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Review:

Key Components of Collaborative Research in the Context of Environmental Health: A Scoping Review

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Abstract

In a collaborative research process, the participation of interdisciplinary researchers and multi-sectoral stakeholders supports the co-creation, translation, and exchange of new knowledge. Following a scoping review methodology, we explored the collaborative research processes in the specific context of environment and human health research. Initially, our literature search strategy identified 1,328 publications. After several phases of reviewing and applying screening criteria to titles, abstracts, and full text, 45 publications were selected for final review. Data were charted by different topics and then collated, summarized, and analyzed thematically. From the different experiences and research approaches analyzed, we identified comprehensive details of the key components, facilitators, challenges, and best practices that impact the collaborative research process. Specifically, we identified the following seven emerging themes: (a) allocating time and resources, (b) addressing disciplinary and sectoral issues, (c) building relationships, (d) ensuring representation, (e) embedding participation in the research, (f) supporting ongoing collaboration, and (g) developing knowledge translation and exchange.

Index Terms: environmental health; collaborative research process; scoping review; interdisciplinary research; knowledge co-production; knowledge broker; integrated knowledge translation

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1. Background

The global burden of disease attributed to environmental factors was estimated by the World Health Organization to be close to 22% and even higher in children (Prüss-Ustün, Wolf, Corvalán, Bos, & Neira, 2016). *Environmental health* research aims to explain how the environment (i.e., the biological, chemical, physical, and social factors external to a person) impacts human health (for more detailed definition of this and other related terms, see Appendix A). This is an evolving and complex research field aimed at creating new knowledge to support and influence practice, policy, or further research and ultimately, to improve human health (Finn & O'Fallon, 2015). Environmental health research considers different levels of investigation, ranging from genetic and cellular effects to population health. It also applies multiple methods of inquiry and expertise from various disciplines and sectors. Current trends in research are also shifting from exploring the relationship between a single exposure and one health outcome of interest to exploring the complex interplay between multiple exposures and outcomes, which imply a *web of causation* (Briggs, 2008; Dixon & Dixon, 2002; Dominici, Peng, Barr, & Bell, 2010; Mauderly et al., 2010).

With this type of research, there is an expectation of additional complexity due to the high level of uncertainty accompanying its conceptualization (e.g., incomplete or aggregated data), the analysis of results (e.g., confidence levels, exploratory nature of the research), and communication of the results (e.g., no research is perfect, and no results are absolute) (Briggs, Sabel, & Lee, 2009). Furthermore, this field of research is highly context-sensitive, since it deals with health-related risk issues that can have significant social, political, environmental, and economic impacts (Briggs, 2008). These impacts can have repercussions beyond the immediately affected communities as the policy requirements for change often have a significantly broader economic and political cost. For example, the use of coal to generate electricity that would presumably create jobs to stimulate the economy, also contributes to air pollution and occupation disorders, which may have severe impacts on the global climate and population health (Lipton & Meier, 2017).

All these factors contribute to the unique aspects related to the study of the environment and human health. Interdisciplinary and collaborative processes were identified as appropriate approaches for co-creating and co-producing new knowledge and practices, and *knowledge translation* (Briggs, 2008; Fazey & Evely, 2013). This emphasizes the contribution of engaged scholarship among academics, practitioners, and stakeholders to respond to big questions (Van de Ven & Johnson, 2006) and facilitate the process of creating and translating new knowledge to inform change (National Institute of Environmental Health Sciences, 2012). Additionally, due to the sensitive context of environmental issues and human health, there is a need for an elaborated decision-making process that defines the knowledge translation plan (Canadian Institutes of Health Research [CIHR], 2016) (e.g., deliverables, messages, audiences, and strategies) and how the new knowledge should be used (Hage, Leroy, & Petersen, 2010) for the benefit of communities and researchers (Brown, Deletic, & Wong, 2015. The expectation is that co-produced knowledge is more likely to be accepted and used by *knowledge users* for action, implementation, decision and policy making, and identification of future research needs (Annerstedt, 2010; Cook et al., 2013; Reed, 2008).

Collaborative and interdisciplinary research may appear ideal; however, this research tends to present practical and conceptual challenges. In this context, there is a need to further understand and learn how to best support collaborative and interdisciplinary research (Krebbekx, Harting, & Stronks, 2012; Meadow et al., 2015). Knowledge on the collaborative process is somewhat fragmented in this area. As well, we are not aware of any publication that solely addresses the collaborative process in the context of environmental health or provides a specific framework for the kind of research conducted in this context.

Thus, in this *scoping review*, our aim was to explore and identify the extent and nature of the scholarly literature regarding research studies that address or describe experiences or research on the collaborative research processes in the context of environmental health research, and with the intent of capturing the following:

1. The key components, facilitators, barriers, and challenges of collaborative research processes in environmental health research context.

2. Potential research gaps in the existing literature regarding collaborative processes in this context.

We expected that collating and summarizing the knowledge and experiences identified in the literature and disseminating our findings would support better understanding of the processes and the accompanying challenges. Our review is intended to provide an overall view of what is known on the collaborative research process and its key components. More specifically, this review will be useful for the collaborative process of an ongoing environment and health project conducted by our research team (i.e., the Data Mining and Neonatal Outcomes [DoMiNO] research team, see DoMiNO, n.d.), as well as the work of other such health research partnerships.

2. Methods

Based on our inability to easily locate studies and publications on collaborative research and other processes specifically related to the environmental health context, the study team opted to conduct a scoping review instead of a systematic review. Scoping reviews differ from systematic reviews mainly by the nature of the research question and a concern for the quality of the studies to be included. A scoping review tends to be broader in scope than a systematic review as it aims to map the field in question and identify literature gaps, whereas systematic reviews aim to generate conclusions related to a narrow research question. Systematic reviews involve an assessment of the quality of the studies to be included; scoping reviews may not involve that kind of assessment. A scoping review would support the need to map out what key collaborative process components, concepts, theories, practices, and related topics had been published and where there were identified gaps (Arksey & O'Malley, 2005; Brien, Lorenzetti, Lewis, Kennedy, & Ghali, 2010). Once we have a clear understanding of what existed in the literature, we could formulate more specific questions related to collaborative processes in the environmental health context.

We implemented the scoping review framework stages suggested by Arksey and O'Malley (2005) and Levac, Colquhoun, and O'Brien (2010). The authors of this review, composed of diverse environment, health, and knowledge translation expertise, were involved at the different stages of the review process. Here, we outline the stages we followed.

