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Environmental science and policy: A meta-synthesis of case studies on boundary organizations and spanning processes

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Abstract

We conducted a meta-synthesis of published qualitative articles to better understand how features and strategies of boundary organizations and spanning processes influence whether environmental science was utilized in politically oriented outcomes. Meta-synthesis is a peer-reviewed research technique which is becoming more prolific as disciplines compare qualitative research studies and generalize qualitative knowledge. In this work, thirty-nine published case studies were analysed through a systematic grounded theory approach and thirty-nine structured interviews were performed with authors to validate the results. Overall, forty-seven boundary spanning variables were evaluated using disaggregated statistics to determine correlation with policy outcomes. Our results develop the possibility that successful boundary spanning linkages may be less about utilizing formal boundary organizations and more about fostering the *process* through which science and policy are intermingled.

Key words: science-policy interface; boundary organization; boundary spanning; environment; meta-synthesis

1. Introduction

Humanity faces increasingly intractable environmental problems characterized by high uncertainty, complexity, and swift change (Crona and Parker 2012). How science is developed and applied to policy-making is one major factor influencing 'humanity's environmental future' (Caldwell 1990). Yet, science is currently underutilized in environmental policy despite the growing call for effective scientific engagement in public policy (National Science Foundation 2002). Current obstacles to effective scientific engagement in environmental policy include the inability to frame information in terms that resonate with policy and decision-makers (Jacobs and Pulwarty 2003); insufficient efforts to 'translate' scientific information in environmental policy (Ascher et al. 2010); poor access to research findings (Driscoll et al. 2011); and the tendency for social and political framings to shape both the formulation of scientific explanations of environmental problems, and the solutions proposed to reduce them (i.e. science and policy are always mutually constituted) (Forsyth 2003; Hess 1997). Further difficulties include the recognition that more science does not mean better policy (Sutherland et al. 2013); knowledge hierarchies that distance scientists from real-world application (Gieryn 1995, 1999); the tendency to frame questions and methods in the absence of early policy engagement; and a paucity of published literatures relevant to policy needs (Janse 2008). Additionally, a growing body of anti-science literature, or 'a twisting of the findings of empirical science' (Ehrlich and Ehrlich 1996), bolsters predetermined worldviews which can support political agendas and undermine scientific credibility. How to effectively research and address these obstacles will be a top priority in the twenty-first century.

Scholarship on boundary spanning from the natural sciences to the humanities is dominated by boundary organization theory (Guston 2001; O'Mahony and Bechky 2008). Boundary organizations are institutions that straddle politics and science (Guston 1999) and are identified based on the formality of the institution and their focus on the science–policy interface (Crona and Parker 2012). Classic examples of boundary organizations include the EPA, the Sea Grant Program, and the Intergovernmental Panel on Climate Change (IPCC) as outlined in Guston et al. (2000). Comparative analyses of boundary organizations and boundary spanning have included analysis of ozone depletion politics, knowledge systems supporting El Nino forecasts, acid rain and climate change, and policy debates around environmental education in public schools and the role of social science in the National Science Foundation (Betsill and Pielke 1998; Buizer et al. 2010; Clark et al. 2011; Gieryn 1995, 1999; Lemos and Morehouse 2005; Zehr 2005).

Yet, additional comparative research is needed which systematically analyses key processes of boundary spanning and associated scientific integration into policy outcomes (Crona and Parker 2012; Hoppe et al. 2013; McNie 2007), especially with regard to environmental topics. This article provides a systematic comparison of environmental boundary spanning published case studies through a meta-synthesis to evaluate the strength of the relationship between variables (i.e. strategies and tactics) employed by boundary organizations and through boundary spanning processes and subsequent scientific integration in policy-oriented outcomes. The intent of this work is to understand the efforts of boundary organizations and/or boundary spanning processes which try to intermingle science and policy. Our work is not focused on the demarcation of science and policy, but rather, on the act itself of intermingling through boundary organizations and/or boundary spanning processes. Each of the case studies chosen specifically focus on boundary organizations and/or boundary spanning processes which seek to interconnect science and policy. Following a literature review describing the theoretical framings of our research, we present the methodology of meta-synthesis. The results of the meta-synthesis follow the methodology with the boundary organization and boundary spanning literature framing our discussion. Finally, we provide concluding thoughts and future recommendations.

2. Boundary organizations and boundary spanning processes

Boundary organizations and boundary spanning processes (processes designed to enhance the integration of science and policy) link scientific and political worlds (Lemos and Morehouse 2005). The boundary spanning literature discusses boundary organization theory and various characteristics of and actions taken by boundary organizations and boundary spanning processes.

The theory of boundary organizations analyses boundary organizations, boundary spanners, and boundary spanning processes in terms of their relations with the domains of science and politics (Guston 1999). Boundary organization theory developed in a variety of contexts, including the environmental arenas related to climate (Miller 2001), health (Guston 1999), agriculture (Carr and Wilkinson 2005; Cash 2001), and water (White et al. 2008, 2010), among others. Boundary organizations are typically defined as formal organizations which create a more 'neutral' space for knowledge co-production, dissemination, and brokering activities (Guston 2001). These organizations frequently (a) provide accountability and responsibility to stakeholders to establish checks and balances between entities at the boundary so trust can develop (Guston 2000, 2001); (b) involve the participation of principals (i.e. policymakers), agents (i.e. scientists), and professional mediators, to facilitate effective communication with the added help of professional facilitation (Braun and Guston 2003); and (c) consult with stakeholders directly affected by policy choices to help grasp 'local realities' during scientific research and public participation efforts (Bremer and Glavovic 2013: 109).

Boundary organizations also utilize boundary spanners (individuals, rather than organizations, which span science–policy efforts) to strengthen the integration of politics and science (Weertz and Sandmann 2010). Scholars argue that boundary spanners are particularly important to maintaining relationships, building trust, communicating information needs and concerns, and bridging gaps between various stakeholder groups (McNie et al. 2008). Boundary organizations further develop and utilize boundary objects (Star and Griesemer 1989) or 'hybrid, flexible, portable tools' (White et al. 2010: 222), which sit among various social worlds (i.e. science, non-science, and public). Boundary objects such as repositories and maps (Star and Griesemer 1989), databases (Quay 2004), computer programs, and modelling (see White et al. 2008, 2010) are argued to enhance the boundary spanning as they fuel collaboration and cooperation between various entities at the boundaries (White et al. 2010).

However, recent literature critiques boundary organization theory (and boundary spanning writ large) as it is problematic to assume a clear distinction among science, politics, and boundary spanning processes. Instead, boundary organizations and spanners occupy a hybrid space in which science and politics co-mingle and constituents embody elements of both (Miller 2001). As Crona and Parker (2012) highlight, the boundary spanning process is a continuous process of negotiating among tensions derived from inconsistent demands placed on boundary organizations and spanners by different stakeholders. Decision-making processes and outcomes are still subjected to local politics and underlying priorities despite the best intention of boundary organizations and partnerships (Cash 2001). Thus, organizations bridging science and policy are inextricably interlinked and 'co-produced' (Jasanoff 2004) with politics rather than separate from it (i.e. boundary organizations do not exist in political vacuums).

To make sense of this wide-ranging literature, we distill evidence and debates surrounding the role of specific *characteristics* of boundary organizations and spanning processes, and specific strategies or *actions* employed at the boundary, that are deemed to be influential in shaping the success of scientific integration in political arenas.

2.1 What characteristics of boundary organizations and spanning processes are deemed most influential in shaping policy outcomes?

