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A review of citizen science and community-based environmental monitoring: issues and opportunities

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Abstract Worldwide, decision-makers and non-government organizations are increasing their use of citizen volunteers to enhance their ability to monitor and manage natural resources, track species at risk, and conserve protected areas. We reviewed the last 10 years of relevant citizen science literature for areas of consensus, divergence, and knowledge gaps. Different community-based monitoring (CBM) activities and governance structures were examined and contrasted. Literature was examined for evidence of common benefits, challenges, and recommendations for successful citizen science. Two major gaps were identified: (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. If new research focuses on these gaps, and on the differences of opinions that exist, we will have a much better understanding of the social, economic, and ecological benefits of citizen science.

Keywords Citizen science · Community-based monitoring · Social capital · Environmental democratization

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Due to the increasing significance, utility, and function of community-based monitoring (CBM) initiatives, a review of status and trends is presented here. The need to have a comprehensive understanding of ecosystem integrity, including function and structure, is often confounded by a lack of, or inadequate and incomplete, data and monitoring initiatives by professional scientists and government agencies. To fill the void, nonprofessionals and citizen organizations have emerged the world over to track trends and to work towards effective and meaningful management planning, management, and stewardship. The following literature review examines consensus, divergence, and gaps in global citizen science literature. Many community-based initiatives are not documented in the peer-reviewed literature; therefore, reputable web sites were examined in some cases. A comprehensive summary of types of monitoring, ways CBM groups are governed, benefits provided by CBM, and challenges for CBM groups is presented. As a result of this review, recommendations are suggested for improving both the way CBM groups work and the way their data are collected and used.

Introduction to citizen science

Citizen science is the process whereby citizens are involved in science as researchers (Kruger and Shannon 2000) and has also been referred to as *community science* (Carr 2004). Citizen science can include CBM, "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 [environmental] concern" (Whitelaw et al. 2003) and/or community-based management, where citizens and stakeholders are included in the management of natural resources and watersheds (Keough and Blahna 2006). This can also be referred to as voluntary biological monitoring (particularly in Britain) when the focus is on collecting data about species and habitats, although this is distinct from much of the CBM in North America which can also focus monitoring efforts on ecosystem functions and environmental quality. The focus of recent citizen science is not the traditional "scientists using citizens as data collectors," but rather, "citizens as scientists" (Lakshminarayanan 2007). For the purpose of this literature review, CBM will refer to both aspects of citizen science: community-based monitoring and community-based management.

The nature of citizen science implies that in many cases, the work being undertaken is not documented in traditional journal articles, although there certainly are exceptions. In order to comprehensively review the state of citizen science, academic journal articles, as well as web sites and nonacademic articles, were reviewed for examples of community-based monitoring. A wealth of CBM initiatives were discovered from around the globe. The Waterkeeper Alliance, for example, which includes so-called Riverkeeper, Lakekeeper, Baykeeper, and Coastkeeper programs and which works towards the goals of ecosystem and water quality protection and enhancement has programs in 15 nations. The majority of these are located in the USA, Australia, India, Canada, and the Russian Federation. A review of the vast academic- and nonacademic-based literature indicates that these nations are among those leading many community-based monitoring initiatives and that by all indications this movement of so-called citizen science is on the rise. This increase in monitoring activities by CBM groups is documented in Canada (Savan et al. 2003; Whitelaw et al. 2003; Conrad and Daoust 2008), the USA (Whitelaw et al. 2003; Keough and Blahna 2006), and many other areas across the globe (Sultana and Abeyasekera 2008; Pattengill-Semmens and Semmens 2003; Nagendra et al. 2005). Kerr et al. (1994) indicated a near tripling of new monitoring programs between 1988 and 1992, all related to water monitoring. Pretty (2003) reported that since the 1990s, up to 500,000 new local groups were established in varying environmental and social contexts. The increase has been particularly dramatic in the USA and Canada (Lawrence 2006). The cause for this has been attributed to an increase in public knowledge and concern about anthropogenic impacts on natural ecosystems (Whitelaw et al. 2003; Conrad 2006; Conrad and Daoust 2008) and recent public and non-government organization (NGO) concern about government monitoring of ecosystems (Pollock and Whitelaw 2005).

Concern about the effectiveness of government monitoring has been attributed to government cutbacks in funding and staffing for ecological monitoring (Stokes et al. 1990; Pollock and Whitelaw 2005; Conrad and Daoust 2008) as well as questions about government staff expertise when dealing with complex environmental challenges (Conrad and Daoust 2008). Despite cutbacks, governments still require monitoring data for decision-making processes and recognize the need to include stakeholders in these processes (Lawrence and Deagan 2001; Whitelaw et al. 2003). Requirements for species data for regulations and conservation have led to an increase in the use of amateur naturalists in Europe (Lawrence 2006).

