Environ Monit Assess (2013) 185:9451–9460
DOI 10.1007/s10661-013-3264-6

Canadian ENGOs in governance of water resources: information needs and monitoring practices

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Received: 12 January 2013 / Accepted: 17 May 2013 / Published online: 29 May 2013

Abstract Water quality monitoring involves a complex set of steps and a variety of approaches. Its goals include understanding of aquatic habitats, informing management and facilitating decision making, and educating citizens. Environmental nongovernmental organizations (ENGOs) are increasingly engaged in water quality monitoring and act as environmental watchdogs and stewards of water resources. These organizations exhibit different monitoring mandates. As government involvement in water quality monitoring continues to decline, it becomes essential that we understand their modi operandi. By doing so, we can enhance efficacy and encourage data sharing and communication. This research examined Canadian ENGOs that collect their own data on water quality with respect to water quality monitoring activities and information needs. This work had a twofold purpose: (1) to enhance knowledge about the Canadian ENGOs operating in the realm of water quality monitoring and (2) to guide and inform development of web-based geographic information systems (GIS) to support water quality monitoring, particularly using benthic macroinvertebrate protocols. A structured telephone survey was administered across 10 Canadian provinces to 21 ENGOs that undertake water quality monitoring. This generated information about barriers and challenges of data sharing, commonly collected metrics, human resources, and perceptions of volunteer-collected data. Results are presented on an aggregate level and among different groups of respondents. Use of geomatics technology was not consistent among respondents, and we found no noteworthy differences between organizations that did and did not use GIS tools. About one third of respondents did not employ computerized systems (including databases and spreadsheets) to support data management, analysis, and sharing. Despite their advantage as a holistic water quality indicator, benthic macroinvertebrates (BMIs) were not widely employed in stream monitoring. Although BMIs are particularly suitable for the purpose of citizen education, few organizations collected this metric, despite having public education and awareness as part of their mandate.

Keywords Water quality monitoring · Volunteer environmental monitoring · Environmental nongovernmental organizations · Geographic information systems · Benthic macroinvertebrates · Data sharing

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Introduction

Water quality monitoring is necessary to manage human relationships with all bodies of water and to understand the influence and impact of anthropogenic activities on the aquatic environment. In Canada, monitoring is normally carried out by provincial governments and their agencies, such as conservation districts in MB, irrigation districts in BC, AB, and SK, the watershed committees in QC, water boards in the territories, and conservation authorities in ON. Many of these entities may share some monitoring mandates with federal governmental agencies, such as Environment Canada.

Some environmental nongovernmental organizations (ENGOs) also undertake monitoring activities. By offering training, tools, staff and knowledge resources, and networks for data dissemination, ENGOs have the potential to become environmental watchdogs and stewards of streams, creeks, rivers, lakes, ponds, and groundwater bodies. These organizations have a variety of monitoring mandates, standards, practices, and most importantly funding. This results in challenges for information sharing and communication (Sharpe and Conrad 2006). It would be helpful to have a clearer understanding of these organizations, how they carry out their mandates, including water quality monitoring and their information technology environments.

With respect to ENGOs that undertake water quality monitoring, this research addressed two areas: (1) water quality monitoring: metrics collected, staff involved in their collection, opinions regarding water quality, reports, and broader topics within the realm of monitoring and (2) information needs: reliance on geographic information systems (GIS) and databases, staff IT competency and training, involvement with specialized computer tools, and metadata.

In this paper, we present the context of monitoring, in which ENGOs play a role, and the survey method used to explore water quality monitoring activities and information needs of these organizations. We then present results of this survey of 21 Canadian ENGOs and discuss these in light of the literature and opportunities to support monitoring activities. We conclude with recommendations addressed at information sharing.

Context

In Canada, government withdrawal from environmental monitoring has been substantial (Canadian Broadcasting Corporation 2008, 2012; Gibson 1999). Attempts to partly fill this gap have been made by citizen volunteers. These volunteers are comprised of concerned citizens working with ENGOs, often as part of community-based monitoring (CBM) initiatives. This public involvement in environmental monitoring is part of the dramatic increase in public environmental consciousness that has occurred in the latter half of the twentieth century (Conrad and Daoust 2008), partially catalyzed by Rachel Carson's 1962 seminal work *Silent Spring*. These groups are increasing in number and gaining recognition in Canada (Pollock and Whitelaw 2005) Furthermore, Sharpe and Conrad (2006, p.396) contend that "the integration of CBM into resource management is one of the most significant developments in that area since the environmental movement itself."

