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Identifying Effective and Sustainable Measures for Community-Based Environmental Monitoring

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Abstract Resource development projects typically result in monitoring programs that fail to fully consider the values and participation of surrounding communities. Also, monitoring protocols for single environmental values can be insufficient for addressing the cumulative impacts of resource development. Community-based environmental monitoring (CBEM) has emerged as a way to meaningfully include local citizens in the decision-making process and assessment of the development of natural resources. Our research explored how to develop effective and sustainable CBEM. Interviews were conducted with staff from 15 CBEM programs established across Canada to identify criteria of what constitutes effective CBEM. Results demonstrate that CBEM offers an effective, locally adapted, and culturally applicable approach to facilitate community participation in natural resource management and to track environmental change. Benefits of CBEM include: locally relevant monitoring protocols, inclusion of cumulative impacts, better informed decision-making, and increased awareness and collaboration amongst community, governments, and proponents. Challenges associated with CBEM are cost, capacity, longevity, distribution of results, and establishing credibility. This research validates the use of CBEM for improving resource management.

Keywords Community-based environmental monitoring · Public participation in resource management · Decision-making · Cumulative impacts · Aboriginal groups

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Introduction

Monitoring programs created for resource development projects typically represent a large number of environmental parameters; however, these programs often fail to fully consider the values and participation of surrounding communities and the cumulative impacts of resource development. Community-based environmental monitoring (CBEM) is emerging as a way to directly include local citizens in the project review and resource development process (Fernandez-Gimenez et al. 2008). CBEM is "a process whereby non-government organizations, community groups or individuals participate in long-term monitoring of selected species, habitats, or ecosystem processes with the ultimate goal of improving management of ecosystems and natural resources" (Yarnell and Gayton 2003: IV). CBEM programs can generate data that reveal change in the ecosystem condition or select environmental parameters; improve management processes and decision-making; contribute to the conservation of biodiversity or management of harvested populations; and, when implemented correctly, CBEM has the capacity to document and address the cumulative impacts of human activities (Danielson et al. 2014; Lawe et al. 2005; Yarnell and Gayton 2003).

CBEM can improve the breadth of understanding provided by formal scientific studies, and the citizens involved are rewarded with education and experience (Loss et al. 2015;

O'Faircheallaigh 2007). Input and participation from local communities can enhance monitoring and management (Noble and Birk 2011). Furthermore, CBEM can result in relationship building between local people, proponents of development projects, and other levels of government (Fernandez-Gimenez et al. 2008; Noble and Birk 2011). CBEM builds trust and credibility for all parties, which can lead to more open and meaningful communication (Fernandez-Gimenez et al. 2008). Monitoring enables communities to communicate effectively their concerns about specific aspects of industrial development or government decision-making in a clear and structured manner (Pollock and Whitelaw 2005). Communities may build capacity, which can lead to a higher level of independence and active participation in resource management decision-making (Fletcher 2003; O'Faircheallaigh 2007). Complementing the local benefits of CBEM, this approach equips decision makers with more information from a broader range of perspectives (Yarnell and Gayton 2003; Conrad 2006). Proponents of development projects may have a strong interest in supporting CBEM as such processes are tangible examples of commitments to local communities and local sustainability, ultimately improving their corporate image which can enhance communication and dialogue related to current and future projects (Noble and Birk 2011).

Across Canada, many CBEM programs are focused on the particular challenges facing small and remote Aboriginal communities (Lawe et al. 2005; McKay and Johnson 2017; Noble and Birk 2011). In such cases, traditional knowledge (TK) is often an important source of culturally relevant information for understanding environmental change (Berkes et al. 2007; McKay and Johnson 2017; Parlee et al. 2014). Applications of scientific methods to environmental monitoring are usually generic and may not accurately represent unique ecosystem processes or local values and perspectives (Fraser et al. 2006). Aboriginal people are local experts that are intimately familiar with the environmental norms on their traditional territories (Berkes et al. 2007). Their culturally defined perception and place in the environment is often termed TK: a "body of knowledge and beliefs transmitted through oral tradition and first hand observation" (Whitelaw et al. 2009, p. 205). Multi-generational, cumulative, and adaptive knowledge held by Aboriginal communities from past and current experiences contains a wealth of information specific to a community, ecosystem, or region (Alexander et al. 2011; Johnson et al. 2015; Tremblay et al. 2008). TK can identify gaps in scientific knowledge, offer alternate interpretations of observations, and provide a more holistic and long-term understanding of the environment (Berkes et al. 2007; Karjala et al. 2004; and Parlee et al. 2014). CBEM programs can structure and empower the participation of Aboriginal people in information collection, analysis, and decision-making (Lawe et al. 2005; O'Faircheallaigh 2007). Including Aboriginal concerns, participation, and knowledge can make monitoring locally relevant and of greater value to the community (Gordon et al. 2008). However, this does not necessarily exclude scientific knowledge as there are often opportunities to combine or identify complementarities for each source of knowledge, ultimately improving environmental monitoring and management (Berkes et al. 2007; Larter 2009).

