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Review

Simplifying the selection of evidence synthesis methods to inform environmental decisions: A guide for decision makers and scientists

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ABSTRACT

Achieving evidence-based environmental management requires that decision-makers have access to evidence that can help identify the most effective interventions for their management context. Evidence synthesis supports evidence-based decision-making because it collates, filters and makes sense of a sometimes large and often conflicting evidence-base, potentially yielding new insights. There are many approaches to evidence synthesis. They each have different strengths and weaknesses, making them suited to different purposes, questions and contexts, given particular constraints. To make sense of the wide array of approaches, we outline the important considerations when selecting the most appropriate method for a particular decision context. These include the purpose for the synthesis, the required outcomes, and the multiple constraints within which decision-makers must operate. We then critically assess a spectrum of approaches to evidence synthesis commonly used within environmental management, detailing the characteristics of each that can be used to determine when it is a suitable method. To guide this selection process we provide a decision tree for those commissioning (e.g., decision-makers or stakeholders) or conducting (e.g., scientists) evidence synthesis, which can be used to identify an appropriate method. The decision tree classifies evidence synthesis methods according to whether their purpose is to test or generate hypotheses, the level of resources they require, the level of certainty in the outputs, and the type and scope of the question being addressed. This tool is a major advance because it helps select an appropriate synthesis method based on the multiple constraints that impact the decision. We conclude that there is an approach to evidence synthesis that will suit all management contexts, but that selecting the right approach requires careful consideration of what is fit for purpose.

1. Background

Over the past decade, evidence-based decision-making has increasingly become the stated goal of environmental management agencies. To achieve this, practitioners need evidence to identify the most effective interventions for their management context. Recent studies suggest that evidence synthesis can be effective in changing conservation practice. Practitioners presented with a summary of the relevant literature indicated they would change their management actions to favour those with strong support for their effectiveness (Walsh et al., 2015). There is a large and rapidly expanding literature aimed at informing environmental management decisions (Fuller et al., 2014). Yet in many ways the sheer volume of evidence itself presents a challenge, and practitioners may face difficulties in accessing, filtering, interpreting and translating that evidence-base into information that can inform decisions (Cook et al., 2013a; Fuller et al., 2014; Young and Van Aarde, 2011). On top of this, studies often yield conflicting evidence, and it can be difficult to arbitrate among the various findings of different studies (Young and Van Aarde, 2011). Similarly, it can be difficult to apply findings from studies conducted in different places or relating to different target species or ecosystems (Cook et al., 2013a).

In response to the above challenges, many tools have emerged to help synthesise relevant evidence and distribute it to practitioners to be interpreted for their decision context (Pullin and Knight, 2001; Sutherland et al., 2004). The term evidence synthesis is used in different ways. However, we use the definition of evidence synthesis

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provided by Pullin et al. (2016): evidence synthesis is the process of identifying, compiling and combining relevant knowledge from multiple sources so it is readily available for decision makers. While this definition explicitly states that synthesis does not generate new empirical data (Pullin et al., 2016), we contend that evidence synthesis can provide novel insights into a topic by drawing together multiple data sources that can increase explanatory power (Mulrow, 1994).

The power of synthesising the evidence-base on a particular topic has long been recognised in the natural sciences. Literature reviews (i.e., qualitative summaries of multiple studies on a topic; Roberts et al., 2006) and meta-analyses (i.e., quantitative analyses of the results of multiple studies; Arnqvist and Wooster, 1995) have been used to synthesise evidence on a particular topic to advance understanding (Cadotte et al., 2012; Haddaway et al., 2015). However, these methods tends to be more widely used by the scientific community, who are not necessarily focused on informing environmental management decisions (Shah et al., 2015). They also pose similar challenges to those described above for practitioners in terms of access to and interpretation of the primary literature, reducing their value for decision-makers.

