Climatic Change (2016) 138:383–395
DOI 10.1007/s10584-016-1756-4

Bridging the climate information gap: a framework for engaging knowledge brokers and decision makers in state climate assessments

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Received: 11 October 2015 / Accepted: 16 July 2016 / Published online: 23 August 2016

Abstract Large-scale analyses like the National Climate Assessment (NCA) contain a wealth of information critical to national and regional responses to climate change but tend to be insufficiently detailed for action at state or local levels. Many states now engage in assessment processes to meet information needs for local authorities. The goals of state climate assessments (SCAs) should be to provide relevant, actionable information to state and local authorities, and to generate primary sources, build networks and inform stakeholders. To communicate local climate impacts to decision makers, SCAs should express credibility, salience and legitimacy. They can provide information (e.g., case studies, data sets) and connect stakeholders to the NCA and its process. Based on our experience in the Vermont Climate Assessment (VCA), we present a framework to engage decision makers in SCAs

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using a fluid network of scientific experts and knowledge brokers to conduct subject area prioritization, data analysis and writing. The VCA addressed economic, environmental and social impacts of climate change at local scales to increase resiliency and manage risk. Knowledge brokers communicated VCA findings through their own stakeholder networks. We include a qualitative impact evaluation, and believe our framework for interaction among scientists, knowledge brokers and stakeholders to be an effective structure for SCAs and a transformative experience for students.

Keywords Climate change assessment · Vermont · Decision support · Stakeholder engagement · Citizen science

1 Introduction

Addressing local consequences of climate change requires information beyond global, national and regional efforts (Hayhoe et al. 2008; IPCC 2013; Melillo et al. 2014) that generally lack information essential for local decisions. The third National Climate Assessment (NCA) provides national and regional analysis of climate change (Melillo et al. 2014), and the implications, uncertainties, mitigation and adaptation needed by decision makers at that scale. The NCA document is necessarily limited in scope and length; it must cover global trends while synthesizing data from smaller units. In some cases, an NCA publication may lack the scope needed for local actions, which is where State Climate Assessments (SCAs) may prove invaluable. For example, the Northeast regional chapter focuses on coastal storms (Melillo et al. 2014) that have little relevance to landlocked states. Previous NCA reports had limited data for Vermont: maps on the ski outlook included only two data points (Karl et al. 2009), limiting their relevance for a state heavily dependent on the winter recreation economy. State level decision makers achieve greater utility by contextualizing information disaggregated at a substate level (McNie 2013).

Extensive flooding and destruction caused by Tropical Storm (TS) Irene in August 2011 led Vermont policy makers to focus on developing flood resilience. This extreme event is one example of the Northeast's increased frequency of heavy downpours (Melillo et al. 2014); in Vermont the number of days with over one inch of rain has doubled, even tripled in some locales, since 1960 (Galford et al. 2014). Therefore, planning for resilience and hazard mitigation has become a priority for risk management for state agencies, local planners, businesses and land owners. Vermont's lengthening frost-free season and warming nighttime temperatures are affecting the state's iconic agricultural sector. They stimulate new business ventures (e.g., vineyards) and season extension opportunities (e.g., hoop houses) but generate such risks as increased susceptibility to fungal infections (Galford et al. 2014). These examples are beyond the scope of the NCA process and should be addressed through state climate assessments, as was the case with the Vermont SCA (Galford et al. 2014).

In order to meet information needs of decision makers, many states are now engaged in analyses that complement broader efforts (e.g., NCA). They now assess their contributions to global climate changes via greenhouse gas emissions inventories (e.g., Landsberg et al. 2015; State of California 2015; Strait et al. 2007). Some inventories are mandated by state laws (Commonwealth of Massachusetts 2013; Oregon Global Warming Commission 2013; State of Washington 2014), or conducted by states for inclusion in the National Emissions Inventory (Florida Division of Air Resource Management 2010; EPA 2015), or are used for regional greenhouse gas trading (e.g., RGGI 2013). Other states have taken additional steps to address

climate change: Connecticut, for example, has focused on adaptation measures needed for agriculture, infrastructure, natural resources and public health (Adaptation Subcommitte 2010). An Executive Order in California mandates state level scientific assessments to inform the legislature and policy makers on climate change impacts and adaptations. Despite these efforts, it may be difficult to conduct in-depth SCAs on economic impacts and resiliency building for lack of financial resources or political will. This gap in capacity means that demands by policy makers and other stakeholders go unanswered.

