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Research article

Linking community-based monitoring to water policy: Perceptions of citizen scientists

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ABSTRACT

This paper examines the relationships between Community-Based Water Monitoring (CBM) and government-led water initiatives. Drawing on a cross-Canada survey of over one hundred organizations, we explore the reasons why communities undertake CBM, the monitoring protocols they follow, and the extent to which CBM program members feel their findings are incorporated into formal (i.e., government-led) decision-making processes. Our results indicate that despite following standardized and credible monitoring protocols, fewer than half of CBM organizations report that their data is being used to inform water policy at any level of government. Moreover, respondents report higher rates of cooperation and data-sharing between CBM organizations themselves than between CBM organizations and their respective governments. These findings are significant, because many governments continue to express support for CBM. We explore the barriers between CBM data collection and government policy, and suggest that structural barriers include lack of multi-year funding, inconsistent protocols, and poor communication. More broadly, we argue that the distinction between formal and informal programming is unclear, and that addressing known CBM challenges will rely on a change in perception: CBM cannot simply be a less expensive alternative to government-driven data collection.

1. Introduction

Involving communities in tracking freshwater quality and availability is often referred to as Community-Based Water Monitoring (CBM) (Conrad and Daoust, 2008; Whitelaw et al., 2003). This approach usually entails volunteers, either non-experts or trained scientists, engaging in one or more stages of collecting, analysing, and using data to answer locally-relevant questions (Conrad and Hilchey, 2011; Whitelaw et al., 2003). CBM is implemented with varying degrees of community participation and collaboration with governments, industry, academic institutions and/or civil society. As such, CBM is generally compatible with the concepts of citizen science (Silvertown, 2009), community science (Armitage et al., 2017), crowd-sourced data collection (Lowry and Fienen, 2013), and participatory monitoring (Danielsen et al., 2005). Above all, CBM is marked by an emphasis on community-driven motivations for generating environmental data (Conrad and Hilchey, 2011; Pollock and Whitelaw, 2005; Whitelaw et al., 2003).

In recent decades, CBM has expanded rapidly – particularly in North America and Europe (Conrad and Daoust, 2008; McKinley et al., 2017; Silvertown, 2009), but also in other countries, including Australia (Wiseman and Bardsley, 2016), Brazil (Cunha et al., 2017), China (Zhang et al., 2017), Malawi (Wanda et al., 2017), New Zealand (Harmsworth et al., 2011), South Africa (Rivett et al., 2013), and Vietnam (Nhan et al., 2015). This growth is attributed to many factors including (1) the limited capacity and scope of monitoring conducted by scientists in government and academia; (2) the growing concerns of communities regarding the health of their local environment; and (3) the rise of affordable and simple technologies for crowdsourcing data and undertaking robust and accurate water monitoring (Buytaert et al., 2014; Conrad and Hilchey, 2011; Pollock and Whitelaw, 2005; Silvertown, 2009). Consequently, data collected through CBM are filling gaps in environmental monitoring, promoting sustainable natural resource management, and engaging communities in the conservation and stewardship of ecosystems (Buytaert et al., 2014; Ochoa-Tocachi et al., 2016). As this phenomenon continues to grow, there is an

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emerging need to understand and document the conditions that foster success in improving local environments through CBM data, as well as the ongoing barriers to community-based approaches in environmental monitoring (Conrad and Hilchey, 2011).

To further explore factors that foster or hinder the usability of CBM data, we conducted a cross-Canada survey of over one hundred CBM organizations. In this paper, we map those findings onto existing academic and grey literature on CBM with an emphasis on four key considerations highlighted in previous scholarship (Alender, 2016; Burgess et al., 2017; Buytaert et al., 2014; Conrad and Hilchey, 2011; Danielsen et al., 2009; Scott and Frost, 2017; Kouril et al., 2015; Pollock and Whitelaw, 2005). Our survey results are presented later in the paper; below, we outline the existing literature on CBM, and highlight four themes. First, we explore the reasons for which CBM programs initiate and the different data trajectories of CBM. Second, we review the credibility of CBM methodologies for collecting, storing, and/or analysing environmental data. Third, we discuss implications of the varying degrees of participation by local citizen scientists and external professional scientists throughout a CBM project life cycle. Fourth, we examine the potential benefits of CBM partnerships with governments, CBM networks, and other institutions in building capacity and fostering data-policy linkages in CBM programs. We utilise these four themes of CBM to shed light on outstanding questions in the CBM literature and to provide an analytical frame for our subsequent research questions: (1) Are CBM programs across Canada addressing the reasons for which they were originally initiated? (2) What protocols are being followed by CBM groups and which parameters are being monitored? (3) To what extent to do CBM program members feel their findings are incorporated into government-led decision-making processes?

1.1. Motivations for CBM

Understanding the diverse and place-based motivations for engaging in CBM is essential to generating sustained interest and participation in CBM programs (Bonney et al., 2014; EPA, 2016; McNeil et al., 2006; Pollock and Whitelaw, 2005). Although the spectrum of community-specific reasons for collecting and using water data can be challenging to classify, at least three broad categories (or progressive stages) exist. First, motivations can stem from a desire to generate community awareness, increase scientific literacy, and contribute to scientific research (Cohn, 2008; Dickinson et al., 2012; EPA, 2016). Second, communities may undertake CBM to fill gaps in government-led monitoring, and to identify and track local concerns about ecosystem and human health (Whitelaw et al., 2003; Conrad and Hilchey, 2011; Garda et al., 2017). Third, CBM can be initiated to leverage scientific knowledge to inform and improve policy and decision-making at various scales of governance (Danielsen et al., 2009; McKinley et al., 2017; McNeil et al., 2006), and to promote better compliance with environmental laws (EPA, 2016). The degree to which these categories motivate individuals will vary, as participant motivations often change across time (Rotman et al., 2014), and can diverge based on age, gender, level of education, and socioeconomic circumstances (Alender, 2016; Beza et al., 2017; Danielsen et al., 2005; Lewandowski et al., 2017; Raddick et al., 2013).