With a growing demand for evidence synthesis within many disciplines (e.g., health sciences, education and social welfare; Hansen and Rieper, 2009), there has been a proliferation of methods, often prompted by the need to ensure the product is fit for purpose within the decision-making context (Livoreil et al., 2016; Webb et al., 2017). However, the increase in different methods has often not been well coordinated within and between disciplines, despite specialist methodology groups operating within the bodies that promote evidence-based decision-making (e.g., the Cochrane Statistical Methods Group; McKenzie et al., 2013). As such, new methods have been developed with little reference to existing approaches (e.g., Eco Evidence; Norris et al., 2012). There is often a clear intent to use evidence synthesis to inform decision-making, but whether these approaches have the desired influence on changing policy and practice is uncertain (Cook et al., 2013b). Recognising these concerns, several authors have suggested improvements to evidence synthesis methods to increase their value to decision-makers (e.g., Bilotta et al., 2014; Cook et al., 2013b; Doerr et al., 2015). The result is a large number of methods for evidence synthesis, and an intimidating scientific literature, which has generated confusion among both scientists and practitioners about the strengths and weakness of different approaches and the circumstances in which they are likely to be most appropriate.

The aim of this paper is to provide guidance for those seeking to understand the variety of methods available to support evidence-based decision-making in environmental management. Recent work by Pullin et al. (2016) has provided an excellent starting point to assist decision-makers to understand a range of synthesis methods available and the importance of considering the policy context. Building on the contribution of Pullin et al. (2016), in this article we describe the important characteristics to consider when selecting appropriate methods for evidence synthesis, including the purpose (e.g., generating or testing hypotheses) and desired features of the synthesis (e.g., the level of certainty required). We do this with an explicit consideration of the interactions between the various constraints on decision-makers (e.g., the available funding, level of technical expertise, time constraints) that limit the types of synthesis that can be achieved. We then discuss a spectrum of commonly used methods for evidence synthesis for environmental management decisions, their strengths and weaknesses, and provide a decision tree as a tool to help identify suitable methods for a given decision context. While we present synthesis methods largely used in natural sciences, there are many approaches from social science, such as focus groups and discourse analysis, which can provide useful supplements to the methods we outline (see Pullin et al., 2016).

1.1. What are the different purposes of evidence synthesis?

Evidence synthesis typically aims to draw key messages from a body of evidence on a topic, often with an explicit goal of providing findings in a format that will support management decisions (Pullin and Knight, 2001; Sutherland et al., 2004). As such, evidence synthesis should be driven by the practical needs of decision-makers (Livoreil et al., 2016). Indeed, different decision-makers might have markedly different intended uses for the products of evidence synthesis, and these different purposes have implications for the selection of synthesis methods. One key issue driving the type of evidence synthesis required is whether the impetus is formulating new hypotheses (*configurative* methods) or testing existing hypotheses (*aggregative* methods) (Gough et al., 2012). Configurative methods use existing studies to generate hypotheses, or apply existing theories to different contexts, and often explore evidence about how a system functions (Gough et al., 2012). On the other hand, aggregative methods draw together findings from primary studies to test specific hypotheses (e.g., the effectiveness of an intervention) (Watt et al., 2008).

The decision-making context can be used as a guide as to whether configurative or aggregative methods are likely to be most appropriate. Configurative methods are suited to situations where decision-makers need to enhance or document of the body of evidence on how a system functions. This may be to inform policy development (Banks, 2009; Bilotta et al., 2014, 2015) or the investment of funds in a management program, or to consider the possible management interventions available (Walsh et al., 2015). Once this knowledge is developed, aggregative methods may be used to determine which intervention is likely to be most appropriate. Aggregative methods allow decision-makers to assess causal associations (Norris et al., 2012) and evaluate the effectiveness, cost-effectiveness (Tyler et al., 2006) and the probability of success (e.g., risk of failure or likelihood of perverse outcomes) of alternative interventions (Pullin and Knight, 2009). While rarely the sole purpose of evidence synthesis, both aggregative and configurative methods can also be valuable for revealing knowledge gaps that can guide the development of a management-relevant research agenda (Cook et al., 2013b).