Various boundary spanning processes affect the uptake of environmental science in policy efforts. First, the kinds of academic disciplines and modes of engagement are discussed as significantly influencing the science–policy interface (Guston 2001; McNie 2007). Boundary organizations and boundary spanning processes which are interdisciplinary or cross-disciplinary in nature are said to enhance scientific relevance for policymaking (Thrift et al. 2009). Transdisciplinarity is also identified as an important feature in enhancing science–policy integration by engaging academic-oriented disciplines *and* various individuals, groups, institutions, and stakeholders who may be impacted by policy decisions or able to contribute valuable insight to addressing problems not captured through disciplinary measures alone (Clapp and Mortenson 2011). Boundary organizations and spanning activities can involve various entities such as scientists, policymakers, universities, industry, consultants, think-tanks, state agencies, private companies, community organizations, representatives of indigenous groups, non-governmental organizations, funding agencies, among others to help influence legislative actions and implementation.

The formality (i.e. pre-established organizations with prescribed practices) of boundary organizations and boundary spanning processes is also discussed as impacting successful science–policy integration measures (Hastings 2011). There is considerable disagreement on whether formality is beneficial or harmful to achieving policy influence. Some argue that the formality of boundary organizations or boundary spanning processes better aids institutional and policy process engagement as pre-established networks and institutional capacity are already in place to aid science–policy interaction (Bremer and Glavovic 2013). Others contend that boundary organizations and boundary spanning processes which are flexible and dynamic are significant to successful environmental science–policy linkages as it allows for multifaceted stakeholder participation as well as ideas about research to remain in flux. Thus, innovative solutions to specific problems can be addressed through best available options, instead of through a fixed team of specialists or traditional metrics applied to addressing policy issues across the board (Hastings 2011). Similarly, some maintain that *ad hoc* and self-organized processes are more effective, as they are organically arranged (Hahn et al. 2006; Kallis et al. 2009) around particular environmental issues and thus are able to assemble appropriate stakeholders (both scientific and non-scientific) to accurately influence environmental policy measures (Bremer and Glavovic 2013).

Scholars seem to also disagree on whether boundary organizations and spanning processes which are operationalized through official (government) or unofficial (non-profit, non-governmental) pathways are most effective. Zehr (2005) and Tuinstra et al. (2006) argue that government-centred processes are more effective, as government involvement lends them added credibility among decision-makers. Boundary organizations or spanning processes which are driven by specific legislation, and therefore tied to specific policy aims, are also said to be more effective as policymakers have already approved the initiative in support of the interests of various stakeholders, [e.g. Resource Management Act of New Zealand highlighted by Bremer and Glavovic (2013) or the Enhanced Forest Management Pilot Projects of Innes (2003)]. Shaw et al. (2013) and Tomich et al. (2007), on the other hand, view science–policy efforts which are not-for-profit as most effective as actions and research on behalf of environmental issues are seen as free from economic influence.

Sources of funding are also relevant to the discussion of the effectiveness of boundary organizations and/or boundary spanning processes (Kirchoff et al. 2013). Some argue for boundary organizations and boundary spanning which are funded by the government as this can increase perceived credibility and accountability by stakeholders (Franks 2010). Other argues that processes funded by a foundation are important as it demonstrates both private and public interest for an initiative (Clapp and Mortenson 2011). Still others suggest that processes funded by the public are most effective for demonstrating the overarching need detailed by members of society (Kueffer et al. 2014), or that processes funded by industry help by supporting more intensive and project-driven efforts (e.g. Clapp and Mortenson 2011).

Finally, issues of scale are also discussed in the literature as relevant to the discussion of the effectiveness of boundary organizations and/or boundary spanning processes. The importance of scale highlighted in science–policy literatures emphasizes how science–policy integration occurs best when operationalized through a multi-dimensional, adaptable approach which recognizes local to global scales while being open and transparent to facility dialogue and collaboration between a wide-range of different actors (Watson 2012). For example, if environmental policy efforts target local riparian protections, scholars argue research should reflect this policy objective through focusing science on local riparian issues. Science–policy engagement exists at a multitude of scales in the literature ranging from local, state, regional, national, and international boundary organizations and spanning processes. Arguments for a more regional boundary spanning approach are stated in the literature as these efforts can pin-point specific environmental strategies finely tuned for an area (Bremer and Glavovic 2013).

2.2 Which strategies at the boundary are deemed most influential in shaping policy outcomes?

Boundary organizations and spanning processes engage in various actions to attempt to influence legislative, policy change, and/or support implementation. But which of these strategies are most influential in shaping policy? Boundary organizations and boundary spanning processes that facilitate dialogue and communication, as well as coordinate entities at the boundary (science, policy, citizens, etc.), are said to influence policy as enhanced communication between entities increases the chance of finding common ground and areas for science–policy incorporation (Breuer et al. 2010). The brokering of information and the effective exchange of research directly help environmental science become more accessible to policymakers, and thus, more easily translated into policy (Cash 2001).

Knowledge co-production further supports policy influence by allowing for the mutual investment of all entities acting at the boundary (Dilling and Lemos 2011). Co-production operates from the foundation that all knowledge is 'co-produced' in science and society as 'each [science and society] underwrites the other's existence' (Jasanoff 2004: 17). A co-productionist model is undertaken by boundary organizations and through boundary spanning processes, whereby the research agenda is shaped in an ongoing, iterative fashion between knowledge producers and users (Dilling and Lemos 2011).

Another set of actions employed by boundary organizations and/or through spanning processes focuses on relational dimensions. Boundary organizations and spanning processes that help develop and maintain strong social relationships enhance social bonding and personal networking that provides improved conditions for knowledge creation and dissemination (Holmes and Savgård 2009). Developing enhanced social relationships are said to occur through building social capital with the target audience through current institutional networks so as to tap into existing social capital as well as the expertise available through organizations, institutes, universities, scientists, policymakers, etc. (McNie 2007). Others maintain social capital is best forged through participating in informal forms of engagement (Bremer and Glavovic 2013) with social events outside of the workplace (retreats, fieldwork activities, luncheons, etc.) to help break down work-related barriers which may impede successful science–policy integration. Finally, some authors explore the importance of managing power differentials (e.g. conflicting demands, positions, and resources) in order to create a more 'neutral' space for collecting information and ideas from all stakeholders (Kirchoff et al. 2013).

Many of the strategies at the boundary focus on creating *salient*, *credible*, *and legitimate* knowledge for all stakeholders (Cash et al. 2003) as it is argued to create an inclusive, objective scientific investigation, while also reflecting the needs of stakeholders affected by decisions. Saliency, credibility, and legitimacy associated with science–policy integration are created through several mediums in the literature:

First, developing standards, recommendations, or plans through boundary organizations and/or boundary spanning processes are argued to enhance the effectiveness of boundary organizations and spanning processes as they provide a strong *salient* starting point for future policy development as plans can easily translate into policy and/or provide evidentiary support for why or why not certain legislation should pass depending on results of a plan (Lopez-Rodriguez 2015). Boundary organizations and/or spanning processes that develop standards and recommendations further aid decision-making processes, as clearly articulated options to address issues can be easily translated into legislation (Kamelarczyk and Gamborg 2014). During the processing of developing standards, recommendations, or plans effective working groups on various topics are also created through boundary organizations and/or boundary processes which ultimately help to influence policy decisions (Tuinstra et al. 2006).

