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RESEARCH ARTICLE

Facilitating use of climate information for adaptation actions in small coastal communities

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Municipalities are key agents in the transition to sustainability, and yet we have poorly developed theories and practices for how to facilitate the use of climate information by local governments in adapting to climate change. Existing research suggests that climate information is more likely to lead to adaptation actions when it is coproduced by researchers and policy makers because doing so increases the likelihood that the content of information is credible, salient, and legitimate. In this study, we explored how the coproduction process facilitated or hindered use of information from two climate adaptation projects in coastal New Hampshire. Based on 17 interviews and document review, we found that, contrary to expectations, highly engaged coproduction of knowledge may not be necessary due, in part, to preexisting trust among New Hampshire coastal municipalities, technical service providers, and researchers. However, we found in small towns with limited capacity, even the best climate knowledge is unlikely to be used without ongoing context-specific implementation assistance. Our research provides both practical recommendations for those actively advancing climate adaptation, as well as contributions to the undertheorized third phase of transdisciplinary research in which knowledge is translated to action.

Keywords: Municipal, Adaptation, Coproduction, Flooding, Climate, Knowledge to action

Introduction

The combination of accelerated rates of sea-level rise over the past two decades (Cazenave et al., 2018; Horton et al., 2018; Nerem et al., 2018) and storm surge associated with large coastal storms has resulted in an increase in flooding in coastal communities along the northeast coast of North America (Ezer and Atkinson, 2014; Dahl et al., 2017). Recent sea-level rise has also resulted in more routine flooding in conjunction with astronomical high tides (Sweet et al., 2018). Furthermore, total annual precipitation for the U.S. Northeast has increased over the 20th century, largely due to greater precipitation extremes, causing more coastal flooding (Thibeault and Seth, 2014; Frei et al., 2015).

The impacts of increased flooding to infrastructure, buildings, and natural habitats are determined not only by changing climate but also by societal decisions about land use, hazard mitigation, and infrastructure design (Woodruff, 2018). In the United States, although the Federal government regulates some activities around, for example, floodplains and wetlands, most land use and hazard mitigation decisions are made by local governments. In fact, climate change adaptation, or the proactive effort taken to reduce negative impacts caused by a changing climate (Melillo et al., 2014), is increasingly framed as an issue for local governments to address. Thus, it is essential that municipalities take actions to minimize climate change impacts to their communities (Nordgren et al., 2016; Philp and Cohen, 2019). This research explores the factors that facilitate adaptation action in Gulf of Maine communities.

Municipal adaptation to climate change

Although some cities are engaging in mitigation and adaptation efforts to address climate challenges, most municipal governments are not prepared to engage in the climate change arena and are uncertain about how to help their communities adapt (Shi et al., 2015; Nordgren et al., 2016). Adaptation requires an ability to use a systems approach to work across departments, disciplines, and community interests to explore how multiple biophysical and socioeconomic changes occur and interact in a local context (Bennett et al., 2016). Further, adaptation is also likely to involve complex trade-offs between biological, physical, and social systems that may be best explored through integrated decision-support models (Lemos and Morehouse, 2005). Local governments have reported that lack of resources (expertise, funding, time), lack of usable

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information, limited national and state leadership, and conflicting public preferences all create barriers to climate adaptation (Hamin et al., 2014; Lyles et al., 2018). As a result, although a few local governments are engaging in adaptation action, most are lagging behind (Graham and Mitchell, 2016; Oulahen et al., 2018).

Further, most research on climate change adaptation has focused on the efforts of larger cities, with much less attention provided to smaller municipalities (Hamin et al., 2014). The challenges are different for large urban cities compared to smaller or more rural municipalities which often have less formal governmental structures, limited professional capacity for analyzing and responding to climate impacts, competing priorities, and even tighter budgets (Cutter et al., 2016; Romsdahl et al., 2018; Johnson et al., 2019). Research on disaster recovery, for example, has found that although urban areas suffer greater overall property losses due to density and value of structures, rural municipalities suffer greater relative impact (Cutter et al., 2016). Further, smaller municipalities do adopt sustainability measures in general, but they tend to be different actions than those employed in larger cities (Levesque et al., 2017). In the northeastern section of North America along the Gulf of Maine, small and midsized local governments comprise the majority of the coastal region. Exploring the mechanisms for supporting these smaller communities in advancing adaptation actions is as important as facilitating adaptation in large cities (Nordgren et al., 2016).

Not only is there relatively little understanding of how to support small municipalities in climate adaptation, the majority of assistance to local governments has focused on identifying areas of vulnerability and creating adaptation plans, with much less effort put into helping with implementing adaptation actions (Nordgren et al., 2016; Philp and Cohen, 2019). Both the Intergovernmental Panel on Climate Change (2014) and the U.S. National Climate Assessment (Melillo et al., 2014; Lempert et al., 2018) laid out iterative climate adaptation processes that follow a general pattern of (1) gathering information to determine local risks and vulnerabilities, (2) developing adaptation plans, (3) implementing adaptation actions, and (4) monitoring and revising. Given the lack of capacity in smaller municipalities, if the limited assistance to these governments focuses only on providing information to assess vulnerabilities, they may not be able to move to the later stage of implementation.

