provide shelter even when electrical power lines are down.

The second path in the key chain model is exemplified by GLISA’s relationship with the Toronto and Region Conservation Authority and the Nature Conservancy, where GLISA is taking on more of a networking function. In one example, in addition to GLISA providing informational support, the Toronto and Region Conservation Authority is looking at its collaboration with GLISA as an opportunity to link with other information-producing organizations like NOAA’s Great Lakes Environmental Research Laboratory (GLERL). In the future, such connections could come to represent an additional link in the chain of tailoring climate information. Another example is the Nature Conservancy’s leveraging GLISA’s connections to other researchers to identify a pool of regional experts with whom they can engage to better understand and assess the potential impacts of climate change on the performance of agricultural best management practices. Rather than providing information, GLISA is providing connections to its own networks that help to support the Nature Conservancy’s work. GLISA has also helped strengthen its connections with other small grant recipients like MSU Extension and has linked them to a researcher at Wayne State University who can provide methodological support for their expert elicitation effort.

Without a designated control group, it is hard to assess how the role of previous relationships that our partner organizations had with stakeholders might have accelerated the process of building trust and legitimacy in the context of users’ decision environments. However, it is reasonable to expect that had GLISA started these interactions with stakeholders from scratch, the process of

establishing trust and successful lines of communication would have been more costly in terms of time, human, and technical resources.

c. Deepening customization: The linked chain approach

In addition to the small grants project, GLISA engaged in relationships with two other organizations: the National Park Service (NPS) and the Great Lakes Adaptation Assessment for Cities (GLAA-C). For GLISA, these relationships represent the linked chain approach (Fig. 3).

The NPS initiated contact with GLISA, following from the NPS's productive engagement with RISA centers in other regions. Though the project focused narrowly on Isle Royale National Park, the engagement was managed by the NPS's Climate Change Response Program (for more information, see <http://www.nature.nps.gov/climatechange/>). The Climate Change Response Program performs boundary organization functions as it "works to foster communication, provide guidance, scientific information, and recommendations that support stewardship actions to preserve our natural and cultural heritage from the detrimental impacts of global climate change" (for more information see <http://www.nps.gov/orgs/ccrp/index.htm>). NPS's goal for the project was to create an adaptation plan for Isle Royale National Park focused on how climate change influences the decisions that park staff will make in managing the park's wolf-moose predator-prey ecosystem.

The NPS has a scenario-planning process that steers its development of adaptation plans (Weeks et al. 2011). Its initial engagement in this project included a small number of people from the Climate Change Response Program and GLISA (for a detailed description, see <http://glisacclimate.org/project/isle-royale>). Using its significant level of scientific resources, the NPS prepared descriptions of climate change based largely on previously published assessments and datasets (Parry et al. 2007; Solomon et al. 2007; Mitchell and Jones 2005). GLISA was first engaged to review this material and to tailor it to NPS users based on 1) more recent literature, 2) climate parameters of special importance to the park (e.g., lake ice), and 3) local effects on weather and climate. Through many conversations between GLISA climate scientists and NPS personnel, a "complete" climate change table was generated that teased out important climate parameters and included recent literature and local expertise. To this first table, others were added representing different scenarios (for a detailed description of the scenarios including the "least change scenario," see <http://glisacclimate.org/wiki/isle-royale-least-change-climate-scenarios>) that became the foundational material

to a conference that included a complete range of discipline experts and managers, including GLISA personnel. Here, GLISA provided a narrative description of localized climate information, past, present, and future (http://glisacclimate.org/sites/default/files/20130114_Isle_Royale_Climate_Adaptation_Localization.pdf). Using the NPS scenario planning process, climate information was combined with other information, especially forest ecology, to develop a set of plausible scenarios of disruptive events that were then synthesized with management tensions between park priorities. The outcomes of this process were four divergent but plausible scenarios that synthesized ecological response to climate and climate-related factors. Participants in the meeting subsequently subjected each of these scenarios to four management responses.