Second, how knowledge is distributed by boundary organizations and/or processes is also identified as important to develop *legitimacy*. Some argue for disseminating research results directly to policymakers, regulators, and regulating organizations as this builds trust between various entities at the boundary and increases input from decision-makers which enhance saliency, and thus, applicability of science to policy decisions (Cutts et al. 2011; Hastings 2011). Others argue instead for distributing information to the media to help relay environmental science to the public and influence policy indirectly as this builds public knowledge and awareness of an issue regardless of its political sensitivity which can either force the hand of the government to act or create conditions conducive to science–policy interaction to put legislation into place to fix an issue (Quay 2004; Schwach et al. 2007). Still others focus instead on how knowledge is packaged, and emphasize the need to produce several types of documents for distribution to stakeholders as this increases effective translation of scientific materials (Eden 2011; Hahn et al. 2006; Bremer and Glavovic 2013).

Some argue for the need to go beyond one-way communication and one-off encounters to foster ongoing engagement with governmental bodies—which is deemed necessary for adequately tailoring the message to policymakers (e.g. governmental organizations, cooperative extension services, and local, state, and federal agencies, among others), to provide consistency in research requests, and to effectively build lasting relationships to enhance the ability for science to inform policy (Brunel et al. 2013; Buizer et al. 2010). Still others argue for approaches that blur the boundaries between research and dissemination, such as promoting conditions conducive for learning through experiential, social, and institutional learning which allows for enhanced collaboration to occur and helps break down situational barriers while fostering a more collective and informed stakeholder group (Klerkx and Leeuwis 2009).

Third, shaping the research trajectory and executing scientific research are effective by enabling boundary organizations to bolster *credibility* by helping manage scientific uncertainty (Holmes and Savgård 2009; Hoppe 2010) when participating in research design and dissemination. Efforts to tailor research approaches are also hailed in the literature as important for the uptake of science in policy as it allows for detailed and tailored attempts to successfully influence legislative actions and implementation measures (Kallis et al. 2009). Those emphasizing the nature of the research process have also argued for scientific research conducted at specific places on specific issues and problems—coined site-specific research (Innes 2003), place-based research (Shaw et al. 2013), and 'problem-oriented' research (Schut et al. 2013: 95)—as this approach provides precise data, thus strengthening its credibility for use by decision-makers. Other research strategies include: (a) long-term or sustained research as decision-makers are more apt to incorporate scientific data due to the capacity to provide enhanced monitoring and follow-up during implementation (Bremer and Glavovic 2013); (b) systematic evaluations throughout research design as it provides enhanced capabilities for adaptation of research and is thus perceived as more precise to address science–policy issues (Schwach et al. 2007); and (c) familiarity with the details of government structures, politics, and cultural practices (Rice et al. 2009) so research can be strategically designed and dispersed into the political arena.

3. Methodology

Qualitative meta-synthesis[1] (Jensen and Allen 1996; Sandelowski et al. 1997; Thorne et al. 2004) is a synthesis in which the findings from qualitative studies are formally combined through grounded theory analysis. Meta-synthesis is a peer-reviewed research technique which is becoming more prolific as disciplines compare qualitative research studies and generalize qualitative knowledge (Sandelowski et al. 1997). Biomedical, health, and nursing research (e.g. Knowles et al. 2014; McCarthy-Jones et al. 2012; Ooi et al. 2016), in particular, utilizes meta-syntheses to extract key medical practices discussed in qualitative studies to further medical application and theory (Timulak and Creaner 2013). Meta-syntheses are also conducted in the fields of education (e.g. Sipe and Curlette 1997), social science (e.g. Hicks and Wood 2016), computer science (e.g. Douglas 2008), social work (e.g. Aguirre and Bolton 2013), psychology (e.g. Fehr et al. 2010), linguistics (e.g. Yoder and van Hover 2016), among others. Qualitative meta-synthesis was utilized in this study to provide a systematic means of deriving new science–policy knowledge from findings available in existing research studies.

3.1 Meta-synthesis phase completion

This meta-synthesis was operationalized through the six key phases. The traditional meta-synthesis approach, conducted by Sandelowski et al. (1997) and Timulak and Creaner (2013), was utilized for our study in addition to structured first-hand interviews with authors of the published case studies. A description of each meta-synthesis phase follows:

3.1.1 *Phase I: Identification of research question*

The following research question guided this meta-synthesis:

What features and strategies of boundary organizations and spanning processes result in effective policy influence and other intermediate outcomes?

3.1.2 *Phase II: Creation of an inclusion and exclusion protocol*

Published case studies[2] that discussed boundary organizations and boundary spanning processes which specifically address environmental policy and decision-making were identified for inclusion in the meta-synthesis. We also included published case studies that addressed themes related to boundary organizations and boundary spanning processes, by either directly or indirectly invoking these concepts. The search strategy included three elements: database searches, citation tracking, and expert contacts.[3] Overall, 6,057 titles and when possible, abstracts of articles were inspected, yielding 278[4] published case studies that potentially met the meta-synthesis inclusion and exclusion protocol. Building upon Timulak and Creaner's (2013) approach towards systematically scoring potential meta-synthesis articles, each of the 278 articles was inspected and given a point value for inclusion. Table 1 depicts the meta-

Table 1. Meta-synthesis inclusion criteria (adapted from Timulak and Creaner 2013).

Criteria	Score
1. Is there an explicit theoretical framework and/or literature review?	1
2. Are the aims and objectives clearly stated?	1
3. Is there a clear description of the context?	1
4. Is there a clear description of the sample and how it was recruited?	1
5. Is there a clear description of methods and data analysis techniques?	1
6. Are attempts made to establish the reliability or validity (credibility, trustworthiness) of data analysis?	1
7. Is the published case study peer-reviewed and from a reputable journal?	1
8. Is there inclusion of sufficient original data (such as quotes from participants) to mediate between the data and interpretation?	1
9. Is the topic focused on environmental issues?	1
10. Is there a clear description of boundary organizations and/or boundary spanning processes and policy outcomes?	1
11. Is the boundary organization and/or boundary spanning processes focused on integrating science into political-oriented (e.g. legislative, executive, and judicial) arenas (rather than demarcating/separating science)?	1

synthesis inclusion protocol. Of the 278 articles analysed utilizing the inclusion criteria, 227 were rejected from this analysis, leaving 51[5] published case studies for review.[6] Each of the fifty-one articles were coded for science–policy variables. While this would typically conclude the data collection phase for a meta-synthesis, information gaps that made coding of variables difficult or ambiguous were identified—requiring follow-up interviews with case study authors. As twelve authors declined participation or were unable (due to time constraints) to participate in the meta-synthesis, only thirty-nine articles are included in the final analysis. Online Appendix E provides a detailed description of published case studies while Online Appendix F displays case study information in table format.

3.1.3 *Phase III: Coding of published case studies*

The systematic coding procedure (*see* Charmaz 2006; Glaser and Strauss 1965) taken in this meta-synthesis was shaped by analysing features and strategies of boundary organizations and spanning processes present in each article, and relating these to outcomes. We built our code lists by adding/collapsing code categories as needed to reflect the data and facilitate coding. We re-coded data as needed. Features were characterized based on the structural component of the boundary organization or boundary spanning process. Strategies were defined as courses of action of boundary organizations and/or through boundary spanning processes. Other variables that did not fit into either of these categories were also identified, and subsequently categorized as factors endogenous to the scientific process. Finally, outcomes were determined based on a review of the science–policy literature as well as studies in political science and law and policy science. We drew on the Institutional Analysis and Development (IAD) framework, a systematic approach towards policy analysis which evaluates complex social situations by distilling them into manageable sets of practical activities (Polski and Ostrom 1999: 25). Drawing on the IAD framework (Imperial 1999; Ostrom 2011; Rudd 2004), policy outcomes were determined by evidence of science influencing: (1) legislative, executive, and/or judicial proceedings (2) and evidence of implementation. Rather than only determining whether environmental science in each case study impacted legislative, executive, or judicial proceedings and its implementation, intermediate outcomes such as increased awareness and other legal and governmental actions were also included. Overall, eight science–policy outcomes were identified.