Coproduction of knowledge

Broader sustainability and transdisciplinary research literatures also suggest that providing needed knowledge or communicating it more clearly does not, by itself, lead to action (Clark et al., 2016b; Miller and Wyborn, 2018). The coproduction of knowledge is a key framework that has emerged from multiple disciplines for understanding how the design of sustainability research projects can influence implementation of solutions (Bremer and Meisch, 2017; Miller and Wyborn, 2018). In science and technology studies, coproduction refers to the process of simultaneously creating science and the social context in which it is produced (Jasanoff, 1996). This concept of coproduction was later built upon by sustainability scientists to become a normative call for researchers to intentionally engage with decision-makers in the production of new knowledge (Cash et al., 2003; Clark and Dickson, 2003; Cash et al., 2006). Coproduced knowledge is more likely to be deemed as salient, credible, and legitimate by stakeholders (Cash et al., 2003; Dilling and Lemos, 2011; Kirchhoff et al., 2013), may result in stakeholder ownership and responsibility for addressing problems (McNie, 2013), and can increase the likelihood that the new knowledge is used by decision makers (Clark et al., 2016b; Jacobi et al., 2020).

Yet, even though coproducing knowledge improves the likelihood that knowledge will be usable, it comes with more time, money, and commitment costs than traditional research methods, and does not, in itself, guarantee action (Lemos et al., 2018; Levesque et al., 2019; Jagannathan et al., 2020). Further, coproduction processes can vary: coproduction can occur as short-term efforts or longer-term iterative engagement, and can engage stakeholders to varying degrees in each stage of research including defining the problem, selecting methods, conducting research, and interpreting results (Lemos and Morehouse, 2005; Djenontin and Meadow 2018; Jagannathan et al., 2020). Additionally, some studies suggest that even if knowledge is coproduced to meet saliency, credibility and legitimacy measures, it may not be put into use if there is no direct link to specific policy or management decisions (Polk, 2014) or if effort was not made to ensure decisions would be deemed legitimate when transferred back to specific decision-making bodies (Binder et al., 2015; Clark et al., 2016b). Finally, there is a wide range of outcomes from coproduction from simple acknowledgment of new joint knowledge to development of new policies to transformation of societal norms and institutions (Klenk et al., 2017; Jagannathan et al., 2020). Thus, there is still a need to better understand the societal impacts of different coproduction processes in various social contexts (Wiek et al., 2015; McCullough and Matson, 2016; Lemos et al., 2018; Jagannathan et al., 2020).

We look to fill this gap with our research, in which we ask: What enables smaller municipalities to use climate information to enact adaptation solutions? We explore this question through a comparative case study of two climate adaptation projects encompassing 12 communities in coastal New Hampshire, near the southern boundary of the Gulf of Maine. Our specific research questions are: (1) To what degree was knowledge coproduced in these projects? (2) To what extent did communities use the knowledge to further their climate adaptation? and (3) Which aspects of the process used to create climate knowledge influenced the ability of communities to use this new information for climate preparedness actions?

Methods

We conducted a comparative case study of two coastal climate adaptation projects that span part or all of 12 municipalities in coastal New Hampshire, United States, near the southern boundary of the Gulf of Maine (**Figure 1**). This case study draws on semi-structured interviews of 17 project participants and content analysis of all formal documents produced in both projects. Below, we provide

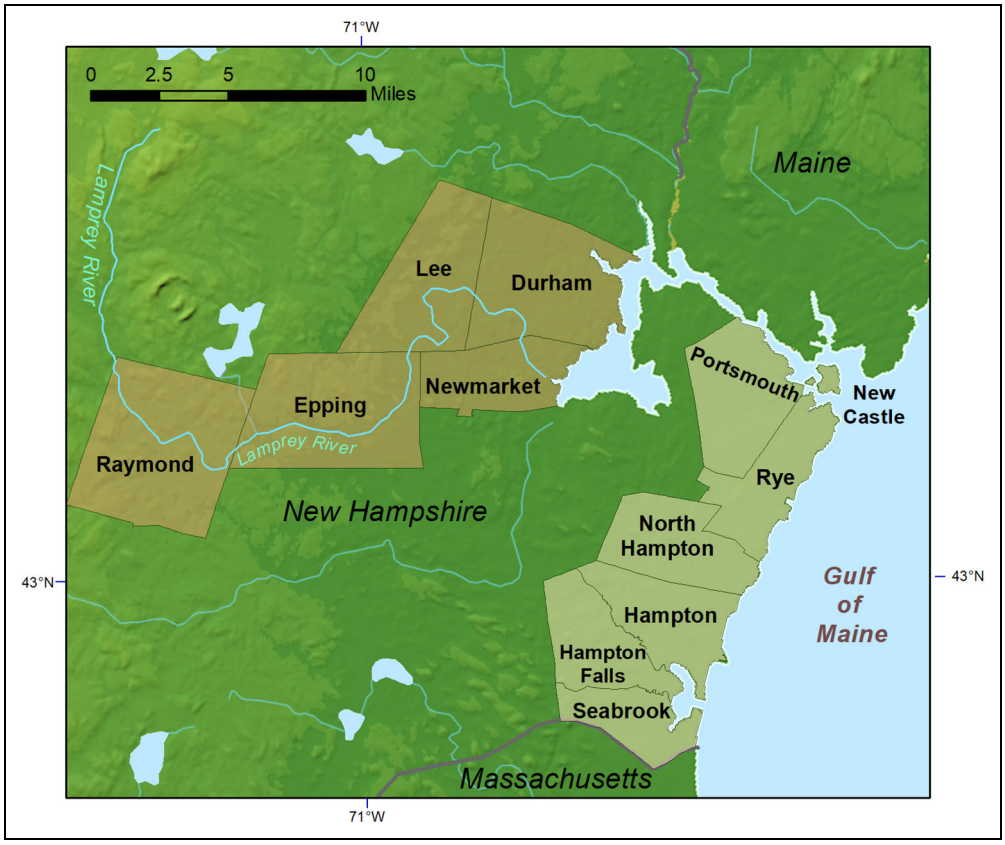

Figure 1. Location of New Hampshire communities in the Lamprey River project (brown) and Tides to Storms project (light green). DOI: https://doi.org/10.1525/elementa.2020.20.00048.f1

the case study context, followed by details of the qualitative research and analysis methods.

