Designing Institutions to Support Local-Level Climate Change Adaptation: Insights from a Case Study of the U.S. Cooperative Extension System

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ABSTRACT

In light of global climate change, adaptation will be necessary at all levels of social organization. However, the adaptation literature emphasizes that because the impacts of climate change and vulnerability are locally specific, adaptation is inevitably local. In this paper, in order to inform the design of institutions that can encourage and support effective local-level adaptation, the authors derive principles for their design theoretically and use a case study to explore how these principles could be practically implemented. Ten design principles are synthesized from principles derived from reviews of the literatures on local-level adaptation, usable science, and boundary organizations. Bringing these three literatures together highlights the characteristics of boundary organizations that make them particularly valuable for addressing the challenges of local-level adaptation. The case study then illustrates how an existing boundary organization, The University of Arizona Cooperative Extension, of the U.S. Cooperative Extension System (CES), implements these principles in its organizational structure and in the daily practice of Extension professionals. It also highlights the significance of the CES's existing social networks and social capital for facilitating their implementation. From the case study it is concluded that the CES is uniquely positioned to serve an important role in a national adaptation strategy for the United States in supporting local-level adaptation in urban and rural communities across the country.

1. Introduction

In light of global climate change, adaptation will be necessary at all levels of social organization. We are beginning to see institutions emerge to address adaptation planning at national, regional, state, and metropolitan levels; however, the adaptation literature emphasizes that because the impacts of climate change and vulnerability are locally specific, adaptation is inevitably local (e.g., Agrawal 2008). By local-level adaptation we mean ''bottom up'' efforts of local governments, local representatives of higher-level government agencies, community organizations, other local groups, households, and individuals to respond to and plan for the impacts of climate variability and change in their locality. These local efforts will be more effective if they have access to knowledge and resources from beyond the local level and are able to coordinate with other localities and with planning and policy processes at higher levels. This paper addresses the question: What types of institutions can encourage and support effective local-level adaptation?

We explore this question both theoretically and empirically. Agrawal (2008) points out that there are large gaps in knowledge about the role of institutions in climate change adaptation. While he focuses on the role of local institutions, we consider the role that broader-scale institutions could play in local-level adaptation. We aim to provoke thinking among researchers, practitioners, policymakers, and others about national-level strategies to encourage and support local-level adaptation that can reach and serve all segments of society. We begin by deriving institutional design principles from the literatures on local-level adaptation, usable science, and boundary organizations and synthesizing them to develop

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TABLE 1. Theoretical design principles for a boundary organization to support local-level climate change adaptation from three literatures.

From the literature on local-level adaptation	From the literature on usable science	From the literature on boundary organizations
LLA1. Support ongoing interaction with community members	US1. Support the coproduction of usable science	BO1. Situated at the boundary between science and society with accountability to both
LLA2. Be trusted by community members	US2. Interdisciplinarity	BO2. Involved in the coproduction of knowledge through the collaborative participation of actors from both sides of the boundary and professionals from the organization who serve a mediating role
LLA3. Have access to a broad range of expertise	US3. Support iterative interaction between knowledge users and producers	BO3. Support the creation and use of boundary objects
LLA4. Have the ability to anticipate future adaptation needs	US4. Have sufficient human, financial, and technical resources to support coproduction	BO4. Bridge multiple boundaries
LLA5. Support ongoing evaluation and adjustment of adaptation strategies	US5. Recognize and reward activities that contribute to coproduction	BO5. Perform boundary-managing functions to bridge the science–society boundary and to ensure the salience, credibility, and legitimacy of coproduced knowledge: convening; communication; translation; mediation
LLA6. Have the flexibility to adjust to changing adaptation needs and challenges	US6. Perform "boundary work" to enhance the salience, credibility, and legitimacy of coproduced knowledge	
LLA7. Be able to span localities and political levels	US7. Evaluate coproduction processes	

a list of theoretical design principles for a boundary organization to support local-level adaptation. By bringing these literatures together, we contribute theoretically to understanding the characteristics of boundary organizations that make them particularly valuable for addressing the challenges of local-level adaptation.

We contribute practical understanding of how these principles could be implemented by means of case study of an existing boundary organization, the U.S. Cooperative Extension System (CES). The case study shows how and the extent to which the CES operationalizes these principles and assesses the potential of the CES to serve as a boundary organization to support local-level adaptation. We argue that its organizational structure and existing social capital are a distinct advantage for addressing four specific challenges of local-level adaptation identified in the literature review: 1) bridging research and local cultures, 2) obtaining knowledge that is relevant to local contexts, 3) providing ongoing monitoring and evaluation, and 4) connecting insights from local efforts to other localities and to planning and implementation processes at higher political levels.

The paper is organized as follows. Section 2 comprises the literature reviews, which are necessarily limited due to spatial constraints and draw on more extensive review already conducted in each field. In sections 2a–c we survey the literatures on local-level adaptation, creating usable science, and boundary organizations respectively and list the design principles derived from each in Table 1. In section 2d we synthesize these principles into design principles for a boundary organization to support local-level adaptation, which are listed in Table 2. Section 3 comprises the case study of the CES. Section 3a describes the methodology used. Section 3b briefly describes the history and organizational structure of the CES in order to show how some of the design principles we have identified were incorporated into its organizational design from its inception. In section 3c we use examples from an organizational ethnography of The University of Arizona Cooperative Extension (UACE) to illustrate how additional design principles are operationalized in the daily practice of UACE faculty. In section 3d we bring the theoretical discussion and the case study together to consider the CES's potential to serve as a boundary organization to support local-level adaptation. The final section summarizes the insights gained from this theoretical and empirical exploration and considers their implications for a national adaptation strategy.

TABLE 2. Synthesized theoretical design principles for a boundary organization to support local-level climate change adaptation. Numbers in square brackets indicate from which principles in Table 1 each was derived.

1. Situated at the boundary between science and society with accountability to both. [BO1]
2. Engage in the coproduction of usable local-level adaptation strategies through the collaborative participation of actors from both sides of the boundary and professionals from the organization who serve a mediating role. [LLA1, US1, BO2, BO3]
3. Develop iterative relationships that build trust and ensure a good fit between knowledge produced and user needs. [LLA1, US1, US3, BO3]
4. Interdisciplinarity. [LLA3, US2, BO4]
5. Perform boundary-managing functions to bridge multiple boundaries and to ensure the salience, credibility, and legitimacy of coproduced knowledge: convening; communication; translation; mediation. [US6, BO4, BO5]
6. Institutional support for coproduction (resources, recognition, reward structure). [LLA2, US4, US5, BO5]
7. Ongoing evaluation and adjustment of adaptation strategies and coproduction processes. [LLA5, US7]
8. Capacity to anticipate future adaptation needs. [LLA4]
9. Flexibility to organize around emerging adaptation needs and opportunities. [LLA6]
10. Ability to share lessons learned across localities and access to planning and implementation processes at higher political levels. [LLA7, BO4]

2. Theoretical design of institutions to support local-level climate change adaptation

In this paper we use the term ''institution'' more informally than the scholarly definition of an institution as a humanly created formal and informal mechanism that shapes social and individual expectations, interactions, and behavior (Agrawal 2008). We include the widespread lay meaning of institutions as organizations established for a specific purpose. Organizations are concrete manifestations of institutions with an identifiable location, personnel, and rule structure.

a. Design principles from the literature on local-level climate change adaptation

We begin our theoretical exploration of the design of institutions to support local-level adaptation with the literature on local-level adaptation because it provides lessons learned and challenges encountered across actual experiences working with local communities to develop adaptation strategies relevant to local conditions and capacities. We consider reviews of the substantial literature on ''community-based adaptation,'' which is based on experience working with poor communities in developing countries (e.g., Huq and Reid 2007; Reid et al. 2009; van Aalst et al. 2008), as well as papers based on experience with participatory assessment processes in developed countries (e.g., Moser and Ekstrom 2011) and more general syntheses of the adaptation literature (e.g., Füssel 2007; Smit and Wandel 2006). We will extract initial design principles for institutions to support local-level adaptation from this practice-based literature (listed in column 1 of Table 1) and also list the challenges for local-level adaptation it identifies.

The first general principle that emerges from this literature is the need for active involvement of ''community members'' in adaptation planning in order to identify exposures, sensitivities, and adaptive capacities that are specific and relevant to the community, as well as factors that constrain choices, and decision-making processes into which adaptation could be integrated. This is stressed in all of the articles we examined. It is often accomplished by a team of researchers from academia or a nongovernmental organization (NGO), who are funded by a one-time, short-term research or development opportunity, and who use ethnographic methods to understand community perspectives. Huq and Reid (2007) emphasize the need for trust between community members and researchers involved in planning efforts in order for these efforts to be effective and to be seen as legitimate by community members. They also emphasize the need for researchers to communicate about climate change using language and means that community members can understand. Thus, the first challenge for local-level adaptation planning is bridging between the cultures, languages, values, expectations, and priorities of researchers and community members in order to establish relations of trust (Huq and Reid 2007; Reid et al. 2009). This general principle suggests two design principles for institutions to support local-level adaptations: they should support ongoing interactions with community members (principle 1) and be trusted by community members (principle 2).