3.1.4 *Phase IV: Construction of the formal conceptual framework*

To systematize the identification of features, strategies, other factors, and outcomes of the boundary spanning process, formal conceptual frameworks (Tables 2–5) were created during the course of the meta-synthesis to accommodate emergent themes and variables that surfaced from the analysis.[7] We utilized a detailed grounded theory approach by adding more codes to the preliminary conceptual framework as they emerged in the case studies, which led to the identification of forty-seven science–policy variables. The presence/absence of these variables was coded for in each article. Based on the collated meta-synthesis codes from the published case studies, excel files were created using binary code (1 or 0, with 1 indicating presence of explanatory variable and 0 indicating absence).

3.1.5 *Phase V: Interviews*

Since it could not be assumed that every author who published their case study had objectively evaluated each of the variables analysed, let alone using the same criteria, phone and Skype interviews were conducted with each case study author in late 2016 and early 2017. During these interviews, we asked the primary author of each environmental boundary spanning case study to identify which variables (Tables 2–5) were present in their case study. A 'yes' or 'no' was gathered from the authors as well as any additional information authors' felt needed conveyed to accurately reply to the science–policy variables and outcomes. Overall, thirty-nine interviews were completed.

When coding differed between case study authors and our coding results, follow-up questions were asked during the interviews for clarification. Differences in reporting detail existed due to the emergence of outcomes following the publication of case studies and the time-lapse between the case studies (which started as early as 1999) and due to the inability of the case study authors to acknowledge and mention certain variables and outcomes due to the limitations of publishing in journals. Ultimately, these interviews checked the accuracy of coding and ensured each of the codes was answered objectively by the primary expert of the environmental boundary spanning case study. This eliminated third party bias and ensured the validity of our results.

3.1.6 *Phase VI: Results*

The sixth and final stage of the meta-synthesis discusses the results and interprets the findings—drawing conclusions, and offering implications for theory, further research, and practice (Timulak 2009). In testing for the relationship between specific features, strategies, and other variables of boundary organizations and/or spanning processes (the independent variables) and policy and other outcomes (the dependent variable), independent variables were run in both

Table 2. Formal meta-synthesis conceptual framework: features.

Variables	Description
F1: Formality	F1: BO and/or BSP occurred through a permanent formal structure utilized for bridging science and policy
F2: Multi-disciplinary Organization or Expertise	F2: BO and/or BSP is interdisciplinary, transdisciplinary and/or multi-disciplinary (i.e. spanning is composed of various individuals from a variety of professional disciplines)
F3: Legislative mandate	F3: Legislation mandated the creation or utilization of a BO and/or BSP
F4: Local	F4: BO/BSP occurred at the local (district or lower) level
F5: State	F5: BO/BSP occurred at state level (state-wide)
F6: Regional	F6: BO/BSP occurred at an interstate–state (regional) level
F7: National	F7: BO/BSP occurred at the national level
F8: International	F8: BO/BSP occurred at the international level
F9: Public	F9: BO/BSP funded through taxpayer dollars (i.e. grants)
F10: Industry	F10: BO/BSP funded through an industry involved with science–policy issue in case study
F11: Foundation	F11: BO/BSP funded through foundations
F12: Funding allocating body/action	F12: BO/BSP involved in the case study operated as a funding allocating body to fund research and/or science–policy actions

Table 3. Meta-synthesis conceptual framework: strategies.

Variable	Description
S1: Utilized boundary organization	S1: A BO is utilized at the science–policy interface
S2: Utilized boundary spanner	S2: A boundary spanner, with or without the use of a BO, is utilized
S3: Co-production of knowledge	S3: The research agenda was shaped in an ongoing, iterative fashion between scientists and policymakers
S4: Facilitation of co-production of knowledge	S4: BO/BSP facilitated the co-production of knowledge between scientists and policymakers
S5: Creation of boundary object	S5: BO/BSP helped scientists and policymakers co-create a boundary object
S6: Created conditions conducive to learning	S6: BO/BSP utilized specialized learning techniques (experiential and/or social learning) to aid scientists and policymakers interacting at the boundary
S7: Relationship and social capital building	S7: BO/BSP facilitated interpersonal relationships beyond knowledge content (e.g. co-production of knowledge) to build effective science–policy interactions
S8: Built a political constituency	S8: BO/BSP actively networked to build informal political capital to gain support for policy issue
S9: Mass media involvement	S9: BO/BSP actively involved mass media to build support for policy decision among the public
S10: Decision-aids developed by scientist	S10: Scientists (either working for a BO or independent from a BO or BSP) created a source of information (e.g. map, database, and model) to aid decision-making
S11: Created scientific advisory group	S11: BO/BSP created external scientific advisory group to aid decision-making processes
S12: Adapted research (scale)	S12: BO/BSP aided scientists and/or policymakers to adapt the scientific research to the scale of a specific environmental policy decision
S13: Adapted research (scope)	S13: BO/BSP aided scientists and/or policymakers to adapt the scope of scientific research to better inform the specific environmental policy decision
S14: Systematic engagement with local knowledge and perspectives	S14: BO/BSP gathered local perspectives (i.e. community and indigenous) to aid scientists and policymakers involved in decision-making processes
S15: Engaged in adaptive management	S15: BO/BSP engaged in adaptive management techniques (continuous monitoring, evaluation, and adjustment of science and subsequent policy recommendations) to enhance research uptake
S16: Government involvement	S16: BO/BSP actively involved government entities/agencies, distinct from decisionmakers, to aid science–policy process
S17: Scientific knowledge dissemination	S17: BO/BSP delivered scientific information (i.e. presentations and reports) to policymakers during decision-making process
S18: Managed scientific uncertainty	S18: BO/BSP worked alongside scientists and policymakers to manage the scientific uncertainty associated with the environmental science utilized for case study
S19: Enhanced transparency (research)	S19: BO/BSP worked to enhance transparency of research methods and data
S20: Joint visits to research sites	S20: BO/BSP structured and facilitated visits for policymakers to research site to enhance their understanding of the research/evidence
S21: Dissemination of research/data to public	S21: Research/data were delivered to the general public by BO/BSP
S22: Conflict resolution	S22: BO/BSP provided traditional conflict resolution techniques (i.e. forcing, collaborating, compromising, and smoothing) during interactions between scientists and policymakers
S23: Skill development	S23: BO/BSP provided skill training and development for policymakers and/or scientists to enhance science–policy interaction
S24: Systematic research evaluation	S24: BO/BSP systematically evaluated research utilized during spanning process to check against political biases
S25: Enhanced transparency (process)	S25: BO/BSP worked to enhance transparency of BO/BSP
S26: Systematic spanning process evaluation	S26: BO/BSP systematically evaluated spanning processes between scientists and policymakers to check against bias

Table 4. Meta-synthesis conceptual framework: other.