In addition to providing information to authorities, other goals of SCAs should be to generate primary sources, build networks and communicate with stakeholders. SCAs can act as a focal point for common understanding and local discourse (Cash et al. 2002; McNie 2013; Hegger et al. 2012). They should be designed to deliver credibility, salience and legitimacy (Cash et al. 2002), and connect stakeholders to the NCA and its process.

The Gund Institute for Ecological Economics (GIEE) at the University of Vermont (UVM) joined the NCA network (Cloyd et al. 2016) to work toward these goals. In fall 2013 we undertook the VCA as a semester-long graduate student project to collect and communicate the current state of knowledge about how climate change affects our state. Student authors assembled primary data and personal testimonies to illustrate the local extent and impacts of climate change and to facilitate incorporation of climate information into local decision making.

We present a framework for engaging stakeholders in the SCA process based on the VCA experience. It uses a fluid network of scientific experts and knowledge brokers to conduct subject area prioritization, data analysis and writing. The VCA author team cultivated partnerships to establish research priorities regarding agricultural production, forests, water resources and the recreation industry. It focused on risk management and empowerment of Vermonters to act locally. Knowledge brokers communicated VCA findings through their own networks. We include a qualitative impact evaluation by brokers on their perceptions of credibility, salience and legitimacy of the process and information.

2 State climate assessment

The impetus for an assessment may originate from legal mandates, local, scientific or sectoral interest in an issue, or a query from the public. The U.S. Global Change Research Act of 1990 established the NCA; similarly, California and other states have mandated climate assessments (e.g., CA Assembly Bill 4420). Some states may have inadequate support for SCAs due to lack of political will or financial backing, even if stakeholders request them. Vermont falls somewhere in between. Executive orders established a Governor's Commission on Climate Change in 2005 and a Climate Cabinet of the Vermont State Government in 2011. The Climate Change Team at Vermont's Agency of Natural Resources (ANR) published an Adaptation Framework Report for the natural resource sectors (VT ANR 2013). These initiatives demonstrated Vermont's commitment to climate information, yet it was evident that an SCA led by higher education would be needed to address critical knowledge gaps.

The VCA process was formalized as a UVM course by the GIEE's graduate practicum in Ecological Economics. Designed to study specific problems, these practicums build on theory and methods learned in coursework. The GIEE offered this practicum as an application of climate change, economics, and social studies to Vermont case investigations. Other universities, particularly state institutions with agricultural extension programs, could conduct a similar course. There are examples, such as the University of Arizona, where a graduate

seminar produced a climate change assessment in 2015 focused on recreation on public lands. The GIEE's competitive grants program, designed for small collaborative start-up projects, funded the VCA effort.

The VCA built bridges among disciplines, scientists and decision makers, and among non-profit, government and private entities, and academia. The VCA team and external stakeholders established academic and policy goals: 1) to further scientific understanding of climate trends and variability using local historical data; 2) to develop a deeper understanding of local climate change impacts; 3) to engage local stakeholders in defining vulnerabilities, information gaps and opportunities; 4) to transmit information to a wide variety of stakeholders; and 5) to use the intellectual and social capital of our graduate program to complete this work within one semester.

As a short-term educational activity, the VCA applied service learning (SL), a pedagogy that partners students with community members to create findings. The UVM designates a course SL when an element of community engagement is connected to academic content, provided there is: a) consultancy that produces a product on a professional level for a community partner, and b) research that collects and/or analyzes data on behalf of a community partner. Students were responsible for conducting needs assessments with these partners; for example, authors of the forest chapter connected with an official studying forest carbon and climate change in the ANR Department of Forests, Parks and Recreation. In this way, students spanned boundaries to incorporate the concerns and perspectives of university and community partners. This dual accountability can be a key element in boundary management (Cash et al. 2003). These interviews provided insights into matters of concern where partners sought more information, and yielded areas where known climate impacts required further social or economic analysis.