1.2. What are the desired outcomes of the synthesis?

To be useful, evidence synthesis must meet the needs of the decision-makers who have commissioned the synthesis (Webb et al., 2017). It is therefore imperative that all aspects of the decision process are understood, including what the decision will influence, the target audience, the most appropriate format of evidence synthesis for the target audience, the resources available to undertake it, and the level of confidence required by the decision-maker. Once these needs are defined, an appropriate approach to undertaking the synthesis can be identified.

A key desirable outcome of evidence synthesis is confidence in the conclusions drawn. This confidence relates to how well the conclusions can approximate the 'truth' and how transferable the findings are to a particular context (Bilotta et al., 2014). While it is generally agreed that uncertainty in decisions can be reduced by using more information (Canessa et al., 2015; Kloprogge et al., 2007), the acceptable level of uncertainty within decision-making is highly context dependent (Nichols et al., 2017). This context will affect the choice of evidence synthesis method used by the reviewer or decision-maker. For example, some decisions are irreversible (or have greater consequence) and require a greater level of certainty. Decision-makers often seek to minimise the risk of negative outcomes by both identifying effective interventions and also those that may do more harm than good (Pullin and Knight, 2009). Methods that aim to minimise the bias in both the evidence and the process used to collect and synthesise evidence can increase the confidence in the decisions based on that evidence (Haddaway et al., 2015; Song et al., 2000). Approaches, such as the type of systematic reviews promoted by the Cochrane Collaboration (see below) employ rigorous, transparent, explicit and repeatable procedures to minimise bias (Gough et al., 2012). For example, extensive

Table 1
The features of different synthesis methods – more detail and rationale for classification are provided in Appendix 1.

	Cochrane-style systematic review	Summaries and synopses	Causal criteria analysis	Stand-alone meta-analysis	Rapid review	Systematic map	Vote counting	Conceptual models	Narrative reviews
Purpose	Provide a transparent repeatable evaluation of the evidence for a hypothesis	Summarise the evidence-base for a broad management area	Test specific cause-effect hypotheses	Combine multiple, comparable studies to test a hypothesis	Provide a rapid evaluation of evidence to test a hypothesis	Describe the state of knowledge for a particular topic	Summarise the evidence for and against a hypothesis	Depict the current knowledge of relationships within a system	Provide a qualitative review of the literature on a particular topic
Style[a]	Aggregative	Aggregative	Aggregative	Aggregative	Aggregative	Configurative	Aggregative	Configurative	Configurative
Follows a defined method	✓	Variable	✗	✓	Variable	✓	✓	✓	✗
Involves mechanisms to minimise biases									
1. Systematic literature search and inclusion criteria	✓	✓	✓	✗	Variable	✓	✗	✗	✗
2. Quality appraisal and inclusion criteria	✓	✓	✓	Variable	Variable	✗	Variable	✗	✗
3. Weights studies according to quality	✓	✓[b]	✓	Variable	Variable	✓[b]	✗	✗	✗
4. Involves meta-analysis	✓	✗	✗	✓	Variable	✗	✗	✗	✗
5. Includes sensitivity analysis[c]	✓	✗	✗	Variable	✗	✗	✗	✗	✗
Makes use of a conceptual model	Variable	✗	✓	✗	✗	✗	✗	✓	✗
Level of transparency/ repeatability	High	Moderate	High	Moderate	Variable	High	Moderate	Low/moderate	Low
Resources required (time, money, expertise)	High	Very high	Moderate	Moderate	Moderate	Moderate/high	Moderate	Low/moderate	Low

[a] Aggregative methods draw together findings from primary studies to test specific hypotheses, such as testing causal relationship or which intervention is likely to be most effective; Configurative methods use existing studies to generate hypotheses, or apply existing theories to different contexts.
[b] Weighting is implicit because studies are reported according to the rigor associated with the methods (see Appendix 1).
[c] Sensitivity analysis is an analytical technique that varies the elements of an analysis (e.g., parameters, the studies included, weighting applied) to determine their influence on the outcome of the analysis. For an example of its use on systematic review see Moher et al. (1998).

systematic literature searches to reduce publication bias, explicit inclusion criteria defined *a priori* to reduce selection bias, and quality appraisals to remove low quality evidence (Haddaway et al., 2015). Such reviews afford a high level of confidence in the conclusions drawn, even if the answer is that we don't know.