Füssel (2007) and Smit and Wandel (2006) highlight the need to recognize multiple stimuli in addition to climate, including political, cultural, economic, institutional, and technological forces, and the ways in which they interact over time and across scales in community-specific ways, in order to develop a very broad range of measures aimed at reducing vulnerability and increasing adaptive capacity. This principle highlights a second challenge for local-level adaptation, which is obtaining scientific information that is understandable and relevant to local contexts

(Reid et al. 2009). It also implies that researchers should have the ability to integrate knowledge from various sources, including from the local level, from policy analysts and decision makers beyond the local context, and from various scientific disciplines. This suggests a third design principle for institutions to support local-level adaptation: they should have access to a broad range of expertise, from climate scientists to experts in agriculture, natural resource management, health, economics, and engineering, and the ability to bridge between different ''knowledges'' (principle 3). Smit and Wandel (2006) found that practical adaptation initiatives that emerge from community-based vulnerability assessments tend to be incremental, to focus on challenges that communities already face, to consider climate in the context of other environmental and social stresses, and to be ''mainstreamed'' into existing resource management, disaster preparedness, and other strategies and plans.

Füssel (2007) and Smit and Wandel (2006) also point out the need to anticipate future risks and adaptation needs in the face of uncertainty of future climate and changing social and environmental processes. Incremental adaptation based on past experience and current conditions may be insufficient to address extreme events and changes that lie outside the current climate envelope. This principle highlights a third challenge for local-level adaptation planning based on one-time, short-term research: the need for ongoing monitoring and evaluation of adaptive strategies (Reid et al. 2009; van Aalst et al. 2008). It also suggests three more design principles for institutions to support local-level adaptation. They should have the ability to anticipate future adaptation needs (principle 4), support ongoing evaluation and adjustment of adaptation strategies (principle 5), and have the flexibility to adjust to changing adaptation needs and challenges (principle 6).

Finally, Füssel (2007) points out that the widespread adoption of adaptation planning is a social learning process that can be facilitated by the establishment of dialogs and forums in which knowledge of what works, what does not work, and why can be shared within and across localities. Van Aalst et al. (2008) emphasize the need to connect insights gained at the local level to planning and implementation processes at higher political levels in order to provide input to policy processes. A fourth challenge for local-level adaptation planning is to connect insights from local-level research to other localities and to planning and implementation processes at higher political levels. This suggests a final design principle for institutions to support local-level adaptation. They should be able to span localities and political levels (principle 7).

In the next section we turn to the literature on usable science to address two of the challenges for local-level adaptation identified above: bridging research and local cultures, and obtaining scientific information that is understandable and relevant to local contexts. We obtain from it design principles that promote interaction and trust-building between knowledge users and producers and the ''co-production'' of knowledge that is understandable and relevant to local contexts.

b. *Design principles from the literature on creating usable science*

The concept of ''usable science'' has emerged in recent years as significant theoretical attention has been devoted to developing new models for the production of science. This model responds to the recognition that the traditional ''mode 1,'' ''linear,'' or ''loading dock'' model of science, based on a strict separation of science and society and a one-way flow of knowledge between them often, results in information that is not useful to decision makers (Cash et al. 2006; Kirchhoff et al. 2013; McNie 2007). It is informed by the understanding that the boundary between science and society is mutually constructed and proposes that a two-way flow of information between knowledge producers and users will result in the coproduction of knowledge that is perceived as salient, credible, and legitimate by relevant stakeholders or decision makers and will therefore be more effective in influencing social responses (Buizer et al. 2010; Cash et al. 2003, 2006; Dilling and Lemos 2011; Jacobs et al. 2010; McNie 2007). Coproduction processes are by definition inter- or transdisciplinary since they include both knowledge producers and users, and knowledge producers from different disciplines who work together to tackle problems that cannot be solved by any single discipline.

We draw on a subset of the literature that focuses on the need for usable science in the context of climate variability and change specifically (Buizer et al. 2010; Dilling and Lemos 2011; Feldman and Ingram 2009; Finucane 2009; Jacobs et al. 2010; Kirchhoff 2013; Kirchhoff et al. 2013; Kloprogge and Van der Sluijs 2006; Lemos and Morehouse 2005; Lynch et al. 2008; McNie 2013; NRC 2009; Tribbia and Moser 2008; Salter et al. 2010) in order to extract design principles for institutions to support the creation of usable science (listed in column 2 of Table 1). Some of these principles reinforce those suggested by the local-level adaptation literature. Taken together, they become design principles for institutions to support the creation of usable local-level adaptation strategies.

An overarching principle in this literature is that knowledge users or stakeholders must be included in the knowledge production process. However, a more dynamic role is envisioned for them than for general community members in the local-level adaptation literature. Rather than just supplying local knowledge to researchers who combine it with other knowledge to develop adaptation strategies, knowledge users must actively interact and collaborate with knowledge producers to coproduce usable science. The usable science literature turns to empirical studies to understand the conditions that promote coproduction and to develop criteria for evaluating the outcomes of these processes. For example, Lemos and Morehouse (2005) focus on the qualities of interactions between knowledge users and producers. They argue that interdisciplinarity and iterativity—sustained, end-to-end interactions that result in relations of credibility, trust, and mutual understanding between participants—promote a ‘‘good fit’’ between the knowledge produced and user needs. They emphasize that building these kinds of relationships requires significant commitments of time, effort, and financial and technical resources, as well as disciplinary and personal flexibility, and that recognition and reward for these types of activities is often lacking in the academy. They argue that the higher the level of disciplinary and personal flexibility and availability of resources, the more likely that iterativity in the relation between knowledge producers and users will occur. The importance of relations of trust, sometimes conceived of in terms of social capital, and the cost in human and other resources of building them are a prominent theme throughout this literature. Another theme is the difficulty of evaluating the outcomes of coproduction processes since they include process outcomes, such as relationship building, group learning, and the degree to which the knowledge influences policy and action, in addition to more concrete products.

Cash et al. (2003) focus on qualities of the coproduced knowledge. They conclude that it is likely to be seen as valuable to the extent that it is perceived as salient (relevant to users' needs), credible (scientifically valid), and legitimate (produce in a fair and transparent manner that is respectful of stakeholders' disparate beliefs and values) by relevant stakeholders. Cash et al. also highlight the importance of ‘‘boundary work’’: managing the boundary between science and society in ways that enhance these characteristics.

We extract from this literature several design principles for institutions to support the creation usable science. First, they must 1) support the coproduction of usable science. To do this, they should 2) be interdisciplinary, 3) support iterative interactions between knowledge users and producers that build relationships of credibility and trust and improve the fit between knowledge produced and user needs, 4) have sufficient human, financial, and technical resources to support coproduction, 5) recognize and reward activities that contribute to coproduction, 6) perform boundary work to enhance the salience, credibility, and legitimacy of coproduced knowledge, and 7) be able to evaluate coproduction processes.

McNie (2007) and Dilling and Lemos (2011) have documented the main institutional arrangements and mechanisms that have been observed to contribute to the creation of usable knowledge. They include participatory group processes, such as community-based vulnerability assessments; information brokers—intermediaries between knowledge producers and users who are fluent in both worlds; and knowledge networks—informal networks of knowledge producers and users who share information across areas of practice; and boundary organizations. We focus on boundary organizations because, as formal and concrete institutions they are more likely to be able to address the second two challenges identified in the literature on local-level adaptation: providing ongoing monitoring and evaluation, and connecting insights from local-level efforts to other localities and to planning and implementation processes at higher political levels. This this focus makes the CES, which is frequently cited as an example of a boundary organization (e.g., Cash 2001; Cash and Moser 2000; Feldman and Ingram 2009; Lynch et al. 2008), a logical choice for a case study to empirically explore the design principles we derive theoretically.

c. *Design principles from the literature on boundary organizations*

In this section, we draw on the literature on boundary organizations to extract design principles for a boundary organization to support local-level climate change adaptation, which we list in column 3 of Table 1.

The ‘‘boundary organization’’ concept emerged from social studies of science, where it was observed that in policy-making processes, the boundary between science and policy is not a manifestation of some essential characteristic of science itself, but a fuzzy, shifting outcome of ongoing negotiation between scientists and nonscientists as they struggle to maintain scientific credibility while assuring political saliency (Jasanoff 1987, 1990; Gieryn 1995). While this boundary work can lead to more effective decision- and policy-making, it risks both the ‘‘politicization of science’’ and the ‘‘scientification of politics’’ (Guston 2001, p. 399). Initially, boundary organizations were defined as institutions that straddle and stabilize the boundary between science and policy in order to link the two domains while resolving this fundamental tension (Guston 1999, 2001). They were involved in coproduction of ‘‘the combined ‘social and scientific’ order’’ (Guston 1999, p. 105). Some of the early examples of boundary organization include the Offices of Technology Transfer (Guston 1999), the U.S. Department of

Agriculture Cooperative State Research, Education, and Extension Services (CSREES; Cash 2001), and the International Research Institute for Climate Prediction (IRI; Agrawala et al. 2001).