The NCA process and publications served as a model for the VCA, with sectors tailored to state level environmental, social, and economic issues. The NCA process endeavored to balance interest in specific information desired by stakeholders, such as sea level rise predictions and storm surge potential in their own communities, while remaining concise, focused and generally comparable across regions. For the VCA, students defined chapter topics through a qualitative assessment of the economic, social, and ecological importance of sectors within Vermont. The following areas emerged from this informal assessment: community development, energy, water resources, forests, agriculture and food systems, recreation and tourism, public health, transportation, and education. No students in the class were ideal matches for public health or transportation sections, so the researchers created placeholder chapters. To provide expertise for transportation, ad hoc experts authored a brief chapter. In the following year, a student intern worked on the public health chapter as a part of a senior thesis.

The VCA relied on existing information in reports from the IPCC (IPCC 2013), NCA (Melillo et al. 2014), regional sources including the Northeastern Climate Impacts Assessment (Hayhoe et al. 2006; Kunkel et al. 2013), and local sources (Guilbert et al. 2014). Stakeholders found most map outputs inadequate because their coarse spatial resolution proved to be a greater problem in small states than in the more expansive West.

Researchers engaged in collaborative analysis of local data, starting from a baseline study of the state's climate change indicators (Betts 2011), then discussed their results with local experts. Assessments by other universities may find climate expertise through local colleges, state climatologists, regional NOAA/NWS offices, or other research groups. Work with experts from various sectors broadens the scope without overburdening any one individual. Involving local experts at the state level benefits the NCA process by providing quality

products and expanding the network of experts and stakeholders. Note that the VCA included global and national trends (Melillo et al. 2014) to frame the local context and analysis.

Expertise from meteorologists at the Burlington NOAA/NWS Weather Forecast Office and from a leading atmospheric researcher who guided data analysis aided in interpretation. Even in a small state like Vermont, multi-station analysis was important, both to understand regional variations (e.g. mountainous versus lowland areas), and to provide a "local" station with which readers could identify. The meteorologists collaborated with us on the presentation of historical data and trends.[1]

3 Framework for information uptake by local decision makers

The NCA process focuses on community building among stakeholders and authors to address the interdisciplinary nature of climate change (Jacobs and Buizer 2016; Cloyd et al. 2016). From the beginning, the VCA team created a stakeholder engagement process designed to improve the uptake of assessment information by state and local decision makers through interaction with climate researchers and knowledge brokers (Fig. 1). The VCA state climate researchers were graduate students at UVM. (In other states, these researchers might include NGOs, independent consultants, and government agencies.) The second group, knowledge brokers, transform and distribute information and create connections between researchers and their various audiences (Meyer 2010). They use their existing organizations to package and redistribute scientific knowledge. State and local decision makers are the end users of the information. Some of Vermont's diverse decision makers include local and regional planners, orchard operators, ski resorts, and town energy-efficiency groups. The VCA acted as a focal point for common understanding and discourse on local climate information (Cash et al. 2002; McNie 2013; Hegger et al. 2012).

Our framework is a web of interactions, a network, between actors (Fig. 1). Here, we focus on a few interactions within the network. Specifically, 1) State Climate Researchers to Knowledge Brokers. Knowledge brokers can provide access to decision maker networks and guidance on information gaps, and can co-produce climate information. 2) Knowledge Brokers to Local and State Decision Makers. Knowledge brokers may translate climate information for local decision makers and may distribute information through their networks to them. 3) State Climate Researchers to Local and State Decision Makers. State climate researchers distribute local information to decision makers, capitalizing on state climate trends, local climate projections, citizen science, and local identities. 4) Local and State Decision Makers to State Climate Researchers. Decision makers provide feedback to state climate researchers on the usefulness of climate information in their decision making process.

Climate assessments can only aid local and state decision makers if climate information is perceived as credible, salient, and legitimate (Lemos et al. 2012; Cash et al. 2002). Credibility is the perception by stakeholders that the information meets scientific standards. Salience describes the degree of relevancy to the audience; for example, information uptake increases when communicated at spatial and temporal scales useful to decision makers (Meadow et al. 2015). Legitimacy is the perception of the information production process and its consideration

[1] An important function of the Weather Forecast Office was to interpret long data records. Some sites appear to have extensive continuous records, but in fact the station had relocated a number of times. Without the institutional memory of the local office this might have been overlooked.