Variables	Description
Oth1: Window of policy opportunity existed	Oth1: B BO/BSP and/or BSP capitalized on a window of opportunity for action to be taken on environmental issue at hand (Kingdon, 1995)
Oth2: Social science only	Oth2: BO/BSP draws *only* on social science (i.e. political science, geography, demography, psychology, sociology, anthropology, history and linguistics)
Oth3: Economics only	Oth3: BO/BSP draws *only* on economic science
Oth4: Biophysical science only	Oth4: BO/BSP draws *only* on biophysical science (i.e. biology, chemistry, engineering, computer science, mathematics and physics)
Oth5: Mixed evidence/methods	Oth5: BO/BSP draws on multiple forms of disciplinary expertise
Oth6: Quantitative only	Oth6: BO/BSP draws *only* on quantitative evidence (statistical, mathematical and/or computational data techniques or models)
Oth7: Qualitative only	Oth7: BO/BSP draws *only* on qualitative evidence (interviews, observation and/or archival techniques)
Oth8: Quantitative *and* qualitative	Oth8: BO/BSP draws on both quantitative and qualitative evidence

Table 5. Meta-synthesis conceptual framework: outcomes.

Variables	Description
O1: Awareness among policymakers	O1: Awareness of scientific issue among policymakers was increased due to BO involvement and/or through BSP
O2: Awareness among public	O2: Awareness of scientific issue among the general public was increased due to BO involvement and/or through BSP
O3: Creation of governmental committee	O3: A special committee was created by government to handle science–policy issue in case study, due to the direct involvement of BO and/or through BSP
O4: Evidence of judicial impact	O4: The environmental science brought to the table by the BO or during the BSP was utilized during court proceedings
O5: Evidence of judicial impact	O5: The environmental science brought to the table by the BO or during the BSP influenced court decisions
O6: Evidence of executive order impact	O6: The environmental science brought to the table by the BO or during the BSP shaped executive orders
O7: Evidence of legislative impact	O7: The environmental science brought to the table by the BO or during the BSP shaped environmental legislation
O8: Evidence of implementation	O8: The pieces of legislation influenced by BO/BSP were implemented

disaggregated (individual variables) forms. Chi-square tests (and Fisher's exact test[8] when necessary) were run, resulting in 376 Chi-square and Fisher's exact tests and 376 gamma statistics (47 variables $\times 8$ outcomes). Gamma tests were also run for each variable to determine the strength of the relationships between variables. A typical significance level (error rate) of 0.05 was used to evaluate statistical significance in this approach. Table 6 depicts the results of these tests, highlighting the variables which correlated with outcomes.

3.2 Limitations of the methodology

It is important to note the main restrictions to this research approach before discussing the results. The sample size is limited ($n = 39$). Even though peer-reviewed meta-syntheses generally analyse ten to fifty case studies (Timulak and Creaner 2013), this sample size may not reflect the diversity of published case studies on environmental science–policy issues worldwide. In addition there are difficulties in tracing the political impacts of scientific research. Difficulties may exist due to (1) the complications of tracking the impact of a particular research project alongside the many other strands of evidence that typically inform a policy decision (Holmes and Savgård 2009); (2) the time lags of research uptake (Holmes and Savgård 2009); (3) an absence of identifying conceptual impacts, not just instrumental (Holmes and Savgård 2009); and (4) a lack of precision in research program objectives (Holmes and Savgård 2009). Thus, while research is often initiated to support policymaking, many research outcomes may not reach the policy arena and may arrive in fundamentally different ways than intended (Schut et al. 2013)—and therefore tend to be underreported. However, due to the variety of boundary spanning case studies analysed and the years in which these took place, the interviews with the authors of the case studies strengthened our results as they were able to report, first-hand, whether policy and other outcomes had materialized over time.

4. Findings

Findings are reported according to each of the outcomes in the conceptual framework. The statistical results are first presented in summary form, followed by a discussion of findings for each of the dependent variables.

4.1 Statistical results

Table 6 depicts the results of the statistical analysis for the two-way tests of the relationship between each of the boundary features and strategies and the corresponding environmental policy outcomes

Table 6. Results: two-way explanatory variables and science–policy outcomes.

Outcome	Predictor	%Predictor = 0 with outcome = 1	%Predictor = 1 with outcome = 1	Gamma	Chi-square test *P*-value	Fisher's exact test *P*-value
O1	F10	100.0	69.2	−1.000	N/A	0.009
O1	S13	50.0	94.3	0.886	N/A	0.045
O1	S15	70.0	96.6	0.846	N/A	0.045
O1	S17	33.3	94.4	0.943	N/A	0.023
O2	F4	33.3	66.7	0.600	0.042	0.055
O2	S9	33.3	66.7	0.600	0.042	0.055
O2	S21	23.1	69.2	0.765	0.006	0.015
O3	F7	17.6	59.1	0.742	0.009	0.020
O3	S1	0.0	51.6	1.000	N/A	0.012
O3	S9	20.0	54.2	0.651	0.035	0.049
O3	S14	13.3	58.3	0.802	0.005	0.008
O3	S18	10.0	51.7	0.812	N/A	0.028
O3	S20	15.4	53.8	0.730	0.021	0.037
O3	S22	21.1	60.0	0.698	0.013	0.022
O6	F5	0.0	30.0	1.000	N/A	0.020
O7	F7	29.4	68.2	0.674	0.016	0.025
O7	F8	36.0	78.6	0.734	0.011	0.019
O7	S25	37.0	83.3	0.789	0.008	0.014
O7	Oth8	81.3	30.4	−0.817	0.002	0.003
O8	F7	23.5	59.1	0.649	0.026	0.050
O8	Oth8	68.8	26.1	−0.724	0.008	0.011

(Chi-square, Fisher's exact, and gamma tests). *Only those statistical tests reported as significant are provided, despite the 376 tests performed.* Positive gamma statistics are indicative of a greater likelihood of the associated outcome when the predictor is present; negative gamma statistics are indicative of a lower likelihood of the associated outcome when the predictor is present.

4.1.1 *Outcome 1: Awareness of policymakers*

Four variables were found to be correlated with increasing awareness of the scientific issue among policymakers due to boundary organization involvement or through boundary spanning processes:

1. F10 (Industry): When the boundary organization and/or boundary spanning process was funded through an industry involved with the science–policy issue in the case study, there was less evidence that the boundary spanning effort had increased awareness of the scientific issue among policymakers.
2. S13 (Adapted Research, Scope): When the boundary organization and/or boundary spanning process adapted the scope of scientific research to better inform the specific environmental policy decision, there was evidence for increased awareness of the scientific issue among policy-makers.
3. S15 (Engaged in Adaptive Management): When the boundary organization and/or boundary spanning process engaged in adaptive management techniques (continuous monitoring, evaluation, and adjustment of science and subsequent policy recommendations) to enhance research uptake, there was evidence for increased awareness of the scientific issue among policymakers.
4. S17 (Scientific Knowledge Dissemination): When the boundary organization and/or boundary spanning process delivered scientific information (i.e. presentations and reports) to policymakers during decision-making process, there was evidence for increased awareness of the scientific issue among policymakers.

4.1.2 *Outcome 2: Awareness of public*

Three variables were correlated with increasing awareness of the scientific issue among the general public due to boundary organization involvement and/or boundary spanning processes:

1. F4 (Local Scale): When the boundary organization and/or boundary spanning process occurred at the local (district or lower) level, there was evidence for increased awareness of the scientific issue among the general public.
2. S9 (Mass Media Invovlement): When the boundary organization and/or boundary spanning process actively involved mass media to build support for policy decisions among the public, there was evidence for increased awareness of the scientific issue among the general public.
3. S21 (Dissemination of Research/Data to Public): When research/data were delivered to the general public directly by either scientists, members of boundary organization, or policymakers, there was evidence for increased awareness of the scientific issue among the general public.