Another angle for examining motivations for CBM is to consider the potential uses of community-generated data. CBM data are variously used in academic publications (Ochoa-Tocachi et al., 2016; Scott and Frost, 2017), collected to supplement datasets collected by governments or NGOs (CABIN, 2012; Mackenzie Datastream, 2017; McNeil et al., 2006), provided as evidence for prosecution in cases of violations of environmental laws (EPA, 2016), and disseminated to the public through reports, workshops, and conferences (Pollock and Whitelaw, 2005; Weston and Conrad, 2015). However, using citizen data to potentially inform and improve policy and decision-making is emphasized consistently across both academic and grey literature on CBM (Alender, 2016; Buytaert et al., 2014; Castleden et al., 2016; Conrad and Hilchey, 2011; Danielsen et al., 2010; EPA, 2016; Kanu et al., 2016; NWT, 2010; Pollock and Whitelaw, 2005). To this effect, Conrad and Daoust assert that “regardless of the specific mandate, [participants in CBM] tend to have the hope that their efforts will be used to assist in local decision making” (2008, pg. 359). Moreover, Alender (2016) studied volunteer water quality monitoring in the United States and found that the highest ranking motivators for CBM was enhancing the environment and using data to address environmental problems, which implicitly requires some level of action by decision-makers.

Thus far we have explored literature on motivations for CBM without explicit attention to place, but connecting data to decision-making also needs to be situated within socioeconomic and geographic realities. For instance, Danielsen et al. (2009) suggest that local communities in poorer countries are more likely motivated by the potential benefits that monitoring offers in terms of community ownership, empowerment and decision-making surrounding their local environment and natural resources. This is supported by Buytaert et al. (2014), who highlight several case studies of low-income rural farmers utilising CBM primarily to inform and improve governance of water resources vital to agrarian livelihoods in Ethiopia, Kyrgyzstan, Nepal, and Peru. Additionally, Berkes et al. (2007) highlight cases of Inuit fishers and hunters in the Canadian Arctic using CBM and Indigenous knowledge to support integrated management of marine ecosystems on which their subsistence depends. These cases highlight the motivation of conducting CBM with the intention of securing remote and vulnerable livelihoods dependent on the preservation of ecosystems, which contrasts with more affluent regions where monitoring can arise out of a culture of volunteerism and outdoor recreation (Danielsen et al., 2005).

Considering the centrality of data-policy linkages within most CBM, it is important that monitoring programs are deliberately designed and implemented with the intention of generating actionable and credible information to decision-makers (Buckland-Nicks et al., 2016; Buytaert et al., 2014; McKinley et al., 2017). However, the credibility of CBM remains an ongoing challenge to achieving linkages between data and decision-making. Indeed, the issue of credibility has sometimes led government agencies and academic institutions to reject CBM findings that could otherwise potentially fill critical information gaps and guide environmental management decisions. Therefore, exploring past literature that has tested the validity of CBM and citizen science programs may shed light on approaches to avoid potential methodological issues that may arise in CBM and maximize the utility of citizen-generated data.

1.2. Credibility of CBM

A long-standing barrier to CBM is the perception among scientists that citizen-generated data is not reliable (Conrad and Hilchey, 2011). In particular, skepticism is often directed toward issues of data accuracy and biases (Burgess et al., 2017; Kosmala et al., 2016). Scientists have expressed concern about the capacity of non-experts to mitigate data errors, calibrate equipment, and undertake robust data analyses, especially in more complex fields of scientific inquiry. Generally, the literature asserts that citizen science and CBM, while suitable when using basic methodologies in fields such as ecology, hydrology, and astronomy, is not appropriate in many other fields of science (Cohn 2008; McKinley et al., 2017).

This corresponds with the fact that the most prolific areas of CBM tend to be ecological studies and environmental monitoring (Silvertown, 2009), which can also be made more accessible and engaging for citizen scientists and community monitors (Cohn, 2008).

However, a number of recent findings are increasingly supporting the validity and suitability of CBM. First, contrary to some academic perceptions of the invalidity of CBM methods, most biases in data interpretation are found equally among both professional scientists and citizen scientists (Kosmala et al., 2016). Second, advances in automatic sensing technology and statistical analysis have improved data accuracy and reduced biases, respectively (Hochachka et al., 2012; Kosmala et al., 2016; Newman et al., 2012). Last, several case studies verify that when proper protocols are followed, citizen scientists can collect data with similar levels of accuracy as professional scientists (Au et al., 2000; Fore et al., 2001; Kosmala et al., 2016; Shelton, 2013; Storey et al., 2016). These findings suggest that a lack of awareness within the scientific community of the credibility of CBM may actually be a larger barrier than the technical competencies of citizen scientists (Burgess et al., 2017).