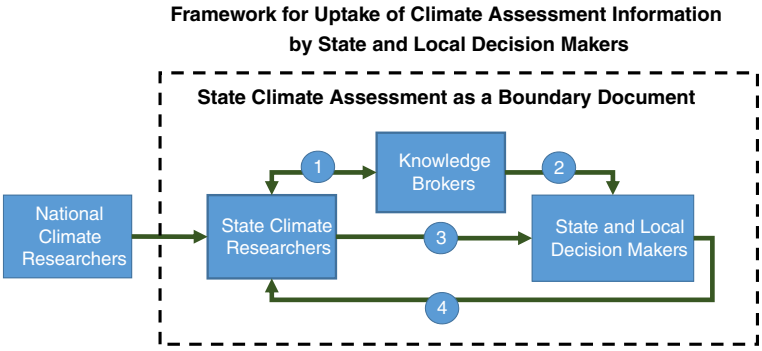


Fig. 1 Framework used in the Vermont Climate Assessment for generation and uptake of salient, legitimate and credible information (Adapted from Cash et al. 2002, 2006; McNie 2013; Hegger et al. 2012; Meyer 2010)

of the values and perspectives of stakeholders (Cash et al. 2002). The following sections delve into the framework that creates salient climate information perceived as credible and legitimate by local and state decision makers.

4 Knowledge brokers

Knowledge brokers are important in the distribution of climate information. To identify them, the VCA team utilized a modified snowball sampling or chain-referral approach. Snowball sampling can identify hidden populations where an initial sample of individuals, in this case our key knowledge brokers, provide access to others (Goodman 1961). Our initial brokers were a target sample of contacts derived from our personal networks (Spreen and Zwaagstra 1994) who then applied the snowball sampling. This strategy for involvement has weaknesses; individuals referred are never random or devoid of biases, and the process may miss more reclusive individuals. For an SCA, the lack of randomness is acceptable since individuals need a climate change knowledge base. Personal referral can be advantageous in strengthening connections within the network and increasing cooperation. The issue that individuals outside the networks of initial brokers may be missing is a serious concern. Reclusive individuals are noteworthy since in the climate assessment process they may represent populations especially vulnerable to impacts (Heckathron 1997). Ideally, ongoing development of a stakeholder network may reach hesitant potential brokers and enhance the perception of legitimacy.

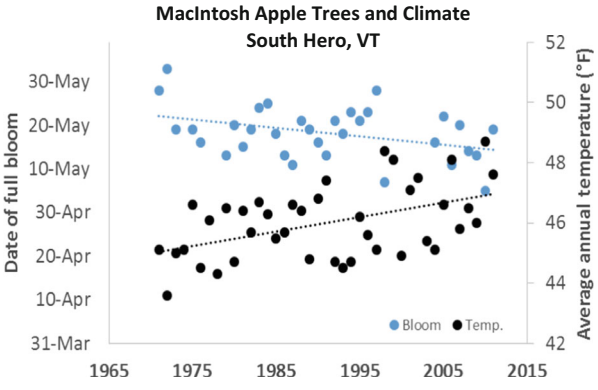
As the research progressed, the team began to collaborate with knowledge brokers such as the Dean of Extension and the Meteorologist in Charge at the NOAA/NWS Burlington Weather Forecast Office. This provided access to stakeholders in their networks. In addition, these individuals maintain personal contact with decision makers at the state and local levels. This enabled our group to build on rapport, understanding, and trust already established (Moser and Luers 2008). These knowledge brokers then identified others in their fields, communities, and organizations, so the network of stakeholders expanded and evolved over the semester.