Despite the many benefits, CBEM is a relatively new process; thus, challenges arise with the acceptance of information generated from such programs (Bonney et al. 2014). Johnson et al. (2015) suggested that there may be a bias against data collected by volunteers who are not formally trained in scientific methods. Herrmann et al. (2014) noted that CBEM is gaining increasing recognition and interest, yet a lack of acceptance can diminish opportunities for the full use of monitoring data (Bonney et al. 2014). Social aspects present a challenge for CBEM programs, such as lack of trust between stakeholders, loss of volunteers, communicating results beyond the program, and communication within the program (Fernandez-Gimenez et al. 2008; Herrmann et al. 2014; Johnson et al. 2015). Resources (i.e., funding, time, and labor) may also limit the success of CBEM (Fernandez-Gimenez et al. 2008; Herrmann et al. 2014).

Government agencies are not fully recognizing or integrating CBEM data within resource management or conservation programs (Conrad and Daoust 2008; Bonney et al. 2014). In many cases, data collected through CBEM are not applied to decision-making processes (Conrad and Daoust 2008). One reason for this resistance may be that CBEM data are "developed apart from the management and policy making processes rather than emerging from within" (Conrad 2006, p. 26). Despite barriers, government and industry decision makers can use CBEM as a reliable and cost effective tool to help manage natural resources (Little et al. 2015). To increase the relevance of a CBEM program, decision makers and communities should collaborate to determine the monitoring protocols and data that are practical and useful for both parties (Spyce et al. 2012). When involving Aboriginal communities, this engagement requires cross-cultural trust and relationship building (Noble and Birk 2011). Without collaboration, effort may be wasted on collecting data that are unusable or resisted by decision makers (Conrad and Daoust 2008).

Our objective for this research was to identify criteria that define effective CBEM. These criteria address both the establishment and maintenance of long-term monitoring programs, with a particular focus on monitoring the cumulative impacts of industrial development. We use results of interviews conducted with staff of 15 CBEM programs from across Canada to gain insight into what constitutes effective programs. As a corollary, we inquired about barriers to the long-term sustainability and overall

effectiveness of CBEM. We conclude with recommendations that inform the refinement or development of CBEM programs. This includes the identification of key elements that are essential to supporting the effectiveness and long-term sustainability of such programs.

Methods

Data Preparation and Planning

Interviews

We used qualitative methods (semi-structured interviews) to identify the strengths and limitations of CBEM programs as noted by practitioners working across Canada. Quantitative methods (e.g., numerical surveys) were not used as they are restrictive and limit integration of social aspects and values (Punch 2014; Winchester 2008). Single participant, semi-structured interviews were conducted to collect information from study participants. This method enhances independent thought and coherence, as group scenarios can be distracting (Quinn 2007). Semi-structured interviews provide many benefits for this type of research, including a flexible yet orderly and focused strategy for collecting qualitative information (Dunn 2008; Kirby et al. 2006). These methods maintain the integrity of the interviewee's message and allow him or her to lead the direction of the interview and ultimately the findings of the research (Dunn 2008).

Interview style

We prepared a semi-structured questionnaire to guide the interviews, with open-ended questions to accommodate various levels of responsiveness. Thus, participants could deviate from the questionnaire and pursue ideas or recommendations that broadly fit the research objectives (Place 2007). We interviewed participants from across Canada that were associated with active or past CBEM programs. Interviews were conducted by telephone, and follow-up conversations occurred via phone calls and email exchanges. Interviewees were provided with an information letter and the questionnaire prior to the interview. The information letter briefly summarized the project, outlined relevant information regarding CBEM and the information we were seeking, and explained how the participants' interviews were to be used. Interviews were audio-recorded and later transcribed.