Case study context

National (Sweet et al., 2017; Fleming et al., 2018; Greenan et al., 2018), provincial/state (Daigle, 2012; Wake et al., 2019; Fernandez et al., 2020), and municipal (Reeves, 2008; BRAG, 2016) based climate assessments have documented the increasing risks of flooding associated with rising seas and storm surge, and an increase in extreme precipitation events in the Gulf of Maine coastal region. Gulf of Maine municipalities, often in collaboration with state/provincial and federal partners, have begun to assess local vulnerability and enhance coastal resilience.

In New Hampshire, as in most of New England, municipalities carry out local governance enabled by state authority. Counties are largely not involved in local governance. New Hampshire's coastal towns and small cities typically operate with small staffs advised by volunteer boards and commissions. With limited professional capacity, most coastal communities in New Hampshire work closely with their regional planning commissions, as well as a host of other technical assistance providers from state agencies, conservation organizations, university research, and university extension. These technical assistance providers work with NH's coastal communities through the New Hampshire Coastal Adaptation Workgroup (CAW) to advance climate change adaptation within each community's context. Over the last decade, communities working with CAW members have taken a wide range of steps in climate adaptation. Representatives from nearly every one of New Hampshire's 43 coastal communities have engaged with CAW at some level. This study explores two CAW-supported efforts: The Lamprey River 100-year Floodplain Mapping project and the Tides to Storms project.

These two projects were chosen because they had similarities and differences that allow for comparison (**Table 1**). Both projects were 3-year, multi-town efforts focused on encouraging municipal adaptation to increased flooding events, with a focus on smaller towns that frequently rely on technical support from their regional planning commissions and that had preexisting relationships with project leads. However, the two projects used different processes to reach their goals, especially in terms of the depth of interaction with municipal officials, as described below. Further, the projects had both been completed within three years of the start of this research project, providing time for potential actions to have occurred as a result of the projects, but recent enough to be recalled by participants. Finally, this study was part of a larger transdisciplinary effort in which CAW was interested in learning what types and characteristics of engagement were most likely to result in community action. As such, this study had the dual purposes of providing on-the-ground assistance to CAW as well as to advance the literature on facilitating adaptation actions in small coastal municipalities.

The Lamprey River watershed covers 214 sq. mi. of southern New Hampshire and includes part or all of 14

Table 1. Town characteristics in Lamprey River and Tides to Storms project areas. DOI: https://doi.org/10.1525/elementa.2020.20.00048.t1

Town	Area (sq. mi.)	Saltwater Flooding[a] (sq. mi.)	Freshwater Flooding[b] (sq. mi.)	POP 2018	Median Age	Municipal Budget[c] (Millions)	Percent Bachelor's Degree	Per Capita Income	Below Poverty	Type of Government[d]
Lamprey River Project										
Durham[e]	24.7	0.2	0.9	16,574	20.8	$27.35	76%	$23,988	26.8%	Administrator & Council
Newmarket	14.2	0.2	1.0	9,147	35.9	$27.52	47%	$39,386	5.9%	Town Administrator & Council
Lee	20.1	0.0	1.2	4,481	48.1	$8.87	59%	$48,610	1.4%	Selectmen
Epping	26.2	0.0	1.4	7,045	40.8	$11.64	30%	$35,459	8.9%	Selectmen & SB2
Raymond	29.6	0.0	1.5	10,451	41.6	$11.71	22%	$34,132	8.1%	Town Manager & Selectmen
Average	*23.0*	*0.1*	*1.2*	*9,539*	*37.4*	*$17.4*	*46.8%*	*$36,315*	*10.2%*	
Tides to Storms										
Portsmouth	16.8	1.6	n/a	21,896	40.3	$64.92	56%	$50,351	6.1%	City Manager & Council
New Castle	2.4	0.9	n/a	981	61.7	$4.00	70%	$105,175	0.9%	Selectmen
Rye	36.7	2.7	n/a	5,452	55.0	$13.53 (2017)	57%	$75,666	3.6%	Selectmen
North Hampton	14.4	0.5	n/a	4,494	50.5	$6.67 (2016)	53%	$60,176	5.2%	Selectmen
Hampton	14.7	4.4	n/a	15,564	51.2	$22.57	50%	$51,748	4.9%	Selectmen
Hampton Falls	12.5	1.9	n/a	2,372	48.9	$2.82 (2018)	59%	$69,656	3.5%	Town Meeting & SB 2
Seabrook	9.6	3.0	n/a	8,869	51.5	$23.52	16%	$35,356	4.9%	Town Manager & Selectmen
Average	*15.3*	*2.1*	*n/a*	*8,518*	*51.3*	*$28.8*	*51.6%*	*$64,018*	*4.2%*	

[a]Estimated area saltwater flooding from 100-year storm surge and 1.7 feet of sea-level rise (Rockingham Planning Commission, 2017).

[b]Estimated area freshwater (riverine) 100-year flood on the Lamprey River main stem with 2005 land use and 8.5" precipitation event (Wake et al., 2013).

[c]2019 unless otherwise indicated.

[d]SB2 is a two-part process including a deliberative session and ballot voting.

[e]Durham, as a university town (the home of UNH), has a high student population.