Knowledge brokers identified local gaps in climate information and, in many instances provided primary data. For example, in the case of the energy sector, initial input on research gaps came from brokers such as the Director of the Planning and Energy Resources Division of Vermont's Department of Public Service. The Director described his role as designer of the research agenda, specifically emphasizing the need for more information on behavioral change applicable to energy

use. Most concerns of VCA knowledge brokers were addressed through literature reviews and by interpreting data in the local context. For example, poison ivy growth and toxicity in response to enhanced atmospheric CO_2 concentrations needed to be studied in Vermont if the Department of Health was to formulate advisories. The researcher produced in-depth analysis of public health effects not tracked by the state, such as changes in pollen levels, poison ivy risks, and non-PTSD mental health impacts. Such coordination enhances stakeholder perception of information and improves the efficiency of the knowledge system (McNie 2013, Hegger et al. 2012).

In a few instances, brokers worked with researchers to co-produce climate information that emphasized science and society (e.g., Buizer et al. 2016). When knowledge is coproduced in collaboration between scientists and decision makers it is more likely to be utilized by these authorities (Meadow et al. 2015) and the information process is viewed as more legitimate (Cash et al. 2006). One example from the VCA is the use of NOAA cooperative observer data at an apple farm (Fig. 2). Ray Allen collects daily weather data for NOAA and records phenological events from the orchard in his personal copy of the log books. Our team worked with Mr. Allen to digitize both the climate trends and phenological changes on his land. The growing season has lengthened by 6–7 days, and this causes McIntosh trees to bloom a week earlier than when he started to record this 54 years ago. The blossoms now coincide with the spring rains, increasing risk of fungal infections according to Mr. Allen and state extension agents.

The most engaged knowledge brokers participated in writing the VCA as co-authors or peer reviewers in their areas of expertise. This further integrated expert practitioners into the SCA process; they previewed the final analysis and provided valuable feedback to the lead authors. Invaluable feedback was also provided by engaging stakeholders who were experts in a topic area (e.g., forests and climate change) as official peer reviewers. Additional reviews were conducted by local climatologists in academia and government (although ideally an SCA should be subjected to a wider review process). This strategy meant the writing teams evolved throughout the process and ensured that climate information was salient at all stages. In the



Apple farmer Ray Allen of Allenholm Farm has been a NWS Cooperative Observer since 1971. He maintains a weather station and records data daily, including temperature minima and maxima, rainfall, and wind. Each month he mails in his records and keeps a bound book of the carbon copies where he also makes notes on spring phenology of his orchard. We digitized these records, which here are compared to observed climate records from Mr. Allen's NWS co-op station. One might assume the lengthening growing season observed in the temperature and phenological record suggests opportunities for increased apple production but Mr. Allen worries about the impacts on his orchard, "I'm concerned about global warming. A year ago, I had the worst apple crop we ever had. We spray for apple scab. When we have a wetting period, the scab spreads to the apples. We have to spray again. We had weeks when we couldn't spray because of water on the land and couldn't get in to spray." Warmer spring temperatures early in the year, when rain is heavy, increases the risk of fungal infections entering the blossoms. This creates "utility" grade fruit sold at a lower price than unscarred "fancy" grade. The risk of diseases increases frequency of spraying, which is costly, undesirable, and dangerous for tractors moving in the mud.

Fig. 2 Example of citizen science data on climate and apple phenology

future, those who contributed to the VCA may also become integrated into NCA activities through official links.

In many instances, knowledge brokers translated climate information for local decision makers. Planning managers for the state river corridors program reported communicating to stakeholders the risks of changing river dynamics using the VCA's analyses of changes in peak and base flow. Most brokers distributed information to decision makers through their existing networks. At the state level, brokers have shared the report on the NWS Burlington and ANR websites. At the town level, regional planners report sharing the document with town planners for hazard mitigation plans. Many knowledge brokers recommended that decision makers in their networks read the VCA.

5 Decision makers

The distinction between knowledge brokers and decision makers is, at times, fluid. At the state level, knowledge brokers, such as the Secretary of Natural Resources, are also making policy and recommendations. These affect the priorities and work of regional planning commissions. In turn, regional planners make local policy and serve as knowledge brokers to towns as well (e.g., hazard mitigation planning). These town plans influence individuals such as landowners, businessmen and women, and farmers, all of whom make decisions at a local scale.