CBM can be defined as "a process where concerned citizens, government agencies, industry, academia, community groups, and local institutions collaborate to monitor, track, and respond to issues of common community concern" (Conrad and Daoust 2008, p. 358). CBM can be seen as operating within the broader concept of citizen science, which is "the participation of nonscientists (and nonacademic researchers) in data collection for scientific investigations" (Lee et al. 2006, p. 2). Unfortunately, issues such as inconsistent funding, loss of volunteer interest, fragmented and inaccurate data, and lack of interest among decision makers continue to plague CBM initiatives (Sharpe and Conrad 2006). Furthermore, their mandates and protocols may be incompatible with each other and with governmental monitoring programs and are not always well-communicated either to the authoritative bodies or the public (Conrad and Hilchey 2011; Kim et al. 2011).

Recent assessments show that government support to enable communities to participate meaningfully in watershed decision making is inadequate (Conrad and Daoust 2008). When community-based environmental monitoring is included in such management, it is hampered by lack of standardized monitoring protocols and frameworks, data fragmentation, lack of linkage to the management process and decision making, and low confidence in the quality of data (Conrad and Hilchey 2011; Conrad and Daoust 2008; Engel and Voshell 2002). Canada does not currently have an overarching national water strategy, and its water governance structure is highly fragmented and decentralized, affecting integration, coordination, and data availability (de Loë 2008; Bakker and Cook 2011).

Canada's federal government continues to erode environmental protection measures, with a recent example being the 2012 Bill C-38 (also known as the

Omnibus Bill). Among other things, this bill contained proposals with deleterious consequences for the environment (including water) and transferred greater responsibility for environmental assessments to the provinces. Critics point out that the bill removes freshwater protection for most fishes in Canada and, in the process, severely weakens the Fisheries Act dating from 1868 (Public Service Alliance of Canada 2012).

With this apparent withdrawal from environmental protection, it may be up to ENGOs and local communities and their small-scale efforts to try to fill the growing gap. Because of this, it is important to remedy spatial and temporal data fragmentation and facilitate bottom-up approach to water management. Understanding the nature of these entities was at the core of this research.

Methodology

We opted for a structured survey as a primary method of inquiry and presented each respondent with the same questions in the same order, so that the answers could be reliably aggregated and analyzed. We favored telephone administration over mail or electronic mail administration, as it ensured greater response rate and minimized respondent drop-off (i.e., respondent losing interest and terminating the survey prematurely). We included participants from all of the ten Canadian provinces and administered the survey from late 2008 until early 2009. NT, the northwestern territories, and YT were excluded due to difficulties finding suitable ENGOs. Closed-ended questions accounted for approximately 75 % of all survey questions, while the open-ended questions accounted for the remaining 25 %. With the former, we sought to assess respondent's attitudes toward water quality practices and information needs using yes/no/don't know five-point rating Likert scales (e.g., strongly agree, agree, neutral, disagree, and strongly disagree) and multiple criteria selection (e.g., lists of parameters).

It is reasonable to assume that the majority of water quality monitoring ENGOs have some level of web presence, e.g., via a web page or an environmental directory listing. Using Google, we produced a list of water quality monitoring ENGOs in Canada, entered their names in a spreadsheet, and selected respondent ENGOs via the simple random sample method. Using the software's random function, we randomly shuffled the cells containing names into a new list. We then contacted the ENGOs in the order presented on this list, until 22 respondent organizations that collected their own water quality data agreed to participate in the survey. (These organizations comprised about half of the original list and also included all the ENGOs on the original list that collected their own water quality data). One respondent ENGO was subsequently removed from the analysis, as they were later determined to be a governmental agency, leaving a final sample of 21 Canadian ENGOs (see Appendix A). The distribution of respondent organizations across Canadian provinces is shown in Table 1.

We carried out additional statistical analyses to compare the three groups: group 1 (organizations that used GIS versus those that did not), group 2 (organizations where paid staff carried out monitoring versus those where it was done by both paid staff and volunteers), and group 3 (organizations that collected benthic macroinvertebrates (BMIs) versus those that did not.)