Despite research supporting the theoretical potential of CBM to be conducted robustly, at least four practical challenges remain. First, CBM is data intensive, and when monitoring programs have inadequate funding and resources, data quality issues are often more prevalent (Alender, 2016; Conrad and Daoust, 2008). In general, more funding needs to be allocated to improving data management and analysis tools in CBM programs to continue advancing standards of CBM data quality (Bonney et al., 2014). Second, it may be difficult to match monitoring protocols with different cultural contexts and locally-specific motivations for monitoring. Pollock and Whitelaw note the experience of CBM coordinators in remote aboriginal communities in Canada with oral cultures, where “the ‘double translation’ of protocols into traditional languages and translation of results into English remains a distinct challenge” (2005, pg. 223). Third, the emphasis on data quality and robust analysis is sometimes at variance with the participatory and place-based nature of CBM (Danielsen et al., 2005). Communities may generate local indicators for watershed health that are incompatible with government-recommended guidelines for collecting and storing water quality samples (Wilson et al., 2018). While professional scientists may recommend that CBM data be stored and analysed by trained professionals in laboratories, several case studies show that when data is stored and analysed within local communities, CBM can have a more significant impact in local decision-making scenarios (Danielsen et al., 2005).

Moreover, evidence suggests that concerns of keeping research place-based are sometimes more important to communities, even if data quality is somewhat decreased as a result (Danielsen et al., 2005). For instance, locally-defined indicators of watershed health may be incompatible with government-recommended guidelines for collecting and storing water quality samples. More broadly, such cases allude to the different tensions between locally-based and externally-driven approaches to monitoring, in which local communities and external experts participate variously throughout the research process. The next section explores different approaches to citizen participation in CBM and citizen science projects, which is a salient consideration when evaluating the potential benefits and challenges associated with the degree of community ownership of CBM projects.

1.3. Degrees of citizen participation

Monitoring projects have varying levels of involvement of professional scientists and local communities. For instance, in monitoring programs established by governments, citizens usually participate only as data collectors whereas professionals determine monitoring objectives, methodology, and data use. In contrast, monitoring programs initiated at the community-level often entail community members taking a leading or collaborative role in data collection, analysis, and usage (Conrad and Hilchey, 2011; Danielsen et al., 2009). The degree and quality of community participation in CBM have far-reaching implications on a program's outcomes and potential policy impact (Danielsen et al., 2010; Shirk et al., 2012).

Several frameworks exist for assessing the level of engagement of citizens in community-based monitoring programs. Whitelaw et al. (2003) describe four approaches to CBM including *government-led, interpretive, advocacy, and multiparty*. This typology acknowledges that multiple approaches to monitoring can coincide, since CBM sometimes involves both interpretive (educational) and advocacy components. Other approaches posit a spectrum of engagement with lesser and greater levels of citizen participation. For instance, Danielson et al. (2009) propose a spectrum of five monitoring schemes based on the varying roles of citizen scientists and professional scientists in data collection and data use. These include *externally-driven, collaborative, and autonomous local monitoring* approaches. Similarly, Conrad and Hilchey (2011) conceptualize three governance structures for monitoring programs, which frame the role of citizens as being *consultative, collaborative, or transformative*.

Common among all these frameworks is a characterization of benefits and challenges for programs across the participatory spectrum, from externally-driven to locally-based approaches. First of all, local and collaborative forms of monitoring are substantially more affordable than external and government-led monitoring (Brammer et al., 2016; McNeil et al., 2006), but the former can face challenges relating to data management, long-term funding, and governance (Conrad and Daoust, 2008; Conrad and Hilchey, 2011). Moreover, Danielsen et al. (2010) find that in locally-based monitoring significantly speeds up the rate at which resource management decisions are made. In particular, the authors note that participatory monitoring can “lead to rapid decisions to solve the key threats affecting natural resources, can empower local communities to better manage their resources, and can refine sustainable-use strategies to improve local livelihoods” (Danielsen et al., 2010, pg. 1). However, the authors also note that government-led monitoring may be better suited for contributing to national and international scales of decision-making (Danielsen et al., 2005, 2010).

Acknowledging trade-offs between these different approaches, Danielsen et al. (2009) suggest criteria for selecting which degree of local participation is most effective given local circumstances and monitoring objectives. For instance, CBM programs aiming for high data quality generally require greater involvement by professional scientists, whereas programs focused on empowering local communities in decision-making necessitate higher degrees of community participation in data collection, analysis, and use (Danielsen et al., 2005, 2009). Therefore, CBM programs must be carefully designed to reflect the appropriate level of local participation for a particular community and environmental issue (McKinley et al., 2017). In some cases, programs are able to achieve both locally-driven monitoring as well as the benefits of funding and capacity support from governments through collaborative arrangements with governments and other parties (McNeil et al., 2006; Whitelaw et al., 2003). This is detailed further in literature focusing on partnerships in CBM.

1.4. Collaboration and partnerships

While communities may be asking questions that are quite distinct from those of professional scientists, the potential for collaboration is optimized when these questions overlap (Buytaert et al., 2014; Célleri et al., 2010). Building synergies through monitoring partnerships and networks can substantially increase the feasibility and technical capacity of a CBM project while reducing potential overlap in monitoring initiatives (Bonney et al., 2014; Latimore and Steen, 2014; McNeil et al., 2006; Pollock and Whitelaw, 2005; Wilson et al., 2018). To this effect, Pollock and Whitelaw note that potential partnerships can be formed with a wide range of actors including “municipal, provincial and federal government agencies, environmental organizations, industry representatives, community groups, academic institutions (from elementary to post-secondary), conservation areas, field naturalists, parks, and biosphere reserves, to name a few” (2005, pg. 221). Determining which among these actors are most suitable for partnerships often depends on the context in which CBM is being implemented and problems communities aim to address.