There are differences in the monitoring intent in different parts of the world as well. In North

America, there is a predominance of monitoring varying aspects of environmental *quality*, whereas biological species monitoring is more common in parts of Europe, where nature tends to be more "micro-managed" (Lawrence 2006, p. 281). The issue of monitoring interest often transcends government boundaries, and many NGOs responsible for cross-state, cross-province, or cross-country concerns have increased their use of citizen scientists as well (Cline and Collins 2003). CBM relationships with universities have also increased, perhaps due to their capacity to provide training, lab facilities, free space, and funding (Savan et al. 2003). Some examples of CBM initiatives linked with academic institutions include:

- The Community-Based Environmental Monitoring Network, housed within the Department of Geography at Saint Mary's University in Halifax, Nova Scotia, Canada (www.envnetwork.smu.ca)
- The Canadian *Nature Watch* programs, which are in partnership with the University of Guelph in Ontario, Canada (www.eman-rese.ca/eman/naturewatch.html)
- The *Citizens' Environmental Watch*, in Toronto, Canada, was founded by academics in response to government cuts in environmental monitoring (www.citizensenvironmentwatch.org/cewsite/)
- The Alliance for Aquatic Resource Monitoring (ALLARM), housed within the Environmental Studies Department at Dickinson College in Pennsylvania (www.dickinson.edu/about/sustainability/allarm/)
- The University of Rhode Island Watershed Watch (www.uri.edu/ce/wq/ww)

The Florida LAKEWATCH coordinated though the University of Florida's Institute of Food and Agricultural Science and Fisheries and Aquatic Science programs (http://lakewatch.ifas.ufl.edu/). Though sometimes thought of as a new idea, some CBM organizations have been monitoring ecosystems (and ecosystem components) for decades (i.e., Christmas Bird Count since 1900 (Audubon 2008) and the British Trust for Ornithology (BTO) for over 50 years). BTO volunteers are estimated to have annually contributed 1.5 million person hours to CBM efforts (Bibby 2003). The UK' Breeding Bird Survey involves tens of thousands of participants annually (Sullivan et al. 2009). The majority of groups have only been monitoring for several decades or less, however.

Types of monitoring

Monitoring is an important tool in citizen science: it "informs when the system is departing from the desired state, measures the success of management actions, and detects effects of perturbations and disturbances" (p. 194, Legg and Nagy 2006). Monitoring can differ in focus, approach or technique. A sample of CBM initiatives is found in Appendix, where several trends emerge. The initiatives in Appendix were chosen from a broad literature review conducted by the authors. This review is not intended to be inclusive of all types of CBM monitoring (especially given the enormous proliferation of CBM information available online) but instead representative of a variety of CBM campaigns across the globe. Of the CBM groups sampled, most monitored water quality (11), with only a few devoted to monitoring birds (three), air quality (two), amphibians (two), plants (two), fish (one), worms (one), and ice (one). These monitoring programs will be discussed throughout the paper.

CBM initiatives have engaged both the resource sector (often referred to as commodity-based monitoring; e.g., the resource fishery) and the non-resource sector (often referred to as non-commodity-based monitoring; e.g., recreational fishery). Commodity-based monitoring deals with issues of economic (as well as social and environmental) importance. Examples include monitoring of fisheries (Sultana and Abeyasekera 2008) and forestry activities (Nagendra et al. 2005). Historically, commodity-based CBM has focused on economic issues, but in more recent years, the focus has shifted to include social and ecological outcomes as well (Water Science and Technology Board 1992). Non-commodity-based monitoring focuses on issues that may not seem to be directly economically important. This is often in the form of monitoring water quality (Mullen and Allison 1999), air quality (Nali and Lorenzini 2007), or indicator species (i.e., benthic macro-invertebrates (Jones et al. 2006), nesting songbirds (Evans et al. 2005), or calling amphibians (de Solla et al. 2005)). The present paper focuses on research and examples of non-commodity-based monitoring.

CBM also differs in the types of monitoring activities the organization undertakes. Monitoring activities include many different types of assessments of ecosystems: (1) status assessment (i.e., population monitoring), (2) impact assessment (i.e., affect of pollution), or (3) adaptive management (i.e., managing based on monitoring) (Stem et al. 2005). Monitoring activities also include different aspects of the ecosystem monitored: ecosystem composition (i.e., indicator species or species at risk), structure (i.e., biodiversity analysis, keystone species, predator–prey relations, etc.), or processes (i.e., linking species with environment, nutrient cycling, etc.) (Milne et al. 2006). Process-based monitoring is suggested as being most desirable in many studies (Milne et al. 2006; Stem et al. 2005).

Governance structures

In June 1998, The Aarhus Convention was signed with the intent to mandate participation by the public in environmental decision-making and access to justice in environmental matters. By 2008, it had been signed by 40 countries (most of which are European and Asian nations) (UNECE 2009). Although attempts have been made to engage the public in science and technology for many decades, there has been a more recent interest throughout western democracies (Chilvers 2008). With this interest, considerable debate and discussion surrounding the meaning of *participation* and the various forms it can take has emerged (Pretty et al. 1995; Lawrence and Turnhout 2005; Lawrence 2005, 2006; Chilvers 2008). There are varying scales of participation which have traditionally been categorized into so-called top–down and bottom–up governance structures. Some authors (e.g., Pretty et al. 1995) have developed scales that recognize the diversity of power relations in public engagement, including passive participation, participation by consultation, functional participation, interactive participation through to self-mobilization whereby people participate by taking initiatives that are independent of external (e.g., government) institutions. Lawrence (2006) argues that regardless of the classification, the "…traditional ladder typology of participation missed key changes taking place in individuals and groups of participants. These changes require a different way of thinking about participation, the environment and governance." (p. 290). Lawrence (2006), on the basis of a synthesis of approaches in the literature, organizes participation into four forms: consultative (public contributes information to a central authority); functional (public contributes information and is also engaged in implementing decisions); collaborative (public works with government to decide what is needed and contributes knowledge) and transformative (local people make and implement decisions with support from "experts" where needed). For many CBM activities, it is difficult to clearly define which category the program falls within (Lawrence 2006). Acknowledging the fact that there are both internal values (contributions of the participatory process to personal learning and development and relationship to nature) and external values gained (public utility of data for decision-making purposes), the following categorization is not intended to imply that there is an either or situation with participation.