Limitations

At 21, the sample size is relatively small. However, during the early stages of survey design, namely during contact identification/list generation, it became apparent that ENGOs collecting their own data (and not merely relying on someone else's) were uncommon. Although it is difficult to estimate what proportion of such entities this survey covers, given the substantial effort to identify those who were interviewed and that every single ENGO from our list that met the criteria ended up participating in the survey, we believe this survey covers a significant proportion of Canadian ENGOs that collect their own water quality monitoring data. Given that most of the primary gathering of organizations was done via Google search engine, it is possible that organizations with an active website were overrepresented. However, attempts to identify further respondents using a snowball method did not result in additional participants.

Results and discussion

Water quality monitoring

Table 2 shows the five most frequently collected water quality indicators.

Table 1 Number of completed surveys per province

Province	Number of samples
Alberta	2
British Columbia	3
Manitoba	2
New Brunswick	2
Newfoundland and Labrador	1
Nova Scotia	3
Ontario	2
Prince Edward Island	2
Québec	2
Saskatchewan	2
TOTAL	21

Temperature and pH are the two most frequently collected indicators (Tables 2 and 3). These can be measured relatively quickly, the necessary equipment and materials are inexpensive and easy to operate, and training requirements are minimal. More than three quarters of the ENGOs measured fecal coliforms (including *Escherichia coli*), and only six organizations collected BMIs. Although BMI sampling can be complex, labor intensive, and require reliable species assessment tools, this metric has great potential to generate a holistic picture of water quality (Engel and Voshell 2002) and easily involve the general public (Ongley 1997).

Table 4 shows the five most suitable indicators for public education, as indicated by ENGO survey respondents. Fecal coliforms were the most frequently reported. One respondent stated that the general public sees this metric as a reliable indicator of water quality health, as it demonstrates whether leaching of human or animal fecal matter reaches the stream. It is possible that since fecal coliforms are microorganisms (and not simply chemical compounds), they may be a more understandable and familiar indicator of water quality to the public.

Table 2 The five most frequently-collected indicators by respondent ENGOs

Indicator	Number of ENGOs (out of 21)
Temperature	20
pH	19
Nitrates	18
Dissolved oxygen	18
Fecal coliforms	16

One respondent criticized the list of indicators in Table 4, saying that none represented point source pollution. Another respondent stressed the importance of developing and using a three-tiered system comprised of “good”, “acceptable”, and “poor” when communicating water quality to the general public. It should be noted that identifying thresholds for these categories can be challenging, since one standard can define any one of these limits differently than another one, thus introducing disharmony and resulting in artificial similarities or differences.

Benthic macroinvertebrates

Although a considerable amount of academic literature points to bioindicators such as the benthic macroinvertebrates (BMI) as particularly suitable for the purpose of education, only 3 of the 21 surveyed organizations reported bioindicators as suitable to that end. When asked to provide a minimal number of BMI samples that must be taken in one sampling season, so that the bioassessment results can be interpreted with sufficient confidence, the average response was 11. As the sampling season was understood to stretch from mid-spring until late summer (May, June, July, August, September), one might think that approximately two samples per month during this sampling season would constitute the minimal BMI collection frequency. However, both the benthic community composition and environmental stressors will change seasonally. Thus, sampling at different times throughout the year (e.g., May versus September) may affect estimates of the degree of impairment (Jones et al. 2004). Comparisons should only be made with samples collected at the same time of year. Jones et al. (2004) also note that, for the Ontario benthos biomonitoring network protocol, 3 samples of 100 organisms is a reasonable minimum to be representative at a site, and that this can be pooled to be comparable with a Canadian Aquatic Biomonitoring Network-like analysis.

The results of this research show that only 6 out of 21 ENGOs collect benthic macroinvertebrates as an indicator of water quality, and even fewer find it to be a suitable indicator for the purpose of citizen education. Considering that a myriad of advantages are described

Table 3 Description of the five most-collected indicators (adapted from Lower Colorado River Authority (2012) and Ohio State University (n.d.))