Based on the literature (e.g.,Lefler 2010) and other monitoring programs we identified a number of key themes to explore during the interviews. Thus, the interview guides focused on several broad topic areas:

- Cumulative impacts—can CBEM explicitly address cumulative impacts?
- Precision of data—is the data collection method repeatable and precise enough to produce rigorous results?
- Sustainability of monitoring protocols—can CBEM maintain long-term participation? Does CBEM typically span the entire life of a resource development project (i.e., 10-25 years)?
- Cultural appropriateness of the monitoring program—does CBEM address cultural values and technical capacity?
- Cross sectoral communication and application of monitoring data—does CBEM facilitate and enhance communication among communities, government, and those organizations that use the land or hold tenures and permits?
- Application of CBEM to external decision-making—what challenges and opportunities are associated with including CBEM processes and information in decision-making?
- Application of CBEM to internal decision-making—in what capacity do municipal or provincial and Aboriginal governments actively use the results of CBEM when interacting with governments and industry in the context of land-use planning, development permitting, or mitigation strategies?
- Ownership of monitoring protocols and information—what factors or processes allow local and Aboriginal communities control over monitoring data, but also preserve the integrity of the monitoring data when applied to external decision-making processes?

Interviewees were free to carry the discussion beyond these topic areas and to introduce novel ideas and experiences.

Data Gathering

Interview participants

We used the published and gray literature (e.g., Whitelaw et al. 2003) as well as the internet presence of monitoring organizations or agencies to identify existing or past CBEM programs. This included programs that exclusively served Aboriginal governments and communities. We contacted the manager or posted contact person for the identified programs and requested an interview. Following an expression of interest to participate in the project, the prospective participants were provided with a detailed summary of the research objectives and methods, and a copy of the interview questions. Using a peer-nomination method, the initial participants recommended other potential

interviewees (Bradshaw and Stratford 2008; Place 2007). We assessed the suitability of nominated participants relative to their knowledge or experience in: CBEM, study and management of cumulative impacts, application of TK to resource management, recent experience working with Aboriginal communities, and experience communicating with decision makers about program results.

We identified a total of 15 monitoring program from across Canada and conducted interviews with employees or managers from these programs. Interviews were conducted between July and September 2013. We had representation from five Canadian provinces and one territory. This included monitoring being conducted in both northern and southern Canada (i.e., monitoring programs >55° latitude). The programs generally focused on monitoring a single environmental parameter, such as lake ice, water chemistry, stream flow, wildlife, tree growth, and indices of climate change, etc. Funding to support these programs typically came from government, local businesses, or local residents. The interviewees' roles within the program included coordinating and training volunteers, analyzing data, seeking funding, communicating with decision makers, and presenting results to the community.

Data Analysis

Interview transcription and checking

The audio record of the interviews was transcribed into text, which facilitated the data analysis and resulted in a written record of the information and knowledge generated through the research process (Dunn 2008). Interviews were transcribed in point-form style and verbatim quotes were entered to add additional context or to capture subtle or nuanced ideas. The interview guide acted as a template for transcribing the interview.

Participant checking enhances the reliability of interview findings by ensuring that the transcripts are correct and that critical concepts are not missed (Dunn 2008; Place 2007). Participant checking has been known to improve the quality, reliability, and rigor of the record (Dunn 2008; Kirby et al. 2006; Place 2007). Thus, each interviewee was provided with the opportunity to check the final transcript for accuracy and clarity, and to remove any information he or she did not want revealed (Dunn 2008). All edits were included in the final version of the transcript.

Information summary and analysis

We used latent content analysis to summarize and categorize relevant information from each transcript, which involved identifying general themes relevant to the research objectives (Cho and Lee 2014; Dunn 2008; Lombard et al. 2002). After becoming familiar with the interview content, we developed a coding system that was structured according to key themes and phrases from the transcripts (Cho and Lee 2014; Cope 2008). Since the interviews were semi-structured, the interview guide served as a template for identifying key themes. Ideas and phrases from individual interviews were then grouped according to the codes that emerged iteratively as each transcript was analyzed. Latent content analysis was the best approach for this research as it facilitated a grounded theory-inspired method, in that key findings were generated from the content of the interviews (Cho and Lee 2014; Karjala et al. 2004). Latent content analysis provided a deeper understanding of the interviewee's perspectives (Dunn 2008).

