Research

Citizen science and natural resource governance: applying a resilience framework to vernal pool policy innovation

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1.

ABSTRACT

2. This paper applies a resilience lens to the development of a 15-year citizen science and vernal pool
3. regulation program in Maine, USA. We describe how citizen science improved adaptive capacities for
4. innovative policies related to vernal pool regulation. We identified three core program elements
5. that promoted adaptive capacities, including how citizen science efforts: (1) generated knowledge
6. about the system; (2) enhanced networks across institutions and communities of expertise; and (3)
7. fostered multiple forms of leadership. These elements allowed the identification of and capacity to
8. act within narrow windows of opportunity for policy development. If citizen science program leaders
9. intend to promote social-ecological systems resilience and natural resource policies as key
10. outcomes, we recommend they create a system for internal project evaluation by partnering with
11. social scientists; publish scientific studies using citizen science data; pursue resources for
12. program sustainability; and plan for leadership diversity and informal networks to promote adaptive
13. governance.
14. Key words: Citizen science; vernal pools; natural resource policy; adaptive governance; leadership

15.

INTRODUCTION

16. Wetlands have long held a revered status in diverse cultures such as the Marsh Arabs in southern
17. Iraq (Young 2011) and the pre-Incan Uros people of Lake Titicaca (Gallagher 2007). Unfortunately,
18. weaving wetlands into a shared cultural fabric has largely not occurred in the United States where
19. wetlands have historically been viewed as places that concentrate disease and dangerous animals

(e.g., malaria, poisonous snakes, and biting insects) and as barriers to building and agriculture (Vileisis 1999). Since European colonization and until the early 1970s, wetlands have been extensively filled and degraded (Dahl and Johnson 1991). The decline of waterfowl species sparked concern for this disappearing resource and in the early seventies a national wetland regulatory framework, the Federal Water Pollution Control Act (now the Clean Water Act), was passed. A minority of states subsequently developed wetland regulations, yet there was strong public outcry and court cases focused on private property rights and overreaching government regulations (i.e., U.S. versus Solid Waste Association of Northern Cook County in 2001; U.S. versus Rapanos in 2006). Vernal pools, relatively small, ephemeral ponds widely distributed on private property in the eastern U.S., were inadequately protected at federal and state levels. As a result, their loss through filling for development and agriculture went largely unhindered. Federal and state-listing of vernal pool fauna in New England heightened attention for the need to conserve this resource (Calhoun and deMaynadier 2008). Yet, the addition of another layer of wetland regulation resulted in regulatory backlash that prompted ecologists, regulators, policy makers, and citizens to organize and participate in public hearings on proposed vernal pool regulations. In Maine, the resistance to top-down regulation was magnified by state vernal pool regulations passed in 2007. Ecologists and regulatory agencies tasked with stewarding vernal pool resources acknowledged that the current regulatory strategy was failing and they needed a more adaptive approach (Calhoun et al. 2014, Hart and Calhoun 2010).

In response to this need, ecologists, regulators, non-profit organizations, local officials, and citizens initiated a citizen science program to collect information and educate people about the importance of vernal pools (Jansujwicz et al. 2013). The multiple stages of this citizen science program promoted regulators' and scientists' abilities to create adaptive vernal pool regulations. A growing body of scholarship demonstrates the impact that citizen science programs can have to generate valid data and promote learning, attitude change, and ecological identities (Brossard et al. 2005, Bonney et al. 2009, Crall et al. 2012, Jordan et al. 2012). However, as Shirk et al. (2012) describe, the process of designing citizen science programs to promote specific types of outcomes, like adaptive natural resource policies for social-ecological systems (SES) resilience, is nascent. In this paper, we respond to the need to better understand the relationship between citizen science program elements and the emergence of adaptive forms of governance for SES resilience by asking: what elements within the citizen science program promoted the vernal pool regulatory policies that formed? We apply a resilience framework to the analysis of this 15-year program of citizen science and policy development (Chapin et al. 2009, Folke et al. 2010, Olsson et al. 2006). Resilience is an appropriate theoretical framework because it allows us to address vernal pools as linked SESs and provides a lens on specific elements that shape adaptive capacities and governance (Folke et al. 2010). We conclude with recommendations for how citizen science programs can be

designed to promote policies that address the complex challenge of natural resource regulation.