Consultative/functional governance

Consultative and functional levels of participation imply that a central agency (government) is asking for information from the public or making decisions and then involving local people. The status quo is maintained and existing structures initiate consultation. The scale of participation is not limited to local scales (Lawrence 2006). This form of participation has been traditionally referred to as top–down. The purpose of monitoring by these groups is to provide early detection (by citizens) of issues of environmental concern, which can then be investigated by scientific experts (most often government) (Whitelaw et al. 2003; Conrad and Daoust 2008). Consultative monitoring has also been suggested for areas (often in developing countries) where illegal poaching of endangered species is a concern (Datta et al. 2008). Citizen scientists can thus provide a "watch-dog" service for government or scientific experts. The data collected by these groups may be used to create long-term data sets that can be used by researchers (Whitelaw et al. 2003). Although often successful in the short term (Mullen and Allison 1999), consultative and functional groups are often funding-dependent and cannot continue on their own without government assistance (Mullen and Allison 1999). Also, these groups may represent a less diverse stakeholder group (i.e., only fishers, only farmers) (Mullen and Allison 1999). There has been a recent shift in most areas from consultative to transformative governance (Pollock and Whitelaw 2005).

An example of the consultative/functional model is the Cornell Lab of Ornithology bird-monitoring project where teams of scientists determine the questions to be answered and decide what segment of the public will be targeted as participants (Ely 2008a). This author indicated both pros and cons of such a monitoring model, with strengths including the coordination of large numbers of volunteers, spanning a wide geographic area, and the collection and management of large datasets. These kinds of programs can also assist in answering scientific questions that would otherwise be difficult or impossible to determine without the presence of such vast resources. There is no conceivable way that paid professionals alone could gather the amount of data annually undertaken by volunteers of the British Trust for Ornithology (Bibby 2003). The downside to this monitoring structure is the limited role that volunteers usually play in the data collection. Most large-scale ecosystem monitoring programs (e.g., bird monitoring programs) tend to be consultative.

Collaborative governance

Collaborative or so-called *multi-party* CBM groups (sometimes involved in co-management or adaptive management, if management is part of the goal of the organization (Cooper et al. 2007)), are often governed by a board or group representing as many facets of the community as possible: private landowners, the general public, businesses, government, universities, etc. (Conrad and Daoust 2008). It is on the rise based on its collaborative nature (Whitelaw et al. 2003) that often yields more decision-making power than other types of monitoring (Conrad and Daoust 2008). Many watershed authorities or councils are governed by multi-party organizations. These authorities are coordinated or appointed by a locally selected board (Mullen and Allison 1999). They are common in Ontario, Canada (Milne et al. 2006) and in the USA (Mullen and Allison 1999; Griffin 1999). In the USA, they seem to suffer from less diverse stakeholders than top–down or bottom–up groups but tend to have good short and long term success (Mullen and Allison 1999). The success of watershed councils in the USA has been attributed to their environmentally (not politically) appropriate physical boundary—the local watershed, non-commodity-based approach, and community-level decision making (Griffin 1999).

In Bangladesh, community based co-management of fisheries was associated with more economic, social, and environmental successes than more simple, bottom–up approaches led by the fishers themselves (Sultana and Abeyasekera 2008). Fisher-led management groups were sometimes economically unrepresentative—with richer, more influential fishers more prevalent than more economically underprivileged fishers. In the multi-party co-management groups, these poorer fishers felt more represented—and less intimidated (Sultana and Abeyasekera 2008).

Transformative governance

CBM groups that are governed from the "bottom-up" (also called transformative, community-based, grassroots, or advocacy groups) are often born out of crisis. The group focuses on an issue with the hopes of initiating government action (Conrad and Daoust 2008). This type of CBM group often focuses on specific local issues and sometimes has no private sector or government support (Whitelaw et al. 2003). Initiation, organization, leadership, and funding of the CBM group are provided by the local community (Mullen and Allison 1999). Some researchers believe that by transferring authority over decision-making to those most affected by it (the public), better, more sustainable management decisions will be made—

thus, making the bottom–up model a desirable type of governance (Bradshaw 2003). However, many failures of bottom–up CBM groups are mentioned in one study (Bradshaw 2003). These include lack of success due to little organization credibility and capacity (Bradshaw 2003). Others suggest bottom–up CBM groups tend to be unsuccessful on a more organizational level, perhaps due to monitoring an issue with no legislation or policy support (Conrad and Daoust 2008). One study (Mullen and Allison 1999) predicted high success for transformative CBM groups in the US state of Alabama but suggested that CBM activities (for any type of monitoring) may not continue after federal or state support is reduced or withdrawn (Mullen and Allison 1999).

The transformative or community-based model has the advantage of involving participants in every stage of the monitoring program, from defining the problem through communicating the results and taking action. In this case, the role of the scientist is to advise and guide community groups rather than to set their agendas (Ely 2008b). This author also notes that water monitoring initiatives are often "tailor-made" for the community-based approach in that you do not "…need thousands of far-flung volunteers to collect the needed data. What you want is a small group of local citizens" (p. 4). The experiences from the Community-Based Environmental Monitoring Network in Halifax, Nova Scotia confirms this observation, with over 50 community organizations active in watershed stewardship and monitoring activities (Conrad 2006).