More recently the boundary organization concept has been taken up by proponents of usable science, where the emphasis has shifted from boundary organizations' role in stabilizing the boundary between science and society to their role in bridging it (Kirchhoff et al. 2013; Tribbia and Moser 2008). In this literature the focus of coproduction has shifted from coproduction of the scientific and social order more generally to the coproduction of knowledge to address specific social needs (e.g., Cash and Moser 2000; Cash et al. 2006; Dilling and Lemos 2011; Kirchhoff 2013; Kirchhoff et al. 2013; Lemos and Morehouse 2005; McNie 2007, 2013; Tribbia and Moser 2008). The National Atmospheric and Oceanic Administration Regional Integrated Sciences and Assessments (NOAA RISA) program is frequently given as an example of this type of boundary organization (Buizer et al. 2010; Cash and Buizer 2005; Dilling and Lemos 2011; Feldman and Ingram 2009; Kirchhoff et al. 2013; McNie 2007).

Guston (1999) initially suggested three criteria for identifying boundary organizations. As the concept circulated more widely and was taken up by proponents of usable science, the characteristics and functions of boundary organizations continued to be elaborated. We have synthesized four characteristics and four functions from the literature (Buizer et al. 2010; Cash and Moser 2000; Cash 2001; Cash et al. 2003, 2006; Dilling and Lemos 2011; Franks 2010; Guston 1999, 2001; McNie 2007; Tribbia and Moser 2008). Boundary organizations 1) are situated at the boundary between science and society with accountability to both, 2) are involved in the coproduction of knowledge through the collaborative participation of actors from both sides of the boundary and professionals from the organization who serve a mediating role, 3) support the creation and use of boundary objects (objects that can be used in different ways by different stakeholders for their own purposes to produce different types of knowledge), and 4) bridge multiple boundaries—first and foremost is that between science and society, but also potentially between disciplines, levels of political organizational (e.g., national, regional, state, local), public and private sectors, and developed and developing countries.

Boundary organizations also perform several fairly well-agreed-upon boundary managing functions to bridge the science–society boundary and to ensure the salience, credibility, and legitimacy of coproduced knowledge: convening, communication, translation, and mediation (Cash et al. 2003, 2006; Franks 2010; McNie 2007; Tribbia and Moser 2008). These functions elaborate on the boundary work mentioned in the usable science literature. Convening means bringing parties together, preferably for face-to-face contact, which provides a foundation for building relationships and for carrying out the other functions. Communication entails active, iterative, and inclusive communication that facilitates two-way flows of information among collaborators. Translation connotes translation among the different languages, types of knowledge, motivations, time frames, and scales of collaborators to make sure they understand each other. Mediation involves processes that lead to perceptions of transparency, fairness, and procedural justice among collaborators. We list these characteristics and functions as institutional design principles for a boundary organization in column 3 of Table 1.

d. Synthesis

We have synthesized the design principles derived from each of the three literatures (listed in Table 1) into 10 design principles for a boundary organization to support local-level adaptation (listed in Table 2). We begin with the defining principle for a boundary organization: 1) it is situated at the boundary between science and society with accountability to both. Next we consider what the three literatures have in common, which is readily apparent from Table 1. First is an emphasis on the need for interaction between knowledge producers and users. The local-level adaptation literature adds the importance of developing trust and the usable science literature adds that interactions should be iterative in order to build trust and improve the fit between knowledge and application. Iterativity also supports the ability to evaluate and adjust adaptation strategies as conditions change. We combine these principles into two. 2) A boundary organization to support local-level adaptation should engage in the coproduction of usable local-level adaptation strategies through the collaborative participation of actors from both sides of the boundary and professionals from the organization who serve a mediating role. 3) This requires developing iterative relationships that build trust and ensure a good fit between knowledge produced and user needs. 4) The three literatures also emphasize the need for interdisciplinarity: access to a broad range of expertise and the effort of researchers and practitioners to work together across disciplinary boundaries. In developing usable local-level adaptation strategies, this will allow for the recognition of multiple stimuli in addition to climate and the ability to develop a wide range of adaptive strategies that take them into account.

From the usable science and boundary organization literatures we add the following requirement: 5) performing boundary-managing functions to bridge multiple boundaries and to ensure the salience, credibility, and legitimacy of coproduced knowledge. In addition, all three literatures point out that building relationships of trust and managing boundaries is time and resource intensive. 6) This points to the need for institutional support for coproduction, both in provision of human, financial, and technical resources and recognition and reward structures.

We add several additional design principles from the local-level adaptation literature to support the coproduction of local-level adaptation strategies specifically. First, because local contexts are constantly changing, not just in response to climate but also in response to changing social and environmental processes at broader scales, institutions to support local-level adaptation should be able to evaluate and adjust adaptive strategies in light of changing conditions, have the capacity to anticipate future, as well as respond to current, adaptation needs, and have the flexibility to organize around new needs and opportunities for adaptation as they arise. The usable science literature also points out the need to be able to evaluate coproduction processes. We summarize these principles as: 7) ongoing evaluation and adjustment of adaptation strategies and coproduction processes; 8) the capacity to anticipate future adaptation needs; and 9) flexibility to organize around emerging adaptation needs and opportunities. The local-level adaptation literature also points to the need to 10) share lessons learned across localities and for access to planning and implementation processes at higher political levels, which involves bridging localities and levels of political organization. In the next section we explore these theoretical design principles empirically by means of a case study of an existing boundary organization, the U.S. Cooperative Extension System.

3. A case study of the U.S. Cooperative Extension System

We undertook an organizational ethnography of The University of Arizona Cooperative Extension, the branch of the CES in the state of Arizona, as part of a larger study that assessed the role that the CES could play in providing climate-related information and programs that would better meet the needs of rural Americans. In this paper, we use the case study to explore empirically how the design principles for a boundary organization to support local-level adaptation we have derived theoretically, could be implemented, to gain insight into additional institutional characteristics that would support them, and to assess the CES's potential to serve as a boundary organization to support local-level adaptation.

a. *Methodology*

The case study draws on literature on the history and current organization of the CES, as well as an organizational ethnography of UACE conducted in 2011. McNie (2007) has suggested that there is need for a better understanding of how the iterative relationships so crucial to the creation of usable science are developed and maintained, and of why some organizations are more successful at building social capital than others. Qualitative methods can address this need. We combine several qualitative methods in the organizational ethnography to provide insight into the dynamics of UACE faculty members' interactions with clientele and how they contribute to coproduction, boundary management, and CES's reputation as a trusted source of information. First, one of the authors is a Climate Science Extension Specialist with UACE and contributed more than seven years of participant observation as a member of the organization. The other author participated in numerous Extension activities during the research period. We collected additional participant observation data by working with UACE county personnel to organize discussion groups with local residents in 8 of Arizona's 15 counties on how rural Arizonans understand, respond to, and plan for weather and climate in their daily lives (Brugger and Crimmins 2012, 2013). Although the CES has a large presence in urban areas and has developed programs for them specifically (Carlson 2012), for this study we focused on rural Arizona counties and did not collect data on UACE activities in urban counties. During the same time period, we also conducted 22 in-depth interviews with UACE faculty: 4 with administrators, 10 with Extension Specialists, and 10 with County Directors and Agents. We also collected and analyzed documents produced by UACE.

Interview questions were open-ended and designed to elicit information about how UACE faculty see Extension, how they actually perform their jobs, the ways in which weather and climate impact their clients' lives, and facets of their work that address these impacts. The interviews were digitally recorded and transcribed. The textual data were analyzed using a qualitative, mixed inductive/deductive grounded theory approach that involves an iterative process of coding the text to identify themes and categories of themes and relations among them (Bernard and Ryan 2010; Strauss and Corbin 1998). Themes emerged both inductively from the data and were deduced from the design principles in Table 2. In the discussion that follows we provide examples from the case study to illustrate how, and the extent to which, the CES implements these design principles. Examples are followed by the principles they illustrate in square

TABLE 3. How the U.S. Cooperative Extension System implements theoretical design principles for a boundary organization to support local-level climate change adaptation.