Citizen science, vernal pools, and resilience

What is citizen science?

Citizen science is an effort to involve people in scientific research processes. This approach is characterized as the "engagement of non-professionals in scientific investigations-asking questions, collecting data, or interpreting results" in partnerships that usually include scientists and those who do not have formal science training (Miller-Rushing et al. 2012: 285). Citizen science can improve abilities to collect, provide access to, and ensure the validity of scientific data (Bonter and Cooper 2012; Dickinson and Bonney 2012). Citizen science also focuses on understanding environmental change (Dickinson et al. 2010) and promoting ecological literacy and ecosystem stewardship (Couvet et al. 2008; Crall et al. 2012; McKinley et al. 2012). Planning for specific types of outcomes at individual, programmatic, and SES scales can help identify elements that may promote outcomes like the development of scientific knowledge, enhanced leadership roles, or the ability for ecosystems and communities to effectively respond to change and self-organize (Jordan et al. 2012; Shirk et al., 2012).

What are vernal pools?

Vernal pools in the northeastern and mid-western U.S. and Atlantic Canada are relatively small (often <0.2 ha), temporary ponds embedded in forested landscapes. They typically dry every year, refill in spring, and provide key breeding habitat for a suite of invertebrate and amphibian species adapted to life in temporary waters (Colburn 2004). In New England, signature species include wood frogs (Lithobates sylvaticus) and a number of ambystomatid salamanders (Ambystoma spp.). The adults breed in the pools for a short period each spring or fall and spend the rest of their life cycle in surrounding forests, often at distances of hundreds of meters from the breeding pool (Calhoun and deMaynadier 2008). Vernal pools offer several challenges to effective and efficient documentation including:

1. Ephemeral resources embedded in forests are hard to pre-identify and map;
2. Documentation of vernal pools is limited to one season;
3. Pools are seemingly abundant and viewed as unnecessary to protect;
4. The amphibian signature species are not animals the public relates to easily;
5. Pool-dependent species require from hundreds of meters of relatively undisturbed forest connecting to other pools and wetlands to persist.

These challenges thus require uniquely tailored approaches to management, which citizen science can offer.

Why citizen science for vernal pool mapping and assessment?

The State of Maine considered regulating vernal pools in the late 1990s but legislators lacked data on the resource and could not craft a regulation with limited knowledge of vernal pool distribution, characteristics, and functions. Furthermore, the term "vernal pool" was not part of the public lexicon and resistance to regulation of an unknown resource was likely to be strong (Johnson and Pflugh, 2008). Because vernal pools are widespread and ephemeral, an inventory by federal or state agency representatives would have been time consuming and expensive. Raising public awareness and collecting data on characteristics (e.g., use by breeding amphibians and other animals, hydrology, physical setting) was essential for laying the foundation for regulation. At the time, citizen science was increasingly being used as way to simultaneously collect difficult-to-gather ecological data and raise awareness about ecosystems (Miller-Rushing et al. 2012). Program coordinators adopted citizen science as a first step in what would become a sustained and successful effort to regulate vernal pools in Maine (Calhoun et al. 2003, Calhoun et al. 2014).

How does resilience thinking help us understand citizen science outcomes?

Resilience thinking is a way to understand relationships between people and environments (Folke et al. 2010). The ability to anticipate and respond to change is a key resilience feature known as adaptive capacity, which depends on learning (Chapin et al. 2009) and can lead to adaptive governance in the form of flexible policies and institutional rules (Folke et al. 2005). Information sharing and learning allow people to understand what is happening within system, anticipate how that system might change in future, and collectively determine how to respond (Olsson et al., 2006).