We used OneNote 2010 software (Microsoft Corporation, Redmond, Washington) to organize the interview content. This included grouping content into themes that were reflective of the successes and limitations of environmental monitoring as observed by the interviewees (Table 3). We used the software to 'tag' interview content that was related to each theme; we then grouped the tags according to topic (Table 3). For example, in each transcript when there was a mention of traditional knowledge, we would tag that sentence with 'TK'. Then, we would use OneNote to create a summary page which included all TK tags from all transcripts.

Results were reported using a qualitative approach. Instead of tabulating or 'quantifying' ideas, as presented by the interviewees, we highlighted consistent themes (i.e., content analysis) and identified key findings, and supported those findings with quotes from the transcripts. This method maintained the qualitative richness of the information, but also provided an unbiased accounting of the participant's perspectives. The themes were presented as broadly representing the views of the participants. Themes generated from the interviews ultimately contributed to developing the recommendations for effective CBEM.

We assigned each participant a number; to maintain anonymity, we have presented direct quotes in the results with the interviewee's identification number and not their name or professional affiliation. Statements and ideas presented in the results were derived from the transcripts of interviewees, even if not written in direct quotations. Some interviewees' had insights that were more directly related to the research, or had a more extensive set of ideas, thus some participants were quoted more frequently. All interviewees were helpful to the research and responsive and knowledgeable of the research topics.

Results

Through interviews of participants from CBEM programs, we developed an understanding of the value and limitations

of CBEM. The interviews provided valuable insight on a number of aspects of environmental monitoring, including: efficacy of monitoring; social cohesion and relationships; ability to inform decision making; and, effectiveness of CBEM for local or Aboriginal communities (see Table 1).

Efficacy of environmental monitoring

CBEM effectiveness

Study respondents reported that CBEM programs were a more bottom-up, proactive approach than current monitoring by industry. When a bottom-up process is invoked, "research and monitoring questions are driven by the community" (Interviewee #5). These questions can consider holistic dimensions of the environment, not just the reductionist components typical of traditional scientific inquiry. A community's interest and investment in the local environment contributes to CBEM success. Commenting on successful data collection, one participated stated: "people are effective at monitoring what they are passionate about. They are doing something they love and we can show them connections with the natural environment" (Interviewee #15).

Study respondents stated that CBEM promoted connections with the natural environment, awareness, engagement, conversation, and education. As expressed by one participant, "people involved increase their education level of lakes and issues affecting water quality, which promotes behavioral changes in a positive way" (Interviewee #11). A CBEM program should report success or failure, positive or negative, so that others may learn. One participant stated: "failure might be more important to find out what did not work, what caused a negative result" (Interviewee #1). Study participants found that the most successful programs were supported by adequate resources, funding, and training. Volunteers need opportunities for training, and to expand skills to develop and maintain monitoring and data management protocols. Volunteers and the community build capacity and through this there is more buy-in. One participant noticed: "people might not believe science but they will believe their own eyes" (Interviewee #15).

CBEM limitations

CBEM is relatively new, thus, it may be difficult for people to understand the objectives and methods of monitoring protocols. However, understanding and ultimately credibility are necessary for broad acceptance of results. Acceptance from proponents (i.e., industry and government) may be even more challenging if they do not want to be monitored, or if "the data say something that is not convenient to the decision maker" (Interviewee #13). One participant stated: "industry might not want the community to check up on them, and might ignore their monitoring results" (Interviewee #13).

Additional limitations mentioned by study participants included: funding, capacity, quality assurance of data, access to resources or labs for data analysis, long-term participation or turnover in staff or monitors, continuity and sustainability of monitoring protocols, and scale of the program. One participant elaborated on the importance of consistent protocols for long-term data collection: "changes to our data collection methods reduced the power of resolution over time, and time-important dimensions to monitoring were lost" (Interviewee #6).

Addressing cumulative impacts through CBEM

Including cumulative impacts in CBEM presents a more comprehensive and holistic approach, that is broader and more ecosystem-based than currently required within most Canadian regulation. A cumulative approach to measuring environmental change could tie multiple projects together with linkages that result in data sharing and revealing complex interactions. Respondents recognized that impacts of multiple developments are cumulative, but that these impacts are not easy to monitor. One participant said: "attributing amount of impact from an individual industry on cumulative change is impossible" (Interviewee #9). Thus, monitoring cumulative impacts may be "more difficult in practice than in theory" (Interviewee #9); there are no guidelines yet for incorporating cumulative impacts into CBEM. Participants believed it would be easier to implement monitoring for cumulative impacts if policy and legal structures demanded such.