Stage 1. Identifying the Research Question

The purpose of our scoping review was to identify what the literature describes regarding collaborative processes in the environmental health research context. Our guiding question was: What are the specific components that influence the collaborative research process in environmental health research?

Stage 2. Identifying Relevant Studies

Relevant literature was searched in August 2015 by an expert librarian (third author, Sandy Campbell), who identified related publications containing the concepts: "environmental health/pollution," "knowledge co-creation/co-production," and

"knowledge translation." Individual searches were executed on the following databases using key search terms that responded to these concepts: Medline (Ovid), EMBASE (Ovid), CINAHL(EBSCO), Global Health (Ovid), SocINDEX (EBSCO), Scopus, Pollution Abstracts (ProQuest), Environment Complete (EBSCO), ProQuest Dissertations, and Theses Global. Dissertations were included, except when the same author and topic were also identified in journal publications. The full extent of all databases included material published any time before August 2015, with follow-up search adjustments made appropriately for each database. Additional references were identified through citations or other known publications. References were exported to the RefWorks citation manager.

Stage 3. Study Selection

The publication selection process is described using the PRISMA (Preferred Reporting Items for Systematic Reviews) flow diagram (Moher, Liberati, Tetzlaff, Altman, & The PRISMA Group, 2009, see Figure 1). Publication selection started by removing any duplicates. Titles and abstracts where then reviewed for relevance by two reviewers (first and second authors, Osnat Wine and Sarah Ambrose) sorted into *Yes*/*No*/*Maybe* lists, based on selection criteria (Table 1). The two relevancy lists were then compared. Publications that did not match between the two reviewers or were classified as *Maybe* were discussed by them, and with a third member of the authors' team (sixth author, Alvaro Osornio Vargas), until consensus was reached. Selected items were fully read and a second phase selection took place considering the selection criteria. Finally, 45 publications were included in the scoping review.

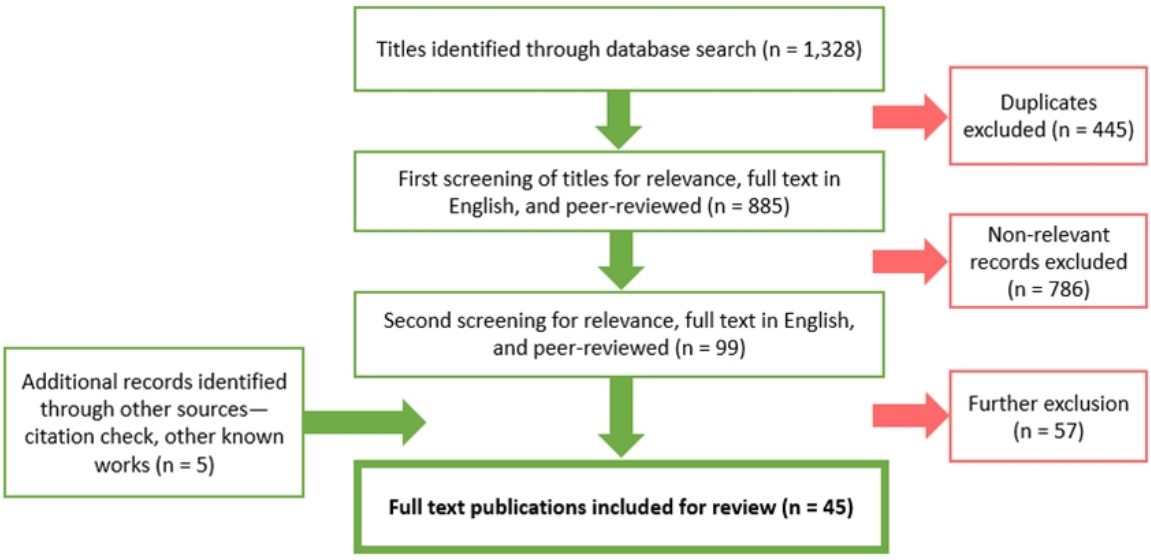

Figure 1. PRISMA flow diagram describing the search strategy.

Table 1. *Inclusion and Exclusion Criteria for Publications*

Characteristics	Selection Criteria
1. Environmental health research context and purpose	(a) Research that explores the association between the environment and human health or is within the context of the impact of the environment on human health. Environmental health is defined as different exposures (biological, chemical, physical, and social) that can have a positive or negative health effect. (b) The purpose of the research must be to create new knowledge on the impact of the environment on human health or in the context of the impact of the environment on health. (c) The research could be policy or action driven. (d) This review excluded publications presenting collaborations for the purpose of intervention, education or raising awareness, networking, and / or creating a research agenda.
2. Collaborative partnership characteristics	(a) Background of partners: Research partners (e.g., collaborators, stakeholders) not only from academia but also from multi-sectoral agencies or public / community groups. (b) Nature of engagement: Engaged throughout the research process (not only in one phase of the research, e.g., framing questions or prioritizing research agenda).
3. Collaborative process	(a) Publications describe and add insight to the collaborative process by specifically exploring the collaborative process or describing research experience employing collaborative research.
4. Publication features	(a) Published in English (b) Peer-reviewed (including thesis/dissertations) (c) Full text available (d) Published before August 2015 (literature search end-date)

Stage 4. Charting the Data

Data from the selected publications were extracted into a spreadsheet. Information gathered included the publications' characteristics and context, collaboration characteristics, and the collaborative process facilitators, challenges, and best practices. Extraction was done by one reviewer (second author, Sarah Ambrose) and, in an iterative review process, the extracted data were reviewed by a second reviewer (first author, Osnat Wine).

Stage 5. Collating, Summarizing, and Reporting the Results

The extracted data were collated and summarized. We also conducted thematic analysis of the identified data on the collaborative process facilitators, challenges, and best practices. The identified emerging themes are reported in the results section.

Stage 6. Consultation With Potential Knowledge Users and Stakeholders

Consultation with stakeholders took place at different times during the scoping review process, in order to share preliminary findings, and to provide opportunities for feedback and advice regarding the scoping review design, resources, findings, and meanings. These stakeholders were mainly environment and health interdisciplinary researchers and research partners involved with the Data Mining and Neonatal Outcomes (DoMiNO) research project mentioned above (DoMiNO, n.d.).