Leadership and networks also influence how people create adaptive forms of governance (Folke et al. 2002; Lebel et al. 2006; Olsson et al. 2006). In their comparison of five cases, Olsson et al. (2006) conclude that adaptive governance "seem[s] to be preceded by the emergence of informal networks that help to facilitate information flows, identify knowledge gaps, and create nodes of expertise of significance for ecosystem management that can be drawn upon at critical times" (p. 12). These flexible networks may play a key role in promoting governance in a wide range of ecosystem management contexts (Anderies et al. 2006; Goldstein 2008; Sendzimir et al. 2008). A citizen science program may contribute to the formation of adaptive governance if it fills knowledge gaps, operates outside of the constraints but still maintains connections to formal government, and helps build relationships among citizens, researchers, and policy makers (Lowman et al. 2009; McKinley et al. 2012).

A CASE STUDY OF CITIZEN SCIENCE AND ADAPTIVE GOVERNANCE

Here we apply a resilience lens to four distinct phases of a 15-year vernal pool conservation initiative to describe how a citizen science program enabled innovative vernal pool policy mechanisms to emerge. Our case study draws from an extensive set of published articles that describe different parts of this effort (e.g. Calhoun et al. 2014; Calhoun and Reilly 2008; Calhoun et al. 2003; Oscarson and Calhoun 2007). We also analyzed an archive of manuscripts and data generated by social scientists associated with the project who were studying municipal official perceptions about vernal pools (McGreavy et al. 2012); landowner and municipal official perceptions about the citizen science programs (Jansujwicz et al. 2013); and the role of collaborative networks in creating innovative vernal pool policy (Levesque et al. under review). We drew interview quotes from this latter and most recent component of the broader research program, where researchers conducted key informant interviews (n=27) with participants who attended three or more of the Vernal Pool Streamlining Working Group meetings described in detail below. We also reviewed project documents and reports, websites (Calhoun et al. 2010), and a documentary produced by the Maine Public Broadcasting Network, Pools, Policies, and People (http://video.mpbn.net/video/2282308778/). Finally, we engaged in a retrospective analysis based on our respective participation in the development of the citizen science and regulatory programs (Patton 2002).

Citizen science program and regulatory development phases

Initial attempts to develop regulations for vernal pools in the early 1990s identified the need for science to improve basic knowledge about pool ecology. Because vernal pools are so widely distributed across the landscape and the peak of activity occurs during a relatively brief window in spring, citizen science became a key strategy to fill data gaps. The Very Important Pool (VIP) program (1999-2004) trained 52 citizens to collect data on approximately 300 vernal pools in 4 towns in southern, central, and northern Maine. The primary objective was to assess pool physical characteristics, landscape setting, and presence of pool-breeding amphibians (Calhoun et al. 2003).

In the second phase of this process, citizen science data were used in peer-reviewed scientific articles about vernal pools (e.g., Calhoun et al. 2003, Calhoun et al. 2005, Oscarson and Calhoun 2007) and regulatory changes. The rigorous science associated with the program provided credible information to support the changes to Maine's Natural Resource Protection Act in 2007 to regulate a subset of vernal pools classified as Significant Vernal Pools. The identification of significance criteria and the resulting legislation used citizen science program data to set egg mass thresholds and timing for pool surveys.

Although the citizen science program provided useful data, the regulation was still highly controversial (Calhoun et al. 2014). The Vernal Pool Mapping and Assessment Program (VPMAP), which occurred as the third phase of the case study from 2007-2012 was prompted by the regulatory backlash from the 2007 legislation. VPMAP was designed to help towns pre-identify regulated pools and provide maps to town officials, landowners, and developers (Jansujwicz and Calhoun 2010). This program was implemented in 14 towns where more than 130 trained citizen scientists collected data needed for legal assessments of vernal pools on private properties. The objective was to provide the State, municipalities, and landowners with a database of regulated pools to allow for informed planning and regulatory predictability (Jansujwicz et al. 2013).