Indicator	Description	Usefulness
Temperature	Temperature is measured in degrees Celsius (°C). Causes of temperature changes in the water include weather conditions, shade and discharges into the water from urban sources, or groundwater inflows.	Aquatic organisms are dependent on certain temperature ranges for optimal health. Temperature affects many other parameters in water, including the amount of dissolved oxygen available, the types of plants and animals present, and the susceptibility of organisms to parasites, pollution, and disease.
pH	pH is a unit that expresses the strength of a solution based on its acidic or basic properties. Pollution from burning fossil fuels increases the amounts of sulfur and nitrogen oxides introduced into the water, thereby increasing the overall acidity.	Aquatic organisms can only function in a particular range of pH and become forced to relocate, when the surrounding water changes.
Nitrates	Nitrates are measured in milligrams per liter (mg/L). Nitrogen is a nutrient necessary for growth of all living organisms. Sources of nitrates may include human and animal wastes, industrial pollutants, and nonpoint–source runoff from heavily fertilized croplands and lawns.	In excess amounts, nitrates in water cause an increase in algae growth. Algae can rob the water of dissolved oxygen and eventually can kill fish and other aquatic life. Under certain conditions, high levels of nitrates (10 mg/L or more) in drinking water can be toxic to humans. High levels of nitrates in drinking water have been linked to serious illness and even death in infants.
Dissolved oxygen	Dissolved oxygen is measured in milligrams per liter (mg/L). The DO test measures the amount of oxygen dissolved in the water.	Oxygen is essential for both plants and animals, but high levels in water can be harmful to fish and other aquatic organisms. Nonpoint-source pollution can decrease the amount of dissolved oxygen in water. The decomposition of leaf litter, grass clippings, sewage, and runoff from feedlots decreases DO readings. Decreased DO can be harmful to fish and other aquatic organisms.
Fecal coliforms	Fecal coliforms are measured in concentrations per volume of water. They are naturally occurring bacteria found in the intestines of all warm-blooded animals (including humans) and birds.	The presence of fecal coliforms is an indicator of contamination by sewage waste.

in the literature with respect to BMI collection and citizen education (Firehock and West 1995; Ongley 1997), it is disappointing that so few organizations collect this metric, especially when considering that their main goal in sharing data is citizen education. Our findings suggest that a significant percentage of ENGOs engaged in water quality monitoring fail to recognize the utility of this highly valuable metric, a finding also reported by others (Savan et al. 2003; Ongley 1997).

On the other hand, organizations collecting benthos data should emphasize and strive to implement a rigorous scientific approach and enhance reliability in their water quality efforts. In this survey, 14 respondents reported a scientific approach as the most important principle that should underlie any successful monitoring effort. Although respondents agreed that duplication in monitoring efforts takes place, they tend to disagree that sufficient data to support the management of waters and rivers exists, rating this on average 3.9 on a 5-point scale. When asked whether they felt that aquatic monitoring reports are easily understood by an average citizen, the average response was neutral at 3.7, leaning towards slight disagreement.

Protocol documentation

Although 14 ENGOs surveyed did have protocol documentation, only 4 present it on their website. This

Table 4 The five most reported indicators suitable for public education

Indicator	Number of ENGOs (out of 21)
Fecal coliforms	13
Dissolved oxygen	11
Temperature	10
Heavy metals	10
pH levels	9

proportion is disappointing and even troubling, as this inability to locate an organization's sampling methodology fails to convey the impression of transparency, rigor, and professionalism in the eyes of not just the public but decisionmakers, potential funders, researchers, and their monitoring counterparts. Comparisons of results between these ENGOs are hampered, if protocol documentation is not available and accessible.

Human resources

Respondents reported that both staff (12) and volunteers (8) are trained in-house by the organization. Training most frequently involves the sampling procedure, followed by the identification of sampling sites, handling and storing of collected samples, and finally sample analysis. The respondents perceive public engagement in water quality monitoring through volunteering to be motivated by volunteers' concern for learning about surrounding waters (7) and a general concern for water issues (6). On the other hand, it is worrisome that volunteers become discouraged by the results and outcomes of their own efforts. It is of interest that one third of respondents believe that the most meaningful way to encourage volunteers is to show them that their efforts are used in decision making. Three respondents stated that volunteers are also encouraged by demonstrating to them that they learn valuable skills and acquire useful information in the process.

It is encouraging to see ENGOs contributing towards social capital and fostering community-based research: 40 % of ENGOs relied on a mixture of paid staff and volunteers to collect and analyze their data, and the volunteers do receive relatively similar training to that of staff. However, organizations should seek innovative ways to maximize their training and collection efficiency, as the main reason for loss of volunteer motivation is the large time commitment that is required of them.