For CBM programs aiming to inform policy and decision-making, partnering with government actors and non-governmental organizations (NGOs) involved in water monitoring and management is usually a necessary step (Conrad and Daoust, 2008; EPA, 2016; McNeil et al., 2006; Whitelaw et al., 2003). In cases of collaboration between communities and governments, Conrad and Daoust (2008) suggest that an effective starting point for communities “identifying the kinds of information environmental managers require to make good decisions” (2008, pg. 359). Another aspect of identifying appropriate decision-makers is assessing the levels of government that have relevant jurisdictional authority to address a particular ecosystem and water resource management issue. In the case of Canada, the mandated authority could be municipal/regional (ex: stormwater runoff, water extraction, municipal sewage), provincial/territorial (ex: mining, forestry, agriculture), or federal (ex: commercial fishing, interprovincial energy projects). In some cases, multiple levels of government are implicated in order to holistically address a water-related issue (ex: fish habitat).

Of course, partnerships with relevant governmental actors do not guarantee that local environmental conditions will improve, or even that CBM data will be used effectively (Conrad and Daoust, 2008). However, the legitimacy of citizen-generated data is often bolstered through such partnerships, as it enables communities to collect data that is compatible with government frameworks for water monitoring (McNeil et al., 2006).

Nevertheless, an ongoing challenge in cases of monitoring partnerships between communities and government is the lack of communication of how CBM data is used (Alender, 2016; Conrad and Daoust, 2008). McNeil et al. (2006) report statistics from a federal government-run CBM program (Atlantic Coastal Action Program) in which metrics are provided for the benefits and uses of citizen data. However, instances of government departments publicly reporting such data outcomes appear less common in the past decade. This is partly because governments supporting CBM are sometimes unable to verify how and if monitoring data is used, it is also due to a recent and past decreases in government funding capacity to support CBM (Au et al., 2000; Savan et al., 2003; Conrad and Daoust, 2008). The uncertainty of whether data is being used in decision-making remains a significant challenge for CBM (Conrad and Hilchey, 2011). Ultimately, overcoming such challenges are necessary to increase the utility of CBM for all parties involved.

Despite the rich literature outlined above, key questions remain central to understanding the barriers to CBM uptake. Specifically: (1) Are CBM programs across Canada addressing the reasons for which they were originally initiated? (2) What protocols are being followed by CBM groups and which parameters are being monitored? (3) To what extent do CBM program members feel their findings are incorporated into government-led decision-making processes? These questions are important because they take current understandings of the challenges and benefits from literature reviews and specific case studies to broader-scale understandings of trends over time. These questions were the focus of the nationwide survey discussed below. As is further detailed in the Discussion section, the results the survey provided unique insights into these questions and can help scholars and practitioners better understand the relationships between CBM programs and the broader water governance landscape.

2. Methods

2.1. Cross-sectional survey

In Canada, as elsewhere, CBM is an increasingly popular and important part of the water governance landscape. With over 200 CBM organizations across the country, Canada provides a rich case study in which to ask some of the broader scale questions that remain unanswered in the literature (see above). To answer these questions, we created a cross-sectional online survey in order to examine (1) the degree to which communities are addressing their environmental concerns through CBM, (2) the monitoring protocols they follow and parameters they monitor, and (3) the extent to which CBM program members feel their findings are incorporated into government decision-making surrounding water resources. The scope of community-based monitoring for the survey includes organizations and groups that involve volunteers and non-professionals in the collection of water quality and quantity data within Canada. This group was inclusive of water monitoring that assesses physical (e.g. temperature), chemical (e.g. pH) and biological (e.g. benthic invertebrates) parameters across freshwater bodies, including lakes, streams, rivers, wetlands, glaciers, and groundwater.

The survey was distributed by email in both French and English between July 2016 and September 2016. Participants were informed that the purpose of the study was to build a better understanding of what CBM initiatives exist across the country, what is being monitored and analysed, and how existing programs are supported and coordinated.

2.2. Participant recruitment

Recruitment was carried out through virtual sampling using purposive and snowball approaches. A purposive sample is constructed from a population for a specific purpose and a snowball sample entails enlisting the help of prospective participants to recruit other suitable participants (Atkinson and Flint, 2001; Palys, 2008). The former method was employed to identify individuals in management or coordination roles within organizations conducting CBM, whereas the latter method was used to recruit participants through existing CBM networks and to reach individuals that may not appear in internet search engine results. Using a combined sampling approach helped to maximize the quality and quantity of the sample size. This was necessary due to the lack of a national inventory of CBM initiatives at the time of the survey design (May 2016–June 2016).

2.3. Limitations

Given the nature of CBM as an inclusive form of scientific research involving the general public, the level of expertise of respondents was variable, ranging from volunteers without formal scientific training to professional scientists. Moreover, participants also varied in their level of involvement in their respective program. Some respondents played a central role in coordination and oversight of a CBM program whereas others were only involved through contributing data. These discrepancies in expertise and experience may affect the accuracy of responses to survey questions that require a more reliable understanding of water science and the history of their CBM program, respectively.

3. Results

The survey was distributed by email to 270 individuals, of which 121 (45%) responded. Most respondents were located in British Columbia (n = 33), Nova Scotia (n = 25), Ontario (n = 13), and Alberta (n = 13), and the majority of respondents (n = 85) were located outside of metropolitan areas (StatsCan, 2016). CBM activities varied widely in geographic scope, ranging from CBM networks monitoring over 240 water bodies to local groups monitoring a single river or stream (Fig. 1).

Initial survey questions prompted participants to report when their organization started monitoring and when gaps in monitoring have occurred. The average length of continual monitoring by the CBM programs sampled was 8.9 years, with shortest being less than a year and the longest continuing for 47 years. Only 9 of 121 programs explicitly reported multi-year gaps in their monitoring activities. However, other respondents reported that their monitoring sites have sometimes changed or expanded over time, and that the intensity of monitoring varies year by year. Lastly, we found here that the number of CBM programs have nearly quadrupled between 2000 and 2016, which supports previous literature that CBM is rapidly expanding in Canada (Conrad and Daoust, 2008; Conrad and Hilchey, 2011).