The Vernal Pool Streamlining Working Group (VPSWG) was an outcome of VPMAP's effort to promote informed planning and regulatory predictability and was the fourth phase of the case study. This working group started in 2010 as a small group of concerned individuals including authors Calhoun, Levesque, 1 federal regulator, 2 state regulators, and 1 UMaine graduate student. Over four years this group grew into a formal entity with more than 50 stakeholders focused on producing local alternatives to conserve vernal pools. Pilot projects to test new regulatory approaches for a local, incentive-based conservation mechanism for pools are currently underway in two towns. This market-based fee mechanism provided an alternative to federal and state vernal pool regulations whereby loss of pools in growth zones resulted in development fees to remunerate landowners in exchange for enhanced protections in rural areas. To incorporate this new option into Army Corps of Engineers regulatory authority, the group has to craft a Special Area Management Plan (SAMP) for vernal pools. A key component is the citizen scientists work which mapped and assessed pools. All municipalities in New England who want to invoke the SAMP will likely have to emulate the Maine citizen mapping program to be eligible for this new regulatory mechanism.

As an alternative to the top-down regulatory mechanism, the VPSWG represents an adaptive approach to governing this resource. This model of adaptive governance intends to promote the persistence of vernal pools on the landscape and at the same time provides municipalities with the capacity to effectively regulate and manage the resource for its multiple values. How did this outcome emerge? What elements of the citizen science programs enabled the development of this innovative policy and adaptive governance mechanism? To address these questions, we take up a resilience thinking lens to explore elements that promote the persistence of vernal pools within the landscape and the adaptive capacities of people who manage and regulate them as a linked SES (Folke et al. 2010).

APPLYING A RESILIENCE LENS TO CITIZEN SCIENCE

Each stage in the citizen science and regulatory process built upon previous work. One interview participant described the development of the vernal pool regulations as having "come out of an initial stage of inventorying and involving citizen scientists and so forth, which in turn emerged out of a stage of new vernal pool regulation, getting them incorporated as significant habitat...So it's been incremental. It's been building." A resilience thinking framework allows us to better understand these incremental stages and identify key features that enabled the subsequent adaptive policy (Folke et al. 2010; Folke et al. 2005; Olsson et al. 2006).

We identified three core elements associated with the citizen science program that promoted adaptive capacity, including (1) improved knowledge about the system; (2) enhanced networks across institutions and expert domains; and (3) the development of multiple forms of leadership. These integrated program elements helped identify and built capacity to act within windows of opportunity to address problems and implement solutions (Olsson et al. 2006).

(1) Improved knowledge about the system

The ability to anticipate and plan for change, a defining feature of resilience, depends on learning (Gunderson 1999; Pahl-Wostl et al. 2007). Effective learning requires credible and useful knowledge and science is important method for producing such knowledge. However, many scientific questions, and especially those that encompass broad spatial or unique temporal scales, are difficult to answer with traditional methods in which small teams of highly trained specialists go into the field alone in small areas or for relatively limited amounts of time.

In the case of vernal pools, there was an early need to better understand the habitat requirements, amphibian movement patterns, and reproductive efforts of vernal pools species and distribution of different vernal pool types across a very broad geographic area. Citizen science was essential for collecting data and filling knowledge gaps about vernal pools. The information on reproductive effort collected by citizen scientists was used by biologists reporting to the state legislature during the initial legislative hearings. The value of the contribution of citizens was validated when special language was added in rule-making that recognized the validity and acceptance of data collected by trained citizens for submission to the state database of recognized exemplary pools (Natural Resources Protection Act, 38 MRSA, Chapter 335). Simply collecting data may not have been sufficient to provide the information to support regulatory action. The fact that these data were also incorporated into formal peer-review gave the citizen science-generated data the credibility that it needed to withstand the scrutiny and deliberation that occurred in the regulatory process.

The development and dissemination of education and outreach materials also helped raise awareness

about vernal pools. The VIP project produced The Maine Citizen's Guide to Identifying and Documenting Vernal Pools which was widely distributed to citizens and the forest industry and updated in 2002 and 2014. Two lay manuals--Best Development Practices for Development Around Pools and Habitat Management Guidelines for Forestry--provided tools for voluntary stewardship of pool resources and to engage key stakeholders. Project leaders hosted more than 50 workshops and public presentations for foresters, land trusts, schools, nature clubs, and various other citizen groups. As one municipal planner described: "I knew virtually nothing about vernal pools before this project. I had no idea ... that they potentially dried out every year and that they provided so much biomass for other things to live on." In 2007, a statewide study of local decision makers demonstrated that a majority of planning board members were familiar with the term vernal pool and expressed positive attitudes towards vernal pools in general (McGreavy et al. 2012).

