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Crowdsourced Delphis: Designing solutions to complex environmental problems with broad stakeholder participation

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ABSTRACT

There is a well-established need for increased stakeholder participation in the generation of adaptive management approaches and specific solutions to complex environmental problems. However, integrating participant feedback into current science, research, and decision-making processes is challenging. This paper presents a novel approach that marries a rigorous Delphi method, borrowed from policy and organizational sciences, with contemporary "crowdsourcing" to address the complex problems of water pollution exacerbated by climate change in the Lake Champlain Basin. In an online Delphi forum that occurred over a six-week period during the Spring of 2014, fifty-three participants proposed and commented on adaptive solutions to address water quality in the context of climate change. In a follow up Multi-Stakeholder workshop, thirty-eight stakeholders participated in refining and synthesizing the results from the forum. To inform modeling and policy dialogue, the resulting list of interventions was analyzed by time horizon, domain, type of adaptation action, and priority level. The interventions suggested by stakeholders within the crowdsourcing forum have contributed to the current policy dialogue in Vermont including legislation to address phosphorus loading to Lake Champlain. This stakeholder approach strengthens traditional modeling scenario development to include solutions and priorities that have been collectively refined and vetted.

1. Introduction

The contribution of stakeholder participation to scientific inquiry is an important strategy in promoting an adaptive management approach in policy and practice, and examining alternative stable states and scenarios (Klenk et al., 2015; Peterson et al., 1997). Although the need for increased participation in the generation of solutions is well-established, integrating participant feedback into current science, research, and decision-making processes is challenging (Fazey et al., 2014; Klenk et al., 2015; Reed, 2008). Stakeholder processes are needed to manage uncertainty, adaptively define problems, and expand the set of solutions that can be considered for multiple end-users in research, policy, and practice (Dietz et al., 2003; Fazey et al., 2014; Patterson et al., 2013; Van der Brugge and Van Raak, 2007). High levels of complexity and uncertainty require diverse knowledge and values of multiple stakeholders across scientific and other communities of practice (Folke et al., 2005; Ostrom, 2009; Patterson et al., 2013). Participatory processes that integrate explicit and tacit knowledge can add legitimacy and accountability in instances when science occurs amid ambiguous political, social, environmental, and economic values (Bäckstrand, 2003; Norton and Steinemann, 2001; van den Hoek et al., 2014).

The need for stakeholder involvement is demonstrated by the gap between scientific knowledge and the generation of useful adaptation information for decision makers, a gap that persists despite a growing body of literature in climate, hydrological, and engineering sciences (Bradshaw and Borchers, 2000; Fowler et al., 2007; Pahl-Wostl et al., 2007). Without stakeholder engagement, scientific models can present solution sets that mishandle ambiguity and tradeoffs, and oversimplify existing knowledge and experience (MacMillan and Marshall, 2006; Susskind, 2013; Zia et al., 2011). In the example of water pollution, biophysical models are constrained by imperfect estimates of complex interdependent climate, hydrological, and biogeochemical interactions (Couture et al., 2014; Fowler et al., 2007; Isles et al., 2015). The legitimacy and effectiveness of model outputs for informing decision making are further constrained in that they often do not account for the dynamic, uncertain, and interdependent governance contexts of social-ecological systems (Bäckstrand, 2003; Folke et al., 2005; Pahl-Wostl, 2009; Patterson et al., 2013). When there is no single right or wrong

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answer in translating science to management, stakeholders can contribute critical input (Bäckstrand, 2003; Clayton, 1997; Moore et al., 2009).

Decision-makers continuously take action to manage land and water resources with present knowledge, priorities, and values (Bradshaw and Borchers, 2000; Kiparsky et al., 2012). Swart et al. (2014) argue climate change adaptation requires a practice-oriented approach that is grounded in scientific inquiry across disciplines. Both biophysical models (Walters, 1997) and a common language (Biagini et al., 2014) are important to understand adaptation and inform management. Biagini et al. (2014) present a typology of adaptation actions based on reviewing climate change adaptation literature, and actual funded Global Environment Facility adaptation projects. Ten overarching actions were identified: capacity building, management and planning, practice and behavior, policy, information, physical infrastructure, warning or observing systems, green infrastructure, financing, and technology (Biagini et al., 2014). Biagini et al. (2014) found that implementation depended on the capacities of the communities where projects occurred, underscoring the need to align policy options with community-level capacity.

Multiple stakeholder engagement approaches have been discussed in the adaptive management and environmental governance literature, including multi-day focus groups, participatory multi-criteria analysis, participative workshops, and round-tables (Clayton, 1997; Folke et al., 2005; Gregory and Keeney, 1994; Hage et al., 2010; Ker Rault and Jeffrey, 2008; O'Neill et al., 2013; Stirling, 2006). Participatory stakeholder engagement approaches have different benefits and trade-offs related to susceptibility to power dynamics, empowerment, surfacing diverse knowledge types, establishing clear problem bounding and structuring, and usability of outputs (Kalafatis et al., 2015; Mielke et al., 2016; Reed, 2008; Stirling, 2006). With the advancement of information technology and social media tools, new opportunities exist for structuring stakeholder engagement. Here, we evaluate the ability of a novel crowdsourcing Delphi method to facilitate stakeholder participation and provide emergent, bottom-up feedback about creative solutions and decision alternatives that inform research and policy pathways in the adaptive management of multi-scale environmental problems. An online crowdsourcing Delphi was employed to facilitate generation of solutions from a diverse set of stakeholders, which was used to direct scientific inquiry, develop models, and inform practice, to address the problem of phosphorus pollution coupled with climate change in Lake Champlain Basin (Vermont & New York USA, and Quebec, Canada).