1. Situated at the boundary between science and society with accountability to both. Organizational structure and public service mission embedded in the Morrill and Smith-Lever Acts; system of county Extension agents; county Extension advisory boards.
2. Engage in the coproduction of usable local-level adaptation strategies. System of county Extension agents; nonhierarchical network structure; ongoing program and needs evaluation; programming responsive to local needs.
3. Develop iterative relationships. Official organizational and financial support structures provide continuity; system of county extension agents; nonhierarchical network structure; face-to-face and one-on-one interactions; existing social capital.
4. Interdisciplinarity. Breadth of Extension programming and expertise; system of Extension Specialists; nonhierarchical network structure.
5. Form boundary-managing functions on-hierarchical network structure; breadth of Extension programming and expertise; existing social capital.
6. Institutional support for coproduction (resources, recognition and reward structure). Mandated by public service mission; official organizational and financial support structures provide continuity; faculty job descriptions include Extension activities; reward structure recognizes Extension activities.
7. Ongoing evaluation and adjustment of adaptation strategies and coproduction processes. System of county Extension agents; ongoing program and needs evaluation; programming responsive to local needs; official organizational and financial support structures provide continuity.
8. Capacity to anticipate future adaptation needs. Nonhierarchical network structure; breadth of Extension programming and expertise; ongoing program and needs evaluation.
9. Flexibility to organize around emerging adaptation needs and opportunities. Organized at state level; nonhierarchical network structure; breadth of Extension programming and expertise; programming responsive to local needs.
10. Ability to share lessons learned across localities and access to higher political levels. Nonhierarchical network structure.

brackets (using the numbers for the principles in Table 2). This discussion is summarized in Table 3, which shows how the CES implements each of the 10 design principles in Table 2.

In section 3b we draw on the history of the CES and its current organizational structure to illustrate how the CES implements these principles structurally. In section 3c we draw on the organizational ethnography of UACE to provide examples that illustrate how UACE faculty members implement these principles in their daily activities. To illustrate how the process-related principles are implemented—engaging in coproduction, developing iterative relationships, and managing boundaries—we use quotes that exemplify themes found in the data and allow faculty members to describe in their own terms the dynamics of their interactions with clientele. We believe this method of presentation gives a better feel for how individual faculty members develop and maintain iterative relationships (McNie 2007), and at the same time, develops analytic understanding of how coproduction is accomplished through the aggregation of these individual accounts. Because these processes are inextricably intertwined in UACE faculty members' interactions with clients, our approach is to examine them from the perspective of boundary managing functions, which the literature describes in some detail, while pointing out how other design principles are being operationalized at the same time.

Throughout the discussion, in order to be able to reflect on the CES's potential as a boundary organization for local-level adaptation, we also point out ways in which existing programs support local-level adaptation by reducing vulnerability or increasing adaptive capacity (summarized in Table 4). In section 3d, we summarize the discussion and evaluate the potential of the CES to serve as a boundary organization for local-level adaptation.

b. *Overview of the U.S. Cooperative Extension System*[1]

The CES was initially conceived and designed to straddle the boundary between science and society with accountability to both. It was created in 1914 by the Smith-Lever Act as the third component of the land-grant university system, with the aim of bringing research and educational programs developed at universities and agricultural research stations to the broader public [1, 6]. The 1862 Morrill Act laid the foundation for this system by granting federal public lands to each state to fund land-grant institutions which were intended to strengthen democracy by extending access to higher education to rural and lower- and middle-class Americans who previously had little access. The foundational public service mission of the land-grant university system provides an ideological basis for the CES's accountability to both science and society. We found that it also motivates many UACE faculty members'

[1] This section draws on Cash (2001), Franz and Townson (2008), McDowell (2001), Rasmussen (1989), USDA (2012), and case study data.

TABLE 4. UACE programs related to climate change adaptation.

Program name (specific to county)	Description	Adaptation potential	Website
Climate and water			
Master Gardeners	Emphasizes the use of native plants; teaches low water use landscaping; rainwater harvesting.	Reduce vulnerability to reduced water supply.	http://extension.arizona.edu/master-gardeners
Master Watershed Stewards	Education and training in the protections, restoration, monitoring, and conservation of water and watersheds.	Increase adaptive capacity through knowledge exchange.	http://www.cals.arizona.edu/watershedsteward/
Water Wise (Cochise)	Portal to water-saving information, educational programs, events, and resources.	Reduce vulnerability to reduced water supply	http://waterwise.arizona.edu
Water Counts (Graham)	Youth and adult education; home, municipal, and industrial water analysis; xeriscape planning.	Reduce vulnerability to reduced water supply	http://extension.arizona.edu/graham-water-counts-program-description
RainLog	A citizen-based cooperative rainfall monitoring network.	Increase adaptive capacity to climate variability through knowledge exchange.	http://rainlog.org/usprn/html/main/maps.jsp
Project WET	Offers no cost water-related curriculum, training, and teaching resources to teachers.	Increase adaptive capacity through increased understanding of water management and conservation.	http://cals.arizona.edu/arizonawet/
Water State Initiative Community Listening Sessions	An initiative designed to engage the state in a community-based water planning dialog to increase awareness of water resource needs and issues by citizen, local leaders, and water practitioners.	Increase adaptive capacity through knowledge exchange.	http://cals.arizona.edu/waterquality/ACE_WaterStateInitiative.htm
Small acreage education	Provides education for new rural residents in skills and knowledge necessary for successful and sustainable rural living.	Reduce vulnerability of new residents; increase adaptive capacity of community.	http://rurallandscapes.extension.arizona.edu/small-acreage-landowner
Arizona NEMO	Educates land use decision makers to make choices and take actions that will lessen nonpoint source pollution.	Increase adaptive capacity to address water quality.	http://nemo.srnr.arizona.edu/nemo/
Smartscape	A training program for landscape professionals that promotes water efficient landscapes.	Reduce vulnerability to reduced water supply.	https://www.ag.arizona.edu/pima/smartscape/201smartscape/
Catch the Rain	A collection of hands-on interactive rainwater harvesting activities for youth.	Increase adaptive capacity and reduce vulnerability.	http://extension.arizona.edu/4h/content/featured-item/catch-rain
Arizona Meteorological Network (AZMET)	Meteorological data and weather-based information to agricultural and horticultural interests operating in southern and central Arizona	Providing baseline information to support improved and more efficient irrigation scheduling in a changing climate	http://ag.arizona.edu/azmet/az-about.htm
Climate and forests			
National Workshop on Climate and Forests	A workshop to extend understanding of current climate change adaptation and mitigation options for forest management.	Increase adaptive capacity through knowledge exchange.	http://www.safnet.org/natworkshop11/index.cfm
Climate and fire			
White Mountain Natural Resource Working Group (Navajo and Apache)	A collaborative initiative designed to restore forest ecosystems in northern Arizona.	Reduce risk of wildfire.	http://www.fs.usda.gov/detail/asnf/workingtogether/partnerships/?cid=STELPRDB5206733
Firewise	Education and training for homeowners in the wildland urban interface on how to keep their properties safe from wildfire.	Reduce vulnerability to wildfire.	http://cals.arizona.edu/firewise/

TABLE 4. (*Continued*)

Program name (specific to county)	Description	Adaptation potential	Website
Community Forestry Program (Coconino)	Helps property owners near public lands implement tree thinning treatments on their property	Reduce vulnerability to wildfire.	http://extension.arizona.edu/coconino-community-forestry
Climate and drought			
AZ DroughtWatch	A web-based monitoring program designed to collect, summarize, and display timely observations of drought impacts across Arizona.	Increase adaptive capacity through knowledge exchange.	http://azdroughtwatch.org
RangeView	A web-based information system that allows users to view and analyze satellite imagery to monitor vegetation dynamics through time and across landscapes.	Increase adaptive capacity through knowledge exchange.	http://rangeview.arizona.edu
Local drought impact groups	State-wide initiative to organize stakeholder groups in each county to develop a drought management plan for the county.	Increase adaptive capacity.	http://www.azwater.gov/azdwr/statewideplanning/drought/LDIG.htm

personal commitment to Extension work and their feeling of accountability toward their clientele.

The dual accountability of the CES is reinforced by its unique organizational structure. To carry out Extension activities, the CES places Extension agents affiliated with the state land-grant institution in each county of the state where they are able to interact with local residents on a daily basis [1]. This arrangement also facilitates ongoing monitoring and evaluation of local needs by local Extension agents [7]. Until recently, Extension offices existed in virtually all of the approximately 3000 U.S. counties, providing the CES with the organizational capacity to address issues nationwide in ways attuned to local conditions. As university faculty, county Extension agents are trained in a scientific discipline, accountable to a specific department at the university, and evaluated on their Extension as well as their academic accomplishments, an organizational arrangement that supports dual accountability and coproduction [6]. As members of the community, they develop experiential knowledge of the local context and form emotional attachments to the community, which contribute to a feeling of belonging and responsibility to the local community [1]. A UACE County Director describes this feeling this way: ''As an Extension agent, I'm part of this community. My kids were born here, my wife's from here, all my adult life, my working career has been here, I own property here, and I'm probably going to die here. And I want our community to sustain itself.'' As local residents, County Extension agents are also able to develop relationships of trust with local-level decision makers that facilitate the coproduction of usable knowledge [2, 3]. In some states, county Extension advisory boards oversee Extension activities in their county and advise county officials on funding the county Extension office, an arrangement that further reinforces Extension's accountability to local clientele [1]. Studies often show Extension to be the most trusted source of new knowledge for ordinary Americans (e.g., Fernandez-Gimenez et al. 2005; ISU 2011), evidence of the success of these organizational arrangements in supporting accountability, coproduction, and trust-building.