As awareness of the concept of vernal pools started to grow, program leaders noted increases in citizen responses to education efforts, higher attendance at public hearings, and increases in the number of hits on the project website (2009 to present, 62,000 hits). One municipal official described how the increasing awareness promoted the capacity for subsequent efforts within their town and another town to survey vernal pools: "The Council invited [a University representative] to come in and talk about vernal pools because the council didn't really understand them at the time. I think that's blossomed into a wonderful relationship. We've done the survey. Did [other town] do a survey? (Interviewer: Yes.) The same kind of thing? (Interviewer: Yes.) I think that's just great." As these quotes demonstrate, the citizen science and education activities in the early years of the program were foundational to the development of the flexible governance and policy mechanisms. These programs generated the scientific information that supported decision making and policy development while at the same time educating important stakeholders about the ecology and importance of vernal pools.

(2) Enhanced connectivity across institutions and domains of expertise

Connectivity and diversity can shape how SESs respond to change (Folke et al. 2005). The diversity of participants and their degree of connectedness influence the flow of information, learning, and the development of insights for problem solving. A diversity of perspectives about wetlands provides a range of knowledge while connectedness can facilitate deep deliberation, both of which contribute to social learning (Heikkila and Gerlak 2013; Leach and Sabatier 2005). The connection between individuals at multiple government levels can improve the translation of science and proposed solutions into regulatory action (Hart and Calhoun 2010) and promote governance legitimacy (Cosens 2013).

The citizen science program brought together representatives from universities, municipalities,

non-profit organizations, and citizens who participated in the program in different ways. In VPMAP university representatives were largely responsible for coordinating the project and generating outputs like the municipal vernal pool assessment and digital database (Jasujwicz et al. 2013). Municipal officials recruited volunteers for the program, hosted training sessions, organized and disseminated data collection materials, and requested landowner permission for citizen scientists to survey their property. Meetings that brought together representatives from multiple towns allowed learning about program activities such as the design of landowner letter, compilation of vernal pool maps, field data sheets, and citizen scientist recruitment. These meetings provided an opportunity for social scientists to solicit feedback from municipal officials and provide recommendations for program implementation (Jansujwicz et al. 2013). Landowners were also invited to join citizen scientists in the property surveys. The new connections among different types of institutions opened up ways for information to flow across these entities and across scales of governance. The focused yet flexible program structure also allowed individuals to take on diverse leadership roles that promoted adaptive capacities.

(3) Fostered different forms of leadership through program participation options

Increased information sharing through enhanced networks allows people to apply their improved understanding of the system for adaptive decision-making. However, the ability to apply knowledge for policy changes also relies on effective and diverse forms of leadership (Folke et al. 2005; Gunderson et al. 2008; Olsson et al. 2006). In their synthesis of citizen science programs, Shirk et al. (2012) advocate for deliberate program design with multiple options for participation to promote specific outcomes, like the development of leadership roles at an individual scale and resilience at an SES scale.

As described above, VIP and VPMAP offered multiple options for participation, aligned with individual preferences and strengths. Participants could choose to contribute data, collaborate with project leaders and town officials, and co-create different parts of the research and program design and thus were able to identify what worked best for them and grow within that role (Shirk et al. 2012). For example, at training sessions volunteers could choose the number and location of pools they wanted to monitor. They could also serve as mentors to other volunteers and work with town officials on mapping-related tasks.