The so-called Bucket Brigade serves as a meaningful example of a transformative community monitoring initiative. This was started in 1995 by attorney Edward Masry (of Erin Brockovitch fame) when both were made ill from fumes from a petroleum refinery he was suing on behalf of citizens in California (The Bucket Brigade 2006). When federal and state environmental authorities were notified, their staff indicated that their monitoring equipment did not detect any air quality issues. Out of anger and frustration Masry had an engineer design a low cost device that citizens in the community could use to monitor their exposure for themselves. The Environmental Protection Agency subsequently undertook a quality assurance evaluation of the device and the monitoring results and accepted their validity. The program has spread across the USA and "armed with their own data and information about the health effects of chemicals, these communities are winning impressive reductions of pollution, safety improvements and increasing enforcement of environmental laws" (Bucket Brigade 2006).

The Global Community Monitor (GCM) also serves as an example of how transformative governance structures can best serve the concerns of a community, although it has evolved into a collaborative framework. The GCM was created to provide community-based tools for citizens to monitor the health of their neighborhoods, with a focus on air quality. One of the organizations in India is the SIPCOT Area Community Environmental Monitors. Villagers have been trained in the science of pollution and have been engaged in environmental monitoring, which over time has led to published scientific reports. This work formed the basis for a Supreme Court order calling for the establishment of national standards for toxic gases in ambient air (Global Community Monitor 2006).

Also in India, the "People's Biodiversity Register" addresses concerns related to dwindling numbers of the Siberian crane. Residents suggested that national park regulations which prevented people from digging for roots of a particular grass actually resulted in soil compaction, making it harder for the cranes to access underground tubers and food sources that are important to their diet (Gadgil 2006). The subsequent creation of "Biodiversity Management Committees," legislated under a Biological Diversity Act, now serves to take science literally down to the grassroots. The main function of the BMC is to prepare biodiversity registers in consultation with the local people. This citizen based approach has now evolved into a collaborative initiative.

Governance structure summary

Some pros and cons have been suggested for most of the three governance structures (see Table 1), with most positives being associated with collaborative governance. However, there is

Table 1 Summary of pros and cons of governance structures for CBM groups

	Consultative/functional	Collaborative	Transformative
Details	Gov. led, community run; gov. recognizes problem and uses CBM group to monitor	Involves as many stakeholders, individuals, etc. as possible; often based on a non-politically demarked area (i.e. watershed)	Community led, run and funded; community recognizes problem-trying to get gov. attention
Pros	May lead to long-term data sets; often successful in short term	Often more decision making power than other structures	Can be successful with community and stakeholder support
Cons	Dependant on gov. funding; less diverse stakeholders	None published	May not be diverse (i.e. only activists), problems with credibility and capacity Monitoring issues that are not governed by legislation

insufficient information on each type to determine if one is necessarily better than the other. At the same time, there is evidence that "… long-term economic and environmental success [comes about] when people's ideas and knowledge are valued, and power is given to them to make decisions independently of external agencies" (Pretty et al. 1995, p. 60). It may be that certain governance structures suit different monitoring situations (and communities), with collaborative and transformative participation being associated with local scales of participation and consultative and functional participation being more feasible across broader geographic scales. Also, there is sometimes an over-lap in the governance structures of monitoring activities. The different approaches have been widely held to be mutually exclusive, although others (e.g. Lawrence 2005) conclude that it is quite possible for more top-down structures to lead to "...more radical changes in personal outlook and values..." (p. 2), while more bottom-up approaches can produce good quality data and change power relations. The Florida LAKEWATCH program, which is a collaborative initiative between the University of Florida, government agencies and communities, is an example of an integration of both the consultative and transformative governance structures. This program has been in existence since 1986 and in 1991 the Florida Legislature recognized the importance of the program and established Florida LAKEWATCH in the state statutes (Florida Statute 1004.49.). This is now one of the largest lake monitoring programs in the USA with over 1,800 trained citizens monitoring over 600 lakes, rivers, and coastal sites (Florida Lakewatch 2008).

Reviewing the governance structures of CBM programs listed in Appendix, there appears to be a relationship between governance structure and a link to decision-making or an influence on conservation. Of the twenty programs listed, nine have documented an influence on conservation efforts. Of the nine programs, the majority (six) are either collaborative or transformative, with the other three being consultative or functional. Although this can lead to a preliminary conclusion that collaborative and transformative governance structures in community-based monitoring will lead to a greater likelihood of influencing conservation efforts, this requires further evidence. It is also of equal importance to further consider the common characteristics of the three more consultative governance structures and investigate the reasons for their unique successes. It should also be noted that of the remaining eleven programs that do not have documented evidence of linkages to decision-making, five are collaborative or transformative and four are consultative or functional. It appears that governance structure alone does not provide a recipe for success when it comes to linking community-based monitoring to environmental management.

Benefits of citizen science

Many benefits to society, citizen scientists, and local ecosystems have been attributed to CBM. These include increasing environmental democracy, scientific literacy, social capital, citizen inclusion in local issues, benefits to government, and benefits to ecosystems being monitored. Democratization of the environment is a relatively new concept based on making environmental science and expertise more accessible to the public, while also making scientists more aware of local knowledge and expertise (Carolan 2006). CBM can help to democratize science through the sharing of information between scientists and non-scientists. This ties in with the growing move to pursue "public ecology" research; where conservation biology research includes more multidisciplinary topics with the purpose of influencing legislation (Robertson and Hull 2001). Some authors (e.g., Carr 2004) go so far as to state that it is "inappropriate to leave (environmental) science solely to institutions and that community science is necessary" (p. 842). CBM also plays an important educational role in communities. By participating actively in scientific projects, community members increase their scientific literacy. This can take the form of augmenting knowledge of scientific processes or by an increased understanding of their role in the local environment (Evans et al. 2005). This "environmental education" can be fostered through volunteer CBM activities; or in a more traditional sense where students from local schools are included in CBM to complement their studies (Nali and Lorenzini 2007; Au et al. 2000).