Typically, different approaches to evidence synthesis are distinguished by a number of processes, which determine the most appropriate method for the purpose at hand. The comparative features of different types of evidence synthesis have been discussed in the literature (e.g., Bilotta et al., 2015; Haddaway et al., 2015; Roberts et al., 2006), and the strengths and weakness of different methods are summarised below (Table 1; Appendix 1). Generally, more rigorous systematic approaches to evidence synthesis incorporate processes to minimise bias and uncertainty, including an explicit and well-structured question that states the subject, population or hypothesis of interest, the intervention being considered, the specific comparator and the outcome measure being used (CEBC, 2013). A detailed *a priori*, peer-reviewed protocol outlining the rationale, method and format for the synthesis can help to ensure that the review process is rigorous, undertaken efficiently and directly addresses the management problem. Other important features of systematic approaches include a comprehensive and well-documented search strategy that aims to capture the available body of evidence, a transparent process for assessing the relevance and quality of studies, and an accepted data (or information) extraction and synthesis method suitable for the question type (Haddaway et al., 2015). Another key decision is whether the synthesis will employ statistical meta-analysis, qualitative (e.g., narrative or vote counting), or a mixture of approaches, which is influenced by the nature of the question posed and whether the purpose is aggregative or configurative (Appendix 1).

1.3. What are the constraints on conducting the synthesis?

One of the primary challenges for robust evidence synthesis lies with the evidence-base available for synthesis. While an initial search will often return a large volume of literature, the number of relevant studies is often small (Fazey et al., 2004). Many studies must be excluded from the synthesis for various reasons, such as failing to meet the required quality standards (Cook et al., 2013b). Sometimes the evidence-base itself is small, inhibiting the ability to determine relevant effect modifiers (factors that alter the effect of the primary intervention of interest, such as the season when weed control was conducted), or to provide insights when the evidence is seemingly contradictory (Cook et al., 2013b). The size of evidence-base and type of evidence available, will also influence the scope of the synthesis, informing for example the ability to achieve a broad, high-level assessment or a narrow, detailed assessment (Cook et al., 2013b). Nevertheless, a limited evidence-based can mean that the products of evidence synthesis provide more valuable information for understanding uncertainty in, or how to improve the quality of, the evidence-base (identifying knowledge gaps) than how to improve management outcomes (the original aim of the synthesis) (Cook et al., 2013b; Hansen and Rieper, 2009).

The level of resources for evidence synthesis, including time, money and technical expertise available, is another important constraint. Rigorous approaches to synthesis, such as Cochrane-style systematic reviews and evidence summaries, can be costly (e.g., US$30,000 to US $750,000) and time consuming (e.g. six months to five years) (Dicks et al., 2014), even though they can represent value for money. However, that level of resource commitment may extend beyond the budget and time available to make a management decision. Therefore, more rapid methods of synthesis have been developed that are not only less resource intensive, but better aligned with the timeframes and budgetary constraints within which environmental management decision-makers often operate (e.g., Khangura et al., 2012; Norris et al., 2012). The challenge is to select an approach that maximises the efficiency, appropriateness and effectiveness of the resources used in the review process to deliver conclusions, with a sufficient level of certainty for the decision context.

2. Types of evidence synthesis

There is a wide range of different methods for evidence synthesis, with different purposes, strengths and weaknesses (Table 1; Appendix 1). Below we outline some common methods used to synthesise environmental evidence. We place these methods on an approximate continuum from least rigorous to most rigorous (Table 1; Appendix 1), starting with narrative reviews. These methods could be used in conjunction with other methods from social science, such as discourse analysis and focus groups, which policy-makers may use in developing and evaluating environmental policy. Indeed many of the methods described below can be combined to take advantage of their different strengths (Webb et al., 2017).