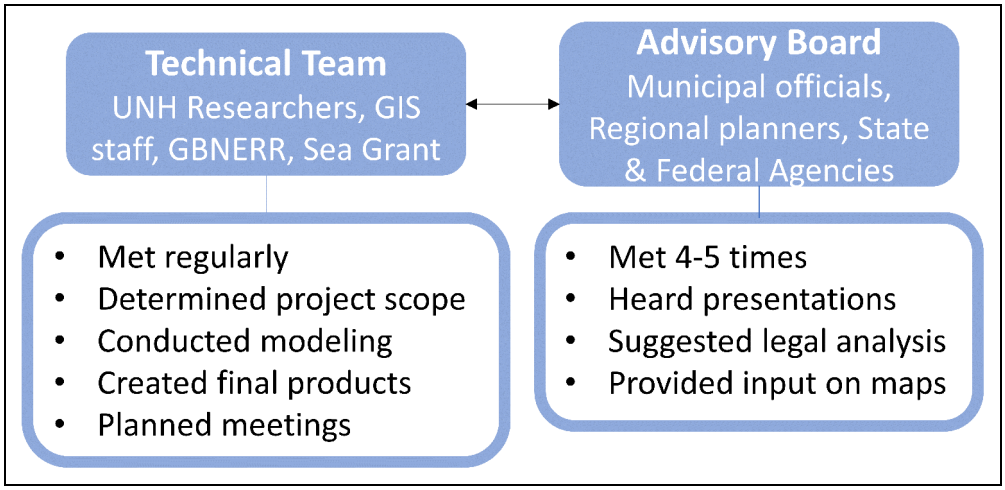

Figure 2. Lamprey River 100-year floodplain mapping project organizational chart. UNH = University of New Hampshire; GBNERR = Great Bay National Estuarine Research Reserve. DOI: https://doi.org/10.1525/elementa.2020.20.00048.f2

municipalities; however, the study focused on the main stem of the Lamprey River that flows through five towns (Raymond, Epping, Lee, Durham, and Newmarket; **Figure 1**; **Table 1**). When the Lamprey River 100-year Floodplain Mapping project began in 2009, there had recently been an increase in the magnitude and frequency of freshwater flooding due to (1) increases in impervious surfaces from development and (2) increased frequency of extreme weather events due to climate change (Hamilton et al., 2016). This project aimed to develop a methodology for assessing flood risk associated with land use and climate change scenarios, apply that methodology to the Lamprey River, and demonstrate how outputs could support land use decisions (Wake, 2013). A technical team (**Figure 2**) led by faculty at the University of New Hampshire developed a rainfall runoff model (Scholz, 2011), a set of land development scenarios based on an exponential best fit to the historical (1962–2005) rates of development in the watershed, and projected future 24-h rainfall depths using statistically downscaled global climate model simulations (Hayhoe et al., 2007). The project was guided by an Advisory Board composed of municipal, regional, state, and federal representatives (Matso and Becker, 2014). Final map products, as well as a legal analysis (Vermont Law School, 2016), were shared with over 65 participants at a workshop in Raymond NH in June, 2012. In addition, copies of all the maps were sent to the town hall and library of all five communities and posted on the New Hampshire's Statewide Geographic Information System Clearinghouse. The research and engagement project was supported by the NOAA funded Cooperative Institute for Coastal & Estuarine Environmental Technology.

Tides to Storms was a regional project designed to "assess the vulnerability of coastal municipalities and public infrastructure to flooding from expected increases in storm surge and rates of sea-level rise" (Rockingham Planning Commission, 2015) for each of seven municipalities facing the Gulf of Maine (Portsmouth, New Castle, Rye, North Hampton, Hampton, Hampton Falls, Seabrook; **Figure 1**; **Table 1**). Tides to Storms was developed and facilitated by the Rockingham Planning Commission, which met three to five times with teams from each of the seven municipalities in the region (**Figure 3**). The project built upon a previous report that mapped coastal inundation from combinations of sea level rise scenarios and estimated storm surge (Wake et al., 2011). Tides to Storms produced both regional and town-level vulnerability assessments focused on risks to roadways and transportation infrastructure, critical facilities, and natural resources. Each municipality received a report with their local vulnerability assessment, maps of flood risk, and recommended actions to improve resilience to storm surge and sea level rise. This vulnerability assessment, completed in 2015, was immediately followed by Tides to Storms 2, a subsequent implementation phase during which each of the coastal municipalities applied for technical assistance from the regional planning commission to carry out a self-selected adaptation project. The Tides to Storms project was funded by Federal Emergency Management Authority and NH Department of Transportation, and Tides to Storms 2 was funded by the Northeast Region Ocean Council.

Qualitative data collection and analysis

We developed a semi-structured interview guide that asked participants about their and other's roles and contributions to the adaptation project, as well as how information was deliberated, presented and used. This interview guide was tested with nonparticipants and revised prior to use (Patton, 2002). Key informants for each project helped identify the participants to interview; in addition, each respondent was asked at the end of their interview who they would recommend we speak to, in order to ensure all core participants were included. We interviewed a total of 17 participants: nine from the Lamprey River project and eight from the Tides to Storms project (**Table 2**). Each interview lasted approximately 1 h and was recorded and transcribed. Using an iterative