It has been suggested that public support for conservation can be increased by building social capital (Schwartz 2006). Social capital has been measured by increases in levels of trust, harmony, and cooperation in communities practicing CBM (Sultana and Abeyasekera 2008). Social capital seems to be increased by CBM through activities that lead to volunteer engagement, agency connection, leadership building, problem-solving, and identification of resources (Whitelaw et al. 2003). This can lead to a more educated community (Pollock and Whitelaw 2005; Cooper et al. 2007) and creation of a stewardship ethic (Whitelaw et al. 2003; Cooper et al. 2007). However, it has been recognized that in areas with little social capital and no motivation for change (i.e., no immediate threat to a water resource, etc.), long term financial and technical resources may be required to create social capital (Mullen and Allison 1999). Also, CBM does not always yield higher social capital, as seen in Bangladesh (Sultana and Abeyasekera 2008) and, in some cases, increases only as a result of a catastrophe (Mullen and Allison 1999).

Citizen science has been recognized in many studies as a way to include stakeholders and the general public in the planning and management of local ecosystems (Pollock and Whitelaw 2005). Citizens in communities with CBM tend to be more engaged in local issues, participate more in community development, and have more influence on policy-makers (Whitelaw et al. 2003; Pollock and Whitelaw 2005; Lynam et al. 2007). Also, CBM has been shown to encourage more sustainable communities (Whitelaw et al. 2003).

CBM is beneficial to government agencies as it offers a cost-effective alternative to government employee monitoring (Whitelaw et al. 2003; Conrad and Daoust 2008). Fieldwork can be undertaken over larger areas and during non-office hours (Whitelaw et al. 2003). Government desire to be more inclusive of stakeholders (Lawrence and Deagan 2001; Whitelaw et al. 2003) is met by CBM. In Martha's Vineyard (USA), neighborhood pond associations formed out of concerns for declining water quality, which was a particular issue in this region due to the importance of good water quality for the local shellfish industry. The numerous dedicated water monitoring initiatives led by nonprofit organizations and the partnerships forged with environmental managers in the area has led to a great number of initiatives (e.g., pressuring the Board of Health to inspect and replace failed septic systems, address boat related pollution, distributing pamphlets and educating boaters, etc.) and consequently improvements to water quality. "Environmental managers who forge partnerships with these organizations have been rewarded with energy, commitment, and passion reserved for issues that hit close to home.…With the vigilance and dedication of a Neighborhood Crime Watch, local pond associations are the eyes and ears that sound the first alerts of environmental pollution" (Karney 2009, p. 2).

Benefits to the ecosystems being monitored by CBM groups are not commonly published. Most published articles on CBM *suggest* that CBM groups provide benefits to the environments they monitor (Evans et al. 2005; Au et al. 2000; Jones et al. 2006, etc.) but few state quantitative environmental success as a result of community monitoring (Legg and Nagy 2006). One author conducted an analysis on the results of surveys on the quantity of "environmental protection" provided by different watershed associations in West Virginia, USA (Cline and Collins 2003). However, "environmental protection" was defined as the number of "protective actions" (defined as: stream litter clean-ups, water-quality monitoring, fish stocking, education programs, river festivals, watershed studies, and recreational access improvements) performed by the monitoring groups and the amount of funding directed towards protecting surface waters. Environmental protection was not measured as an actual improvement in water quality in the areas monitored. The number of protective actions and the dollar amount of funding alone is not an adequate measure of the environmental success of such groups. Although there is much anecdotal discussion and web site documentation of the environmental benefits of citizen science, more peer-reviewed studies must actually show a relationship between CBM group efforts and environmental improvements to substantiate these claims.

Challenges for citizen science

Challenges for CBM groups have been well documented in academic journal articles (Conrad and Daoust 2008; Milne et al. 2006; Whitelaw et al. 2003) and tend to be related to three issues: (1) CBM organizational issues, (2) data collection issues, and (3) data use issues.

Challenges for CBM at the organizational level include a lack of volunteer interest (Conrad and Daoust 2008) and networking opportunities (Milne et al. 2006), as well as funding (Whitelaw et al. 2003) and information access challenges (Milne et al. 2006).

Issues for CBM groups also arise during data collection. These include data fragmentation, data inaccuracy, and lack of participant objectivity (Whitelaw et al. 2003). Studies are often lacking in experimental design and do not consider issues such as adequate sample size (through a priori power analysis, for example). This furthers the mistrust (by the scientific or government community) in the credibility and capacity of CBM data. It has been suggested that information collected by community groups is not taken seriously by decision-makers due to questions regarding the credibility, non-comparability and completeness of the data (Gouveia et al. 2004; Bradshaw 2003). In 1994, the US Congress called for the National Biological Survey to exclude data gathered by volunteers because of the belief that their "environmentalist agenda" would lead to biased data collection (Root and Alpert 1994). Many researchers are not confident the level of training volunteers receive is adequate to prevent both false positive and false negative data (especially in the case of biological identification) (Royle 2004). Certainly some of this concern is related to disagreement in the conservation field of the value of monitoring in general (Vos et al. 2000; Legg and Nagy 2006), and this issue for CBM is not a small hurdle to overcome. The "wrong data" might also be collected; many CBM groups focus on monitoring tasks as opposed to processes (Conrad 2006). This could lead to the folly of "monitoring for the sake of monitoring" (Conrad and Daoust 2008).