When the scenarios were compared to initial expectations documented in the initial table of climate drivers and the incremental impact of climate change, two important issues emerged. First, the climate discussion evolved from incremental effects of temperature and precipitation change toward the role of high-variability processes such as the Arctic Oscillation, which is the largest statistical predictor of persistent extreme weather anomalies in the Northern Hemisphere (Carbone and Dow 2005). The focus on variability of extreme weather was indicative of the workshop participants' growing focus on adaptive management. Rather than viewing climate change as a straightforward progression of changes, participants considered the complex interaction of the dynamic climate system with park ecosystems. For participants, the result was a greater understanding of the necessity of developing strategies that accounted for more uncertain future conditions by cultivating greater ecosystem resiliency and planning for adaptive management via 3–5-yr assessments. Second, the focus of the discussion evolved from trying to preserve the past conditions on Isle Royale to how to achieve the best possible future and make sound resource investments for an ecosystem facing inevitable change. For example, because Isle Royale is a fragile transition zone between northern hardwood and boreal forest, some of its most significant inhabitants from an ecosystem perspective will be lost as climate change makes the area uninhabitable for boreal species. Better understanding of these processes is crucial to supporting NPS's planning for the future.

In this example, GLISA is one link in a longer chain formed by the NPS, its Climate Change Response Program, and the Isle Royale Park staff. The NPS and its Climate Change Response Program's facilitation role made interactions with Isle Royale much more efficient. Through repeated interactions, GLISA and NPS's Climate Change Response Program tailored climate information

into a frame that would more easily fit Isle Royale's actual approach of making decisions. In addition, the NPS provided links to other sources of scientific expertise that helped interpret the implications of GLISA's climate projections for NPS staff. In the critical workshop session where all of these links came together, representatives from Isle Royale gave feedback to the representatives of GLISA and the NPS that ultimately resulted in Isle Royal representatives' current information needs being more directly met.

The linked chain approach is also well represented by GLISA's interaction with GLAA-C. GLISA's core involvement is helping GLAA-C respond to cities' requests for narrative descriptions of changes that have taken place in their own climate. GLISA climate scientists developed specific climatology products for the cities based on summaries of local temperature and precipitation observations. The climatologies also include seasonal and annual mean presentations of information as well as basic measures of extremes (for an example of the region's and cities' climatologies, see http://glisa.umich.edu/great_lakes_climate/climatologies.php and http://www.glisa.umich.edu/docs/WindsorON_Climatology.pdf). To support the Great Lakes cities' climate adaptation decisions, GLAA-C formed the Council of Sustainable Cities, composed of six cities in the U.S./Canada Great Lakes Basin. The council and GLAA-C meet every 6 months in person and more often through conference calls, reinforcing a closely interactive relationship. GLAA-C also engaged the participation of Headwaters Economics, an independent, nonprofit research organization, to tailor socioeconomic data to support the cities' adaptation decisions. With these efforts, GLAA-C leverages human and technical resources to bring together different sources of climate adaptation information for the cities (for more details see the project description at <http://graham.umich.edu/glaac/>).

GLAA-C has also organized specialized events (local workshops) in which all the information in support of adaptation (climate and nonclimate based) is discussed by different city officials and sectors projected to be negatively affected by climate change impacts. In these events, participants discuss how GLISA information can be tailored to fit city officials' decision processes (knowledge *fit*) as well as how it may interplay with other information that is important for adaptation (e.g., socioeconomic data, adaptation options) and/or other kinds of knowledge currently being used by city officials (knowledge *interplay*). As brokers of information, GLAA-C personnel organized meetings where different kinds of information were presented and discussed through visually attractive prepared materials that combined climate and nonclimate information (see

<http://graham.umich.edu/glaac/research>), and created an environment for the communication of both scientists' and decision makers' challenges and expectations. While the long-term outcome and sustainability of the chain between GLISA, GLAA-C, other organizations such as Headwaters Economics, and the cities is uncertain, at this point the expectation is that this kind of iteration will accelerate the usability of climate (and nonclimate) information.

d. Developing capacity: The networked chain approach

GLISA's relationship with the NPS and GLAA-C is based on complementary roles that together enhance the fit and interplay of climate information and hence the usability of information to stakeholders' decision processes. The potential to extend usability via retailing information to other similar users in the region offers the promise of further strengthening regional knowledge networks both geographically (GLAA-C) and sectorially (the NPS) through networked chains (see Fig. 4).