The flexible yet focused program structure allowed diverse forms of leadership to emerge. We identified distinct leadership roles across the phases of this case study, including visionary, spanning and network, integration and communication, and problem-solving (Folke et al. 2005; Gunderson et al. 2008; Olsson et al. 2006). We highlight key leadership roles and provide additional details in Table 1. Visionary leaders helped the group set a clear agenda and provided the sustained

motivation and institutional memory from one phase to the next. The University-based ecologist and program coordinators were essential in this role, as demonstrated when one interview participant said to a program coordinator "[You]...played a really key role of energy and direction, so keeping the ball moving, responding to questions that at the time we didn't have answer to, bringing information back to the group that allowed the conversation to continue in a constructive fashion. I would say that your unit has been like the spark plug." Not only did these leaders provide the continuity between program phases, their vision and motivation served as the *spark plug* to initiate and sustain efforts within the group more broadly.

The spanning and network leaders were instrumental in moving across institutional scales, making connections among diverse groups, and promoting the legitimacy of the governance (Cosens 2013). This leadership clearly emerged from the second structural element in which participants from diverse institution were invited and encouraged to participate. The representatives from the Army Corps of Engineers, town planners and other municipal officials were key spanning and network leaders. Frequently, these leaders used the project documents such as maps and educational materials as boundary objects that helped facilitate these connections (Calhoun et al. 2014). This program feature is demonstrated when one planner said "Some people would come in and meet with me, look at the map, and try to understand where the pool was." Planners became a network contact who could listen to landowner questions, provide information about the project, and facilitate getting answers from scientists. This role helped promote connections and information sharing but it also improved the legitimacy of the adaptive governance. In addition to the local governance role played by key municipal officials and town planners, the consistent participation of the representatives from Army Corps of Engineers further enhanced cross-institutional coordination and governance legitimacy. As one participant noted: "Without [Army Corps representative], there would have been no federal approval of this and things would have stopped." The multiple scales of leadership thus helped build local capacity for understanding regulations and vertical and horizontal networks that promoted coordination among leaders with different but potentially overlapping authority (Cosens 2013).

In terms of leading integration and communication, the social scientists on the project and influential state and town planners became important leaders. The social scientists conducted participant observations, interviews, and focus groups in which they documented perceptions about the project and then fed their findings back to project coordinators to improve program implementation (Jansujwicz and Calhoun 2010, Jansuwicz, Calhoun, and Lilieholm 2013). One state planner who participated in the citizen science and policy development phases, was particularly influential in communicating the need for vernal pool regulation in municipalities and state legislature. This person's role was described in an interview when a participant said "[This person] is sort of the last woman standing in terms of planning efforts in the state of Maine. She

successfully gets the ear of her committee and elected officials, so I think she's a great promoter at the state level in terms of 'Why we're doing this, why it's important to hold onto growth planning, what we have left, and here's an example of how it meets the needs and interests of the current administration.'" Town planners played a similar role yet on a different scale as one said: "What I tried to stress was that...this is a law. People are going to have to deal with vernal pools, and if we can proactively identify them, we are going to assist people. We are going to ease development by knowing ahead of time what is or is not on their property. And I think that was really the selling point." This town planner helped communicate the need for coordinated efforts and how this was a problem-solving opportunity.

Problem solving became an important leadership role, one played by the town planner above and also frequently adopted by the citizen scientists themselves. These individuals were able to identify needs for creative solutions and additional capacities. Two towns in particular did not have the municipal capacity to participate, lacking town planners and other resources. Recognizing to reconcile the need to solve the problem of limited capacity, citizen scientists in these towns stepped in to coordinate mapping and provide other organizational support that was needed.

CONCLUSION & RECOMMENDATIONS

Our case study analysis demonstrates core elements within the citizen science program that enabled the development of an innovative vernal pool regulation. Knowledge about system interactions and status, networks that help move knowledge across domains, and diverse leaders who promote responsiveness allowed the identification of and capacity to act within windows of opportunity (Olsson et al. 2006). These citizen science program elements promoted adaptive capacity so that when opportunities to advance vernal pool regulatory approaches arose, an informed and connected cadre of citizens and collaborators was ready to act (Table 1). How can these insights be applied to citizen science program development? The following recommendations are intended as points of reflection for programs where the goal is to promote adaptive governance for complex natural resource management issues.

Create a system for internal project evaluation and learning.