Finally, one of the greatest challenges for CBM is the use of the data collected through the monitoring program. Many groups find their data is not used in the decision-making process (or published in scientific peer-reviewed journals), either due to data collection concerns or difficulty getting their data to the appropriate decision-maker or journal (Milne et al. 2006; Conrad and Daoust 2008). Journal articles using volunteer-collected data are not as common as expected, especially with the wealth of volunteer-collected data available (see Ely 2008a for a list of such journal articles). Many articles (Warren and Witter 2002; Kershaw and Cranswick 2003; James et al. 2006; Fore et al. 2001) use data collected by volunteers but do not cite any attempts at training or compensation for volunteer error. It is not uncommon to see statements like the following: "While no evaluation of the effectiveness of the participatory aspects of the plan has been made..." (Contador 2005). Inaccuracy in CBM data collection is a valid concern, with several studies (Kershaw and Cranswick 2003; de Solla et al. 2005) showing volunteer difficulty particularly when volunteers are estimating sizes of groups of individuals. However, some researchers select and train their volunteers thoroughly (Easa et al. 1997), and some have found through validation and calibration that volunteers collect data comparable to professional researchers (with limitations) (Newman et al. 2003; Foster-Smith and Evans 2003; Fore et al. 2001).

Recommendations for citizen science

Do the benefits of CBM outweigh the challenges? Table 2 lists both benefits and challenges that were reviewed in the previous section. The benefits are substantial and although the challenges need to be addressed comprehensively, and are not insignificant, they appear to be items that can be overcome if those who have the capacity to address them do. For example, if relevant government agencies have the foresight to acknowledge the multiple benefits of CBM programs and want to link their efforts to enhanced environmental management, they can make funding for CBM a priority. Linkages to information access and training, as well as enhanced skills of volunteers can be overcome by linking to Academic Institutions as well as building upon the many existing models that have proven successful. Recommendations to overcome challenges have been outlined by some researchers (Whitelaw et al. 2003; Legg and Nagy 2006; Gouveia et al. 2004, etc.). They include a few key recommendations for organization problems, and a list of best practices for overcoming issues of data collection and use. Organizational framework guidelines have been developed by others (Milne et al. 2006; Stem et al. 2005; Conrad and Daoust 2008, etc.) to help prevent these challenges from occurring. So while the challenges can be addressed, the benefits are substantive. Challenges to effective CBM should not be used to devalue the significance of citizen-based initiatives, since the benefits far exceed the challenges that can be overcome. If challenges primarily relate to concerns such as scientific rigor, but benefits include societal changes, the decision need not be to engage citizens or not. The decisions need to surround solving challenges while building on social capital. With benefits to society and challenges to science, how exactly can the former be capitalized while not undermining the science? Consensus from the examples in Appendix indicates that in all cases, the challenges are addressed and met.

When it comes to issues within the CBM organization itself, there have been several proposals that have yet to be tested for their effectiveness. Volunteer dropout or disinterest could be tackled with positive reinforcement (i.e., informing them how they are impacting conservation, recognizing them for their efforts) (Whitelaw et al. 2003; Legg and Nagy 2006) or by matching monitoring protocols to the interests and skills of the volunteers (Whitelaw et al. 2003). Collaboration with other organizations (perhaps through a network of CBM groups) could help with access to infor-

Table 2 Summary of benefits and challenges of CBM

Benefits	Challenges
Increasing environmental democracy (sharing of information)	Lack of volunteer interest/lack of networking opportunities
Scientific literacy (Broader community/public education)	Lack of funding
Social capital (volunteer engagement, agency connection, leadership building, problem-solving and identification of resources)	Inability to access appropriate information/expertise
Citizen inclusion in local issues	Data fragmentation, inaccuracy, lack of objectivity
Data provided at no cost to government	Lack of experimental design
Ecosystems being monitored that otherwise would not be	Insufficient monitoring expertise/quality assurance and quality control
Government desire to be more inclusive is met	Monitoring for the sake of monitoring
Support/drive proactive changes to policy and legislation	Utility if CBM data (for decision-making; environmental management; conservation)
Can provide an early warning/detection system	

mation and networking. Finally, funding should be acquired before the monitoring begins to prevent budget issues (Whitelaw et al. 2003).

Best practices have also been described to deal with the problem of data credibility and capacity. Gouveia et al. (2004) provides detailed recommendations to overcome and address issues of data credibility, non-comparability of results, and data completeness.

Other suggestions include: increase sample size and perform power analysis prior to monitoring plan design (Legg and Nagy 2006), ensure monitoring methods are simple and scientifically appropriate and incorporate training into all aspects of CBM monitoring. In order to increase the likelihood of results being published or used by decision-makers, CBM groups should focus on outcomes that serve society, and ensure monitoring data will be relevant to the policies the CBM group is hoping to influence (Whitelaw et al. 2003).

Organizational frameworks are recommended by many researchers (Milne et al. 2006) as a tool to better improve CBM. A study in Nova Scotia, Canada (Conrad and Daoust 2008) found the majority of CBM groups surveyed did not feel the data they collected was used by decision makers. However, these same groups admitted to not using consistent monitoring protocols. A standardized framework could help reconcile many of the challenges to CBM organizations. A number of studies (Stem et al. 2005) suggested using the following basic framework outlined by Conrad and Daoust 2008:

- Step 1: Identify stakeholders (including governance analysis, consultation and outreach, identification of champions, partnership development, and selection of organizational structure (Whitelaw et al. 2003)).
- Step 2: Identify skills and resources (including fundraising and securing adequate future funding (Whitelaw et al. 2003; Legg and Nagy 2006), skills assessment, capacity building (Whitelaw et al. 2003)).
- Step 3: Create a communication plan (including achieving influence (Whitelaw et al. 2003), feeding back results and management recommendations (Cooper et al. 2007)).
- Step 4: Create a monitoring plan (including community visioning (Whitelaw et al. 2003)), data collection and organization (Cooper et al. 2007; Legg and Nagy 2006), basic research on monitoring topic (Stem et al. 2005).