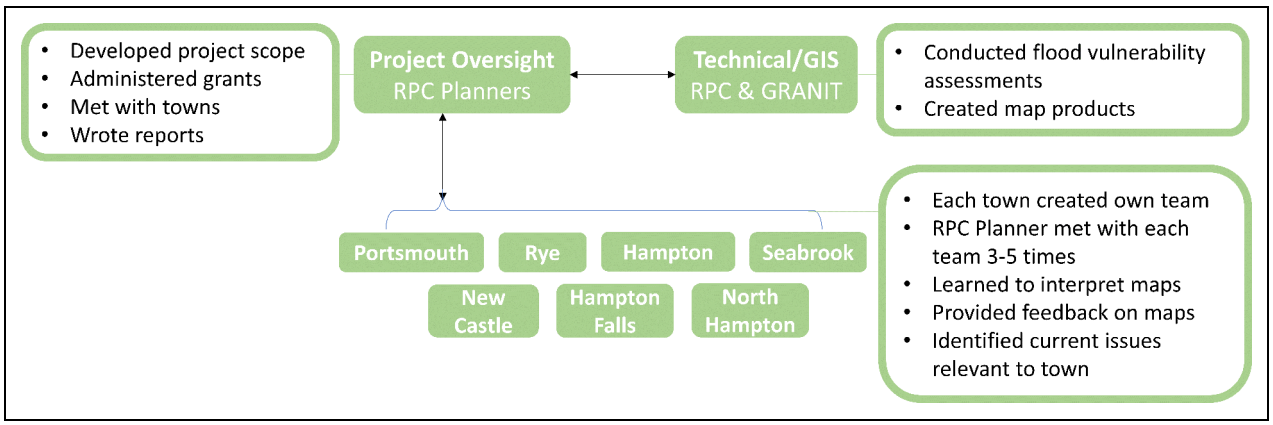

Figure 3. Tides to Storms organizational chart. Town names represent a self-designated team from each municipality. RPC = Rockingham Planning Commission; GRANIT = NH GIS clearinghouse. DOI: https://doi.org/10.1525/elementa.2020.20.00048.f3

Table 2. Affiliation of interview respondents. DOI: https://doi.org/10.1525/elementa.2020.20.00048.t2

	Interviewee Affiliation		
Project Name	**Researcher/ Technical**	**Municipal Representative**	**State & Regional Entities**
Lamprey River	3	3	3
Tides to Storms	1	5	2
Total	4	8	5

coding process (Yin, 2010) and NVivo (v.11) software, we initially coded data using a deductive process based on key concepts in the transdisciplinary and knowledge-to-action literature such as salience, credibility and legitimacy, coproduction of knowledge, and usable knowledge. Interviews were further coded using an inductive process, and themes were created that explained broad categories (Yin, 2010). Coding was completed by the first author of this paper and a research assistant. To ensure intercoder reliability, we co-defined codes, coded the same interviews and compared results until we matched each other's codes, and held weekly meetings to compare coding results and discuss questions (Church, 2019). In order to assess validity of research findings (Yardley, 2000), we (1) compared interview themes to formal project documents to identify any discrepancies between formal and informal explanations of project process and outputs, and (2) we shared and discussed research results with project participants in meetings with CAW and by sending draft versions of this article to key informants for comment. Based on the feedback, we were able to refine and provide additional nuance to research results.

Results

The coproduction of knowledge (RQ1)

Our analysis of the degree of coproduction uncovered two primary themes: (1) the degree of coproduction can vary by project phase; and (2) the degree of coproduction may have varying impacts on credibility, legitimacy, and saliency. In both of these projects, there was minimal coproduction of climate-related flood information in the phases of defining research questions, determining methodological choices, and conducting analysis. It wasn't until later stages of displaying and interpreting data in which technical experts consulted with stakeholders. It was often believed that the data analysis occurring behind the scenes would be too complicated for project stakeholders, as mentioned by this researcher, "the input was mostly on how to improve the presentation of the results, not so much on the methodology of the project because that's kinda beyond the scope of expertise of the people that were commenting." Thus, stakeholders were brought in to "ground truth" the maps, as a Lamprey project planner explained: "[the communities] had a lot to say about the language that was used on the mapping products themselves, about the symbology, about what timeframes the technical team should be concerned with. They provided some level of ground truthing because they were familiar with some of the communities that were within the mapped area." This degree of input was corroborated by technical experts, as mentioned by a Tides to Storm respondent, "For me it was pretty insular . . . it was pretty much just me dweebing out on the computer for hours on end . . . There was no community participation in what I did, beyond being aware of what my audience was, so to speak, and making sure that I did what I could to answer questions and zip up any holes."

Although neither project had substantial coproduction of research questions or flood impact modeling, the Lamprey River project process did enable the Advisory Board to identify additional information needs. A noteworthy outcome of that Advisory Board collaboration was the commissioning of a legal analysis by the Vermont Law School focused on a municipality's ability to adopt and use floodplain maps in town regulatory documents that are based on projected conditions rather than solely those provided by the Federal Emergency Management

Authority. Despite this added component to the Lamprey project, one researcher stated,

> *Moving from, "We can model this" and then provide the information, I would go much more to a model of, "What information do you need and how do you want to use it? Let's figure out how we generate that information together." That is the big piece for me. We had the Advisory Board, they really advised us, we changed [things], but thinking of it, I would much rather have [a town planner] say, here's the three pieces of information I need' and we would give those to her and she would use them.*

Although both projects demonstrated only minimal coproduction of climate information, participants from both projects reported that the final products were credible and reflected the true situation from their perspectives. From researchers to community members, interviewees reported that "the whole modeling effort is believable" (Lamprey) and "it was very state of the art information, really, from the national and international level to the New Hampshire seacoast" (Tides to Storms). As one project facilitator explained, "When they first looked at those maps, they were all shaking their heads like, yeah, that's where it floods, that's exactly where it floods . . . They know where flooding happens and the maps were corroborating their own experiences." Both because flooding had occurred in these communities prior to the mapping and because project participants respected and trusted researchers involved in the projects, they did not need to be involved in the modeling decisions in order to believe the final products were representative of future realities.