The evolution of the GLISA model from a more traditional approach of brokering and bridging information directly to clients to growing diversification and customization through boundary chains suggests the possibility that the links that are created could become sustainable network ties in the future. Consistently providing the opportunity for GLISA boundary organization partners to interact both through required conference calls and annual meetings allows for the exchange of information and experiences. For example, when working on its outreach to farmers, the Toronto and Region Conservation Authority benefited from discussions it had with other GLISA grant recipients from MSU Extension about its own experiences with the agricultural community. In addition, discussions of weather phenomena between GLISA and other boundary organizations in the networked chain have exposed the network of stakeholders to new knowledge and impacts previously not considered. For instance, the Toronto and Region Conservation Authority is now interested in the ice storm and snow descriptions that GLISA initially developed for the Illinois-Indiana Sea Grant program with the city of Chicago. Sustained communication and interaction through a broader network of boundary organizations and stakeholders may not only increase usability among participants but it may also speed up the dissemination of climate information both within the network and potentially to other networks as well. However, exploring the characteristics and drivers of such a network may require a longer maturation time and further investigation of the processes initiated by GLISA.

5. Conclusions

As boundary organizations, RISAs have been notably successful in enhancing the production and use of climate information. However, they also face the challenges of high transaction costs and a limited range when engaging in highly interactive relationships with stakeholders, especially with the potential for increased demand for climate information in the future. Seeking to adapt and innovate and become more responsive to changing conditions and resources, RISAs have been trying different models of interaction to achieve their dual goals of producing/brokering relevant regional climate information and increasing its usability. In this article, we describe GLISA's efforts to share transaction costs and pool resources through a new model of stakeholder engagement, the boundary chains approach. We identify three main types of chains: the key chain approach, through which GLISA partners with a number of different boundary organizations to diversify its client base; the linked chain approach, in which GLISA is one of a number of organizations spanning the range between information production and use, and the networked chain approach, in which partnering organizations from different chains establish supportive relationships with one another. In each of these approaches, the goal is to minimize transaction costs and increase usability by building on each link's strengths to complement and leverage resources and experiences.

GLISA is using the key chain approach to leverage resources and capacities (especially trust and legitimacy) with six other boundary organizations. These boundary organizations have both long-term, established relationships with stakeholders and the ability to broker and bridge climate information produced by GLISA climate scientists (and others) with their stakeholders. Using the linked chain approach, GLISA is providing customized climate information while other organizations help to further tailor the information, drawing on their understanding of stakeholders' decision contexts to help improve information fit and interplay. Through the currently nascent networked chain approach, GLISA is playing a guiding role in cultivating relationships between partnering boundary organizations facing similar challenges. In all of these approaches, GLISA is seeking to increase the range of clients it can serve while preserving its ability to sustain close levels of interaction with each of them. Moreover, by creating links between complementary boundary organizations in a larger network, GLISA expects to strengthen individual links such that the network may be more sustainable in the long run.

The ongoing formation of such networks emphasizes the adaptive quality of "linked" approaches to connecting

climate science with decision making. These approaches foster flexibility in two important ways: first, there is flexibility to add and subtract new contributors to suit changing requirements for each application as they arise and are resolved. Second, as illustrated in the cases described herein, flexibility is also enhanced in the supported organizations, as they have the opportunity to tailor the process itself to suit their emerging and evolving needs.

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