Data sharing

Most respondents make their data available to others with the intent of educating the public. Only three respondents shared their data in order to compare their results with other water quality collecting entities. Only two lobby governments and decision makers. Considering that four ENGOs had no specified purpose (i.e., "anything") for water quality data that they collect, it is apparent that some organizations do not exhibit careful planning or strategic thinking when it comes to sharing their data, and that too few envision long-term implications of their data. The most frequent challenge to sharing water quality information did not relate to IT. Rather, it involved the general public and their attitudes and reaction towards the shared information. Almost 30 % of respondents stated that the public tends to misinterpret the reports and the data that the organization publishes. One respondent even mentioned regretting having shared their findings (on a regular basis) due to the public's persistent misinterpretation and many attempts to refute their methodology and results. Determining the nature of such experiences and concerns, as well as potential solutions to address those, would be an interesting area for future research.

In general, the ENGOs interviewed were willing to share their raw data. However, they preferred to do so only by request: emailing raw data appears to be the preferred method for most respondents. Summarized data is best shared via the website and made available to anyone. A considerable proportion of respondent ENGOs (6) felt that their data might be misinterpreted, which could explain why most prefer to only share this information by request. When asked to identify the principles and values that should underlie a successful monitoring effort, scientific approach and reliability of the process (14) was rated by far as the most important trait. This could potentially indicate an impression amongst respondents that protocols are not followed sufficiently and/or consistently. This is further supported by the second most selected trait, namely the importance of consistent techniques and methods (6). The principle of sharing data (5) ranked third.

While the ENGO respondents desired to share their environmental monitoring results and engage the public, the methods they employ to do so are neither fully oriented to modern modes of citizen's access to data nor modern methods of data dissemination by organizations. It is worth noting that individuals aged 16 or older use the internet for personal use (78 %) and researching other matters (73 %) (Statistics Canada 2011). Only 6 of 21 ENGOs surveyed took advantage of the web to share their results. In addition, availability and sharing of water quality monitoring protocols continued to remain a challenge for these ENGOs, although more than two thirds (14) of organizations did rely upon some collection protocol.

Quality of volunteer-collected data

Respondents rated their confidence of volunteer-collected data on a scale of 1 (unreliable) to 5 (reliable). Respondents exhibited a generally neutral stance with respect to the quality of volunteer-collected data (an average of 3.4). However, the respondents agreed that (BMIs) offer a holistic snapshot of stream health. They rated it on average as highest among all statements at 1.5, despite the fact that most do not collect that metric. This begs the question: why is it that this metric is perceived to be an excellent indicator of quality, while at the same time it is only collected by a third of all respondents? One reason why so many ENGOs may not collect BMI is due to potential quality control issues compared to other more common indicators that have much simpler sampling procedures (e.g., pH, dissolved oxygen, and fecal coliforms). In addition, the latter can provide more data points per dollar compared to BMI.

As most ENGOs agreed that duplication of monitoring efforts takes place, rating it on average at 2.2, it is possible that they eschew the aforementioned bioindicators and prefer to focus on “harder” indicators, such as those presented in Table 2. Despite the neutral stance of respondents in their perception of volunteer-collected data, when asked how they perceived their own data, that average was significantly higher, at 4.4. Furthermore, when asked what metadata they need to know about water quality data, respondents were highly interested in knowing who collected the data, as well as what the sampling methodology was. This suggests that ENGOs could be concerned with whether data is collected by professionals or volunteers. This finding is similar to that of Engel and Voshell (2002), who list data concerns, namely credibility and standardization, as the prevailing barriers to the acceptance of volunteer biological monitoring efforts. Sheppard and Terveen (2011) identify quality and Loperfido et al. (2010) identify accuracy as additional barriers. Foster-Smith and Evans (2003) do however recommend that all ecological studies should include quality control of data, whether or not they involve volunteers.

Most ENGOs see volunteer data to be primarily suitable for educating those from the public who are actively engaged in the process of water monitoring (Savan et al. 2003). Although studies show that volunteer data can be comparable to that of expert data (Sharpe and Conrad 2006; Engel and Voshell 2002; Savan et al. 2003), the mixed quality (some good, some bad) of various programs that employ volunteer-collected data may explain the “neutral” stance to volunteer-collected data of respondents in is this research.