Conversations with decision makers revealed an awareness of climate change and variability locally, particularly its impacts on their work. For example, following Vermonters' experiences with TS Irene, town-level emergency managers became interested in storm-ready infrastructure and floodplain corridor planning. Ski resort owners are concerned with water quality and snow consistency. Farmers are considering new crops and other methods for capitalizing on the extended growing season. Decision makers seek salient regional information such as the VCA to ensure proper responses in outreach, staffing, and policy. These decision makers respond to climate information when presented as observed state trends, local citizen science, and local identities.

Discussion of state climate trends may validate impressions and personal experiences of climate change or clarify disagreement between evidence and impressions. Most long term Vermonters perceive climate change indicators out their back door, such as shifts in phenology, lengthening of ice-free time on a lake or increased number of peak flow events on rivers. Pairing these stories with climate science piques audience interest and makes climate change personal. The statistic "the number of heavy precipitation days (greater than 1" of rain) has more than tripled in Rutland County since 1960," was reported to the Rutland Regional Planning Board. These members commented that this quantified their own experiences and bolstered climate information credibility. This is the type of statement in straight-forward language that affirmed changes decision makers had observed; many volunteered stories of how this affected their community. The VCA also used an example from Joe's Pond, where the lake association holds a contest to guess the date the ice melts, as measured by a cinder block that crashes through the ice and unplugs a clock anchored on shore. This is a local news highlight. The data begin in 1983 and show that, on average, ice off is now occurring 5–6 days earlier than in the 1980's. Vermonters have long been familiar with Joe's Pond Ice Out; the VCA refocused the event through the lens of climate change. Historical changes in climate may not reveal the variability or acceleration of climate trends but observed changes often resonate with decision maker's experiences or identification with proximity to the site of the measurements. Acceptance of these historical patterns is the basis for interpreting future

scenarios of change, so to identify changes already underway increases comprehension of scenarios for the future. Thus historical trends were presented to introduce future climate change, with further authority and understanding provided by local vignettes from citizens.

The VCA discovered rich citizen records of climate and climate change impacts that gained salience by associating a human voice, a memorable story or personal observation with a climate record. Exchanges with citizen scientists regarding their experiences, such as with Mr. Allen (Fig. 2) also greatly enhanced the VCA. "Reality checks" of decision makers' personal experiences are an important part of framing risk management and opportunities for resilience. This is a strategy similar to the NCA's 2014 rollout event; for example, a county commissioner in Florida commented on the voided warranties of police cruisers due to salt water damage from flooded streets during high tides exacerbated by sea level rise. Such narratives are more accessible to the lay person than graphs and numbers and are compelling because of the human dimension. The use of SCAs to collect quantitative and qualitative data from citizens may feed directly into future NCA reports to give them immediacy and make them more salient.

For communication involving climate change and variability, important regional, state and sub-state level differences, such as in governance and cultural identifications, must be recognized (Moser 2014). Early stakeholder engagement brought to our attention the significance of "resilience" in the Vermont vocabulary and in local governance. The VCA defined resilience as the capability of both social and natural systems to respond to and recover from climate change and variability. Typically, adaptation (adjustments made by social ecological systems to reduce vulnerability) and mitigation (processes that moderate climate disruption through reduced contributions to emissions) are used to talk about climate change action and preparedness. Adaptation can present new opportunities that take advantage of specific changes in climate, such as growing crop varieties that require a longer growing season. Mitigation and adaptation are linked, in that effective mitigation reduces the need for adaptation. Vermont has embraced "resilience" as a way to incorporate adaptation and mitigation in policy, lifestyles, infrastructure development and planning, and as an essential component of a comprehensive response strategy.

One reason Vermonters use the word "resilience" regularly is due to Vermont Act 16 of 2013, passed following the devastating effects of TS Irene in 2011. This law requires each town plan, updated every five years, to include a resiliency plan that addresses flood preparation. The resiliency plan may include zoning, infrastructure improvements and relocation. Today, "resilience" resonates with Vermonters as an empowering term to describe anticipated actions needed to manage risk under climate disruption. It presents opportunities for new ventures and development as well as management of risks to businesses, communities, infrastructure, and food systems. Resilience is also replacing adaptation at the federal level, a shift that highlights the need for climate communications to be responsive to the social milieu. Other regions may have additional language or policy frameworks where SCAs can be responsive.