2.1. Narrative reviews

Narrative reviews are the traditional model of literature review, providing a qualitative synthesis of published studies (Roberts et al., 2006). They provide a relatively fast and cheap approach to summarising a selection of existing literature on a topic (Petticrew and Roberts, 2008). Depending on the purpose of the review, they may attempt to 'tell a story' concerning a topic, or to reach an overall conclusion concerning competing hypotheses based on an expert review and judgements about the available evidence. They generally do not include any of the safeguards of more systematic approaches that minimise bias (Table 1; Appendix 1), often lacking a systematic approach for searches (or documented search strategy), have no clear inclusion criteria for studies, and fail to assess study quality or publication bias (Haddaway and Pullin, 2013; Haddaway et al., 2015). Without such procedures in place to maximise transparency and minimise bias there is a tendency for reviews to be influenced by a non-representative portion of the literature, and the biases of authors (Egger and Smith, 1998; Haddaway et al., 2015; Roberts et al., 2006). This said, many of the criticisms of narrative reviews arise from the manner in which they are currently conducted, and not because it is inherently impossible to conduct a narrative review in a rigorous and transparent manner (Haddaway et al., 2015; Roberts et al., 2006; Woodcock et al., 2014). The value of narrative reviews could be increased if authors followed a set of minimum standards informed by those of more formal evidence synthesis methods (Haddaway et al., 2015).

2.2. Vote counting approaches

Vote counting or scoring approaches to evidence synthesis summarise the number of studies that report an overall positive, negative or no impact of an intervention (Haddaway et al., 2015). The number of studies in each category are tallied and used to make judgments about whether there is general support for or against the effectiveness of an intervention. Vote counting is an aggregative approach to evidence synthesis that is able to capture a broader range of relevant literature than more stringent approaches, such as meta-analysis, because studies must address the same question but do not need to be conducted using the same methodology. Studies included do not need to report the summary statistics necessary for meta-analysis (see below), just the overall result. The selection of studies should involve a systematic search of the literature and a quality assessment to minimise bias and strengthen the reliability of the findings (e.g., Newton et al., 2007). However, all studies deemed worthy of inclusion are generally given equal weight regardless of quality and there is typically no process to take account of the sample size or magnitude of the effect sizes reported by the individual studies (Haddaway and Pullin, 2013).