4.1.3 *Outcome 3: Creation of governmental committee*

Seven variables were correlated with the creation of a governmental committee to handle the science–policy issue due to the involvement of a boundary organization and/or boundary spanning process:

1. F7 (National Scale): When the boundary organization and/or boundary spanning process occurred at the national level, there was evidence of government committees being created to handle the science–policy issue in case studies.
2. S1 (Utilized Boundary Organization): When a boundary organization was utilized at the science–policy interface, there was evidence of government committees being created to handle the science–policy issue in case studies.
3. S9 (Mass Media Involvement): When the boundary organization and/or boundary spanning process actively involved mass media to build support for policy decision among the public, there was

evidence of government committees being created to handle the science–policy issue in case studies.

4. S14 (Gathered Local Perspectives): When the boundary organization and/or boundary spanning process gathered local perspectives (i.e. community and indigenous) to aid scientists and policymakers involved in decision-making processes, there was evidence of government committees being created to handle the science–policy issue in case studies.
5. S18 (Managed Scientific Uncertainty): When the boundary organization and/or boundary spanning process worked alongside scientists and policymakers to manage the scientific uncertainty associated with the environmental science utilized for case study, there was evidence of government committees being created to handle the science–policy issue in case studies.
6. S20 (Joint Visits to Research Sites): When the boundary organization and/or boundary spanning process structured and facilitated visits for policymakers to research site to enhance their understanding of the research/evidence, there was evidence of government committees being created to handle the science–policy issue in case studies.
7. S22 (Utilized Conflict Resolution): When the boundary organization and/or boundary spanning process provided traditional conflict resolution techniques (i.e. forcing, collaborating, compromising, and smoothing) during interactions between scientists and policymakers, there was evidence of government committees being created to handle the science–policy issue in case studies.

4.1.4 *Outcomes 4 and 5: Evidence of judicial impact*

Zero variables were found to be correlated with evidence of environmental science utilization during court proceedings or influencing court decisions.

4.1.5 *Outcome 6: Evidence of executive order impact*

One variable correlated with environmental science impacting executive orders due to the involvement of a boundary organization and/or boundary spanning process: boundary spanning occurring at the state level.

4.1.6 *Outcome 7: Evidence of legislative impact*

Four variables were correlated with environmental legislative changes due to boundary organization involvement and/or boundary spanning processes:

1. F7 (National Scale): When the boundary organization and/or boundary spanning process occurred at the national level, there was evidence of the environmental science brought to the table during the boundary spanning process shaping environmental legislation.
2. F8 (International Scale): When the boundary organization and/or boundary spanning process occurred at the international level, there was evidence of the environmental science brought to the table during the boundary spanning process shaping environmental legislation.
3. S25 (Enhanced Transparency of BO/BSP Process): When the boundary organization and/or boundary spanning process worked to enhance transparency of the boundary spanning process, there was evidence of the environmental science brought to the table during the boundary spanning process shaping environmental legislation.
4. Oth8 (Utilized Quantitative and Qualitative Evidence): When the science–policy interface in case studies drew on both quantitative and qualitative evidence, there was evidence that this undermined the tendency for the environmental science brought to the table during the boundary spanning process to shape environmental legislation.

4.1.7 *Outcome 8: Evidence of implementation*

Two variables correlated with evidence of implementation of the legislative changes associated with boundary organization involvement and/or boundary spanning processes:

1. F7 (National Scale): When the boundary organization and/or boundary spanning process occurred at the national level, there was greater evidence that these processes shaped the implementation of legislation.
2. Oth8 (Utilized Quantitative and Qualitative Evidence): When the science–policy interface in case studies drew on both quantitative and qualitative evidence, there was a lower percentage of cases with evidence of implementation.

5. Discussion

Features associated with scale (F4, F5, F7, F8) and industry funding (F10) correlated with several outcomes (O1, O2, O3, O6, O7, and O8). One strategy (S9, Mass Media Involvement) correlated with two outcomes (O2 and O3) while 10 strategies (S1, S13, S14, S15, S17, S18, S20, S21, S22, and S25) correlated with one outcome. Finally, one other variable (Oth8) correlated with two outcomes (O7 and O8). Below, we explore the possible interpretations for our findings by drawing on the wider literature.

5.1 Features

Only features associated with scale (F4, F5, F7, and F8) and industry funding (F10) correlated with science–policy outcomes for this sample.

5.1.1 *Scale*

Predictors associated with scale correlated with several science–policy outcomes including increasing public awareness of scientific issues (O2), the creation of governmental committees (O3), impacting executive orders (O5), and legislative changes and implementation (O7 and O8). Attention to scale when integrating science and policy is well established across boundary spanning and science–policy literatures (*see* Cash and Moser 2000; Sarkki et al. 2013). The suite of opportunities present at different scales and the factors that matter the most at those scales produce favourable policy changes with scholars noting how scientists are better able to influence the uptake of science into policy, when scientists adapt their research to the scales that match policy interests (Sarkki et al. 2013).

When boundary organizations and/or spanning processes were executed at the more local-level it correlated with increasing the public's awareness of the environmental science–policy issue at hand (O2). In line with our results, Bremer (2009) and Bremer and Glavovic (2013) as well as Reid et al. (2006) found that boundary spanning processes which exist at the local scale led to greater awareness by the general public due to the enhanced ability to mobilize local stakeholders' participation in the science–policy interface and thus, increase their knowledge concerning the scientific issues at hand.

Hoppe et al.'s (2013) work provides an explanation for why boundary organizations and spanning processes occurring at state and national levels correlated with several science–policy outcomes in our study as relationships of trust influence science–policy co-operation as well as providing precise expertise as to how environmental science can influence policy in the political sphere in which it exists. As Hoppe et al. (2013) argued, 'successful boundary arrangements are those that have adjusted to their diverse national contexts of policy issue politics and political-cultural spheres' (p. 17). Hoppe et al. (2013) found in their work on the science–policy interface and climate change that boundary spanning is a social relationship between a provider and user of expertise with boundary organizations and spanning processes at the national-level displaying strong instrumental roles in support of their national governments. Overall, this 'nationalized' expertise provided enhanced trust and political control, or a closer link between science and national politics.

When boundary organizations and/or spanning processes were executed at the international level, it correlated with evidence that environmental science impacted legislation (O7). The science–policy literature recognizes how research at global scales lends itself to larger policy endeavours. For example, science–policy boundary spanning through the IPCC impacts national legislation and international agreements (Bremer and Glavovic 2013); the Southern African Millennium Ecosystem Assessment (Fabricus et al. 2006), the Intergovernmental Platform on Biodiversity and Ecosystem Services (Perrings et al. 2011), and the United Nations Environment Programme, are further international-scale efforts which resulted in shaping national and international environmental policies. Additional research concerning issues of scale should focus on how boundary organizations and/or spanning process mobilize stakeholder participation and how models of participation could influence science–policy efforts across varying scales.