GIS and information needs

Since one of our aims was to generate knowledge that would inform web-GIS support for water monitoring activities, we were particularly interested in organizations' experience and current practices for data analysis, storage, and sharing. Only ten of the interviewed organizations used GIS. This may be because operating a GIS requires trained personnel and investment in software and hardware to support the technology. ArcMap and MapInfo, found to be the two most commonly used GIS software packages at five and four, respectively, are both prominent, commercial, and industry-standard desktop GIS packages. In our survey, they account for more than 80 % of responses by organizations using GIS (9).

Ten ENGOs in our survey have been using GIS for only 5 years or less, even though ArcMap, MapInfo, and other commercial as well as free and open-source software GIS tools have been on the market for decades. However, GISjobs’ (2009) survey of more than 41,000 worldwide active GIS professionals found that the length of GIS usage was 4.8 years for international users and 4.9 years for North American users (the more recent survey from 2012 shows these figures to be 6.8 and 7.2, respectively). Therefore, it appears that GIS started to enter the mainstream in the mid-2000s. This could be due to a number of factors, including the decreasing cost of a personal computer observed during the last decade. It is worth pointing out, however, that this same source indicates that ESRI accounts for 78 % of GIS software used and 19 % for MapInfo—proportions comparable with the findings of this research. (The 2012 survey shows a significant decrease in their dominance: 56 % for ESRI and 10 % for MapInfo).

Our research suggests that among the interviewed ENGOs, GIS is not a widely-embraced technology. Some authors suggest that the data-driven export-oriented and even "elitist" nature of GIS is a barrier to adoption (e.g., Dunn 2007; Caldeweyher et al. 2006; Peng 2001). However, it is worth pointing out that, in our survey, there were no noteworthy differences between organizations that did and did not use this tool (for example in the levels of staff education and training). It is also apparent that the average number of years that the interviewed ENGOs have relied upon GIS is under 5 years. It is possible that the potential for this technology in spatial, and temporal analysis has not yet been fully grasped, e.g., by small organizations or those not exposed to the technology in their schooling. Alternatively, Sharpe and Conrad (2006) argue that lack of trained staff and consistent funding may be a limiting factor. The finding that about one third of respondents did not participate in any kind of activities involving computerized systems raises questions about computer literacy in ENGOs'. This concern is echoed by Miller et al. (2004), who cite problems of poor IT communication between monitoring bodies.

Thirteen respondent ENGOs have been involved in projects, where computerized systems (excluding global positioning systems) have been used. Thus, a large proportion of respondent organizations were not supported by standard computer tools in their information management tasks. This becomes even more alarming, when one considers that ENGOs that do rely on information systems tend to use them for record analysis, reporting, and even modeling.

Comparing groups of ENGOs

We compared three groups of ENGOs: (1) those that employed geomatics tools versus those that did not, (2) those that employed only paid staff to generate monitoring data versus those that used both paid staff and volunteers, and (3) those that collected benthic macroinvertebrate data versus those that did not. We explored differences in the responses of these groups using the chi-square statistic, testing at the generous level of $p=0.1$. We found no significant differences within group 1.[1] This suggests that GIS does not significantly alter the ENGO's modi operandi.

When comparing group 2, the only significant difference to single questions was found to exist, when respondents were asked what principles and values should underlie a successful monitoring effort ($\chi^2(1, N=11)=5.16$, $p=0.02$). Organizations in which both volunteers and paid staff carried out monitoring were less likely to emphasize a scientific approach as an important property of a monitoring effort. A possible explanation is that within organizations, where both paid staff and volunteers collect data, a certain level of procedural tolerance is allowed as a result of perceived limitations from using volunteers. We also noted significantly different frequencies of responses to the questions "what indicators are most useful for citizen education?" ($\chi^2(1, N=73)=2.88$, $p=0.09$), and "which … sharing methods you find to be most useful?" ($\chi^2(1, N=37)=3.14$, $p=0.08$). Organizations that depended only upon paid staff to monitor water quality had a greater number of responses to these questions. This may indicate greater confidence in the quality of data collected by staff as opposed to volunteers, and thus, greater willingness to share and disseminate data. Though it is beyond the scope of this work, it may be interesting to pursue these questions further in future research.