3.1. Effectiveness of CBM programs

To identify trends in effective CBM programs, we first employed an open-ended question to discern the initial reasons for which respondents implemented a CBM program, and whether or not these reasons have been, or are being, addressed. Here we define "effectiveness" as the respondents' perception of their CBM program to produce or contribute to a desired outcome (ex: improved community stewardship of a local stream, or stricter regulations on industrial wastewater treatment). We coded key words in responses by frequency and conducted a thematic analysis to distinguish subtleties in expression. Of 107 respondents to this question, the majority (n = 67) provided multiple reasons for which their CBM program started. Responses generally fit within five categories: (1) addressing local concerns about ecosystems (n = 63), (2) fostering education, engagement, and stewardship (n = 32), (3) filling gaps in existing data, monitoring, and local knowledge (n = 26), (4) informing decision-making and local ecosystem management (n = 24), and (5) conducting scientific research and establishing baseline data to assess long-term trends and impacts (n = 18).

Evidently, the above categories are not mutually exclusive. It is possible that some respondents may have not listed certain categories as an initial reason for monitoring, but these may have become a justification for continuing the program at later stages once CBM data start to reveal ecological trends. For instance, categories (2), (3), (4) or (5) can variously act as necessary strategies to achieve category (1). Many of individuals from Category (1) reported that their concerns derived specifically from impacts of mining (n=8), farming (n = 7), urban development (n = 7), flooding (n = 4), logging (n = 3), boating and recreation (n = 2), municipal water extraction (n = 2) hydraulic fracturing (n = 1) and hydropower development (n = 1). This may suggest that CBM programs have to be carefully designed to address the appropriate questions

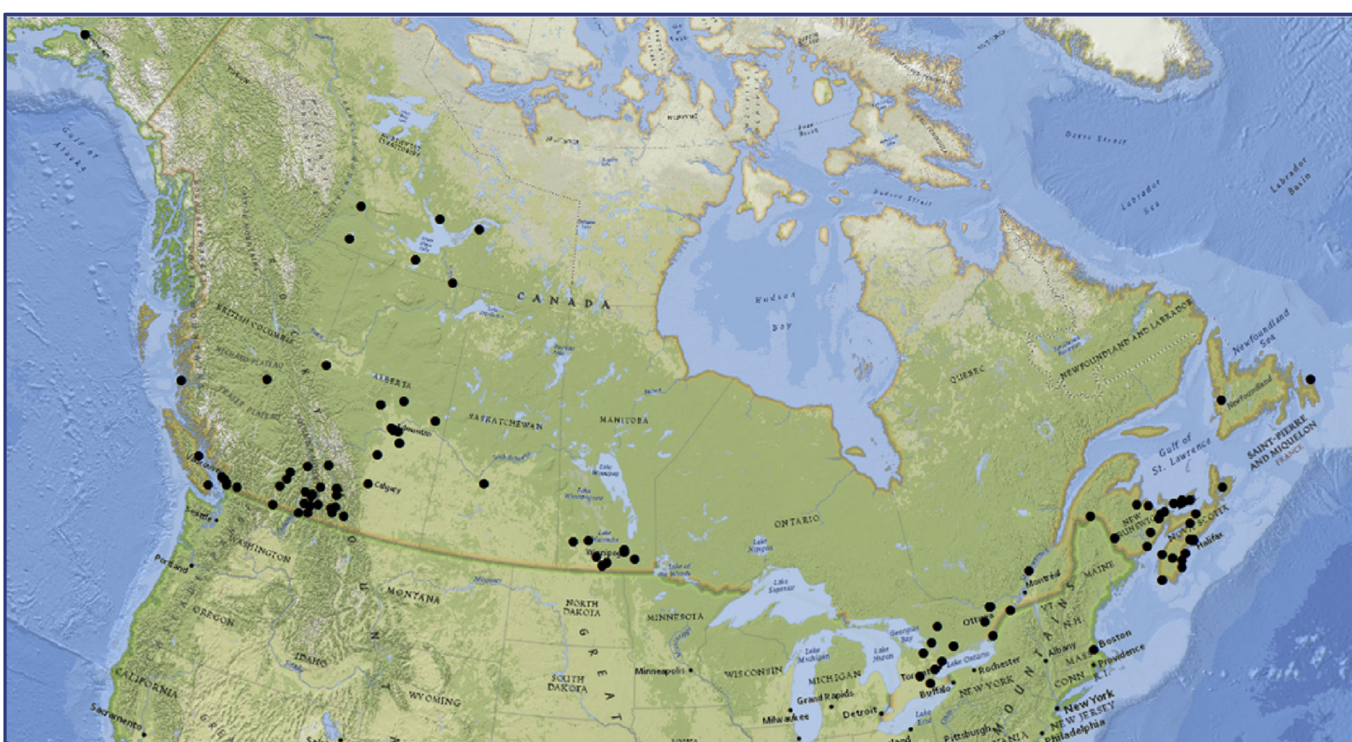

Fig. 1. Map of CBM organizations by postal code.

that corresponds with a particular water quality or quantity issue.

Participants were then asked whether their CBM program is addressing their initial reasons for monitoring. 107 responses were coded as "yes", "somewhat", "no", and "on going/to be determined" – to account for temporary and continual evaluations of monitoring efficacy. 59% (63/107) of participants reported that their reasons for monitoring are being addressed, whereas 18% (19/107) indicated that their reasons are partially or somewhat addressed, 7% (7/107) stated "No", and the remaining 15% (16/107) reported that their evaluation of CBM outcomes is "ongoing" or "to be determined."