5.1.2 *Industry funding*

When the boundary organization and/or boundary spanning process was funded through industry, there was less evidence of increased awareness of the scientific issue among policymakers. Possible explanations for this negative correlation could be limitations placed (e.g. through possible defunding) on boundary organizations and/or spanning processes funded through industry to relay scientific results to policymakers. This would not be out-of-the-ordinary as evidence exists of industry suppressing scientific evidence (e.g. climate change, *see* Dunlap and McCright 2010), particularly studies associated with environmental science (Kuehn 2004; Martin 1981). Furthermore, scholarship demonstrates that when scientific research is funded through industry efforts, faculty behaviour in the aftermath of their involvement in industry/commercially funded projects changes as scientists engaged in entrepreneurial activities are more likely to deny requests from fellow academics for research results (Louis et al. 2001) and faculty members with industry support are more secretive regarding their research findings (Blumenthal et al. 1996). Thus, industry funding could suppress scientific dissemination by boundary organizations and/or through spanning processes as well as restrict research sharing *vis-à-vis* scientists at the boundary, impacting the ability to inform policymakers involved at the science–policy interface. More research should be conducted regarding the impacts of industry funding as well as a broader study of how various funding mediums shape science–policy outcomes as there remains considerable disagreement over the appropriate funding for shaping science–policy outcomes with scholars advocating for government (Franks 2010; Kirchoff et al. 2013), foundation (e.g. Clapp and Mortenson 2011; Hastings 2011), public (e.g. Klerkx and Leeuwis 2009; Kueffer et al. 2014), and industry funding (Clapp and Mortenson 2011) and subsequent science–policy influence.

5.2 Strategies

One strategy (S9, Mass Media Involvement) correlated with two outcomes (O2 and O3) while 10 strategies (S1, S13, S14, S15, S17, S18, S20, S21, S22, and S25) correlated with one of the eight outcomes.

5.2.1 *Media*

Our results indicate the direct involvement by boundary organizations and/or through a boundary spanning processes with the media (S9) correlated with increasing awareness of the scientific issue to the general public (O2). Our results reflect other studies which conclude the use of mass media as an influential tool for widening public awareness of environmental issues (Schoenfeld et al. 1979; Slovic 2000). It also points to research on the science–policy–media interface which details how social relationships are built over time between scientists, policy actors, and the public through media distribution (Boycoff and Boycoff 2007). Thus, media involvement enhanced relationship building at the boundary which correlated with increasing public awareness and the creation of a governmental committee as media coverage itself served to intersect public, science, and government entities.

5.2.2 *Boundary organizations*

Our results indicate utilizing a boundary organization (S1) correlated with the creation of a separate governmental committee to continue handling science–policy issues associated with the case studies (O3). This result is not surprising as the literature argues boundary organizations provide a more 'neutral' space for knowledge co-production, dissemination, and brokering activities (Crona and Parker 2012; Guston 2001). The stability associated with providing accountability and responsibility to a variety of stakeholders (Bremer and Glavovic 2013; Crona and Parker 2012; Guston 2001; Vogel et al. 2007), and professional mediation and facilitation (Braun and Guston 2003) further create ideal conditions in which a government entity can successfully forge meaningful long-term reciprocal relationships (both scientific and personal) with those occupying a stable science–policy space through a boundary organization.

In contrast to this interpretation, the positive correlation between utilizing a boundary organization and the creation of a separate governmental committee to continue handling science–policy issues may also indicate that boundary organizations (nor perhaps scientists) are not trusted by policymakers, and thus a committee is created to provide oversight to the boundary process and to handle ongoing scientific issues (*see* Roux et al. 2006). In addition, governmental committees may be constituted to better align the scientific aspect of the policy process with special interests by 'stacking' committees. As Sarewitz and Pielke (2007) argued, scientific research trajectories are often influenced by political pressure and powerful political entities who have a stake in the outcome of research results. Thus, continued influenced between boundary organizations and/or processes and governmental committees regarding scientific issues could impact research trajectory, results, and the uptake of information in policy. Further exploration into how government entities/committees influence boundary organizations and/or spanning process should occur especially with regard to deeply political issues associated with the environment.

5.2.3 *Scientific and boundary spanning process*

Our results indicate when boundary organizations and/or boundary spanning processes adapt their scope or research (S13), engage in adaptive management techniques (S15), manage scientific uncertainty (S18), provide conflict resolution (S22), and enhance the transparency of the spanning process itself, several outcomes resulted (O1, O2, O3, and O7). Adapting the scope of research to the issue at hand is well documented in the literature to ensure relevance to policymakers while linking the results to specific measurable policy goals and strategies (Bremer and Glavovic 2013; Hoppe et al. 2013). In addition, engaging in adaptive management behaviour and is further discussed as an effective means to increase the uptake of science in policy as it ensures the applicability of knowledge in changing economic, political, and climatic contexts (Eden 2011). For example, Innes' (2003) work in sustainable forest management in British Columbia found adaptive management successful in intermingling science and policy through 'learning by doing' or the adoption of a controlled approach to management experiments, complete with replication. Managing scientific uncertainty and the spanning process itself is further documented as effective as policymakers expect interaction and information to be as objective *and* certain as possible (Brugnach et al. 2007). Finally, providing conflict resolution during spanning processes correlated with outcomes. The CALFED Bay-Delta Program highlights not only the importance of a transparent boundary spanning process, but also the execution of conflict resolution to keep stakeholders on task (Karl et al. 2007). Overall, our work demonstrates the importance of boundary organizations and/or spanning processes in designing scientific work and spanning processes with decisionmaker needs at the forefront. Additional research should focus on identifying additional research and management adaptation mechanisms and how these can be incorporated into existing and future science–policy efforts.

5.2.4 *Collaboration and knowledge dissemination*

Our results indicate when boundary organizations and/or boundary spanning processes engage with local knowledge and perspectives (S14), disseminate scientific knowledge to policymakers (S17) and the public (S21), and provide trips for policymakers to research sites (S20), several outcomes resulted (O1, O2, and O3). The case studies analysed gathered local perspectives in a variety of ways: Tomich et al.'s (2007) work focused on 'participatory research with rural communities' through 'documenting local ecological knowledge' (p. 278). Other forms included 'special consultative processes' (Bremer and Glavovic 2013: 109) involving a 'systematic engagement with local knowledge' (Bracken and Oughton 2013: 16). Consultation with First Nations also occurred and included 'effective grassroots communications strategies with Aboriginal people and communities' (Innes 2003; Thrift et al. 2009: 990). Overall, the aim with this type of consultation was to grasp 'local realities' as Vogel et al. (2007: 358) noted, to ensure local needs were met in subsequent policy decisions. Newman et al. (2004) suggest that the field of social and public policy are opening to new forms of interaction between state and citizens, including the development of collaborative governance. With collaborative governance a shift from 'governing to governance, from hierarchies to networks, from representative to deliberative democracy, and from direct control by the state to strategies designed to engage civil society' occurs (Newman et al. 2004: 217).

Unsurprisingly, when scientific knowledge was disseminated to policymakers (S17), this correlated with increasing awareness of the scientific issue for policymakers (O1). This finding demonstrates the awareness of better science communication over the last 40 years (Mea et al. 2016) and how scientists are facilitating a discussion of their work through various mediums (e.g. boundary organizations and/or spanning processes) to build bridges between themselves, their work, and the policymakers who need scientific information to make informed decisions (Fishcoff 2013; Treise and Weigold 2002). Also, when scientific knowledge was disseminated to the public (S21), this correlated with increasing awareness of the scientific issue for the public (O2). Scientists have long argued the public must be able to understand the basics of science to make informed decisions (Brownell et al. 2013). Increasingly, the communication of science to the general public is recognized as a responsibility of scientists and those working at the science–policy boundary (Greenwood 2001; Leshner 2003). Finally, while the dissemination of knowledge is important, it is also significant for interaction at the boundary to occur between stakeholders. Actively building and maintaining relationships with those at the boundary and policymakers through field days will increase the likelihood that research outcomes will inform policy decisions (Gibbons et al. 1994).