There were suggestions from participants about how to incorporate cumulative impacts into CBEM. The program could establish baseline conditions and monitor how industrial development influences those conditions. This would involve some measure or assessment of historical conditions or parameters. The program could use environmental indicators that are easy to monitor to track cumulative changes. The program could use systems models to investigate the influence of cumulative developments on an ecosystem. Regardless, "[cumulative impacts] need to be addressed, we need to recognize they are happening and then we can make changes to protocols" (Interviewee #4).

Ability to Inform Decision-Making

Study participants found that CBEM can encourage teamwork and data sharing amongst parties. Also, CBEM can capture additional information to what is normally collected during compliance monitoring. One participant reported that CBEM can "collect more data because there are more

Table 1 Criteria of effective CBEM and recommended actions to achieve those criteria, with supporting quotes and coding tags

Criteria of Effective CBEM	Recommendations	Representative quotes	Coding tags
Efficacy of environmental monitoring	• Research driven by community interest	"research and monitoring questions are driven by the community"	• Environmental monitoring: cumulative impacts, general
	• Consider holistic perspective	"[cumulative impacts] need to be addressed, we need to recognize they are happening and then we can make changes to protocols"	• CBEM limitations: funding, volunteers/ participation
	• Report successes and failures	"people might not believe science but they will believe their own eyes"	• CBEM effectiveness: inclusion, data/ resources,
	• Adequate support (e.g., resources, funding)	"failure might be more important to find out what did not work, what caused a negative result"	• Aboriginal CBEM: inclusion, TK, capacity/ resources, monitoring general
	• Training and capacity building opportunities		
	• Include cumulative impacts		
	• Locally adapted		
	• Credible methods		
Ability to inform decision-making	• Use results to develop baseline	"people accountable and responsible for decision making should be part of the CBEM design process"	• Decision making: challenges, data/program use, benefits, community involvement
	• Supplement external results and reports with CBEM results	"locals know what is going on in the area, if we [the volunteers] notice a rise in temperature they can answer why it might be changing"	• CBEM limitations: resistance
	• Influence local policy	"these people (program volunteers) know the area, they frequent it, and they know the norms"	• CBEM effectiveness: data
	• Early involvement of decision makers in CBEM program		• Aboriginal CBEM: TK
Social cohesion or relationships	• Establish partnerships	"we have partnered with government, First Nations, and other programs. The partnerships made [the CBEM program] successful"	• Social aspects: communication, relationship/ partners, trust
	• Frequent communication	"industry may go into [CBEM] with expectations for findings or anticipate findings, which will add bias"	• CBEM effectiveness: partners
	• Develop trust		• Aboriginal CBEM: inclusion
	• Data, knowledge, and resource sharing		
Effectiveness of CBEM for local communities	• Include local and traditional knowledge	"there is a richer story when TK and western science are put together"	• Aboriginal CBEM: TK, inclusion, capacity/ resources, benefits/control
	• Address cultural values and interests	"[the proponent] used community data on	• CBEM limitations: resistance, data/resources
	• Community support	water quality and water levels in the hearing for the expansion"	• CBEM effectiveness: inclusion, participation, volunteers
	• Use CBEM to develop mitigation ideas	"[communities can] lever themselves into a decision-making position about how development should be unfolded on their traditional territory"	
	• Community control over data use and sharing		

Criteria and recommendations were developed from interviews with participants from 15 CBEM programs from across Canada

people accessing a larger area" (Interviewee #8). As stated by one participant: "we saved 8 months of work by involving the community" (Interviewee #5), which illustrates CBEM as a cost-effective approach. Participants have found that decision makers value discussions with the community about local issues, and community members' local knowledge "adds to the richness of the discussion" (Interviewee #12). For example, one program monitors stream temperature; "locals know what is going on in the area, if we [the volunteers] notice a rise in temperature they can answer why it might be changing" (Interviewee #4). Another participant stated: "these people (program volunteers) know the area, they frequent it, and they know the norms" (Interviewee #1).

Respondents reported that decision makers were excited about using CBEM for developing baselines and measuring trends in important environmental values. For example, one CBEM program was called upon to help with an oil spill response as no other baseline data were available (Interviewee #8). Referring to the use of CBEM data by decision makers, one participant said "the keenest are those interested in new permits and licenses, this kind of involvement would look good for them" (Interviewee #5). Referring to how local government uses CBEM data, one participant said "we get to see local decisions in policy and action as a direct effect in a short time period. There is a straight correlation and direct feedback from our program" (Interviewee #3). One participant cautioned that using CBEM data to promote resource management changes may be a lengthy process: "we knew in the beginning that our data would be used in decision-making, but it takes a while after monitoring because it is hard to ask people to change" (Interviewee #14).