Similarly, even without substantive coproduction, both projects maintained legitimacy through two methods: minimizing explicit discussion of climate change and engaging in two-way dialogue with the participants. Town officials, state and regional representatives, and researchers all recognized that climate change can be a controversial subject. As one researcher stated, "A lot of it's about the packaging. If you don't have to use the word climate change, don't. Not that I'm afraid of the word but it's about knowing your audience." Meanwhile, participants in both projects expressed satisfaction with the level of input they had on improving final maps, which gave them a sense of being heard. One municipal representative in Lamprey stated, "My input was listened to. I wasn't just a person there . . . And that's the sort of thing that pulls you into the rest of it. It's like, OK, they're gonna listen to me, I want to engage in this." As a result of these two strategies, none of the interviewees in either project suggested that the results were biased or were promoting a specific climate agenda. Participants often mentioned that, due to the long-term, preexisting relationships they had with project leads, they trusted them to provide unbiased information. One participant, for example, referred to "the New Hampshire Way" to describe the ease of regularly calling up their regional planning commission representative to talk about these and other on-going efforts that built the trust on which climate adaptation projects rest.

However, minimal coproduction may have impacted the saliency of the results, depending on the project and stakeholder group. In Tides to Storms, most participants confirmed the relevancy of the project products, as described by one municipal representative: "As a town, we just have a lot of flooding issues. I think whether or not we have residents that agree with climate change or sea-level rise, they're seeing more frequent flooding, more intense storm events, and I think we've got a lot more people that are concerned about protecting their investments." But some Tides to Storms towns discovered that very little of their land would experience flooding. The project coordinator, recognizing that the degree of impact influenced the interest in each community, stated, "I think our approaches had to be slightly different with the communities that didn't see a lot of impact . . . It just means that geographically you have less land to have to worry about. But impacts to major infrastructure in certain parts of town are really important. So, we had to kind of keep the immediacy going and the relevancy there even though it is not going to be so bad." Thus, framing the results differently based on community context helped maintain saliency.

Participants in the Lamprey River project, on the other hand, expressed less interest in the results. While most of the technical and state/regional representatives considered the analysis to be extremely relevant, the municipal representatives expressed different sentiments. As one town official stated, "Even though that project came on the heels of these two big floods, by the time the results came out, I don't think people cared anymore." One explanation for the lack of saliency may be that the Lamprey project information did not match the geographic or regulatory context of the municipalities. Unlike the town-by-town analysis in Tides to Storms, the Lamprey River "mapping was done on a watershed scale, largely because that makes sense technically for hydrologic studies. But communities need to make decisions and policies . . . for the whole city or town." Had researchers engaged with stakeholders in the early stages of determining the extent of their analysis, the final flood information may have matched the town boundaries and been perceived as more salient.

Use of climate information in adaptation actions (RQ2)

The two projects varied significantly in the degree to which they used new knowledge to further climate adaptation in local communities. We regularly heard that the Lamprey River project did not result in action on-the-ground, as noted by a project participant, "I mean, it all sounded good and everything, but I feel like it didn't really go anywhere . . . I was hoping that a lot of communities would have been more interested in this, but it seemed like they just didn't." One planner hinted that a loading dock model of knowledge production and dissemination

may be partly to blame, "I think it's just the old model of, like: research, hand off, try to implement it. I think that that is changing . . . but to continue to move that forward in any way would be great."

Meanwhile, the Tides to Storms respondents all reported some use of new information in adaptation actions in project towns. One town participant explained, "And thanks to the Tides to Storms . . . we've actually created a . . . Coastal Hazard and Climate Adaptation Chapter that we're going to be putting into our master plan . . . And I had a meeting just last night with a subcommittee of our planning board. We're now looking at putting in freeboard into our floodplain ordinance to go to the next step." Another town respondent explained "We did our flood plain ordinance over and that was just approved by the voters this pass March, so that's in place now."

In addition to the implementation of town plans and policies to address increased flooding, the Tides to Storms participants discussed how the project increased capacity, both in terms of knowledge and social capital. One town planner stated, "The major benefit is educating my department heads. It didn't just come from me . . . so, the benefit was now we have some data, we have actual maps that I can show the department heads, as well as the selectman, saying, 'this is based on science.'" In addition, the project strengthened the network connections between the multiple entities focused on local adaptation and resilience, as well as improved communications between municipal departments and committees within individual towns, as explained by a town planner: "I think it was helpful to hear other departmental perspectives—like we all have our own focus, so bringing them all to one spot [was key]. You might not realize the impact for police. We might be like, 'oh save all the wetlands, we shouldn't have any wetland crossings,' . . . but then there's a whole human health and safety aspect." Municipal respondents explained that before this project they rarely, if ever, sat in a room where emergency response personnel discuss flooding impacts with a conservation planner and a public works director from their own town.

Aspects of the knowledge creation process that facilitate use of climate information (RQ3)

Our analysis of how the process of creating flood information in the two projects influenced eventual use of that climate data in adaptation decisions centered around three primary themes: (1) engagement of those responsible for implementation in every municipal jurisdiction, (2) assistance developing and implementing context-specific solutions, and (3) the need to continue working to address climate impacts beyond the time frame of the projects.

In regard to differences in stakeholder participants, in the Lamprey River project (where new climate information has not been put to use), the Advisory Board contained only two municipal representatives from the watershed, rather than staff from every town that would be expected to take action based on the knowledge created. Other Advisory Board stakeholders provided regional and state-level perspectives on the project, and although their input and support were important, they were not in the position to implement adaptation actions in the individual municipalities. Tides to Storms, however, met multiple times with separate teams from each municipality. The project facilitator in Tides to Storms was purposeful about this decision, "from day one, the primary focus was going to be municipal decision makers - that's the audience that we really wanted to target because we know that in order for the town to take any kind of actionable steps using the information, it would have to be the decision makers who would become familiar with it and know it and feel confident enough to use it." Each Tides to Storms town was asked to assemble their own team to work on the project, so that decision makers in all relevant departments would be involved.