The CES was established as a partnership between the land-grant institutions and the U.S. Department of Agriculture (USDA), with the state land-grant institution taking responsibility for leadership, administration, and day-to-day operation of the organization within its state, an arrangement that gives the State Cooperative Extension the organizational flexibility to tailor itself to state needs and conditions [9]. While land-grant institutions initially focused on education in agriculture and the practical arts for a population overwhelmingly rural and employed in agriculture, over time they came to interpret their educational mandate to include a broad array of subjects that pertain to the welfare of individuals, households, and local businesses and governments, and assembled a broad range of expertise to address them [4].

In addition to agents located locally, the CES includes Extension Specialists with advanced degrees who are based at the land-grant institution and conduct applied research and community educational programs in their area of expertise [4]. They provide an interface between county agents and other scientists in the specialist's area of expertise at the home and other land-grant institutions, and with higher-level state and national agency representatives. Additionally, professional organizations, such as the Association of Natural Resources Extension Professionals, the National Association of Community Development Extension Professionals, and the National Association of County Agricultural Agents provide opportunities for Extension professionals to interact with other Extension professionals in their field of expertise nationally [10].

This nonhierarchical network structure greatly facilitates two-way communication and ongoing interaction among a broad cross section of clientele, scientists, and decision makers across localities and at different levels of political organization via intermediaries located locally and at the university [2, 3, 4, 5, 10]. It also gives the CES organizational flexibility to respond to current and emerging local, regional, and national issues in locally relevant ways and supports the capacity to anticipate future adaptation needs [8, 9]. A UACE County Director explained the CES's uniqueness in this regard:

> Extension's strength is its flexibility. We've always been able to shift direction on a turn of a dime. As long as the resources are there to support and sustain those kinds of things. Our life blood is being able to see new issues coming along and to adapt quickly to meet those issues. That's why Extension is so valuable. Because there is not anybody else that can do that. Why are we the only ones that can do that? Well, number one is that our mission is to address the issues, the big needs in the county. So we are focused on small areas. Well, they're not that small in Arizona. But we have a certain framed area of target that we're aiming at. Someone who is on a national level, they have to have a broad brush. We can be very specific, we can focus on the community needs. And every community has a different need. Another reason is because we have a flexible mission. Our objective is to identify. We are rewarded on identifying new issues and moving forward into those issues, taking initiative. And not everybody has that flexibility. Most government agencies are focused on very tight parameter of areas that they focus on: NRCS [Natural Resources Conservation Service]; Farm Service Agency is another; county government is more focused on non-agriculture issues. In fact they see us as their action arm on addressing issues. You look at private corporations which are in it for the profit: a lot of times in these small issues there's no profit in it. So they have no interest. Small companies or 501c3s may have an interest in a particular issue but they don't have the capacity or the focus or the desire even to incorporate the big picture; they're very focused on the delivery. I don't see anybody else in the county, I don't see anybody else in the state, I don't see anybody else in the nation that has the flexibility that Cooperative Extension does to meet changing issues. In a quick, and very efficient, way.

Evidence that CES has the flexibility and organizational capacity to organize around emerging national issues is also provided by its success helping to overcome national challenges in the past. For example, during World War II, the CES organized the popular Victory Garden Program, which provided gardening supplies and expertise to millions of families to help ease food shortages. And during the Cold War, the CES was given the role of educating the public about bomb shelters.

Since 1914 the land-grant university system has evolved to adapt to changing social conditions at the national, state, and county level. Today only about 17% of the U.S. population lives in rural areas (Lal et al. 2011) and agriculture-related jobs account for only 11.7% of rural employment (W. K. Kellogg Foundation 2002). Although many Americans still think of the CES as ''Agricultural Extension,'' the organization has adapted its programming to address important urban and suburban, in addition to rural, issues (Carlson 2012) and in the process has moved from its initial technology transfer model to a coproduction model [2, 4, 7, 9]. The CES now works in six major areas: 4-H and youth development; agriculture; natural resources; family and consumer sciences; and community and economic development (USDA 2012). CES also administers the USDA food stamp program, now known as the Supplemental Nutrition Assistance Program. These wide-ranging programs further demonstrate the CES's flexibility and its accountability to local clientele as it continuously strives to meet their changing needs [1, 3, 7, 9]. They also illustrate the breadth of programming into which climate change adaptation could be mainstreamed [4].

c. *Results from an organizational ethnography of The University of Arizona Cooperative Extension*

In this section we examine how UACE implements the design principles for a boundary organization for local-level adaptation. We begin with a brief overview of the challenges that climate change presents in Arizona and of the organization of UACE. Then we provide examples that illustrate how UACE faculty perform each of the boundary managing functions, as they simultaneously work to maintain relations of trust and credibility with clientele, coproduce usable knowledge, and implement additional design principles for a boundary organization for local-level adaptation.

Climate change is a particular challenge for UACE for two reasons. First, the current and projected effects of climate change are more significant in the Southwest than in any region of the United States outside Alaska. The region has experienced warming of over 1°C since the middle of the last century, and temperatures are projected to continue to increase up to 3° to 6°C by century's end, along with aridity, more frequent, longer-lasting, and warmer drought conditions, more intense precipitation and flooding, and increasing risk of wildfire (Karl et al. 2009; Overpeck and Udall 2010; Westerling et al. 2006). Additionally, there is mounting evidence that water management systems in the region are running up against physical, economic, and ecological limits that constrain the expansion of water supplies, while at the same time climate change and the fastest-growing population in the nation heighten the threat to current supplies (Gleick 2010). These changes will impact many aspects of Arizona residents' lives. Second, climate change is a politically charged topic in Arizona, so UACE faculty must find ways to address adaptation that are not controversial. The understanding of local beliefs and values and the ability to anticipate future adaptation needs that they acquire by living in and interacting with local communities is indispensable to this effort [2, 3, 5, 7].

Arizona has only 15 counties, in contrast to much smaller states that may have 5 times as many, so UACE faculty must cover a lot of physical territory to meet with clients. Each county has a Director and one or more agents with a focus in one of the CES's six program areas, who may serve multiple counties. Administrators and specialists see their job as facilitating the work of county-based faculty, who have a great deal of flexibility to develop programs to meet local needs [6, 9]. Specialists also have great flexibility and often work with other Extension specialists, scientists from UA and other land-grant institutions in the region, federal and state agencies, and other groups to develop programming and research projects to meet identified needs [9, 10]. For example, a Water Quality Specialist is working closely with the Arizona Department of Water Resources (ADWR), the Arizona Department of Environmental Quality (ADEQ), the Environmental Protection Agency (EPA), the Gila Watershed Partnership of Arizona, and local residents to address water quality issues in the Gila River Watershed. A unique feature of UACE, which also expands its breadth of expertise to address current and future climate change adaptation needs, is its partnership with the National Aeronautical and Space Administration (NASA) to fund a Specialist in Geospatial Technology, and with the National Oceanic and Atmospheric Administration (NOAA) to fund a Specialist in Climate Science [4]. UACE faculty also collaborate with nonprofit associations, professional and business organizations, private industry, citizen groups, the military, and other groups in programs related to agriculture, natural resources management, youth development, community development, and family, consumer, and health sciences [4]. Figure 1 illustrates the nonhierarchical network structure of UACE. Examples in the following discussion will demonstrate the importance of this network structure for supporting many of the theoretical design principles for a boundary organization to support local-level adaptation (see Table 2), especially interdisciplinarity, ongoing evaluation and adjustment of adaptation strategies, and bridging boundaries between localities, levels of political organization, and public and private sectors. The following sections are organized by boundary management functions but provide examples of additional theoretical design principles.