Social Cohesion or Relationships

Developing partnerships through CBEM

Addressing the role of partnerships, one responded stated: "we have partnered with government, First Nations, and other programs. The partnerships made [the CBEM program] successful" (Interviewee #14). Respondents reported that CBEM can provide opportunities to involve stakeholders and create new partnerships, which can push the bounds of research. Partners can offer credibility, educational opportunities, and technical advice to the program. For example, one monitoring program linked their data with graduate projects (Interviewee #1). This resulted in published journal articles and a further extension of the results from the monitoring program. However, one respondent cautioned about partnerships with industry: "industry may go into [CBEM] with expectations for findings or anticipate findings, which will add bias" (Interviewee #2).

Partnerships with decision makers can improve their understanding and acceptance of CBEM protocols and results. Involving decision makers early in the design process can provide vision to the program, identifying important environmental parameters for monitoring and appropriate methods. One respondent stated that: "people accountable and responsible for decision making should be part of the CBEM design process" (Interviewee #4). Study participants found that program partners valued frequent communication and reporting of results from CBEM.

Communication and trust

Communication of the current and changing state of the local environment can be improved and facilitated by CBEM. Early, clear, and frequent communication with proponents empowers the community to vocalize their concerns about developments and "have a powerful voice in negotiation" (Interviewee #7). Including decision makers in CBEM can improve direct communication and keep all parties informed of current data and monitoring results. The majority of respondents reported that communication of monitoring results and activities was also critical to the community and to other communities. CBEM programs can distribute results in a number of ways; one program sends an annual newsletter to participants, while another frequently updates their website (Interviewees #8 and 1).

Study respondents reported that there was a strong need for parties involved in CBEM to develop relationships and trust. Participants recommended communication to help establish trust and increase decision makers' use of program results. One participant commented on the current state of communication with proponents; "when we ask for information from proponents then it is given, but they will not go out of their way to pass information onto us" (Interviewee #5). Trusting relationships would lead to information sharing and opportunities for groups to learn from each other.

Effectiveness of CBEM for Local or Aboriginal Communities

Local or Aboriginal CBEM: effectiveness

Ideally, a CBEM program would be locally adapted to address issues and questions important to the community. Study respondents reported that successful CBEM requires support from community leadership and interest from members of the community. Decision makers can use CBEM to supplement external results and reports. In the case of a proposed mine expansion, one respondent commented that the proponent "used community data on water quality and water levels in the hearing for the expansion" (Interviewee #9). In many cases, the monitoring program

studied areas unfamiliar to the project proponents; the Aboriginal or local communities were able to provide background and ongoing information on the local environment and systems (Interviewees #1, 5, 12, and 14).

The Aboriginal perspective tends to be holistic, which brings "a more complete approach to monitoring" (Interviewee #14). Additionally, a CBEM program that includes TK will enhance monitoring with specific and long-term local knowledge. Although TK has unique qualities and importance, when coupled with western science there are synergistic opportunities to further investigate environmental change. As stated by participants, "there is a richer story when TK and western science are put together" and "western science and TK complement each other, and it is becoming common to marry the two" (Interviewee #9 and 14). One CBEM program supplements data with Aboriginal nomenclature to uphold cultural values (Interviewee #10). Aboriginal communities can use CBEM to address cultural values and interests that produce long-lasting benefits. With CBEM, communities can "lever themselves into a decision-making position about how development should be unfolded on their traditional territory" (Interviewee #9). The community can build capacity, tools, and confidence to better manage their traditional territory. One respondent commented on a successful Aboriginal CBEM; "their awareness and systematic approach to catalog data helps them advocate for their rights" (Interviewee #9). However, one participant stated: "there are many TK surveys but results are not available to government or industry, so the missing piece is getting results into the decision-making processes" (Interviewee #5).

CBEM can influence the local community in ways such as "encouraging positive behavior towards the land through social marketing" (Interviewee #11) to mitigate environmental harm. The program can "promote awareness and education about monitoring" (Interviewee #10). Community engagement in CBEM provides opportunities for growth and development, and for producing local solutions.