3. Findings

3.1. Publication Characteristics and Context

We identified 45 out of 1,328 publications for final review, describing various aspects of collaborative research in environmental health (Figure 1). The identified publications were published between the years 1998-2015, and included original research, reviews, and commentaries from different locations. Table 2 provides a list of all identified publications and their detailed characteristics (location, context, collaborative account/type, and collaborative approach). A list of 57 publications that were excluded from this review in the second screening phase is provided in Appendix B.

Our search process identified publications that originated from diverse research fields, such as health, environment, biology, education, policy, environmental management and assessment, and environmental justice. The context of environment and human health was discussed differently by the publications. Most publications referred to exposures and health outcomes as comprehensive/broad concepts (n = 14). Some indicated a specific health outcome (e.g., respiratory morbidities, cancer); others explored specific exposures already known to impact health (e.g., air pollution, toxicants, or multiple exposures) (n = 31).

Table 2. *Details on the 45 Publications Included in the Scoping Review*

	Publication	Location	Environmental Health Context	Environmental Exposure	Collaborative Account	Collaborative Approach
1	Angelstam et al., 2013	Sweden	Comprehensive	Not specific	Principles	Trans-disciplinary
2	Arcury et al., 2001	USA	Specific	Pesticide	Principles	CBPR
3	Austin, 2010	USA	Specific	Not specific	Experiences	CBPR
4	Bharadwaj, 2014	Canada	Comprehensive	Not specific	Principles	CBPR
5	Boon et al., 2014	Nether-lands	Comprehensive	Not specific	Experiences	Trans-disciplinary
6	Brown et al., 2012	USA	Specific	Indoor and outdoor pollutants	Experiences	CBPR
7	Burger et al., 2009	USA	Specific	Radiation	Experiences	CBPR
8	Burger et al., 2007	USA	Specific	Radiation	Experiences	Other

	Publication	Location	Environmental Health Context	Environmental Exposure	Collaborative Account	Collaborative Approach
9	Collman, 2014	USA	Specific	Uranium, arsenic, air pollution from cook stoves	Principles	CBPR
10	Conrad et al., 2013	USA	Comprehensive	Not specific	Principles	Trans-disciplinary
11	Corburn, 2007	USA	Specific	Pollution	Experiences	Other
12	Cummins et al., 2011	USA	Specific	Water pollution	Experiences	CBPR
13	Downs et al., 2009	USA	Specific	Air pollution	Experiences	CBPR
14	Ferris & Sass-Kortsak, 2011	Canada	Comprehensive	Not specific	Principles	Other
15	Garcia et al., 2013	USA	Specific	Air pollution	Experiences	CBPR
16	Gonzalez et al., 2011	USA	Specific	Diesel bus emissions (air pollution)	Experiences	CBPR
17	Harding et al., 2012	USA	Comprehensive	Not specific	Principles	CBPR
18	Haynes et al., 2011	USA	Specific	Airborne manganese exposure	Experiences	CBPR
19	Israel et al., 2005)	USA	Comprehensive	Not specific	Principles	CBPR
20	Israel et al., 2001	USA	Comprehensive	Not specific	Principles	CBPR
21	Israel et al., 1998	USA	Comprehensive	Not specific	Principles	CBPR
22	Jack et al., 2010	Canada	Comprehensive	Not specific	Principles	Other
23	Johnson et al., 2014	USA	Specific	Lead	Experiences	CBPR, trans-disciplinary
24	Matso et al., 2008	USA	Comprehensive	Not specific	Principles	Other
25	McCauley et al., 2001	USA	Specific	Pesticide	Experiences	CBPR
26	Meadow et al., 2015	USA	Specific	Climate science	Principles	Other
27	Metzler & Higgins, 2003	USA	Comprehensive	Not specific	Experiences	CBPR
28	Minkler, 2010	USA	Specific	Diesel bus emissions (air pollution)	Experiences	CBPR
29	Minkler et al., 2006	USA	Specific	Diesel bus emissions (air pollution)	Experiences	CBPR
30	Minkler et al., 2008	USA	Specific	Pollution (including air, lead, other toxic exposures)	Experiences	CBPR

	Publication	Location	Environmental Health Context	Environmental Exposure	Collaborative Account	Collaborative Approach
31	Nielsen, 2001	Canada	Comprehensive	Not specific	Principles	Trans-disciplinary
32	Parker et al., 2003	USA	Specific	Air pollution	Experiences	CBPR
33	Parkes et al., 2004	New Zealand	Specific	Campylobacter	Experiences	Other
34	Pereira et al., 2009	Italy	Specific	Atmospheric composition change	Experiences	Other
35	Ramirez-Andreotta et al., 2014	USA	Specific	Contaminated sites / hazardous waste	Principles	Trans-disciplinary
36	Ravenscroft et al., 2015	USA	Specific	Land and water environmental toxicants	Experiences	CBPR
37	Reed et al., 2014	UK	Comprehensive	Not specific	Principles	Other
38	Romero-Lankao et al., 2013	USA	Specific	Air pollution	Experiences	Other
39	Rosenthal et al., 2007	USA	Specific	Climate change associated exposures	Experiences	Other
40	Schell et al., 2007	USA	Specific	Organochlorides, lead, and mercury	Experiences	CBPR
41	Schell et al., 2005	USA	Specific	Polychlorinated biphenyls	Experiences	CBPR
42	Schell & Tarbell, 1998	USA	Specific	Polychlorinated biphenyls	Experiences	CBPR
43	Strosnider et al., 2014	USA	Specific	Air and water pollution	Experiences	Other
44	Wing, 2002	USA	Specific	Hog odors and waste from hog operations	Experiences	Other
45	Witten et al., 2000	New Zealand	Specific	Water pollution	Experiences	Other

Note. CBPR: Community-based participatory research

3.2. Collaboration Characteristics in Environmental Health Research

Our selection criteria required that all the selected publications should describe projects involving participation of partners from various sectors in the research process. Partners involved in the research included academic researchers, community members (public and leaders), advocacy groups and non-governmental organizations (NGOs), policy and decision makers, government agency representatives, and other various stakeholder groups (e.g., church, farmers, and private sector). The engagement of stakeholders and knowledge users varied throughout different phases of the research, such as problem

formulation, data gathering, analysis, and knowledge translation and dissemination. The collaborative processes described in the publications included:

(a) Descriptions of various research experiences in the context of environmental health research, which included accounts about strategies, partners, evaluation, perceptions, policy promotion, ethical considerations, stakeholder involvement, governance, promotion and support to policy and action, and environmental risk impact and assessment (n = 31).