The sections above outlined the VCA framework for climate information uptake, emphasizing the role of local knowledge brokers and information delivery that focuses on state trends, citizen science, and local identities. The next section shows the results of our qualitative research with local knowledge brokers and decision makers.

6 Qualitative assessment of impact

In order for climate information to be used by decision makers, it must be relevant to the audience (salient), meet scientific standards (credible), and perceived as legitimate (Lemos

et al. 2012; Cash et al. 2002). In order to assess the effectiveness of our framework for uptake, the researchers surveyed VCA knowledge brokers and decision makers. Qualitative questions focused on the VCA development process (identification of information gaps, material co-production) and project outcomes (climate information communication and distribution). Nine of our initial brokers responded to the survey. This information was augmented by transcription of four speeches by knowledge brokers at the roll-out event, and the survey response of two regional planners who identified themselves after the roll-out. The surveys and transcripts were coded for saliency, credibility and legitimacy themes.

All respondents emphasized the saliency of the information for decision making. There are excellent examples of this. Knowledge brokers from NOAA/NWS used portions of the VCA roll-out presentation at the Vermont Emergency Preparedness Conference. The Secretary of ANR noted, "We can use this to make our policies around managing the pollution to Lake Champlain." Regional planners put the VCA into practice: "The report's data and predictions aided us in making our flood resilience and extreme weather related decision for our Regional plans, some Municipal plans, and some local hazard mitigation plans."

Knowledge brokers noted the credibility of VCA in our survey. The Secretary of the ANR noted that "we need to act on good science and good data," in reference to the VCA content. Two knowledge brokers linked the VCA from their webpage for reference by their stakeholders. Another noted that the "deep collaboration" between the student scientists and knowledge brokers "leads to credibility." One knowledge broker specifically mentioned that they "recommended decision makers to read [the VCA]."

Legitimacy was demonstrated by the brokers who requested sustained partnership. Typical comments expressed that, "we need continued information. This can't be a one-time thing." Other knowledge brokers suggested an "ongoing partnership with the GIEE" to continue to produce climate information. Another stakeholder commented that "this assessment is a great foundation from which to continue that conservation and move forward." Another point of legitimacy identified by a knowledge broker was the use of official local data analysis (e.g., NOAA/NWS) and citizen science records.

7 Conclusions

It seems the overall framework for interaction between scientists, knowledge brokers and stakeholders is an effective structure for SCAs based on qualitative feedback from knowledge brokers.

Knowledge brokers who identified the messaging or research questions within each sector focused the scope of assessment and minimized information gaps. Diagraming relationships and sectoral coverage within an SCA framework may help insure that the SCA is representative and may reveal new connections to include. On-going communication within the network will strengthen relationships, according to our knowledge brokers. In the case of one broker, repetition of information was an important dissemination suggestion since their stakeholders were busily occupied with a large river corridor planning project at the time of the VCA roll-out. Another way to approach communication is to issue annual updates, as suggested by several brokers. Sustained communication within the network would generate new directions for salient topics as stakeholders' needs evolve or respond to events like TS Irene. One addition to the implementation of this framework would be to draft SCA goals with specific criteria for evaluating successes.

In structure, SCAs have the opportunity to span boundaries so as to move science into the policy realm with the aid and input of knowledge brokers. The VCA has been an integrating activity that helped brokers and stakeholders within the state develop a shared understanding of the local impacts of climate change and variability. It is an example of how SCAs can effectively manage boundaries to link salient, credible and legitimate climate information to local decision making. The SCA document can be a focal point for common understanding and then becomes a coordination device.

There may be trade-offs among professional or student authors. Many knowledge brokers lacked the expertise and time to conduct the primary data analysis presented in the VCA, so highly engaged students were beneficial. The challenge of a collaborative student project of one semester cannot match the professional expertise of the Northeast climate report produced under the NCA process (Kunkel et al. 2013) but such local authors may be constrained by funding, logistical or time limitations. The most engaged knowledge brokers participated in writing the VCA as co-authors or peer reviewers. This further integrated expert practitioners into the SCA process; they previewed the final analysis and provided important feedback to lead authors. Invaluable feedback was provided by stakeholders who were experts in a topic area (e.g., forests and climate change) as peer reviewers. Additional appraisal was conducted by local climatologists in academia and government (although ideally every SCA should be exposed to a wider review). This strategy meant that writing teams evolved throughout the process and ensured the significance of the climate information at all stages.