3.2. Correlation between effective and collaborative CBM

Based on previous literature emphasizing partnerships as a key factor in effective CBM (McNeil et al., 2006; Latimore and Steen, 2014; Ochoa-Tocachi et al., 2016; Kouril et al., 2015), we investigated potential correlations between CBM programs with partnerships and the likelihood of achieving program goals. Notably, 74% (35/47) of respondents that collaborate with both government(s) and CBM networks reported that their program is addressing its original purpose. In contrast, programs collaborating only with government(s) or only with CBM networks answered "Yes" 50% (13/26) and 44% (8/18), respectively. Only 29% (4/14) of programs without any partnership or collaboration reported that they were addressing their initial reasons for monitoring.

This finding may support the notion that partnerships with governments and CBM networks often strengthen the capacity and effectiveness of local initiatives. For instance, in many cases, respondents reported that municipalities, regional districts, and provincial governments loaned monitoring equipment, provided data storage, and supported program planning and coordination – all of which can potentially increase the efficacy of monitoring. Interestingly, no significant correlation was found between the number of governments (i.e. municipal, regional, provincial, federal, and Indigenous) a CBM group collaborated with and the perceived success of the program.

3.3. Prevalence of standardized monitoring protocols

We asked respondents to state whether or not they follow a standardized monitoring protocol.[1] We provided an option to respond "Unsure" to account for respondents who may not be acquainted with the protocols their organization follows. The majority of respondents (78%) followed a monitoring protocol, while 12% were unsure and 10% did not. These results contrast with those of Conrad and Daoust (2008), who surveyed CBM groups based in the province of Nova Scotia and found that 73% of respondents did not use a standardized protocol to collect data. Moreover, within our sample size from the same province (n = 20) that these authors studied, we found that 75% of respondents follow standardized monitoring protocols. At the very least, this indicates that CBM has likely become more standardized in the past decade in this particular province, but may also suggest monitoring protocols have become more prevalent for CBM programs across Canada.

Monitoring protocols are often designed for specific water quality parameters. We asked participants what parameters they monitoring in order to understand how it may inform of a protocols. The most common parameters were Temperature (n = 107), pH (n = 97), Dissolved Oxygen (n = 93), Conductivity (n = 87), Turbidity (n = 67). Total Phosphorus (n = 57), Total Nitrogen (n = 47). We then provided participants with five options to convey how these parameters were selected. The results are as follows: "monitoring protocol standards" (34%), "federal, provincial, or territorial standards" (36%), "community priorities" (38%), and "capacity of monitoring equipment and/or resources" (56%). The remaining option available to participants was an open-ended answer, in which some participants (26%) clarified that monitoring parameters were selected based on the advice of professional scientists or due to the specific nature of the program (e.g. accessibility for high school students, or relevance to monitoring climate change impacts).

Other aspects of monitoring protocols we considered are their respective scope and coordinating entity. The most commonly followed protocols came from the Canadian Aquatic Biomonitoring Network (CABIN) (n = 22) and Community Based Environmental Monitoring Network (CBEMN) (n = 13), which are coordinated by a federal government department and a non-governmental organization, respectively. In contrast, many of the remaining respondents reported following various provincial, territorial, regional and municipal (PTRM) protocols[2] (n = 38). The latter were amalgamated in this analysis because these were too numerous to evaluate and a comparison would be skewed by provinces with the highest response rates (British Columbia and Nova Scotia). When separated by sector, CBM groups were following protocols coordinated by: government (n = 69), NGOs (n = 18), internal protocols (n = 7), and private consultants (n = 2).

3.4. Perceptions of CBM data uptake in policy and decision-making

We asked respondents to indicate if their data is informing policy at any level of government. All but one participant responded to this question (n = 120) and we measured responses as a percentage of total sample size. When asked if their data informs policy, respondents (n = 115) stated "Yes" (46%), "No" (30%), or "I don't know" (24%). Those who responded "Yes" reported that the level of government primarily using the data was provincial (n = 20), municipal (n = 15), federal (n = 7), regional (n = 6), and Indigenous (n = 3) (Fig. 2).

The finding that nearly one-third of respondents reported that their data are not informing policy is plausible considering that several respondents did not report this as an objective of their program. To explore this hypothesis further, we cross-tabulated the reasons for initiating CBM as discussed in section 3.1 and the frequency at which participants responded that their program informs government policy. We found that initial reasons for monitoring were not a significant indicator of how CBM programs responded to the above question. For instance, programs with primary objectives of "informing ecosystem management and decision-making" (55%) were not substantially more likely to inform policy than programs with primary objectives of "education" (47%) and "engagement" (36%).

Next, we compared responses across the most common monitoring protocols followed by CBM organizations (as discussed in section 3.2) to determine potential distinctions across the different coordinating entities for monitoring protocols. We found that 50% of respondents following provincial, territorial, regional, or municipal protocols perceived they were informing policy, whereas the same was true for only 36% and 25% of respondents following

[1] Here, we define 'monitoring protocol' as any prescribed methodology for collecting, analyzing, and/or interpreting water quality or quantity data. Examples include municipal or provincial monitoring protocols that include testing parameters for particular substances.

[2] No Indigenous monitoring protocols were mentioned by participants. However, 30% of respondents (n = 121) reported they incorporate traditional ecological knowledge (TEK) into their monitoring.