Regarding the degree of implementation assistance provided in each project, we also found a striking difference. In addition to providing each town with a set of standardized recommendations, the Tides to Storms report contained a set of issues and suggested considerations for each town based on concerns raised by town officials in project meetings. This detailed assessment was then followed up with an implementation grant for the regional planning commission to assist each town in achieving one priority adaptation action. In contrast, a town official in the Lamprey River watershed noted the absence of this type of assistance,

> *So now we have maps . . . but it's not something that a planner who's working in a planning office by themselves has the technical expertise to actually put it into action. You'd have to have a special grant and hire somebody who could focus on that for you. It just wouldn't happen . . . At the local level, we sometimes need a little more hand holding to get things done because of the multitude of demands placed on us and the limited resources to get the job done effectively.*

The initial Lamprey River project ended with disseminating the final products to towns and holding a public meeting, without any assistance in developing and implementing adaptation actions.

One final theme emerged regarding applying climate knowledge to new adaptation actions: Participants in both projects stressed the need to continue to bring up the projects and maps, continue to update them, and build on this work going forward, beyond the time frames of the projects. Municipal representatives did not express fatigue with climate projects. Rather, there was the recognition that because of change in leadership at local levels, new data that emerge, and new contextual issues that arise, continued exposure to climate adaptation information and recommendations is essential. One planner stated, "Keep it coming. I think that if this can evolve, take what we did for Tides to Storms, make it into something else, keep it evolving, keep it growing, because towns are changing, the world is changing, climate is changing. It doesn't stop here. We gotta keep moving it, keep growing it, and take what we've learned, adapt, learn from other

communities." Municipal officials have many issues to deal with on a day-to-day basis, and with climate change often feeling like a "future" issue, reminders help keep adaptation on their radar.

Discussion

Most of the coastal region in the Gulf of Maine is governed by small and midsized municipalities. These local governments are in the position of making land use, hazard mitigation, and infrastructure decisions that will affect their ability to adapt to climate change, and yet there is little understanding of what supports these smaller communities in implementing adaptation actions. Both the climate adaptation literature and the sustainability literature have focused on how to provide usable climate data and vulnerability assessments, with little guidance on translating that knowledge to action. We compared two municipal climate adaptation projects in the southern Gulf of Maine and found that, contrary to expectations, highly engaged coproduction of knowledge was not always necessary for use of information in policy decisions. Rather, we discovered a more nuanced understanding of when and how coproduction ensures usable climate knowledge. We conclude that the coproduction of adaptation actions themselves may be the missing link in assisting small municipalities to apply climate information to new action.

It is often argued that it is through the coproduction of knowledge that new information is deemed salient, credible, and legitimate and, thus, more likely to be used (Cash et al., 2003; Dilling and Lemos, 2011; Kirchhoff et al., 2013). Our study suggests, however, that highly engaged coproduction may not be necessary for new climate knowledge to gain these attributes in some cases. Despite minimal coproduction processes, participants in both projects not only reported feeling they contributed adequately to the projects but that they also believed that the information was credible and legitimate. Much research suggests that it is only through an intensive knowledge coproduction process that decision makers will trust the new knowledge (Clark et al., 2016b). However, in small municipalities that have long-standing, preexisting relationships with technical assistance providers such as regional planning commissions, local researchers, and state agencies, enough trust may already exist for new knowledge to be deemed credible and legitimate with minimal coproduction effort. This can allow project leads to direct limited time and money to coproduction engagement in the research phases that are most needed for the particular project (Lemos et al., 2018).

Saliency, on the other hand, may be more sensitive to coproduction, or, at a minimum, to the ability of project leads to draw on well-established prior knowledge of the local context. Only the Tides to Storms participants felt the knowledge produced was relevant to their needs, partly because they experience more frequent coastal flooding, but also because project leads proactively framed the results in each municipality to account for that community's projected impacts and included a section in the final report that responded to concerns raised by local officials. The project facilitators used preexisting knowledge of local context to ensure products were deemed salient and relied on a low-intensity coproduction process to gain municipal input into local flooding concerns to help shape final products.

Meanwhile, even though the Lamprey study included a more typical coproduction process in the identification and response to stakeholder requests of a legal study, the project participants did not view the project's primary products, the flood map and report, as relevant to their needs. Although this is partly due to the less frequent flooding in these municipalities as compared to the direct ocean-facing Tides to Storms towns, the larger problem was that flooding research did not match the scale of the regulatory framework used by municipal decision makers. This finding echoes a prior study of the Lamprey River project that suggested that funders should do more to ensure that those responsible for enacting adaptation measures are included early in the problem definition phase of project (Matso and Becker, 2014). Thus, even when coproduction is done well in one phase, and even if project leads have long-standing trust relationships with project partners, if the central research does not integrate the needs and context of local decision makers, the resultant knowledge may not be salient or usable in adaptation decisions (Clark et al., 2016a). This suggests that in some cases, putting limited resources into fully engaged coproduction in early phases of the research process of defining research questions and methods may have the highest payoff in terms of ensuring saliency of results.

A major finding of this research centers on the need for deep engagement of municipal officials who can make and implement adaptation plans. When appropriate decision makers are included throughout a collaborative process, not only are they more likely to deem new knowledge and related recommendations credible, legitimate, and salient, but also they have greater capacity to advance related actions in their own regulatory spaces (Levesque et al., 2019). However, there has been little discussion about what this means in terms of adaptation planning in small municipalities. This study suggests that adaptation actions occur in multiple municipal arenas that traditionally have minimal communication with each other such as public works departments, conservation commissions, emergency management personnel and planners. Thus, robust adaptation action in a town may depend on engaging a team of decision makers, as was done in Tides to Storms. A common alternative, to include a few representatives of a stakeholder constituency in a broad collaborative group, as done in the Lamprey River project, may not be robust enough to either ensure the diversity of municipal perspectives and contexts is incorporated into the project outputs or facilitate eventual implementation of adaptation actions within all municipalities in the project area (Wall et al., 2017).