5.3 Other

5.3.1 *Utilizing quantitative and qualitative evidence*

Interestingly, when the boundary organization and/or spanning process in case studies drew on both quantitative and qualitative evidence, there was a lower percentage of cases with evidence that the environmental science utilized during the boundary spanning process had shaped environmental legislation or implementation. There were also no positive correlations with the use of *either* qualitative or qualitative evidence. These results counter much of the literature and longstanding science–policy experiences which argue that both quantitative and qualitative modes of evidence and analysis are critical to inform decision-making processes (Curry et al. 2009; Jick 1979), to reject 'epistemological hierarchy' (O'Neill et al. 2010), and provide fruitful social and political responses (O'Neill et al. 2010). To address this issue, additional research should explore whether and how the use of mixed-evidence qualitative *and* quantitative currently influences political decision-making.

5.4 Statistical insignificance of variables emphasized in the literature

Some of the key features, roles and strategies hailed in the literature as substantial to the uptake of science in policy were not correlated with science–policy outcomes in our sample. The co-production of knowledge (Jasanoff 2004) and creation and use of boundary objects (Star and Griesemer 1989), for example, are discussed as significant activities undertaken by boundary organizations and spanning processes (Clark et al. 2011; Dilling and Lemos 2011; Driscoll et al. 2011; Jasanoff 2004; Lemos et al. 2012; Rice et al. 2009Lemos et al. 2012). A lack of correlation among co-production of knowledge and the creation and use of boundary objects with science–policy outcomes was particularly surprising, given their prevalence in the literature and their almost taken-for-granted status as key strategies of boundary organizations and spanning processes.

Prior research has also consistently identified the need for institutionalized formal boundary organizations (Cash 2001; Guston 2001; White et al. 2010). Yet, the utilization of a boundary organization did not correlate with several science–policy outcomes in this study including the uptake of science in legislation and subsequent implementation. This is surprising, given the reliance (both academically and practically) in science–policy contexts. However, as Hoppe et al. (2013) noted, formal boundary organizations can become vulnerable to losses in credibility and trust as organizations become entangled in politics surrounding scientific issues which can negatively impact policy results. In addition, Blades et al. (2016) found that formal boundary organizations require high levels of investment and resources from all participants which can negatively impact science–policy integration efforts; a need for more short-term partnerships between scientists and policymakers is needed, they argued.

6. Conclusion

This study provided a systematic analysis of published environmental boundary organization and boundary spanning case studies ranging from 1999 to 2016, to better understand which boundary spanning processes (including those utilized by boundary organizations) result in science–policy outcomes; key information currently lacking in boundary spanning scholarship (*see* Crona and Parker 2012; Hoppe et al. 2013; McNie 2007; Vogel et al. 2007). While providing detailed processes and variables associated with boundary organizations and boundary spanning, this extended cross-case comparison also provides the necessary conditions to further develop the theory of science–policy linkages, and boundary organization theory specifically.

Overall, thirty-nine published environmental science–policy case studies were analysed through the peer-reviewed method of meta-synthesis, a systematic grounded theory approach of analysis (Sandelowski et al. 1997; Timulak and Creaner 2013). We updated the method of meta-synthesis to also include structured interviews which occurred with the thirty-nine authors of the published science–policy case studies to validate our grounded theory efforts and to check the accuracy of the results of this meta-synthesis. Overall, forty-seven explanatory science–policy variables were coded and evaluated using the Chi-square test (and Fisher's exact test when necessary).

When evaluating the strength of relationships between boundary organization and spanning processes and science–policy outcomes, the most frequently correlated feature was the national-level scale of the boundary organizations and/or boundary spanning process. This variable correlated with the creation of governmental committees for continued guidance over science–policy issues (O3), and evidence of legislative changes and implementation (O7 and O8). Additional research on boundary spanning should occur which explores national science–policy endeavours and the mechanisms through which boundary spanning effectively links with government initiatives at the national level.

The most frequently correlated strategy variable was the use of mass media (S9) by the boundary organization and/or boundary spanning process. This science–policy variable correlated with the increasing awareness of the public (O2) and the creation of governmental committees for continued guidance over science–policy issues (O3). Even with media involvement positively correlating with two science–policy outcomes, the literature points to how environmental issues frequently attract widespread attention and yet, tend to decline from public view which ultimately lends them to remain largely unresolved (Downs 1972). This explains why media coverage may have increased public and some governmental response, but did not correlate with impacting legislation or implementation. The lack of media influence on legislation and/or implementation is disheartening especially as Kitzinger and Reilly (1997) found that high levels of media coverage do not last long and that a lack of policy events (i.e. legislation) leads to a lack of media interest. Peters (2012) provided a 30-year assessment of research centred on science and the media which found scientists consider visibility in the media as important; however, their communication practices are outdated (with science purposefully distancing itself from the media for issues ranging from credibility to the belief that scientific results will be mis-interpreted)—even within the younger generation of scientists. As the contentiousness between science and politics grows in the twenty-first century, it behooves scientists to study and transform the media–science interface to ultimately improve the likelihood of increasing awareness for the general public.

Overall, similar to Blade et al. (2016), our results question whether boundary organizations are the most effective means to span science–policy boundaries and effectiveness of formal features of boundary organizations and spanning processes. Instead, effective boundary efforts may be less about the formal organization or structure itself, but about the process itself. A shift in focus from development of formal/institutional boundary organizations may be fruitful to overcome current science–policy interface obstacles. As the literature indicates, boundary arrangements include a wide variety of hybrid organizational forms that straddle and mediate the boundary between science and policy, of which formal boundary organizations are one type (Hoppe et al. 2013). The focus of boundary spanning as seemingly separate from a formal institution or organization may enhance its perception (and reality) of being distant from political interference, thus bolstering its potential credibility to influence science–policy efforts. By concentrating on the process itself, the alignment of different types of knowledges from different actors (e.g. citizens, professionals, bureaucrats, and experts) may be better exercised to ultimately coordinate the effective production, dissemination, and acceptability of knowledges for political decisions (Hoppe et al. 2013).

Our work provides a starting point for understanding the crucial role played by specific boundary organization and spanning variables and how these connect to outcomes, but additional work is required to understand the nuances and dynamics involved within each of these processes. Academic and applied researchers should focus on exactly *how* variables result in science–policy outcomes, while investigating other explanatory variables (alone and in combination) which may also significantly influence the uptake of environmental science in policy efforts. Finally, this work highlights the need for an updated approach towards meta-synthesis to include more qualitative approaches towards understanding the nuances involved in producing the science–policy outcomes.

Notes

1. Also referred to as qualitative meta-data-analysis (Paterson et al. 2001), meta-ethnography (Noblit and Hare 1988), meta-study (Paterson et al. 2001), thematic synthesis (Thomas and Harden 2008), formal grounded theory (Kearney 1998), and meta-interpretation (Weed 2008).
2. Defined for the purposes of this research as "a particular instance of something used or analyzed in order to illustrate a thesis or principle" (Oxford Dictionary 2015).
3. Online Appendix A. Environmental Science and Policy: Meta-synthesis Search Strategy.
4. Online Appendix B. Environmental Science and Policy: Articles Reviewed by Meta-synthesis Inclusion Criteria.
5. Online Appendix C. Environmental Science and Policy: Search and Appraisal Process Flowchart.
6. Online Appendix D. Environmental Science and Policy: Published Case Studies Included in Meta-Synthesis.
7. Online Appendix G: Environmental Science and Policy: Preliminary Meta-Synthesis Conceptual Framework.
8. The Fisher's exact test was appropriate to use when the expected number of observations in a cell was <5.

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Supplementary data

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