Individual groups may find one tool or framework works better than another based on their individual purposes, and several studies have discussed how best to decide what tool or framework to use (Conrad and Daoust 2008; Lynam et al. 2007).

Discussion and conclusions

Citizen science research is a relatively new subject of interest with a multidisciplinary approach. Perhaps the wide range of researchers involved (biologists, watershed planners, environmental scientists, social scientists, etc.) explains some of the diverse opinions in the field. However, this blend of different backgrounds brings many perspectives to the field and helps to lend credibility to areas of consensus.

Monitoring activities by CBM groups (and the numbers of CBM groups themselves) have increased worldwide, with a few shifts in focus over the last few years (e.g., increase in relationships with universities, move from commodity to non-commodity-based monitoring, and move to process-based monitoring), which seem to have only strengthened the capability and capacity of these groups. Although many large-scale organizations have consultative and functional governance structures (e.g., Cornell Lab of Ornithology 2008), many groups have moved towards transformative governance with some outstanding successes (e.g. the Bucket Brigade), but also some documented struggles. Although collaborative governance may not be as common as consultative or transformative, it may have the potential to be very successful (see Table 1). More research comparing the benefits of all types of monitoring and governance (or the situations when it is best to use one governance type over another) could help improve upon global CBM.

There is a general consensus in the field about many of the societal benefits of CBM: the creation of environmental democracy and social capital (although the ease with which these are acquired is debatable), increased scientific literacy and inclusion in local issues, and time and money saving benefits to government. Many researchers (Milne et al. 2006; Stem et al. 2005) agree that process-based monitoring is one of the most efficient forms of monitoring, and many (Whitelaw et al. 2003; Legg and Nagy 2006; Cooper et al. 2007; Stem et al. 2005; Conrad and Daoust 2008) recommend the use of a monitoring framework to encourage success. Although recommendations have been made to overcome the challenges of organizational struggles, improper data collection, and data use; the success of the recommendations, best practices, and associated framework should be identified and evaluated. Particular focus on increasing use of data by decision makers and scientists; and how that use influences conservation, would be particularly valuable.

There is increasing evidence that community-based monitoring efforts are making an impact. The Florida LAKEWATCH program, the Bucket Brigades and the Waterkeepers in the USA as well as the Global Community Monitor and People's Biodiversity Register provide examples of direct linkages between the monitoring activities undertaken by community organizations and changes in policy and decision-making with respect to conservation, air and watersheds. However, there remains a need to enhance our understanding of community-based monitoring. We make the following recommendations for future research in the field:

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

Some of these questions can begin to be answered by comparing the successes of a selection of CBM groups (Appendix). Transformative groups (11 of 20) are more common than all other types, and many groups (11 of the 20) had unclear evidence of a link to changes in legislation or data use by scientists. Are there particular characteristics and common characteristics of the nine that have been linked to conservation, and improved environmental management? There does not appear to be, as they involve water, air and species monitoring, there are varying forms of governance, and some are local (e.g., the Neighborhood Pond Associations of Martha's Vineyard) whereas others are global (e.g., the Earthwatch). In the absence of an obvious profile that suggests success for linkages between monitoring efforts and conservation, a deeper exploration of the characteristics that make such linkages is warranted.

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Appendix

Table 3 Selection of CBM entities, their monitoring mandates, governance structures, and influence on conservation

Community monitoring initiative	Monitoring activity	Governance structure	Influence on conservation
			Evidence of influence on conservation documented:
Cornell Lab of Ornithology (United States) and Bird Studies Canada (Canadian version)	Numerous seasonal and year-round bird monitoring programs, from "FeederWatch" to "PigeonWatch" and "eBird"	Consultative	By integrating public outreach and scientific data collection protocols, this form of citizen science has become an established method for advancing scientific knowledge in many areas, including population trends in wildlife (e.g., Hochachka et al. 1999, Hochachka and Dhondt 2000, Oberhauser and Solensky 2004, Cannon et al. 2005), avian life histories (e.g., Cooper et al. 2005), and management recommendations (e.g., Rosenberg et al. 1999, 2003, Gregory et al. 2005). The eBird data is use to test models required to prioritize areas for conservation actions and for species management (Sullivan et al. 2009).
Waterkeeper Alliance	Water monitoring	Collaborative/ Transformative	An alliance of over 117 organizations world-wide with various forms of conservation successes. (www.waterkeeper.org)
The Bucket Brigade	Air quality monitoring	Transformative	Now recognized by the US Environmental Protection Agency and monitoring results have been linked to reductions in pollution, safety improvements and enhanced enforcement of environmental laws in several states. (www.gcmonitor.org)
Global Community Monitor (GCM)	Air and water quality monitoring	Transformative	The GCM has programs around the world, some of which have had documented success, including the SIPCOT Area Community Environmental Monitors in India, which assisted in the establishment of national standards for toxic gases in ambient air. (www.gcmonitor.org)
The North American Amphibian Monitoring Program (NAAMP)	Amphibian monitoring	Functional	The NAAMP is a collaborative effort among regional partners in the US, state agencies, educational institutions and nonprofit organizations and the USGS to monitor populations of calling amphibians. The USGS provides central coordination and database management.
University of Rhode Island Watershed Watch	Water monitoring	Collaborative/ Transformative	The URI Watershed Watch Program produces quality data for a broad range of parameters for over 200 monitoring sites statewide. Produced using well established methods, and processed in state certified laboratories; this information is used by the Rhode Island Department of Environmental Management for assessing the State's waters, as well as by municipal governments, associations, consulting firms and residents for more effective management of local resources. (http://www.uri.edu/ce/wq/ww/Data.htm)