(b) Research on the principles or frameworks for best practices related to collaborative research such as ethics, disclosure, health disparities, building and maintaining partnerships, and informing future research (n = 14).

The publications reviewed included two main collaborative approaches: *community-based participatory research* (CBPR), also described as community partnership research (n = 25), and *transdisciplinary research* (n = 6). No specific collaborative approach was identified in the other 14 publications. One publication presented a project described as both CBPR and transdisciplinary research.

We identified that the purposes for collaboration in the publications were mainly for co-producing new knowledge and/or *knowledge translation and exchange*, that is, initiatives aimed at cultivating mutually-beneficial connections between researchers and knowledge users, thus establishing a link between environmental health research and the improvement of health research, policies, programs, and practices.

3.3. The Collaborative Process in Environmental Health Research

All 45 publications provided descriptions of research collaboration—offering either a reflection on their own collaborative research experience or the results of their research on the nature of collaborative research process, exploring its principles. The publications provide details on the different components that influenced the collaborative research process, covering factors both external and internal to research projects.

3.3.1. External Components

Some publications discussed the external contextual factors that could impact the collaborative research approach, such as institutional (n = 15) and socio-political (n = 9) factors. Authors of these publications identified institutional factors as critical in supporting collaborative research and the partners engaged. These factors include: (a) available funding to support interdisciplinary and collaborative research, (b) acknowledgments and reward systems (e.g., performance reviews), (c) adequate training on collaborative and interdisciplinary research to those participating in collaborative research, as well as (d) institutional priority and support services for collaborative research (e.g., ethics review boards that advocate sharing results with participants, and/or policies that promote hiring community members for research purposes). Other external factors identified in the publications were socio-political in nature, which included the political climate as well as social and cultural structures, especially engagement structures to facilitate consultation with stakeholders.

3.3.2. Internal Components

Authors of some of the publications also identified components, which refer to internal collaborative research processes. They described facilitators and challenges that influence team development in different phases. Some publications provided advice on the best practices based on research, experiences, and lessons learned. In response to our research question, we coded the literature and identified the following emerging themes with respect to internal factors influencing the collaborative process in environmental health research:

1. Allocating time and resources
2. Addressing disciplinary and sectoral issues
3. Building relationships
4. Ensuring representation
5. Embedding participation in the research
6. Supporting ongoing collaboration
7. Developing knowledge translation and exchange

The themes are described below.

Theme 1. Allocating Time and Resources

Time and resources were identified as instrumental. It was acknowledged that collaborative approaches were time consuming because they required a longer time to build and maintain trusting relationships, support ongoing and inclusive engagement, and mediate conflicts. Additionally, the need for individual time commitment was challenged by competing demands. The process also required adequate funding and planning to support activities such as relationship-building (e.g., face-to-face meetings, travel, and knowledge translation and exchange). Funds were usually required to cover the long timeframe necessary to reach these goals. Another challenge related to resources was the distribution of funds among partners, which can be a source of conflict.

Theme 2. Addressing Disciplinary and Sectoral Issues

The authors of the reviewed publications acknowledged that the collaborative process builds on the participation of representatives from different disciplines, with diverse expertise and experiences. It was suggested that leadership of the research project should be built with key participants and that additional knowledge users and staff should be considered to enhance diversity of perspectives (e.g., support staff, community organizers, and activists). They also described how the interdisciplinary context presents conflicts from differences in cultures, ideas, goals, priorities, languages (e.g., terminologies), and communication styles. Furthermore, learning from each other, conducting the ongoing research, mediating assumptions and views, and integrating different concepts of research were also identified as challenges. Other disciplinary challenges referred to disciplinary control (i.e., domination of one discipline over other disciplines), traditionally focused disciplinary training, and the lack of experience and guidance on working with other disciplines/sectors and perspectives. Some also reported

issues in maintaining discipline legitimacy, scientific independence, credibility, and the ability to demonstrate value and impact. Studies recommended avoiding disciplinary dominance and encouraged the willingness to challenge norms, take in new ideas, adopting a holistic understanding of environmental issues, promoting understanding of interdisciplinary expectations (i.e., how the research will be conducted), and accepting different disciplinary cultures, languages, and methods. It was also suggested that more training opportunities in interdisciplinary and transdisciplinary research should be offered.

Theme 3. Building Relationships

Developing strong and trustworthy relationships within research teams were identified as essential to supporting the collaborative process. Moreover, studies described that partner engagement could help build research capacity: building on competence, interest and prior relationships, and by focusing on knowledge co-production. However, authors of the reviewed publications reported that developing and maintaining strong, trusting, and respectful relationships were a challenge that demanded teams to learn how to communicate effectively. This challenge was especially great if team members had prior negative experiences. Building and maintaining relationships considering human constraints (e.g., availability, personality, etc.), power imbalances within the team, and personnel turnover were other obstacles identified. Continuous investment in building trust and sustaining long-term relationships was noted as essential for the collaborative process and important factors that could help balance power issues.

Theme 4. Ensuring Representation

Authors of the reviewed publications identified that the representation of different sectors is instrumental to the collaborative research process. However, some publications described difficulty in identifying and obtaining adequate disciplinary or sectoral/community representation to create a diverse team. In some cases, this was due to an inaccessibility of different stakeholders, and in other cases, communities with previous bad experiences with research projects did not want to get involved in research again (e.g., aboriginal communities).

Theme 5. Embedding Participation in the Research

It was suggested that mitigating the challenges and obstacles that collaborative research presents can be done by embedding participation in the research. Framing includes identifying and involving partners early, and ensuring their participation throughout all research phases, including jointly framing the research questions and responding to user needs in the publication process. It was advised to build on previous mutual experiences to support the collaborative process. Additionally, it was recommended to perform a thorough preliminary background work including contextual factors and policy processes in order to better frame participation in the research.