While the citizen science program promoted SES resilience, it is important to note that perspectives about the citizen science program were not uniformly positive. The communication among the coordinators, municipal planners, and landowners in the VPMAP program needed improvement, as information transfer is often challenging. (Jansujwicz et al. 2013). The social scientists' participation allowed the identification of these and other issues. Program coordinators could then

adjust the program for improved information sharing, relationship development, and related outcomes.

Publish scientific studies using citizen science data.

Data collected by citizen scientists can be comparable to those collected by trained experts (Kremen et al. 2011; Oscarson and Calhoun 2007). However, one cannot expect policy makers to have familiarity with demonstrated validity of this method. When a citizen science program intends to provide data to inform a regulatory process, it may be essential to subject those data to peer review and publishing. Incorporating formal recognition of the validity of citizen science data in rule-making can also improve the status of citizen science data in natural resource policy.

Pursue resources for program sustainability.

Towns involved in the mapping program appreciated in-kind or direct financial support. The program coordinators garnered funds from private foundations, NGOs, state agencies, UMaine, and the National Science Foundation. Four graduate students devoted their graduate work to the citizen science and mapping programs and their outcomes. These resources helped maintain and expand program phases and constituted an important contribution from the visionary leaders.

Plan for leadership diversity and informal networks to promote adaptive governance.

Programs that allow participants to choose from a range of participation options may be well-poised for innovation. Program planners can encourage diverse leadership by inviting participants from different scales of government and institutions like municipal planners, land trust representatives, and federal regulators. These participants enhance the learning, connectivity, and problem-solving potential in groups and, as our vernal pool case shows, can promote adaptive forms of governance to address complex natural resource policy issues.

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Table 1. Table 1. Diverse leadership roles and examples of how knowledge, networks, and leadership promoted the capacity to act within windows of opportunity.

Leadership Type[1]	Description	Example and Quotes from Case Study
Visionary	Help the group set a clear agenda and provide the sustained motivation and institutional memory between phases	-Program coordinators and ecologists based at UMaine shaped the science and regulatory efforts, built trust among participants, provided sustained resources for project continuity, and maintained institutional memory between project phases.
Spanning and Network	Able to move across scales of government and institutions and adept at making connections across groups	-Representatives from the Army Corps of Engineers spanned governmental scales and promoted legitimacy in the governance. -Municipal officials who were part of VPMAP had a strong relationship with a prominent local developer and with a leader of the town council, both of whom became involved in the VPSWG. These leaders provided essential information and promoted support for the new regulatory mechanism. -Town planners made connections between landowners, scientists, municipal officials, and developers, often using project documents and maps to facilitate conversations. -Two citizen scientists who were also representatives of a local land trust regularly attended the VPSWG meetings and helped coordinate the involvement of their organizations.
Integration and communication	Promote processes of translation and communication about the need for vernal pool regulation in municipalities and state legislature and project-based communication.	-A state planner, town planners, and municipal officials became spokespeople for the program as they recognized the technical and financial value that VPMAP contributed to towns for proactively mapping pool resources. -Social scientists studied and provided feedback about municipal, landowner, and other researcher perceptions in ways that sought to improve program implementation. -Citizen scientists and landowners wrote letters against legislative proposals to repeal the law or who were vocal supports of vernal pool protections at state hearings.

(con'd)

Problem solvers	Reconcile different problems and identify solutions	-In two towns with limited town resources, citizen scientists volunteered to produce maps, collect and organize data, and help to submit data to the State. -Social scientists also played a key problem-solving role as their research helped identify future research needs, such as a study focused on the economic impacts of vernal pool conservation on private land. This research helped to better understand municipal and landowner questions and concerns to adjust targeted communication strategies (Jansujwicz et al., 2013; McGreavy et al., 2012). The vernal pool team began to address this need by developing fact sheets with "Most Frequently Asked Questions" for use by planning boards, developers, politicians, local citizens. Importantly, these were created in partnership with state and federal regulators.

1. Leadership types adapted from Gunderson et al. (2008), Folke et al. (2002 & 2005), and Olsson et al. (2006)