Comparison of the third group (organizations that collect BMI data versus those that do not) also demonstrated a significant difference in responses. Organizations that collected benthos data responded more frequently to seven potential methods for sharing summary reports (not raw data) of water quality monitoring information ($\chi^2(1, N=77)=3.12$, $p=0.08$), while those that did not were relatively quiet in this respect. We speculate that this may indicate a stronger orientation of BMI-collecting ENGOs to communication for purposes of drawing

[1] Since responses to "check all that are appropriate" questions are optional, and the total number of participants was 21, the overall responses for many of these questions have small numbers. Results are only reported for those chi-square tests, having expected values for each group of five or more. We report the chi-square statistic with degrees of freedom and sample size in parentheses, the chi-square value, and the level at which the test is significant.

attention to impaired streams (e.g., to stimulate further investigation or remedial measures). This speculation was provoked by another significant result, pointing to the use of volunteer water quality monitoring for the purposes of "catalyzing further investigation" by benthos-collecting ENGOs but with only four responses to this question; the results of a chi-square test are not dependable. Again, further research might illuminate this finding.

Conclusion

In addition to acting as a springboard for more focused studies, the goal of this research was to enhance our knowledge of ENGOs that collect water quality monitoring data, while providing a basic understanding of their monitoring operations and their informational environments. This research painted a preliminary picture of Canadian ENGOs engaged in water quality monitoring and contributed to our increased understanding of these entities. Future research should aim to employ a comparable research paradigm and survey conservation authorities and other quasi-governmental bodies across Canada. It would be of value to contrast such findings with those of this paper.

At the time of this work, GIS and other information management tools adoption were not widely used by respondent ENGOs. Information sharing was rudimentary, not well-planned, and not oriented to particular needs of potential users and consumers of the information. ENGOs should strive to improve their dialogue with the public, while simultaneously adopting modern channels of information sharing. Furthermore, considering the potential of benthic macroinvertebrates as a holistic metric of water quality, ENGOs should strengthen efforts to ensure the rigor of BMI monitoring efforts and of communicating the quality of this data. This may over time increase adoption of this metric. We also recommend that ENGOs involved in water quality monitoring should make available their monitoring protocols to improve confidence about the quality, reliability, and thus usefulness of their water quality monitoring efforts. At the same time, the organizations should seek ways to maximize efficiency pertaining to volunteer training and minimize the time required to carry out the set of monitoring steps. By doing so, these key entities may be able to grow water quality monitoring activities and contribute not only to environmental education but to understanding and management of our watersheds, rivers, streams, lakes, and ponds.

Acknowledgments The authors thank two anonymous reviewers for providing meaningful feedback that improved the quality of this manuscript. This project has received funding support from the Ontario Ministry of the Environment. Such support does not indicate endorsement by the Ministry of the contents of this material.

Appendix

Table 5 List of interviewed organizations

Province	Organizations
Alberta	Alberta Lake Management Society
	Trout Unlimited Canada
British Columbia	Alouette River Management Society (ARMS)
	Bilston Watershed Habitat Protection Association
	Peninsula Streams Society
Manitoba	Deerwood Soil and Water Management Association
	Seine-Rat River Conservation District
New Brunswick	Eastern Charlotte Waterways Inc.
	Petitcodiac Watershed Alliance in Moncton
Newfoundland and Labrador	Northeast Avalon Atlantic Coastal Action Program
Nova Scotia	Clean Annapolis River Project
	Sackville Rivers Association
	St. Mary's River Association
Ontario	Citizen Scientists
	Lake Ontario Waterkeeper
Prince Edward Island	Bedeque Bay Environmental Management Association
	Hunter-Clyde Watershed Group
Québec	H20 Chelsea
	Société de Conservation et d'Aménagement de la Bassin de Châteauguay
Saskatchewan	Friends of Good Spirit
	Swift Current Creek Watershed Stewards

References

Bakker, K., & Cook, C. (2011). Water governance in Canada: innovation and fragmentation. *International Journal of Water Resources Development, 27*(02), 275–289.

Caldeweyher, D., Zhang, J., & Pham, B. (2006). Open CIS—open-source GIS-based web community information system. *International Journal of Geographical Information Science, 20*(8), 885–898.

Canadian Broadcasting Corporation. (2008). Tories to pull out of Canada-led water-monitoring program. Retrieved from: http://www.cbc.ca/news/canada/story/2008/11/13/harper-water.html

Canadian Broadcasting Corporation. (2012). Canada's air pollution experts moved to 'other priorities'. Retrieved from: http://www.cbc.ca/news/technology/story/2012/02/15/pol-environmental-monitoring-stations.html

Conrad, C. T., & Daoust, T. (2008). Community-based monitoring frameworks: increasing the effectiveness of environmental stewardship. *Environmental Management, 41*, 358–366.