Theme 6. Supporting On-going Collaboration

Reviewed publications reported that supporting on-going engagement as well as sustaining relationships are essential components of the collaborative process. They advise that this can be achieved by having continuous dialogue, two-way communication, meetings in person, and providing multiple opportunities for collaboration. Providing learning opportunities (context, languages, and methods) was also identified as essential. However, maintaining the ongoing collaboration was identified by some as challenging with regard to mediating conflicts and debates, involving partners in all research phases, creating an equal working environment, defining the level of partners' commitment, keeping an iterative and collaborative process, and balancing research and action. Some suggestions to overcome these challenges were that the partners identify and clarify early on the common and different goals, strategies, limitations, and model of participation. Inclusion of a social scientist who could support effective collaboration and formative evaluation of the collaborative process, governance, and decision making was recommended. Publications also recommended that the collaborative process should build on feedback and critical reflection, partners' joint development of operating norms, obtaining consensus or agreement during and at the end of the project, and allowing the process to be creative and flexible for changes in the research protocol.

Theme 7. Developing Knowledge Translation and Exchange

Another significant aspect identified in the publications related to different components that supported or challenged the process of developing knowledge translation. The publications acknowledged that the research design should involve knowledge translation and exchange from an early stage of the research process. Negotiating knowledge translation strategies as well as assessing knowledge user needs should be maintained throughout the research project. Reviewed publications also recommended keeping clear communication strategies about the knowledge translation plans, committing to implementation, delivering tangible outcomes to users early in the project, as well as sharing findings in an accessible and relevant format for different audiences. However, some publications identified that the ethics approval process involved in sharing findings with participants and the lag time between knowledge exchange and outcomes were challenging. Additional challenges identified included differing views of the research products, ownership of the data and results, and the dissemination of results. Some publications suggested early agreement on data sharing with participants and using knowledge brokers whose role as intermediators would be to support the dissemination process and activities that could mitigate conflicts.

Finally, the publications also discussed the importance of passion, commitment, motivation, respect, and shared values/goals in positively contributing to and facilitating the collaborative process and helping to overcome some of the barriers and challenges.

4. Discussion

The selected publications addressed the collaborative research processes in the context of environmental health research. We identified contributions from different research fields including, health, environmental management, and other disciplines, highlighting the

interdisciplinary nature of environmental health research. Moreover, what we have found in this scoping review for key components of collaborative research may apply not only to environmental health research but generally to other collaborative research contexts.

The collaborative and interdisciplinary approach (i.e., participation of different disciplines and stakeholders) has been acknowledged to benefit the breadth and depth of research in this field by integrating different perspectives, methods, and experiences (Annerstedt, 2010; Matso, Dix, Chicoski, Hernandez, & Schubel, 2008; Podestá, Natenzon, Hidalgo, & Toranzo, 2013) as well as contributing to the relevancy and usability of the research (Campbell et al., 2015; Cook, 2008; Reed, 2008). Partners benefit from learning experiences, contributing to issues of individual and societal interest, and building long lasting relationships. However, challenges result from the differences among partners and among the disciplines or organizations they come from (Armstrong & Jackson-Smith, 2013). Careful planning and framing of the research and the ongoing partnership can help to mediate differences. One approach to enhance interdisciplinary and collaborative capacity is training of students, faculty, and other partners in the theory and practice of interdisciplinarity, transdisciplinarity, and collaborative research (Ramirez-Andreotta, Brusseau, Artiola, Maier, & Gandolfi, 2014; Repko & Szostak, 2017) or by supporting the development of *transdisciplinary individuals* (Morales, 2017).

Interdisciplinary and collaborative research approaches are increasingly practiced and being promoted by funding agencies (Ramirez-Andreotta et al., 2014; Rylance, 2015). In the environmental health research context, which is an emerging field of research, and still grappling with the complexities and challenges inherent in its interdisciplinary and collaborative research approach, this requires attention from researchers, institutions, publishers, and funders (Brown, Deletic, & Wong, 2015). As more research team collaboration is required for credible research results, there will be more need to examine the significant components of collaborative research.

4.1. Contextual Barriers

The identified publications addressed contextual and external barriers, which may hamper collaborative research processes. These include institutional, political, social, and cultural barriers. For example, the political atmosphere can dictate if environmental health research is funded or not, and whether or not agencies or stakeholders would be included as partners. Social constructs can also impact the nature of research and partnerships. For example, stakeholders from different backgrounds may not view the partnership and research success in the same way.

Institutional support for academics and for different organizational representatives, in terms of funding and acknowledging the time requirements, is crucial to enable collaborative research and sustain collaborative research teams. The lack of suitable reward systems in place for those engaged in collaborative research could be challenging (given greater time commitment from those involved in such research and different outcomes of interdisciplinary collaborative research compared to discipline-based research). Reviewed publications suggest the need for new reward systems for researchers engaged in collaborative research, viewing these researchers as *scholars of*

outreach (Ramirez-Andreotta et al., 2014). Although there has been ongoing discussion around these contextual issues, they continue to influence current collaborative research practice and still require attention.

Thus, on a policy and organizational level, changes may be required in the culture and practice of research support agencies. Specifically, changes are required in the allocation of funding for collaborative research projects, ongoing support of their sustainability, adjustments of expectations around research progress and outcomes, establishment of reward systems, and support for training programs that focus on collaborative and interdisciplinary research.

4.2. Approaches to Research Collaboration

There are several approaches to research collaboration, including: *transdisciplinary research*, *participatory research*, *community-based participatory research* (CBPR), *integrated knowledge translation*, *team science*, *mode 2 research*, and *engaged scholarship*. While each approach has a somewhat different emphasis on the various elements of the collaborative process, these may also share common elements. The main collaborative approaches we identified in this review include transdisciplinary research and CBPR. Many of the identified publications have used a CBPR approach.

CBPR is a well-defined collaborative research approach aiming to respond to environmental health problems. The principles of CBPR include a research partnership approach with community stakeholders, building on the strengths and resources of the community and responding to community needs. It involves power sharing with the community, so as to build an equitable relationship among the collaboration partners. CBPR aims to achieve community engagement in all phases of the research, including the dissemination phase. Through co-learning and capacity building, CBPR aims to integrate knowledge gained with action which may benefit all partners (Cook, 2008; Israel, Schulz, Parker, & Becker, 1998; Israel, Parker et al., 2005; Parker et al., 2003). In this review, the issue of power imbalance among research partners was raised only in publications using CBPR (Arcury, Quandt, & Dearry, 2001; Downs et al., 2009; Israel, Schulz et al., 1998, 2001; Johnson et al., 2014; Metzler & Higgins, 2003). Power imbalance could arise in all types of research teams and may be based on many factors (e.g., seniority, gender, discipline, sector, etc.).