1.1. The Delphi method and crowdsourcing

The "Delphi method" is a transparent and robust strategy to interpret factual evidence, and anticipate future solutions and priorities under uncertainty (MacMillan and Marshall, 2006; Powell, 2003; Rikkonen and Tapio, 2009; Webler et al., 1991). In a structured Delphi communication process, a group of participants, typically with expertise in the subject matter, undergo multiple iterations of a questionnaire exercise to discover opinions, determine the most important issues, and identify areas of agreement. Feedback throughout the process is structured via a coordinator to ensure anonymity and to generate the findings and conclusions of the process (Hasson et al., 2000; Linstone and Turoff, 1975; Plummer and Armitage, 2007). In a Delphi group setting, with anonymous participation and repeated phases of refinement, points of consensus and disagreement are validated, and the inhibition of novel ideas (Dalkey and Helmer, 1963), destructive power dynamics, and bandwagon effects creating bias can be avoided (Powell, 2003). The Delphi method can provide a "shortcut" strategy to synthesize and harness complex information promoting an adaptive management approach to decision-making within socio-ecological problems where science is incomplete (Hess and King, 2002).

The Delphi method has been used for a range of applications such as forecasting, decision making, analysis, and scoping, in fields as diverse as technology (Dalkey and Helmer, 1963), commerce (Addison, 2003), nursing (Hasson et al., 2000; Powell, 2003) education (Clayton, 1997), agriculture (Angus et al., 2003; Menard et al., 1999), planning (Hess and King, 2002), public policy (Hilbert et al., 2009), environmental management (Moore et al., 2009; Plummer and Armitage, 2007), ecology (MacMillan and Marshall, 2006), and vulnerability analyses (Brooks et al., 2005; Webler et al., 1991). These different studies address local, regional, national, and global problems and give examples of narrowly and broadly defined "expert" groups of researchers, regulatory authorities, project managers, resource managers, civil society, and contractors (Addison, 2003; Angus et al., 2003; Hess and King, 2002; Hilbert et al., 2009; Plummer and Armitage, 2007; Webler et al., 1991). Traditionally, studies using the Delphi method have used repeated rounds of mail-in questionnaires and semi-structured interviews (Hess and King, 2002; Rikkonen and Tapio, 2009), but examples have also involved group approaches (Webler et al., 1991) and the use of online tools (Hilbert et al., 2009). Mail-in Delphi surveys can be labor and time intensive hampering the study's impact, while a "real-time Delphi" using an online format to gather multiple perspectives reduces processing burden and the study duration (Nowack et al., 2011; Hess and King, 2002).

The interactive, social, World Wide Web and communication technologies have greatly expanded researchers' capabilities of reaching broad audiences, and enabled applications of participatory methods to address scientific, public policy, and societal questions on a massive scale (Crain et al., 2014; Dickinson et al., 2013; Prpić et al., 2015; Wiggins and Crowston, 2011). Examples of applications of crowdsourcing to problem solving, task completion, and idea generation include: Galaxy Zoo, MIT's Climate CoLab, Sustainia and Quirky (Lohr, 2015; MIT Center for Collective Intelligence, n.d.; Prpić et al., 2015; Sustainia, n.d.; Wiggins and Crowston, 2011). Crowdsourcing can take many forms, but refers to the open call for contributions from a large network of people to address a problem (Wiggins and Crowston, 2011). Beyond business, it extends to public policy and planning to surface collective intelligence and creative solutions (Brabham, 2009) through virtual labor markets, tournament crowdsourcing, and open collaboration techniques (Prpić et al., 2015). Prpić et al. (2015) review applications of crowdsourcing to different stages of the policy cycle (Howlett and Ramesh, 1995), with open collaboration being the most common technique.

1.2. The case of Lake Champlain Basin and phosphorus pollution

Despite significant efforts over decades to address nutrient pollution (primarily phosphorus), eutrophication and harmful algal blooms persist across portions of Vermont, New York, and Quebec in Lake Champlain (Crawford, 2014; Lake Champlain Basin Program, 2012; Osherenko, 2013) (See Fig. 1). The land uses that contribute to phosphorus pollution across the basin include development (stormwater and wastewater), agricultural, forested, floodplain, and riparian land; their settings involve interwoven physical processes, management practices, and governance systems (Patterson et al., 2013 U.S. Environmental Protection Agency (EPA), 2016). The responsibility for cleanup is not under one agency, but is within the purview of federal, state, and local governments, the International Joint Commission, non-governmental organizations, landowners, concerned citizens, the private sector, and interest groups (Koliba et al., 2014; Scheinert et al., 2015). This ambiguity contributes to tension among farmers, city dwellers, and lakefront landowners as well as local governments and national agencies regarding how to effectively mitigate water pollution in the basin (Gaddis et al., 2010). The landscape of phosphorus sources, drivers, and institutions requires adaptive policy and planning solutions that account for climate change impacts and different time lags associated with possible interventions and best management practices (Meals et al., 2010; State of Vermont, 2015). After an earlier plan did not