Use of student authors risks unevenness and lack of expertise or limited knowledge and requires flexible strategies for filling gaps. It is a challenge to anticipate student fields of expertise; in our case, they typically register one week before classes. To cover sectors outside the graduate students' expertise we had an honors student to work on a health chapter. This worked well because the student was highly self-motivated, the reward to the student (senior honors) was high, and input was available from knowledge brokers. For transportation, we turned to researchers to draft a brief placeholder chapter who ran late according to our timeline, leaving little opportunity for feedback. Seek to anticipate such gaps and recruit additional authors well in advance, provide a clear structured outline, and require draft reviews.

Our service learning structure developed mentorships between students and brokers that seemed to promote the quality of engagement and communal ownership of the product. More work should consider the relative types of engagement among students or professional experts with knowledge brokers. Service learning partnerships have spillover benefits, such as social capital to invite guest speakers to courses, student publications (e.g., Palchak et al. 2015), collaboration on projects, and opportunities for student experiences (e.g., internships). In several cases, student experiences with the VCA provided job qualifications or direct connections to future employers. Ideally, a plan to track educational outcomes would be developed to assess impacts. This has been done informally through follow-ups with students on presentations and job opportunities.

Feedback on information dissemination illuminates areas where modest investments could have large impacts. For example, knowledge brokers often commented that they used VCA graphics to communicate climate change information to their stakeholders, but that even more would have been useful. Additional communication opportunities could come from graphic consultants or students in communications or design. Knowledge brokers suggested that a four-page summary would be useful in addition to the 10-page summary and full report; several sources recommended this specific length. Adoption of the linguistic style that brokers commonly use with stakeholders would also help with communication; for example, terms used in hydrology may be different than those used by policy makers with regard to flood zones.

There are ample opportunities for synergetic interaction between NCA and SCAs activities. The NCA writers may take a leadership role in fostering a community of practice among SCA agents. Perhaps the next step forward would be to develop a network of higher education partners who engage in state level assessments, share ideas, and learn from one another. The NCA network may be able to facilitate pairing of local experts with SCAs through their enduring relationships with participants as well as provide access to local data sources, knowledge brokers and other resources (Cloyd et al. 2016).

Increased SCA coordination with the NCA process will help to integrate messaging on global and national components of climate change with state level concerns, thus increasing the reach of the NCA, while at the same time enhancing the communication strategies at both levels. Future SCA coordination with the NCA's sustained assessment process could build local context to complement NCA topics, thereby providing an information feed to the NCA, and a local outreach context for NCA results. In the future, SCA knowledge brokers could also become integrated with the NCA program through official links. The VCA reached beyond the NCA network to knowledge brokers who might not engage at the national level due to time or job constraints. The SCAs can provide another contribution by feeding case studies or local information to enhance the NCA's work. For example, the University of Arizona graduate students that produced a recreation impacts assessment will submit the report for consideration in the NCA sustained assessment process. Local features of climate change in SCAs, such as citizen science and personal narratives, help communicate the real challenges facing our country. Course-based SCAs conducted at regular intervals would complement the NCA process as it moves toward a sustained, rather than periodic, assessment process. A well-coordinated system of university-based assessment efforts could be transformative for both the states themselves and for the NCA.

Acknowledgments This work was supported by a collaborative grant from the Gund Institute for Ecological Economics at the University of Vermont. G. Galford was supported by the Gund Institute. G. Galford, A. Hoogenboom, K. Underwood and A. Betts were supported by Vermont EPSCoR with funds from the National Science Foundation Grant EPS-1101317. UVM's Office of Community-University Partnerships and Service Learning provided Service Learning course designation and a teaching assistant. Vermont Agency of Natural Resources, the state climatologist, Dr. Dupigny-Giroux, UVM Extension, SkiVermont, Vermont Tourism and Marketing, Green Mtn. Power, VT Department of Public Service, VT Agency of Education, and Vermont Natural Resources Council provided important feedback on the concept and content.

The views expressed are those of the authors and do not necessarily represent those of the National Weather Service.

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