Conrad, C. C., & Hilchey, K. G. (2011). A review of citizen science and community-based environmental monitoring: issues and opportunities. *Environmental Monitoring and Assessment, 176*(1–4), 273–291.

de Loë, R. C. (2008). *Toward a Canadian National Water Strategy. Final Report. Prepared for the Canadian Water Resources Association*. Guelph, ON: Rob de Loë Consulting Services.

Dunn, C. (2007). Participatory GIS: a people's GIS? *Progress in Human Geography, 31*(5), 616–637.

Engel, S. R., & Voshell, J. R. (2002). Volunteer biological monitoring: can it accurately assess the ecological conditions of streams? *American Entomologist, 48*, 164–177.

Firehock, K., & West, J. (1995). A brief history of volunteer biological water monitoring using macroinvertebrates. *Journal of the North American Benthological Society, 14*(1), 197–202.

Foster-Smith, J., & Evans, S. M. (2003). The value of marine ecological data collected by volunteers. *Biological Conservation, 113*(2), 199–213.

Gibson, R. B. (1999). *Voluntary initiatives and the new politics of corporate greening* (1st ed.). Toronto: University of Toronto.

GISJobs. (2009). Salary Survey Results – All Countries. Retrieved April 15th, 2009 from: http://www.gisjobs.com/survey_all/

Jones, C., Somers,K. M., Craig, B., Reynoldson, T. B. (2004). Ontario Benthos Biomonitoring Network Protocol Manual Version 1.0. Dorset, ON, Dorset Environmental Science Center, Ontario Ministry of the Environment.

Kim, S., Robson, C., Zimmerman, T., Pierce, J., & Haber, E. M. (2011). Creek watch: pairing usefulness and usability for successful citizen science. Proceedings of the 2011 annual conference on Human factors in computing systems (pp. 2125–2134). ACM

Lee, T., Quinn, M. S., & Duke, D. (2006). Citizen, science, highways, and wildlife: using a web-based GIS to engage citizens in collecting wildlife information. *Ecology and Society, 11*(1), 1–13.

Loperfido, J. V., Beyer, P., Just, C. L., & Schnoor, J. L. (2010). Uses and biases of volunteer water quality data. *Environmental Science and Technology, 44*(19), 7193–7199.

Lower Colorado River Authority. (2012). Water quality indicators. Retrieved from: http://www.lcra.org/water/quality/crwn/indicators.html

Miller, R. C., Guertin, P., & Heilman, P. (2004). Information technology in watershed management decision making. *Journal of the American Water Resources Association (JAWRA), 40*(2), 347–357.

Ohio State University. (n.d.). Traditional Water Quality Indicators. Retrieved from: http://tycho.knowlton.ohio-state.edu/chem.html

Ongley, E. D. (1997). *Matching Water Quality Programs to Management Needs in Developing Countries: The Challenge of Program Modernization*. Burlington, ON: Environment Canada.

Peng, Z. R. (2001). Internet GIS for public participation. *Environment and Planning B: Planning and Design, 28*, 889–905.

Pollock, R. M., & Whitelaw, G. S. (2005). Community-based monitoring in support of local sustainability. *Local Environment, 10*(3), 211–228.

Public Service Alliance of Canada. (2012). PSAC criticism of Budget Implementation Act. Retrieved from: http://www.psac-afpc.com/news/2012/issues/20120606-e.shtml

Savan, B., Morgan, A. J., & Gore, C. (2003). Volunteer environmental monitoring and the role of the universities: the case of citizens' environment watch. *Environmental Management, 31*(5), 561–568.

Sharpe, A., & Conrad, C. (2006). Community-based ecological monitoring in Nova Scotia: challenges and opportunities. *Environmental Monitoring and Assessment, 113*, 395–409.

Sheppard, S.A., Terveen, L. (2011). Quality is a verb: the operationalization of data quality in a citizen science community. Proceedings of the 7th International Symposium on Wikis and Open Collaboration, Pages 29–38, New York, NY.

Statistics Canada. (2011). Individual Internet use and E-commerce. Retrieved from: http://www.statcan.gc.ca/daily-quotidien/111012/dq111012a-eng.htm