Local or Aboriginal CBEM: limitations

Monitoring provides many benefits, but Aboriginal organizations and communities have a "hierarchy of needs with social needs preceding environmental needs" (Interviewee #9). In that context, monitoring may be difficult to implement due to limited capacity and the prioritization of resources to other more pressing challenges and responsibilities. One solution suggested by study participants is that communities develop partnerships to alleviate costs and improve efficiency. However, Aboriginal communitiesmay be hesitant to work closely with proponents due to "checkered history and dealings" (Interviewee #3) in the past.

Summary of Results

Through this research, we identified criteria of what constitutes effective CBEM, based on past and current experiences of monitoring programs from across Canada. The interviews provided valuable insight into the workings and objectives of environmental monitoring programs. This included decision-making, communication, and the role of local knowledge in CBEM; proper considerations of these components can lead to an effective CBEM program. Four key themes emerged from the interviews as being critical to consider in CBEM: efficacy of environmental monitoring, social cohesion or relationships, ability to inform decision-making, and effectiveness of CBEM for local communities (Table 1).

Discussion

A CBEM program can improve communication amongst government, industry, and communities. In our research, study respondents recommended that frequent communication will help develop trust, and strengthen relationships or create partnerships. Some study respondents were wary that while CBEM would benefit industry through enhancing their corporate image, the program would provide little value to the community. Similar concerns were noted by others (Noble and Birk 2011). Partnerships, especially with universities, may help establish or maintain the integrity of a program (Whitelaw et al. 2003). Study respondents revealed that CBEM can be an impartial, common-ground for partnerships and collaboration among industries, governments, and communities without competition or secrecy. New partnerships formed from CBEM can help to push the bounds of research and enhance environmental protection (Yarnell and Gayton 2003).

Resources for environmental monitoring are currently limited or declining; however, both the literature and the study participants reported that CBEM may be a cost effective solution to fulfill monitoring objectives for government, industry, and communities (Parlee et al. 2014; Tulloch et al. 2013). Loss et al. (2015) recommended that decision makers seek opportunities to use CBEM. Yet, study participants recognized that it was challenging for decision makers to be aware of local CBEM programs if there was a lack of communication of monitoring protocols and results. Programs may not be publicized or linked to broader networks and therefore they are not used to their full potential (Conrad and Daoust 2008). As a result, decision makers can be unaware of how best to support the development of such programs or how to employ information and data provided through CBEM (Johnson et al. 2015). As a solution, study participants recommend that programs involve decision makers in initial planning stages.

Table 2 Key elements necessary for effective and sustainable CBEM programs

Key Elements to include in CBEM	Description of elements
Community-driven	The program should reflect community interest and values, and should include local knowledge.
Support	The program requires support by adequate funding, technical resources, capacity, community participation, and opportunities for training.
Defined methods	Monitoring protocols must be credible, accepted by decision makers, and to ensure consistency in data, methods should not be altered over time.
Data confidence	Data and resulting information from the program must be accurate and reliable for use in decision-making.
Reporting	Results from the program (both success and failure) should be distributed to participants, partners, community members, and decision makers.
Cumulative impacts	The program should consider impacts from multiple development projects and attempt to explicitly monitor cumulative impacts.
Partnerships	Partnering with multiple organizations may bolster program credibility and acceptance, and encourage data and resource sharing.
Communication	Frequent communication with proponents and government will help the community build relationships, keep parties current with program information, and can encourage buy-in.
Trust	Trust is a critical component of strong relationships which will lead to acceptance and use of CBEM data, as well as information sharing amongst parties.
Linked with culture	When appropriate (i.e., CBEM for an Aboriginal community), Aboriginal values and TK should be incorporated into CBEM to investigate trends, supplement program results, and help create baseline data.
Influence	The program should help the community better manage their environment and use local solutions to address resource management issues.

The elements were inferred from the perspectives of representatives of 15 programs from across Canada

Study respondents recognized that cumulative impacts were a prevalent and pressing issue. Respondents recommended developing protocols that addressed the cumulative environmental impacts of resource development. More focused conventional monitoring programs may not address the impacts from multiple resource sectors occurring at broad spatial and temporal scales (Burton et al. 2014; Tulloch et al. 2013). Additionally, taking a cumulative approach to monitoring complements the holistic perspective that many communities share on environmental use and change. Study respondents noted the challenge to incorporate cumulative impacts into CBEM as there were no guidelines or standard protocols. This is an area where partnerships and collaboration amongst communities, governments, and industries would produce beneficial results, especially if multiple industries adopt a collective approach to monitoring (Franks et al. 2010).