1) CONVENING

There are many ways in which UACE programs bring people together from across multiple boundaries to participate in creating usable knowledge that addresses local issues. While these programs do not focus specifically on climate change adaptation, many are climate related. To begin with, national-level programs, such as Master Gardeners and Master Watershed Stewards, are tailored to local needs [2, 3, 7, 9]. Other program address needs unique to Arizona. For example, Project WET (Water Education for Teachers) provides K–8 curricula and teacher training; Water Counts provides water auditing for homes and businesses; and a series of "community listening sessions" organized by UACE in 2010–11 in four Arizona counties brought local stakeholders together to participate in statewide water planning efforts. These efforts not only address clients' concerns about water availability in a desert state, they also reduce vulnerability to climate change, which is expected to exacerbate water scarcity. Small Acreage Landowner Education addresses challenges associated with the influx of new residents to Arizona by providing training in land management for people who are new to land ownership. McLeman (2009) suggests that the influx of new residents, who are often retirees, lack experience living in the local environment, and have a lower degree of self-reliance than longtime residents, increases the vulnerability of rural communities to climate change. Thus, this program can also be seen to

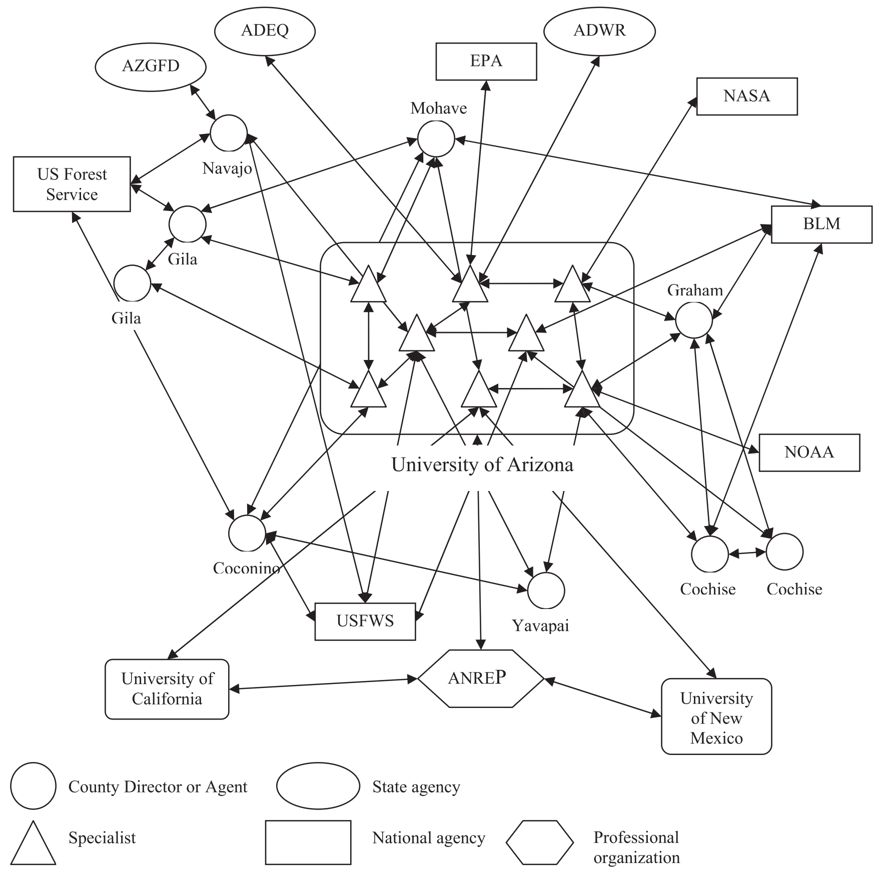

FIG. 1. The network structure of The University of Arizona Cooperative Extension. This is a schematic and is not meant to accurately represent existing relationships.

reduce the vulnerability of rural communities to climate change.

A more informal and flexible approach to convening is the "working group" [2, 3, 4, 9]. An example of this approach is the White Mountain Natural Resource Working Group (NRWG), which formed in Navajo and Apache Counties in 1996 after a series of wildfires threatened local communities. A group that included business owners, loggers, environmentalists, local decision makers, and others who were often on opposing sides of issues, began meeting informally over lunch to try to find solutions to a common local problem (Lenart 2006). The Navajo County Extension Director, one of the initial organizers, became the group's first chairman and continues to serve as a sustaining force, a role made possible by his longtime residence in the region, relationships of trust and credibility he has developed with local decision makers despite differing viewpoints, and the broader expertise within UACE and respect for the organization on which he can draw. Members came to include mayors, county supervisors, and representatives from the Arizona Game and Fish Department (AZGFD), the U.S. Fish and Wildlife Service, and the U.S. Forest Service. The group was instrumental in organizing the largest 10-yr stewardship contract with the Forest Service in the United States to thin 150 000 acres in the Apache-Sitgreaves National Forest. This set the stage for an even more ambitious vision, the Four Forest Restoration Initiative, a collaborative effort to restore forest ecosystem health on four national forests in northern Arizona [10]. While these efforts are not framed as climate change adaptation, they are adaptive because they reduce vulnerability to wildfire, which is projected to increase with climate change in the region (Westerling et al. 2006). This and the following example also illustrate how UACE is able to organize to address the emerging issue of climate change and its ability to expand local solutions to broader scales [9, 10].

An example of a working group organized specifically to address the impacts of climate change on vegetation in Arizona is the Climate and Vegetation Working Group, organized in 2004 by a Gila County Extension Agent. Because he is embedded in a broader extension network, he was able to bring together Extension professionals, University of Arizona (UA) faculty, and members of

Climate Assessment for the Southwest, the NOAA RISA located at UA, to consider the impacts that climate change would have on vegetation in Arizona and how Extension programs could address them. The Working Group organized a series of workshops to explore potential climate change impacts on riparian areas, forests, and rangelands, respectively, and brought in university and agency scientists doing research in these areas [8]. Their efforts culminated in a National Workshop on Climate and Forests, held in May 2011 and cosponsored by UACE, UA, Northern Arizona University, the U.S. Forest Service, the Society for American Foresters, and the USDA, which brought together Extension professionals, scientists, managers of national, state, and private forests, and other decision makers, for the purpose of extending understanding of the current adaptation and mitigation options for forest management and making state-of-the-art climate and ecological planning tools accessible and useful for forest resource managers and extension educators [10].

2) Communication

UACE faculty members strive to facilitate two-way flows of information among themselves, local clients, decision makers, partner organizations, and scientists in a variety of ways. To begin with, the nonhierarchical network structure of UACE and the fact that Extension faculty are located locally encourages the flow of information from different sources, sectors, and organizational levels throughout the network. Here a Specialist describes the work he does to keep information flowing both ways:

> Extension agents have some responsibilities of understanding what's going on at the university but it's really our job to make sure they have an idea. We are the knowledge broker in the chain. That means we have to have one foot in the science world and research world and one foot out locally. I mean we need to be going back and forth as much as we can and we need to be trying to convince the scientists to hand it over. And to make it more operationally accessible and we need to be trying to make sure that whatever they hand over is related to what the people in the counties are asking about at the local level [1, 2, 3].

Specialists at the university are able to have ''one foot out locally'' throughout the state because they are embedded in a network of relationships with Extension agents located in each county.

To convey information to its clientele, UACE produces publications and newsletters, organizes talks, workshops, and courses on a variety of topics, and maintains a website with information for each county. To ensure that information flows both ways, UACE faculty ask participants to evaluate programs to make sure they are meeting client needs, typically via end-of-session surveys. They also conduct ''needs assessments'' on a regular basis to better understand the information and programming needs of their clientele. These may consist of focus groups, surveys, consultation with the County Extension Board, or informal conversations [7]. Ongoing interactions also serve a monitoring role, by giving UACE faculty a ''feel'' for clients' changing needs, as this Specialist explains:

> What we do is, we talk to a lot of people through our jobs. When I go to give presentations, or every day, I get things here, ''Can you tell me about?'' And there are phone messages that say, ''I need to know.'' And so we kind of get a feel if there are multiple requests for the same thing, we get a feel, this is kind of urgent. And maybe we can do a better job to get out the existing information, but maybe we find out there is no information. So then, that is something we usually work on [2, 7, 9].

This two-way, iterative communication process also contributes to a better fit between the knowledge produced and users' needs. It is different from simple ''outreach,'' as this Extension administrator explains:

> And that's a fallacy that a lot of people think that you can do with extension. You can go out with a few cameo appearances and there's where they begin to confuse outreach versus extension. Extension, the education, has continuity. It has repetitiveness. You're going to work with some clientele, learn from them as well as offer to them what you have. And it becomes a feedback, that's continual. That's an extension program. Outreach is when I just go out and talk to some people because I have something to offer and they'll applaud when I'm done and I'll drive off and never see them again, very likely. That's outreach. Extension is where there's continuity, there's repetitiveness, there's the building of a program.

What he describes as ''continuity'' and ''the building of a program'' is building and maintaining iterative relationships that contribute to the coproduction of usable knowledge and ongoing evaluation of its usability [2, 3, 7]. The legal and financial structures supporting the CES are important to maintaining this continuity [6].

As methods of communication in society change, and some of UACE's methods of communication and engagement are becoming less effective, Extension faculty are developing new ways of interacting with their clientele [7, 9]. In addition to conducting in-person outreach activities and training, and responding to public inquiries in person, by telephone, and through publications, they use the Internet and web-based communication technologies to reach different audiences. For example, UACE supports the eXtension website (http://www.extension.org/), which aims to provide round-the-clock access to trustworthy, balanced information on specific issues and education on a wide range of topics to all Internet users. At the same time, UACE faculty recognize the continuing importance of face-to-face interactions for building relationships and trust with clientele, as this Specialist emphasizes: ''People [still] want the one-on-one. I mean, you can't just provide electronically delivered programs, and maintain your viability and your relationship and your trust with people. It doesn't work. You have to do the one-on-one and that takes going out there, and it's really time consuming'' [3]. UACE provides institutional/organizational support for these ''time consuming'' extension activities by including a percentage to be devoted to them in faculty job descriptions [6].