Other issues identified mainly in CBPR publications refer to the following challenges: (a) inaccessibility of partners from affected community members, (b) balance between participation and research project requirements demanding too much time investment, (c) developing leadership within the community so that community members can head the community's engagement in the research, (d) lack of clarity about the ownership of data and results, (e) balance between action and research (in many cases, academics are cautious with research results while community stakeholders push for action), (f) conflicts around funds distribution among the research partners, and (g) the challenge of overcoming communities' previous bad experience with research engagement.

Another collaborative approach identified was transdisciplinary research, which is a collaborative interdisciplinary and multi-sectoral research approach where the focus is on

addressing major real-world problems. It seeks to integrate knowledge and perspectives from different scientific disciplines as well as nonscientific resources (Repko, 2008). It has some participatory elements and it seeks the unity of knowledge beyond disciplines (Hadorn et al., 2008).

4.3. Practices to Support Collaborative Research

This scoping review provided comprehensive description of the key components of the collaborative research process. Specifically, it identified the different facilitators and challenges and offered lessons, strategies, and advice for supporting collaborative research. We cannot identify one component that could be the sole factor to influence the process; rather, it is a complex process that requires attention to the different components. The themes we describe, although described separately, are all interconnected, and depend on each other. Different research project may have different emphases on these components.

Through the different themes described above, the publications reviewed offered good practices to optimize and strengthen the collaborative research process, many of which should be considered by collaborative research teams. However, the publications reviewed do not completely address questions regarding the applicability and feasibility of their recommendations. For example, it is unclear whether partners would always embrace engagement, collaboration, and training, even if ample opportunities for these were provided. The impact of team size and the distribution of team members across different locations on the collaborative process is unclear (this point emerged from our consultations with the DoMiNO team members, see DoMiNO, n.d.). Additionally, the partners' difficulty in maximizing engagement given the other demands on their time was not fully explored. In many cases, locations, busy schedules, priorities, work habits, and other factors appeared to prevent partners from participating in the collaborative activities. Equal participation is not always possible but the principle of equity should be pursued and early decisions should be reached on the level of participation targeted and operating norms (Cargo & Mercer, 2008). One of the suggestions was to leave the management of the collaborative process to experts (i.e., social scientists) (Meadow et al., 2015; Ramirez-Andreotta et al., 2014) or to a neutral collaborative research expert (Matso et al., 2008). This may not be feasible in every case. Alternatively, we could consider including collaborative research as part of academic training, so that the relevant expertise may be available more broadly.

4.4. Knowledge Translation

Another significant component that was identified by this review was the development of knowledge translation and exchange and the collaborative process that contributes to it. The reviewed publications portray the collaborative approach as means to knowledge creation and translation into policy or practice. Whereas past paradigms left knowledge creation to academics and knowledge was transferred as a product (Gibbons, 2000), the emerging paradigm treats knowledge as a result of co-production or co-creation (Mauser et al., 2013; Rycroft-Malone et al., 2016; Voorberg, Bekkers, & Tummers, 2015). The publications identified specific references to the inclusion of knowledge translation as part of the collaborative process to promote the use of the new knowledge created, which

is an inherent component of environmental health research. Some of the publications acknowledged the contribution of collaborative approaches and the partners' role in supporting knowledge translation. Few elaborated on the process of building knowledge translation through the different phases of the research (Jack et al., 2010; Reed, Stringer, Fazey, Evely, & Kruijsen, 2014; Strosnider, Zhou, Balluz, & Qualters, 2014) and discussed the complex issue of sharing results (Schell et al., 2005; Ferris & Sass-Kortsak, 2011; Harding et al., 2012; Parkes, Eyles, & Benwell, 2004; Pereira et al., 2009; Ramirez-Andreotta et al., 2014). Very few publications suggested the inclusion of *knowledge brokers* as those who could help disseminate results and serve as cultural brokers (Jack et al., 2010), despite recent attention to their roles in various domains (Dobbins et al., 2009; Lam, 2017).

Nevertheless, it would be beneficial to learn more about the development of knowledge translation planning and the process of decision making (i.e., determination of goals and audiences, messages, and strategies). It would be especially important in a context such as environmental health characterised by conflicting priorities.

5. Conclusions

This review contributes to an understanding of the collaborative research processes in the context of environmental health. Several key lessons were derived from this review:

(a) Understanding the collaborative process can be enhanced by learning from different collaborative research approaches.

(b) The collaborative research process is a complex web of interrelated components.

(c) The main components of collaborative research pertain to allocating time and resources, addressing disciplinary and sectoral issues, building relationships, ensuring representation, embedding participation in the research, and supporting on-going collaboration.

(d) Planning for knowledge translation is an important part of the collaborative research process.

A review of the short and long-term impact of the collaborative approaches in the study of the environmental health would complement our review. Other future research could focus on the gaps identified here which include: the applicability and feasibility of best practices for research collaborations as well as knowledge translation development in research partnerships; and stakeholder engagement and contribution to the knowledge translation planning. These gaps may be answered through learnings from other real-life experiences.

Our own experience as participants in a collaborative research project motivated this review and ended up informing our collaborative activities. The significant components of collaborative research identified here may be of interest and use not only to individuals involved in the area of environmental health research but also to researchers across other areas and sectors.

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Appendix A:

Terms and Definitions Used in the Review

Term	Definition
Co-production / Co-creation	Implies a process where new knowledge is or can be produced through interaction and collaboration between scientists and knowledge users possibly with people with different perspectives and backgrounds, through cooperative endeavors and mutual learning (Fazey & Evely, 2013; Meadow et al., 2015).
Collaborative research	An umbrella term for methodologies that actively engage researchers, communities and policy makers in the research process from start to finish (Centre for Collaborative Research for an Equitable California, 2010).
Community-based participatory research (CBPR)	CBPR is currently one of the more widely recognized participatory research approaches, with a growing number of applications, particularly in geographic and racial/ethnic communities. The emphasis is on the participation and influence of nonacademic researchers in the process of creating knowledge and specific community's needs with the aim to empower the community and support action for the community. The collaborative approach to research equitably involves community members, organizational representatives, and researchers in all aspects of the research process. The partners contribute "unique strengths and shared responsibilities" to enhance understanding of a given phenomenon and the social and cultural dynamics of the community, and integrate the knowledge gained with action to improve the health and well-being of community members (Cargo & Mercer, 2008; Israel et al., 1998).
Environmental health	Environmental health addresses all the physical, chemical, and biological factors external to a person, and all the related factors impacting behaviors. It encompasses the assessment and control of those environmental factors that can potentially affect health. Such effort is targeted towards preventing disease and creating health-supportive environments (Prüss-Ustün et al., 2016).
Integrated knowledge translation	Potential research knowledge users are engaged in the entire research process by collaborating to determine the research questions, and methodology, being involved in data collection and tools development, interpreting the findings, and helping disseminate the research results. This approach should produce research findings that are more likely to be relevant to and used by the end users (Canadian Institutes of Health Research, 2016).
Interdisciplinary	Refers to a process of addressing a complex topic, which draws on several disciplinary perspectives and integrates their insights to produce a more comprehensive understanding (Repko, 2008).
Knowledge brokers	In public health knowledge brokers are intermediaries between researchers and intended users / knowledge users (Dagenias et al., 2015). Knowledge brokers can facilitate translation of scientific expertise to influence regulatory processes by connecting academic researchers with decision makers to facilitate the translation of research findings into policies and programs (Pennel et al., 2013), or act as cultural brokers with communities (Jack et al., 2010).

Term	Definition
Knowledge exchange	Refers to the interaction between the knowledge user and the researcher resulting in mutual learning. It encompasses the concept of collaborative or participatory, action oriented research whereas researchers and knowledge users work together as partners to conduct research to sole knowledge users' problems. It Implies a two- or multiple-path process with reciprocity and mutual benefits, with multiple learning, but not necessarily recognition of the equitable value of the different forms of knowledge being exchanged (Fazey & Evely, 2013).
Knowledge mobilization	Implies eliciting or spreading knowledge to a wider range of recipients, possibly with the intent of increased application of knowledge (Fazey & Evely, 2013).
Knowledge translation	A dynamic and iterative process that includes synthesis, dissemination, exchange and ethically-sound application of knowledge which takes place within a complex system of interactions between researchers and knowledge users (an individual who is likely able to use the knowledge generated through research to make informed decisions about health policies or practice to improve the health of Canadians) (Canadian Institutes of Health Research, 2016). Also, could imply communication using a mediated language modified for recipients (Fazey & Evely, 2013).
Participatory research	An umbrella term for a school of approaches that share a core philosophy of inclusivity and of recognizing the value of engaging in the research process (rather than including only as subjects of the research) with those who are intended to be the beneficiaries, users, and stakeholders of the research systematic inquiry, and with the collaboration of those affected by the issue being studied, for purposes of education and taking action or effecting change (Cargo & Mercer, 2008).
Scoping reviews	A form of knowledge synthesis that addresses an exploratory research question aimed at mapping key concepts, types of evidence, and gaps in research related to a defined area or field by systematically searching, selecting and synthesizing existing knowledge (Colqhoun et al., 2014).
Transdisciplinary	Similar to interdisciplinary, transdisciplinarity is descriptive of collaborative research and problem solving that, unlike interdisciplinary, it crosses both disciplinary boundaries and sectors of society by including stakeholders in the public and private domains. Transdisciplinary research generally focuses on a larger scale questions (e.g., climate change adaptability, eco system health) and its leading principle is interdisciplinary approach to the research question that aims for innovation and creative solutions (Hadorn et al., 2008; Repko, 2008).

Appendix B:

Excluded Publications (n = 57), Phase 2 of Screening Process (Not Included in This Review)

Author(s)	Year	Title	Source
Anex & Focht	2002	Public participation in life cycle assessment and risk assessment: A shared need	*Risk Analysis*, *22*(5), 861-877
Anwar	2005	Possibilities and pitfalls for modern biotechnology in the development of African genetic toxicology	*Toxicology and applied pharmacology*, *207*(2), 706-711
Baker	2001	Community Based Research of Autoimmune Disease & Asthma	University of Buffalo
Beyer	2009	Exploratory spatial data analysis in community context: Integrating geographic information science and community engagement for colorectal cancer prevention and control	The University of Iowa
Christopher et al.	2008	Building and maintaining trust in a community-based participatory research partnership	*American Journal of Public Health*, *98*(8), 1398-1406
Cochran et al.	2008	Indigenous ways of knowing: Implications for participatory research and community	*American Journal of Public Health*, *98*(1), 22-27
Cole et al.	2011	An agriculture and health inter-sectoral research process to reduce hazardous pesticide health impacts among smallholder farmers in the Andes	*BMC International Health and Human Rights*, *11* (Suppl. 2), S6
Cook	2008	Integrating research and action: A systematic review of community-based participatory research to address health disparities in environmental and occupational health in the USA	*Journal of Epidemiology and Community Health*, *62*(8), 668-676
Corburn	2002	Street science: The fusing of local and professional knowledge in environmental policy	Massachusetts Institute of Technology
Crowe et al.	2008	Striving to provide opportunities for farm worker community participation in research	*Journal of Agricultural Safety and Health*, *14*(2), 205-219
Di Chiro	1995	Local actions, global visions: Women transforming science, environment, and health in the united states and India	University of California, Santa Cruz
Drechsel et al.	2008	Linking research, capacity building, and policy dialogue in support of informal irrigation in urban west Africa	*Irrigation and Drainage*, *57*(3), 268-278