Study participants clearly noted that CBEM has the power to help community participants increase their knowledge and awareness of the environment, while subsequently increasing their respect for local resources. Additional benefits to the community can include capacity building, training, and networking (Conrad 2006; Luzar et al. 2011). Study respondents reported that participants involved in CBEM work together more effectively to identify and address (e.g., mitigation) environmental issues resulting from local resource development. Enhanced collaboration amongst the parties involved in CBEM also encourages communication and resource sharing which results in more effective natural resource management.

The four key themes that emerged from the interviews were: efficacy of environmental monitoring, ability to inform decision-making, social cohesion or relationships, and effectiveness of CBEM for local or Aboriginal communities (Table 1). Proper considerations of these components can lead to an effective CBEM program that integrates the local-level management and monitoring priorities as well as the participation and knowledge of the community. In particular, interviews with 15 CBEM practitioners revealed 11 key elements important for an effective and sustainable program. Those elements were consistently noted by participants from across Canada and ranged from a focus on community interest and values (Community driven) to consistent and credible methods for data collection (Defined methods, Data confidence, Reporting) to the recognition and incorporation of Aboriginal values and TK (Linked with culture; Table 2).

Conclusions and Recommendations

Our study was limited to 15 participants from CBEM programs from across Canada. Increasing our sample size would have provided a more extensive representation and allowed for a deeper investigation of the perceived effectiveness of CBEM from the views of practitioners. However, there are a limited number of active programs. Nonetheless, we observed broad agreement amongst the participants on criteria and the supporting elements for

effective CBEM. Although our research focused on only CBEM programs, the recommendations may be applied broadly by a range of groups (i.e., communities, governments, industries) and extended outside of Canada. CBEM is an idea with international relevance, but we suspect that programs beyond Canada face similar challenges to what we documented in this study (e.g., Bonney et al. 2014; Fernandez-Gimenez et al. 2008; Pandya 2012; Topp-Jorgensen et al. 2005).

Supporting the conclusions of others (Conrad and Hilchey 2011; Fernandez-Gimenez et al. 2008; Little et al. 2015; Noble and Birk 2011), our research further documents the effectiveness of CBEM for monitoring environmental values, considering cumulative impacts, and encouraging local participation in natural resource management and decision-making. CBEM programs are most effective when premised on the following criteria: efficacy of environmental monitoring, social cohesion or relationships, ability to inform decision-making, and focus on the needs of local communities. Also, we noted a number of elements that supported these criteria and should be incorporated in the development of new or existing programs (Table 2).

Including cumulative impacts in CBEM was important to study participants. Many communities look at their local environment as a whole, not as a combination of discrete resources. Addressing cumulative impacts aligns with this perspective and could greatly enhance local resource management. Few interviewees from this study had direct experience including cumulative impacts in CBEM. There is a need for focused research that moves beyond simply talking about cumulative impacts to actually developing protocols to monitor cumulative impacts within a CBEM program.

Results from this study and others (Johnson et al. 2015) suggest that there is great potential for the success of CBEM and much interest from various parties in further developing such programs. Yet, CBEM is far from reaching its full potential (Bonney et al. 2014; Loss et al. 2015). Study participants were clear that CBEM can increase the likelihood of achieving monitoring objectives, leading to better resource management. More broadly, our research produced a set of criteria and supporting elements for evaluating the effectiveness of CBEM. These criteria can guide the collection and potentially the multi-party application of data and information resulting from a CBEM program. This aspect of the research is directly transferable to other disciplines, projects and communities.

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Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no competing interests.

Ethical Approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed Consent Informed consent was obtained from all individual participants included in the study.

Appendix

Table 3

Table 3 Content themes and tags used to code interview transcripts of practitioners involved in community-based environmental monitoring programs from across Canada

Content theme	Content tag
Environmental monitoring	General
	CBEM general
	Cumulative impacts
CBEM limitations	Funding
	Volunteers/participation
	Data/resources
	Resistance
	Partners
CBEM effectiveness	Funding
	Volunteers/participation
	Data/resources
	Inclusion
	Resistance
	Partners
	Benefits
Aboriginal CBEM	Monitoring general
	TK
	Capacity/resources
	Limitations
	Inclusion
	Benefits/control
Decision making	Challenges
	Data/program use
	Benefits
	Community involvement
Social aspects	Communication
	Relationships/partnerships
	Trust

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