3) Translation

For UACE faculty, translation is more than a one-way translation of scientific into practical knowledge or technical into ordinary language clients can understand; it also involves translation among the different languages, types of knowledge, motivations, time frames, and geographical scales of researchers and clientele, as well as translating contextual knowledge about local communities back to scientists and government officials in the network so they can produce more usable knowledge and formulate better policies and programs. In the words of one Specialist:

> Extension can go two ways. One is communicating information to the public, and this has diversified over time. . . . Another part is disseminating information back up the chain to other people in science, other people in government, about what is agriculture, what are rural communities like, what problems do they actually face [2, 4, 10].

Translation also involves learning to understand what clients do and what they care about and engaging in coproduction by framing information in those terms. This is especially important for supporting local-level adaptation in a context where ''climate change'' is a sensitive issue. This Specialist explains how he learned the importance of understanding how to frame information in terms of what is important to clients:

> Early on in the job I recognized, I actually learned the hard way, that training on technology for technology's sake failed miserably. So every GPS training . . . that I did when I first started, resulted in zero adoption: not a single person bought or used a GPS after those trainings. It was a miserable failure. . . . So then I realized I needed to actually get engaged in all the actual programs where the demand was for geospatial technology and then create an approach that brought the technology to bear on those issues. In the end, I still trained in GPS but it was disguised as for invasive species mapping, or for watershed and water quality assessment, or whatever. Which meant that I had to really understand what those issues were. Speak the language a little bit, and then slide it in there as best I could. But I also tried to do it with where they saw some potential too, I didn't try to shove it down their throats [2, 3].

Training in geospatial technologies also supports climate change adaptation because people can use it to document changes in their local environment.

In the following example, another Specialist explains how he engages in the coproduction of adaptation knowledge that is useful to farmers who may be skeptical of climate change:

> I talk about climate change with just about every talk I give, but I don't spend a lot of time on it. And when you go out and talk about issues like that, or that are rather controversial, or people's opinions are very strong, then you're going to take a lot more abuse and create a lot more friction when you're out there. So . . . for me it's not climate change most of the time, it's how is the current weather pattern going to impact your planting season, your growing season or your water supply issues. But I show them why things are happening, and I show them why [NOAA's long-range] forecasts have certain biases in them. . . . I've given three or four talks already this year saying this is the reason it's always hot and dry in Arizona. Here's the patterns. . . . And the heat thing is very easy. . . .'Cause the trend's been warm and they're going with the trend [3].

UACE faculty are able to acquire the depth of understanding of scientists and local clientele that makes two-way translation possible because they are embedded in a network that enables interaction with both over an extended period of time [3, 4].

4) Mediation

Mediation involves interactions that lead to perceptions of transparency and fairness of the coproduction process and legitimacy of coproduced knowledge. The public service mission of the CES and its long history contribute to widespread perceptions of it as an ''honest broker,'' and studies have found that it is still the most trusted source of information in rural areas (e.g., Fernandez-Gimenez et al. 2005; ISU 2011) [1, 3]. The social capital that the CES has acquired from working at the local level over a long period of time facilitates mediation for Extension professionals, as this UACE administrator explains:

> The thing that we enjoy, that Extension enjoys, . . . is that, when you go into a community and you say you're from Extension, the doors are more likely to open than not. They may not know you, but they certainly know the organization. And, the best part of Extension in the university is that you can be the unbiased broker of information. Your constituents know that you're not there

to sell them anything. You're there to help. And they've dealt with Extension most of their careers, or at least their professional careers. . . . But it makes a huge difference if you can say you're from the College of Agriculture, with Cooperative Extension. Because I've run into ranchers on the border into New Mexico, and you say that, and they say: ''Oh yeah! Do you know [name]?'' And I say: ''Oh yeah, I used to work with him.'' And then everything's cool. And you're obviously much more likely to get an unvarnished, unguarded response [3].

The extent to which local clientele trust the CES to be an honest broker is reflected in this Specialist's account of his role in a public land dispute:

There was going to be a land exchange between [a federal agency and a railroad company], and it was going to change development patterns and grazing leases in [a specific] County. And before you can do a land exchange, the government has to demonstrate that it's in the public interest to do this. . . . Well [the federal agency] contracted with consultants of [the railroad company] to do the analysis of whether the exchange was going to be in the public interest. So, the county people and local residents and ranchers were not particularly happy about this. And so, they said, ''Why don't you have Cooperative Extension do this?'' So the idea was that the University and Cooperative Extension was an impartial arbiter. . . . We were kind of like a go-between, we were somebody that they thought, ''Okay, we can talk to you, you're going to listen. We can give you information and you don't have a particularly vested interest in this deal.'' So [there's] this idea of impartiality. But a lot of what I ended up doing in that was trying to educate people in [the federal agency] about why the ranchers were not particularly happy about the way they were doing things [2, 3, 5].

This example also illustrates how UACE faculty span the boundary between the public (land management agency) and private (railroad company, ranchers) sectors [5].

UACE also collaborates in creating boundary objects: objects that can be used by different stakeholders in different ways to produce different types of knowledge (Guston 2001). One example of a boundary object that could facilitate climate change adaptation for rangeland managers is RangeView, a web-based information system that allows users to view and analyze satellite imagery to monitor vegetation dynamics through time and across landscapes. It can be used to complement traditional field-based rangeland monitoring methods and to monitor the effects of climate change on vegetation over broader scales.

5) Design principles specific to adaptation

UACE also implements design principles 7 through 10, which are specific to local-level adaptation. We have given several examples of how UACE faculty evaluate and adjust programs to respond to client needs, which are affected by social and economic conditions. The CES's organizational structure, with people in place in local communities, means that monitoring and evaluation can be ongoing by means of the daily observations and interactions of county Extension agents. In the context of adaptation, evaluation in the face of changing climatic conditions is also necessary [7].

We have also given examples of how UACE faculty are anticipating the future climate change adaptation needs of their clientele and coproducing usable adaptation knowledge by combining their knowledge of research in their field of specialty with knowledge of clients' needs [8]. Another example is provided by a Specialist in Urban Horticulture who is conducting research that anticipates a time when water shortages might force restrictions on using water for landscaping. The goal of the research is to determine the minimum amount of water needed for trees suitable for urban landscaping in the climate of southern Arizona to continue to serve their important functions in the urban landscape. The Specialist explained that the regional nature of the research, and the lack of perception of an immediate need for it, make it difficult to fund. She conceives of it as a combined research and demonstration project that communicates the need to address the issue as the results become visible, and refers to her efforts as being ''ahead of the forefront.''

I like to be ahead of the forefront, because I know it's a big problem, it's going to be a big problem, but the producers don't think it's a big problem. . . . I always do a couple of things that are unfunded but I have high hopes that eventually I will attract funding, and I am just trying to be extremely creative to get money for this stuff.

Other examples of research that anticipate adaptation needs that UACE faculty are conducting include developing drought- and heat-resistant crops and sources of biofuels that require less water.

The social capital that the CES has built up over time also uniquely position it to address adaptation in the context of the uncertainties of climate change and skepticism about it, to depoliticize climate science, to make climate change meaningful in local contexts, and to coproduce ''no regret'' adaptation strategies (Füssel 2007). A UACE administrator explains what Extension can do in this regard:

It can help us understand why we as residents of community X should care about it, be concerned about it, what do we do about the uncertainty about it, how do we adapt? The idea of, what does adaptation mean? And are we doing it and don't know it? Are we adapting by doing? I mean is rainwater harvesting a form of adaptation? Where you're less dependent on, let's say we live in Tucson, you're less dependent on the Central Arizona Project? Maybe it's a way of becoming more self-sufficient in food production because you have a garden and you're producing food? Is that part of adaptation? Is that sustainable communities, is that both? I mean, helping people understand what they need to do. And that's the challenge I feel's been all along: okay, we know we should be doing it, but what is it that we need to do? We don't know that yet. People do understand if you make your water system more resilient, for these different scenarios, well that's a form of adaptation, right? So, helping people define what adaptation is, and identify what it means to adapt, and how they can do things in their lives that make them more resilient, and make their communities more resilient to some of these uncertainties. Because I don't think you're going to convince people that we know with high probability what's going to be.

d. *Potential of the CES as a boundary organization for local-level adaptation*

The foregoing discussion indicates how the CES implements many of the design principles for a boundary organization to support local-level adaptation (summarized in Table 3). It also brings out several additional organizational characteristics of the CES that facilitate the implementation of these principles. 1) It is supported by federal legislation and an ongoing funding process that give it continuity. 2) Its public service mission mandates organizational support for iterative interactions between producers and users of information and the relationship-building activities that create and sustain them; it also serves to motivate Extension professionals. 3) Together with its long history, this has generated substantial social capital. 4) Its system of county agents provides access to local knowledge and relationships and the ability to monitor local conditions and evaluate programs. 5) It supports expertise and programming to address a wide range of issues important to local communities. 6) Its nonhierarchical network structure promotes interdisciplinarity, flexibility, and bridging boundaries between localities and levels of political organization. These characteristics reduce the time and effort needed to build relationships of trust and credibility, which in turn reduce the cost associated with relationship-building activities, which has been identified as a major challenge in the three literatures we examined. These characteristics have also led to the development of a network that is broad geographically and reaches from the local to the national level. A system of county Extension agents embedded in a nonhierarchical network means that local knowledge resides in the network and is continually refreshed, rather than always having to be brought in through organized stakeholder engagement processes. These characteristics also support the implementation of the design principles specifically for climate change adaptation: ongoing evaluation and adjustment of adaptation strategies, flexibility, capacity to anticipate future adaptation needs, and sharing lessons learned across localities and political levels.