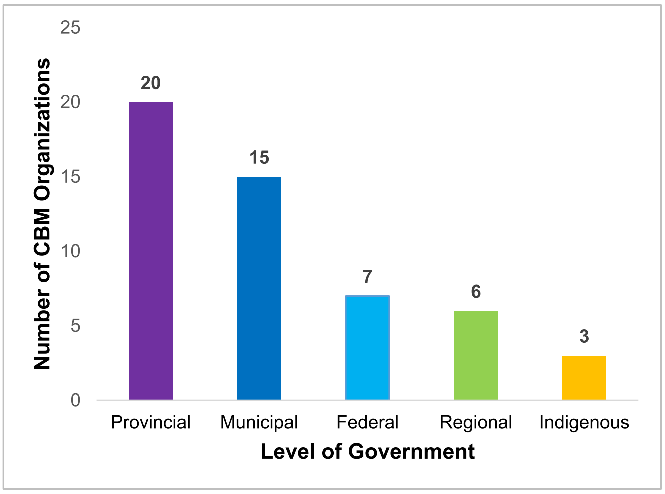

Fig. 2. Levels of government using CBM data as perceived by respondents.

CBEMN and CABIN protocols, respectively. Although the amalgamation of PTRM protocols reduces the granularity of the data analysis, it is still notable that the rate at which respondents perceive data-policy linkages within a federal government protocol (CABIN) is half (25%) (n = 22) of that of respondents following protocols from lower orders of government (PTRM) (50%) (n = 38).

The final analysis conducted in relation to data-policy linkages within CBM is the potential effect of the longevity of programs. We grouped the age of CBM programs into four categories: <2 years (n = 19), 2–5 years (n = 36), 5–15 years (n = 31), >15 years (n = 31) – these temporal ranges were selected to ensure comparisons relied on relatively even sample sizes. We found a trend in which the oldest programs (>15 years) were the most likely to be informing policy (58%), longer and shorter-term programs (5–15 years and 2–5 years) ranged in the middle (45% and 44%, respectively), and the most recent programs (<2 years) reported the lowest rate of informing policy (26%) and the highest rate of responding "I don't know" (37%). Not surprisingly, this finding indicates that program longevity is an important factor in measuring potential impacts on decision-making, possibly due to time lags between program initiation, sufficient data collection and analysis, and translation of findings into relevant policy and management actions (Danielsen et al., 2010; Kouril et al., 2015).

In sum, the survey found the following: (1) partnerships tend to increase the efficacy of monitoring, (2) two-thirds of respondents perceived that their program's data was being used by one or more levels of government, (3) programs using government-driven protocols were more likely to report their data being used by government – especially by lower orders of government, and (4) a correlation exists between program longevity and perceived data usage in policy. These findings build on and enrich existing CBM research (Conrad and Daoust, 2008; Conrad and Hilchey, 2011; Jollymore et al., 2017; McNeil et al., 2006; Pollock and Whitelaw, 2005) and may offer some concrete suggestions to groups hoping for policy uptake.

4. Discussion

Our survey results address important questions raised elsewhere in the literature. Specifically, we build on Conrad and Hilchey's conclusions from their CBM review, where they state that "there remains a need to enhance our understanding of community based-monitoring" (2011, pg. 284). In particular, they make the following recommendations for future research:

> (1) A need to "compare and contrast the success (and the situations that induce success) of CBM programs which present sound evidence of citizen scientists influencing positive environmental changes in the local ecosystems they monitor" and (2) "more case studies showing use of CBM data by decision-makers or the barriers to linkages and how these might be overcome" (pg. 284).

In the subsequent sections, we respond to this call for further research (4.1) and raise a new one: the potential tensions between the importance of locally-defined monitoring protocols and the push toward standardization (4.2).

4.1. Connecting monitoring objectives with actionable data uses

Although we agree on Conrad and Hilchey's first point about the need to draw connections between CBM and ecological outcomes, it is often infeasible to definitively identify causal relationships between CBM, citizen science, and environmental changes. For instance, CBM in the context of ecological restoration may discern a positive long-term impact on water quality resulting from improved aquatic and riparian habitat, but in cases where CBM data is amalgamated to inform a broader water management process, it is usually unrealistic to provide sound evidence of a positive environmental change.

We do, however, address Conrad and Hilchey (2011)'s second point about the relationship(s) between CBM and the use of CBM data by decision-makers. Indeed, the paucity of information about the relationship(s) between these two factors was one of the driving forces for the survey. To that end, we explicitly asked survey participants if they felt their results were being used by decision-makers in municipal, regional, provincial, national, or Indigenous governments. The results of that survey question indicate that almost half of the CBM programs believe their programs were informing government policy, while nearly one third were unsure.

These findings raise further questions. First, how might one know if a government is using CBM data? If the CBM data are being shared with one or more governments, are those governments reporting back to CBM groups with respect to the use of that data? Moreover, in what way(s) are the data being used? One could imagine any number of "use" scenarios, including, for example:

- The incorporation of baseline data into government databases;
- Ongoing monitoring for contaminants of concern and watching for concentrations or amounts above a prescribed threshold;
- Assessment of downstream effects;
- 'Before and after" monitoring with respect to particular developments on a given waterway;
- Examining potential links between monitoring data and public or ecological health;
- Measuring community involvement and public outreach (i.e., the number of volunteer monitors, turnout at community events, etc.).

This list brings up a second question, namely, on what timescale are the data being used? This question links to the point in Section 3.4 about the correlation between program longevity and increased likelihood of perceived data usage. Indeed, it seems obvious that the longer-running the program, the more opportunities exist for data usage. For example, if the data are being used for ongoing monitoring of contaminants of concern with a 'flag' raised if concentrations or amounts exceed allowable levels, are the data being 'used' if said amounts or concentrations are never reached? This is the problem of the null hypothesis as outlined in the case of conservation biology by Legg and Nagy (2006), where they suggest that a change within acceptable limits is still indeed a change. Similarly, if the purpose of a given CBM program is to generate baseline data, that baseline data can be used for any number of things, over a highly variable timeframe.