Related, it is essential that engagement continues beyond the vulnerability assessment and recommendations phases of adaptation planning processes to the implementation phase. Although many researchers focus on the quality of the climate knowledge as the primary

barrier to adaptation action (Le Cozannet et al., 2017), others are beginning to recognize that even when knowledge is considered "usable," it may not be linked to action (Polk, 2014). Our research suggests that in smaller municipalities, it is especially important to help municipal officials apply new climate information to specific adaptation actions in their communities. Although this includes basic assistance with finding funding and facilitating the implementation process, it also entails an extension of the knowledge coproduction process into the implementation phase. Developing solutions, prioritizing actions, and executing implementation plans can be viewed as an applied phase of the coproduction process. Further, the implementation phase itself is likely to occur over the course of multiple steps. It is well known that adaptation efforts have proceeded slowly (Meerow and Woodruff, 2020). Our results emphasize that adaptation actions, especially in small municipalities, may be more appropriately recognized as a series of steps that include building local capacity (knowledge, attitudes, funding) within municipal government as well as public support before advancing policy change, supporting the concept of an "adaptation ladder" proposed by Hamin and Gurran (2015). Some of these broader, earlier steps are necessary transformations within the larger social ecological system in which adaptation actions must occur (Jacobi et al., 2020).

As many of this study's participants argued, it is essential to "keep going" when working with small municipalities to prepare for climate change impacts. We suggest that projects be planned, when possible, to include partners such as regional planning commissions or other technical assistance providers who are equipped to provide long-term technical and funding support, sometimes over a series of multiple related projects. High functioning coalitions such as New Hampshire's Coastal Adaptation Workgroup may be uniquely positioned to assist small coastal communities in moving from knowledge to action because they possess a range of expertise in both climate information and collaboration processes, a long history of relationships that have built up trust, and access to external resources such as funders, planners, and researchers that are needed over time as communities make their way along the spectrum of adaptation actions. For example, when the town of Lee, partially in the Lamprey River project, recently expressed interest in revising their municipal floodplain ordinances to incorporate the Lamprey flood projections, the Strafford Regional Planning Commission collaborated with an engineering consultant and the University of New Hampshire to complete the flood analysis for the portion of their town outside the Lamprey River watershed and assist with updating the town's ordinance. Not only does this example show the need for continued implementation assistance, but it also provides hope; even when an initial project does not result in adaptation steps, if partners work to identify and address barriers to action, even years later, small municipalities are willing and able to act.

Conclusions

This research suggests that in small municipalities that are part of preexisting networks of decision makers, project facilitators, and researchers, less effort might be required to build trust and ensure content meets user needs in early stages of producing knowledge but that much more effort is needed to help municipalities implement actions at the final stages of adaptation projects. This is not to say that coproduction of knowledge is unnecessary. Our research showed that decision makers appreciated having some input, even if it was minor, and that when project leads do not fully understand the local context, coproduction is indeed essential. However, in small towns with limited capacity, even the best climate knowledge is unlikely to be used without ongoing implementation assistance. Project leads must engage decision makers from a range of municipal departments in identifying relevant issues and solutions, ensure products are tailored to each municipality, and connect communities to funding and technical assistance, sometimes over many years and multiple projects in order to support adaptation in smaller municipalities.

In this study, the distinction between minimal and highly engaged coproduction processes was based on the degree to which primary stakeholders had an influence on research choices throughout each phase of the projects: Were research questions or methods revised due to stakeholder input? Was there joint interpretation of data? Who determined what the next steps would be? It was not based on number of meetings or specific type of engagement approach, although arguments could be made for using these and other criteria for measuring and assessing coproduction effort. We suggest that future research explore this "spectrum of coproduction engagement" in more depth to better define different degrees of coproduction throughout a research project in order to more explicitly assess, as promoted by Lemos et al. (2018), if and how coproduction can foster better solutions.

As this study focuses on one region in the Gulf of Maine, it is essential to determine the degree to which our findings hold up in other smaller coastal municipalities. Of particular interest would be to compare our results to those from adaptation projects in small communities that lack strong preexisting relationships with technical assistance providers. We have suggested here that these networks created preexisting trust between municipalities and data providers, resulting in products that decision makers view as credible and legitimate despite a minimal coproduction process. However, we do not know how strong or well-established these relationships need to be. Would any coastal community trust flooding maps and suggested recommendations if they already see impacts of sea level rise and storm surge in their communities, regardless of their preexisting relationships to the researchers? Similarly, we suggest that even when initial adaptation project outputs do not meet municipal needs, follow-on projects can result in climate adaptation, especially because smaller municipalities' adaptation actions fall on a spectrum of approaches. However, it would be worthwhile to identify what, if any, factors associated with

initial adaptation projects might preclude this finding. For example, participants in both our projects found results to be credible and legitimate. If municipal representatives in another project considered outputs to be biased, it may not be possible to overcome that perception to simply build on initial efforts. In short, further research is warranted on the extent to which coproduction is needed in each research phase for developing the credibility, legitimacy, and saliency needed to put knowledge to action in various contexts.

In conclusion, we propose a model of climate adaptation in small municipalities that acknowledges the tremendous effort that must be put into implementation assistance over time, even when the knowledge and outputs created are deemed credible, legitimate, and salient. In some areas, this implementation assistance may be offset by a much more minimal knowledge coproduction effort than is often expounded in the literature, especially when municipal representatives have long-standing positive relationships with their technical service providers.

Data accessibility statement

No data sets were generated for this research.

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Competing interests

The authors have no competing interests to declare.

Author contributions

Levesque, Wake, and Peterson jointly conceived of and designed this research.

Levesque conducted the research, analyzed the data, and led the manuscript preparation.

All three authors contributed to writing and editing the manuscript.

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