While current UACE programs do not address climate change adaptation specifically, we have identified existing programs and research that contribute to adaptation by decreasing vulnerability or increasing adaptive capacity (summarized in Table 4). In addition, there are many opportunities to mainstream adaptation strategies into other CES programs. For example, Family and Consumer Sciences programs that address health issues could also address those related to climate change in the Southwest, such as heat-related illness or the increased risk of mosquito-borne illness. Vulnerability reduction strategies could be incorporated into programs that target populations expected to be more vulnerable to climate change, such as the elderly or low-income families. We have also shown that the CES has the capacity to anticipate future adaptation needs and the geographic reach and organizational flexibility to organize nationally around emerging national issues, in addition to regional or local ones, in locally relevant ways.

The CES also overcomes some of constraints to coproduction that have been identified by research on the RISA model. The RISA model was studied in the context of coproduction of usable climate science (Feldman and Ingram 2009; Kirchhoff et al. 2013; McNie 2013) rather than usable local-level adaptation strategies, which has been the focus of this paper. However, this research still provides valuable insights for the purpose of exploring institutional design. These studies argue that coproduction is costly, that the RISAs tend to reach mainly high-capacity information users located near them leaving large segments of society underserved, and that the need for usable climate science is expanding faster than the RISA program can grow to meet it. Bidwell et al. (2013) have suggested that the RISAs could be more effective by facilitating extended networks among existing local bridging organizations rather than acting as centralized bridging organizations themselves. We argue that the CES's existing social capital, system of county agents, and extended network of information producers and users can reduce the costliness. Together with the breadth of its existing programs, these features also enable it to reach clientele with a wide variety of adaptation needs and capacities over a broad geographical scale. In addition, while the RISA model tends to be project-based, due to its cyclic funding mechanism, the CES model can accommodate sustained engagement over long periods of time.

Therefore, we suggest that the CES is presently serving as a boundary organization to support local-level adaptation in ways that are often not recognized as formal climate adaptation efforts, and that it has significant potential to increase its role in more coordinated national adaptation efforts. However, it would face several challenges in fulfilling this potential. First, there are significant gaps in its geographical breadth and ability to reach diverse groups. For example, of 314 federally recognized reservations in the United States, there are dedicated Extension programs in only 27 of them (Hiller 2005). In addition, since federally recognized tribal extension programs have only been present since 1994, they have not built up the same network of local relationships and trust that CES has off the reservation. Nor does Tribal Extension enjoy the same cooperative funding arrangements with states and counties as it does elsewhere; it depends solely on very limited federal funds. Vásquez-León (2009) also found that Hispanic farmers in southeast Arizona do not interact with UACE to the same extent as white farmers.

Second, our research and others' suggest that, while the system of county agents facilitates informal monitoring and evaluation, the CES's capacity for formal evaluation may be low (Rennekamp and Arnold 2009; Workman and Scheer 2012) UACE faculty have little training in evaluation and are expected to perform evaluation in addition to their many other responsibilities. More systematic evaluation may be needed for programs that support adaptation. We did not investigate whether evaluation is better supported in other State Extension programs.

However, the greatest challenge to the CES as an effective boundary organization for local-level adaptation is a lack of financial and human resources due to decreased funding and support for the organization at all levels nationwide and changing funding mechanisms. Counties and states have had to slash Extension funding because of the economic recession (Fischer 2009). But even before the recession, funding and support for the CES were decreasing due to widespread perceptions that it was no longer relevant (Bull et al. 2004; McDowell 2004). Without sufficient funding, the organization will be unable to support current programs and follow through with projects, much less take on additional functions in support of local-level adaptation. This threatens the continuity of programs, relationships with clients, and trust in the organization.

In addition, the USDA has changed the way it funds the CES. Traditionally the USDA supported the CES through ''formula funding,'' direct, block-grant funds to land grant universities based on demographics and need, which afforded a great deal of flexibility and local discretion in how the funding was used (Huffman and Just 1994) [9]. However, it has moved to a competitive grant environment, with funding focused on large-scale basic science projects rather than local-scale applied research and outreach. This not only challenges the effectiveness and sustainability of existing programs, it limits Extension's flexibility to develop new programs even when new needs are identified (Shields 2012). For additional funding, Extension faculty can apply for grants from the USDA and other sources, but then, as UACE faculty pointed out in our research, they spend their time ''chasing money'' instead of doing extension work. Turning to alternate funding sources has also raised issues regarding maintaining open access to information and supporting the public good (Barth et al. 1999). A UACE Specialist explained that funding from other sources ''morphs your mission a little bit because you have different people to respond to.'' A funding mechanism for CES in which users pay for services rendered has also been proposed. However, a shift to a user fee model of cost recovery and funding also potentially limits the reach of Extension programming to those who can afford it, which is antithetical to the public service mission of land-grant institutions (Barth et al. 1999). In some states, land-grant universities have responded to the funding crisis by decreasing faculty, closing Extension offices in some counties, and regionalizing services, which threatens the CES's ability to serve clientele throughout the country.

4. Conclusions

In the United States, recent events have highlighted the need to consider national level strategies to encourage and support local-level adaptation. In 2011, *America's Climate Choices: Adapting to the Impacts of Climate Change* (NRC 2011), a National Academy of Sciences report produced in response to a request by Congress to study the challenges associated with climate change and provide advice on the most promising ways to respond, recommended the development of a ''national adaptation strategy'' to support and coordinate decentralized efforts. On 25 June 2013, President Obama announced a Climate Action Plan, which addressed preparing for the impacts of climate change at the local level in several ways, including 1) establishing a task force to advise on key actions the federal government could take to help strengthen communities on the ground, 2) delivering usable knowledge to the agricultural sector and landowners, 3) helping communities prepare for drought and wildfire by launching a National Drought Resilience

Partnership, and 4) providing climate preparedness tools and information needed by state, local, and private sector decision makers through a centralized ''toolkit.''[2] In his 2014 State of the Union address, the President promised to use his executive power to ''prepare our communities for the consequences of climate change.''[3] What insights can this theoretical and empirical exploration of design principles for an institution to encourage and support local-level adaptation provide for researchers, practitioners, policymakers, and others who are considering how national-level adaptation strategies could reach and serve most segments of society?

To begin with, it provides a set of principles for designing institutions to support local-level adaptation that can be used to evaluate proposed and existing programs and organizations. These principles address the main challenges for community-based adaptation that have been identified in practice by 1) supporting the creation of usable scientific information for the local context; 2) bridging academic/research and local cultures, behaviors, and institutional designs; 3) providing for ongoing monitoring and evaluation; and 4) connecting insights gained at the local level to planning and implementation processes at higher political levels. We have grounded these principles in a case study of an existing organization in order to provide a practical grasp of the advantages and disadvantages of implementing them in different ways. The case study of the CES brought out additional institutional/organizational characteristics that facilitate the implementation of these principles. We have also offered insight into how the CES develops and maintains the iterative relationships so crucial to the creation of usable science and how it has been successful at building social capital. We have provided a useful counterpoint to studies of the RISA model. And finally, we have raised awareness of the potential of the CES to serve as a boundary organization to support local-level adaptation on a national scale.

We argue that the CES is already participating in adaptation work and could be a key partner in a national adaptation strategy. Our theoretical discussion shows that interaction between information producers and local-level users is critical to coproducing usable local-level adaptation strategies and that the level and quality of interaction needed is costly in time and resources. The CES provides a robust organizational model with existing infrastructure, social networks, and social capital that can reduce these costs, reach into and support the adaptation needs of urban and rural communities across the country, and provide the flexibility to adjust to changing local adaptation needs and challenges. However, fully engaging and leveraging the CES to support local-level adaptation at a national scale would require reinvesting in the organization at the federal, state, and county levels and providing creative and flexible funding mechanisms.

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