Together, these two questions raise a critical point about the relationship between monitoring and government. Since, as others (e.g. Conrad and Daoust 2008; Kebo and Bunch, 2013) have pointed out, many CBM initiatives have developed to fill the void left by the withdrawal of government from ongoing monitoring activities, it stands to reason that governments would have an interest in incorporating the results of this lower-cost alternative into their existing (or recently cut) programs. But CBM cannot simply be about replacing government programs with a less expensive alternative, and the unique advantages of CBM can – and indeed should – be drawn out to work in concert with government programs and not in their stead. These distinct advantages and their ability to work synergistically with (rather than replace) those programs for which governments are responsible present a fruitful avenue for future research.

4.2. Diverse monitoring protocols

A second set of CBM issues arising from the survey addresses the diversity of monitoring protocols used across the country. Monitoring protocols exist across multiple sectors and jurisdictions in Canada. In general, water monitoring is fragmented across numerous actors, including local to national governments with mandates relating to health, environment, fisheries, wastewater, stormwater, and land use planning (Bakker and Cook, 2011). This is compounded by local, Indigenous, industry, and NGO water monitoring protocols that were identified by respondents to our survey. This diversity of protocols is not necessarily a challenge in and of itself. Indeed, since one of the benefits of CBM is the perceived ability to address locally-relevant concerns, and since Canada is large enough to have a wide array of local water-related issues (see Results section), it makes sense that each locale works with the protocol that is best suited to their program's purpose and their particular issues of concern. At the same time, however, such diversity of protocols can stymie the collection of regional, provincial, or even national meta-data, complicating the compilation of the types of longitudinal data required to assess the impacts of climate change, or particular developments, or to measure downstream impacts on waterways hundreds or thousands of kilometres long. Moreover, our finding that 56% of respondents identified "capacity of monitoring equipment/resources" as the driving force behind their monitoring parameters of choice is problematic. While equipment capacity is indeed a practical consideration in developing CBM programs, we suggest that the underlying monitoring questions should be driving protocol and instrument choice – not the other way around.

For this reason, we suggest that the solution to the 'problem' of diverse protocols lies perhaps in our earlier discussion point about the overall purpose of a given CBM program beyond filling a government void: that form could follow function. That is, once a desired dataset is identified on the basis of a particular question (or set of questions), the monitoring protocols and appropriate scale of decision-making follow from there.

5. Conclusions

There are a diversity of motivations to undertake CBM. Community concerns about aquatic ecosystems have been an impetus for the expansion of CBM, along with local objectives of raising awareness, filling data gaps, contributing to scientific research, and informing policy. The latter objective is arguably the most complex to implement or evaluate. Nevertheless, the initial stage of problem identification is essential to the critical path for a CBM program, as scientific questions and monitoring objectives should correspond with a trajectory for citizen-generated data.

5.1. Fostering collaborative and adaptive CBM

At its core, CBM provides an opportunity for governments to rapidly increase the spatial coverage and temporal frequency of water monitoring, and an opportunity for communities to leverage scientifically-robust data to inform decision-making about their local environment. However, realizing these mutual benefits requires a more formal recognition of the value of CBM. In other words, citizen scientists, who are often seldom compensated for the data they collect, cannot be expected to undertake single-handedly the work of government scientists. Considering that CBM is often indirectly supporting the mandates of multiple levels of government responsible for water-related issues, governments should play a role in alleviating the financial, technical and logistical burdens associated with CBM. At the same time, there is a need for future research to explore the perceptions of policymakers regarding the successful inclusion of CBM data into decision-making processes.

When CBM organizations form partnerships with governments and broader CBM, it ideally creates a multidirectional flow of data, expertise, and resources to collectively improve water stewardship. However, the time scale of establishing effective and collaborative CBM with observable results is usually at odds with the durations of government-funded programs, which very rarely exceed a decade (McNeil et al., 2006), and electoral cycles. On this latter point, changes of government can lead to fiscal austerity for CBM – as witnessed by now-defunct CBM programs in Canada, the United Kingdom, and elsewhere (Mackechnie et al., 2011; Whitelaw et al., 2003). Subsequently, these fluctuations in government capacity highlight the need for CBM programs to develop more adaptive funding models and collaborate with other stakeholders such as NGOs, local industry, and community organizations to build their capacity beyond government partnerships.

5.2. Standardizing CBM at appropriate scales of governance

Although skepticism regarding the robustness and accuracy of CBM remains, standardized monitoring protocols are increasingly followed by CBM groups. This is a positive finding from the perspective of literature advocating for broader standardization of CBM in order to increase its scientific credibility (Au et al., 2000; Fore et al., 2001; Kosmala et al., 2016; Silvertown, 2009). However, there is a need for future research to analyse the broader implications of standardization, as it may hinder the incorporation of local and indigenous knowledge systems (Berkes et al., 2007), and the benefits derived from locally-driven monitoring (Danielsen et al., 2005).

To this effect, our findings suggest that monitoring protocols from local or sub-national scales of government are more likely to link data to decision-making, based on perceptions of CBM participants. This outcome can be partly attributed to the place-based nature of CBM and the regionally-specific issues impacting water quality and quantity. It is also possibly due to the jurisdictional authority of lower orders of government is more appropriate for addressing many community concerns related to water quality and quantity. Connections must therefore be drawn between the nature of a water issue, the appropriate management scale to address the issue, and the desired level of community ownership of a CBM project.

More broadly, we posit that understanding local motivations, employing robust methods, fostering citizen participation, and establishing collaborative partnerships remain key elements in CBM, and will ensure communities can continue playing formative role in the monitoring of freshwater resources.

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Competing interests

The authors have no competing interests to declare.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.jenvman.2018.04.077.

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