Author(s)	Year	Title	Source
Easley	2002	Community empowerment through participatory research: Environmental enhancement on the west side of Chicago	Northern Illinois University
Eggers	2014	Community based risk assessment of exposure to waterborne contaminants on the crow reservation, Montana	Montana State University
Finn & Thompson	2012	Community-based participatory research through the lens of environmental health: More than a catchy sounding name	*Epidemiology*, 23(5, Suppl. 1), S256
Guttmacher	2013	The future of scientific research	*Hematology Reports*, *5*(Suppl. 1)
Heaney et al.	2007	The west end revitalization association's community-owned and -managed research model: Development, implementation, and action	*Progress in Community Health Partnerships*, *1*(4), 339-349
Israel et al.	2001	The Detroit community-academic urban research center: Development, implementation, and evaluation	*Journal of Public Health Management & Practice*, *7*(5), 1-19
Israel et al.	2010	Community-based participatory research: A capacity-building approach for policy advocacy aimed at eliminating health disparities.	*American Journal of Public Health*, *100*(11), 2094-2102
Keeler et al.	2002	Assessment of personal and community-level exposures to particulate matter among children with asthma in Detroit, Michigan, as part of community action against asthma (CAAA)	*Environmental Health Perspectives*, *110* (Suppl. 2), 173-181
King	2012	Collaboration program effectiveness: Comparing two community partnership programs.	George Mason University
Korfmacher et al.	2014	Unconventional natural gas development and public health: Toward a community-informed research agenda	*Reviews on Environmental Health*, *29*(4), 293-306
Kyle et al.	2006	Integrating research, surveillance, and practice in environmental public health tracking	*Environmental Health Perspectives*, *114*(7), 980-984
Linkov et al.	2011	A decision-directed approach for prioritizing research into the impact of nanomaterials on the environment and human health	*Nature Nanotechnology*, *6*(12), 784-787
Loh et al.	2002	From asthma to AirBeat: Community-driven monitoring of fine particles and black carbon in Roxbury, Massachusetts	*Environmental Health Perspectives*, *110*(Suppl. 2), 297-301
MacDonell et al.	2002	Integrating information for better environmental decisions	*Environmental Science & Pollution Research*, *9*(6), 359-368

Author(s)	Year	Title	Source
Mathe	2014	Integrating participatory approaches into social life cycle assessment: The SLCA participatory approach	*International Journal of Life Cycle Assessment*, *19*(8), 1506-1514
McGrath et al.	2009	The limits of collaboration: A qualitative study of community ethical review of environmental health research	*American Journal of Public Health*, *99*(8), 1510-1514
McPartland et al.	2015	Building a robust 21st century chemical testing program at the U.S. environmental protection agency: Recommendations for strengthening scientific engagement	*Environmental Health Perspectives*, *123*(1), 1-5
Miller et al.	2013	Community-based participatory research projects and policy engagement to protect environmental health on St Lawrence island, Alaska	*International Journal of Circumpolar Health*, *72*(1), 21656
Minkler et al.	2010	Using participatory research to promote environmental justice in a Latino community in San Diego, California	*Journal of Urban Health*, *87*(5), 796-812
Molina & Molina	2004	Improving air quality in megacities: Mexico city case study	*Annals of the New York Academy of Sciences*, *1023*(1), 142-158
Nativi et al.	2014	The GEOSS solution for enabling data interoperability and integrative research	*Environmental Science & Pollution Research*, *21*(6), 4177-4192
Neri et al.	2015	Common pathways toward informing policy and environmental strategies to promote health: A study of CDC's prevention research centers	*Health Promotion Practice*, *16*(2), 218-226
O'Mullane	2009	An investigation of the utilization of health impact assessments (HIAs) in Irish public policy making	University College Cork (Ireland)
O'Fallon et al.	2000	Improving public health through community-based participatory research and outreach	*Environmental Epidemiology and Toxicology*, *2*(2-3), 201-209
Orozco and Cole	2012	Tackling challenges to farmers' health and agro-ecosystem sustainability in highland Ecuador	In *Ecohealth Research in Practice* (pp. 47-58). Springer New York
Osuch et al.	2012	A historical perspective on breast cancer activism in the united states: From education and support to partnership in scientific research	*Journal of Women's Health*, *21*(3), 355-362
Parkes et al.	2003	Converging paradigms for environmental health theory and practice	*Environmental Health Perspectives*, *111*(5), 669-675
Parkinson	2013	The arctic human health initiative: A legacy of the international polar year 2007-2009	*International Journal of Circumpolar Health*, *72*(1), 21655

Author(s)	Year	Title	Source
Passerini & Wu	2008	The new dimensions of collaboration: Mega and intelligent communities, ICT and wellbeing	*Journal of Knowledge Management*, *12*(5), 79-90
Pennell et al.	2013	Bridging research and environmental regulatory processes: The role of knowledge brokers	*Environmental Science & Technology*, *47*(21), 11985-11992
Phillipson et al.	2012	Stakeholder engagement and knowledge exchange in environmental research	*Journal of Environmental Management*, *95*(1), 56-65
Plagerson & Mathee	2012	Changing an urban community through health research: A South African case study	*Health Promotion Practice*, *13*(3), 339-343
Postma	2008	Elucidating empowerment in El Proyecto Bienestar (the well-being project)	*Journal of Advanced Nursing*, *62*(4), 441-450
Powers et al.	2014	Sparking connections: Toward better linkages between research and human health policy-an example with multiwalled carbon nanotubes	*Toxicological Sciences*, *141*(1), 6-17
Quigley et al.	2000	Participatory research strategies in nuclear risk management for native communities	*Journal of Health Communication*, *5*(4), 305-331
Quigley	2009	Promoting research ethics training: Understandings of community, partnership, virtue and diversity	Syracuse University
Schug et al.	2013	ONE nano: National Institute of Environmental Health Sciences's strategic initiative on the health and safety effects of engineered nanomaterials	*Environmental Health Perspectives*, *121*(4), 410-414
Senier et al.	2008	Brown superfund basic research program: A multistakeholder partnership addresses real-world problems in contaminated communities	*Environmental Science & Technology*, *42*(13), 4655-4662
Spiegel et al.	2011	Establishing a community of practice of researchers, practitioners, policy-makers and communities to sustainably manage environmental health risks in Ecuador	*BMC International Health & Human Rights*, *11*(2), S5
Wallerstein et al.	2011	Integration of social epidemiology and community-engaged interventions to improve health equity	*American Journal of Public Health*, *101*(5), 822-83
Wallington et al.	2013	The co-location of academia with the community in addressing cancer health disparities: A new model of partnerships for environmental public health	*Cancer Prevention Research*, 2013, 6 (11, Suppl. 1)
Wesche et al.	2011	Community-based health research led by the Vuntut Gwitchin first nation	*International Journal of Circumpolar Health*, *70*(4), 396-406

Author(s)	Year	Title	Source
White-Newsome et al.	2009	Climate change, heat waves, and environmental justice: Advancing knowledge and action.	*Environmental Justice*, *2*(4), 197-205
Wilson et al.	2007	Use of EPA collaborative problem-solving model to obtain environmental justice in North Carolina	*Progress in Community Health Partnerships*, *1*(4), 327-337
Wilson et al.	2012	The science of community engagement: Lessons from the field of environmental health	*Epidemiology*, 23(5, Suppl. 1), S267

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