Table 3 (continued)

Community monitoring initiative	Monitoring activity	Governance structure	Influence on conservation
Florida LAKEWATCH	Water monitoring	Collaborative/ Transformative	In 1991 the Florida Legislature recognized the importance of the program and established Florida LAKEWATCH in the state statutes (Florida Statute 1004.49.). LAKEWATCH is now one of the largest lake monitoring programs in the nation with over 1800 trained citizens monitoring 600+ lakes, rivers and coastal sites in more than 40 counties. Volunteers take samples to collection sites located in 38 counties.
Neighborhood Pond Associations of Martha's Vineyard	Water monitoring	Collaborative/ Transformative	The environmental accomplishments of the various pond associations have been impressive. One funded a water quality study resulting in the establishment of a free septage pump out facility for boaters; another provided the leadership to coordinate a local, state, and federal partnership to complete a major dredging project which restored shellfish habitat; others have addressed farm and roadway runoff with fencing, buffer strips and innovative catch basins; and all have conducted successful public educations programs, water quality monitoring studies and protective zoning initiatives (Karney 2009).
Earthwatch	Collection of field data in the areas of rainforest ecology, wildlife conservations, marine science	Consultative	Founded in 1971, Earthwatch supports scientific research by offering volunteers the opportunity to join research teams around the world. Earthwatch recruits close to 4000 volunteers every year to collect field data for a variety of purposes (www.earthwatch.org). Scientists engaged in Earthwatch initiatives have generally had very good things to say about the volunteer monitoring, including the very high quality of their data collection (e.g. "...no difference between the data collected by volunteers and the project staff ") (www.earthwatch.org/aboutus/research/scientistopps/scientistssay/). In reference to a leatherback turtle project, one scientist stated that their project would not have been possible without the assistance of the 1337 volunteers who was been assisting in the 23 years of monitoring, patrolling over 91,024 miles of beach. The data for many of the studies would not have been possible without the volunteers' participation. Volunteers' impact on conservation appears equally impressive, with numerous results cited (http://www.earthwatch.org/browse.aspx?ContainerID=reaccomp).

			Evidence of influence on conservation lacking:
British Trust for Ornithology	Bird surveys	Consultative	The collaborative venture between volunteers, amateurs and professionals has proved an enduring success over two or three human generations. Surveys have returned unexpected values and the value of historic data has grown (Bibby 2003). If substantive *conservation* measures haven't been documented, at the very least enhanced *understanding* is a consequence.
Citizen's Environment Watch (CEW)	Primarily water monitoring	Transformative	Launched in communities across Ontario in 1997, CEW has worked with hundreds of community groups and school youth to assess the health of local waters: an understanding of the link to conservation is incomplete.
Community-Based Environmental Monitoring Network	Primarily water monitoring	Transformative	Launched in 2003, the CBEMN has worked with dozens of community groups to enhance their understanding and stewardship capabilities. Efforts are being made to make linkages to decision-makers and to conservation efforts, but this remains a barrier.
Atlantic Coastal Action Program	Primarily water monitoring	Collaborative/ Transformative	Although this program, which includes multi-stakeholder groups across Atlantic Canada has been touted as having had a strong impact, direct evidence remains somewhat elusive (Sharpe and Conrad 2006)
The Alliance for Aquatic Resource Monitoring (ALLARM)	Water monitoring	Transformative	Difficult to ascertain the impact on conservation, although this organization has been in existence since 1986 and has established programs both within and outside of the United States.
Pacific Streamkeepers	Water monitoring	Transformative	Although the mandates include the intent to foster co-operation amongst watershed stakeholders and promote local management of aquatic resources, concrete examples of links to decision-makers and impacts on conservation measures are elusive.
Shorekeepers	Water monitoring	Consultative	Although the Shorekeepers' Guide was developed by Fisheries and Oceans Canada and is a rigorous monitoring methodology, there is little evidence that this program has been linked to enhanced conservation measures.

Table 3 (continued)

Community monitoring initiative	Monitoring activity	Governance structure	Influence on conservation
Reef Environmental Education Foundation (REEF)	Fish monitoring	Transformative	The volunteer fish monitoring program and fish survey project produce data that are provided to scientists, marine park staff and the general public. To date, the National Oceanic and Atmospheric Association, the State of Florida and the Bahamas Government have utilized this data. http://www.reef.org/programs/monitoring)
Nature Watch programs in Canada	Frog Watch, Plant Watch, Ice Watch, Worm Watch	Functional	There is little evidence that these programs are linked to decision-making and conservation measures, although a plethora of CBM groups, schools and clubs area active participants. Conservation awareness is raised but conservation action is more elusive.
USDA Forest Service Nature Watch		Consultative	There is little evidence that these programs are linked to decision-making and conservation measures, although a plethora of CBM groups, schools and clubs area active participants. Conservation awareness is raised but conservation action is more elusive.
US National Phenology Network	Project Budburst (plant monitoring)	Consultative	The USA National Phenology Network brings together citizen scientists, government agencies, non-profit groups, educators and students of all ages to monitor the impacts of climate change on plants and animals in the United States (http://www.usanpn.org/). There is little evidence that these programs are linked to decision-making and conservation measures, although a plethora of CBM groups, schools and clubs area active participants. Conservation awareness is raised but conservation action is more elusive.

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