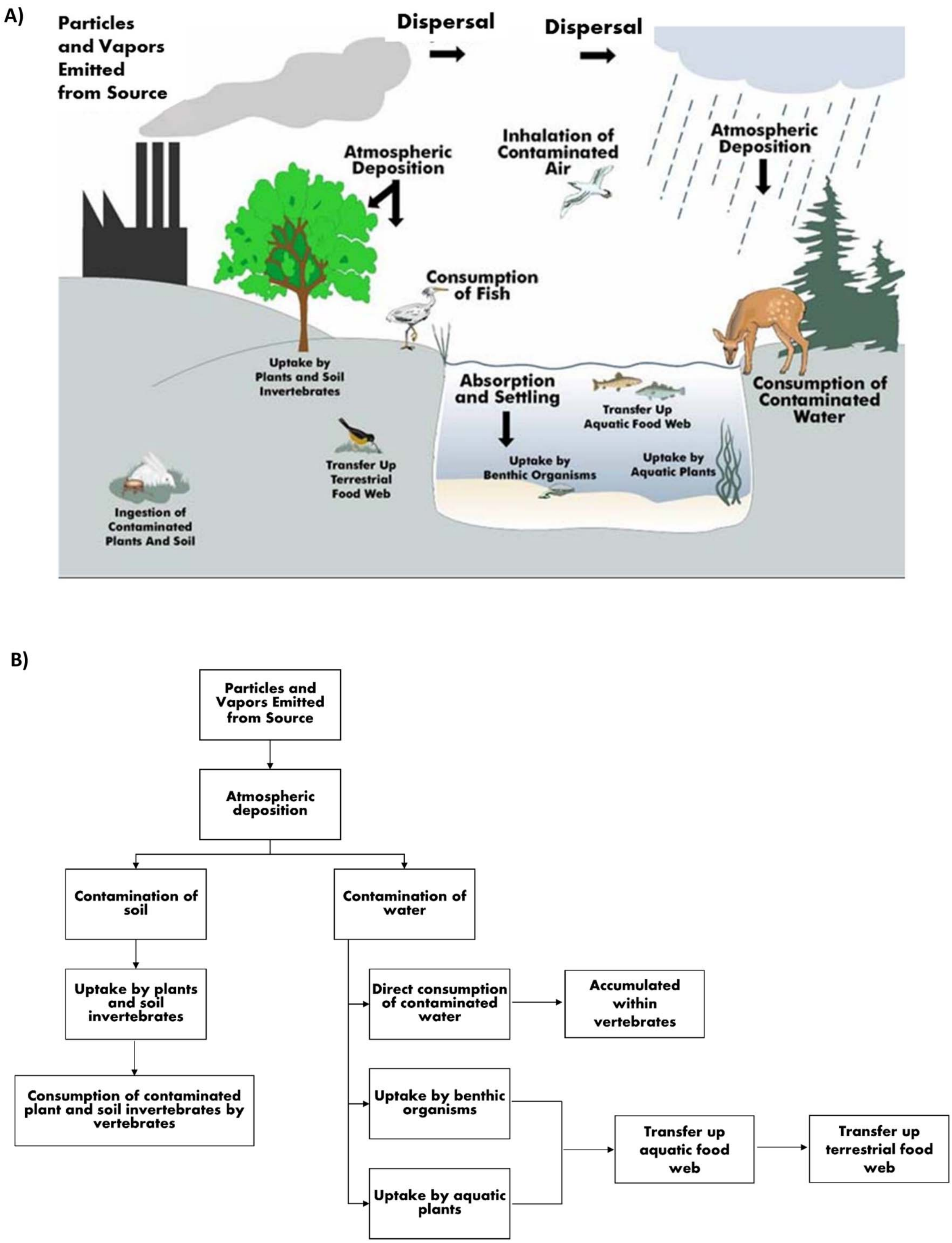

Fig. 1. Examples of (A) pictorial versus (B) a box and arrow format for conceptual models for air pollutant transfer in ecosystems.
(Source: US EPA National Ecosystem Assessment Toolkit.)

2.3. Conceptual models

Conceptual models are graphical representations of cause and effect relationships within a system (Fig. 1), providing a simplified view of complex processes (Fischenich, 2008). They are frequently used in environmental research (Fischenich, 2008), evaluation (Margoluis et al., 2009), education (DEHP, 2012), and communication (Heemskerk et al., 2003), and can be produced in many different ways. In representing the evidence for relationships in a system, conceptual models are configurative reviews, visually describing the hypothesis or theory that evidence synthesis may aim to test (Norton and Schofield, 2017). The cause and effect relationships within natural systems are often complex, and literature can be used to provide an indication of the amount of evidence for each hypothesised relationship, although there is rarely a formal quality assessment with this type of synthesis. Representing cause and effect relationships can enable specific effect modifiers to be identified and their influence described for each relationship. Understanding these effect modifiers is essential to the interpretation and application of review findings. As such, conceptual models can be used to provide a richer explanation of why and when something works, rather than just whether something works (Anderson et al., 2011). They can also reveal alternative pathways to achieve desired outcomes, such as alternative policy options or environmental practice interventions.

A conceptual model may be the end point of synthesis, or they can be included as a step in some methods (Table 1). For example, developing conceptual models can help frame an evidence synthesis process by identifying the inclusion criteria for evidence and informing the search strategy (Norris et al., 2012). Likewise, developing a conceptual model at the review scoping stage can be used to identify where evidence is needed, organise the available evidence, and assist in mapping the topic. The visual representation of this information through a conceptual model is useful for clarifying and gaining agreement on the scope and the wording of the review question (Anderson et al., 2011). Once the evidence has been compiled, conceptual models can be used to identify and communicate complex program or scientific concepts to end users, along with critical gaps in the evidence-base (DEHP, 2012). This potentially increases the uptake of review findings by some practitioners and policy-makers who may find traditional text-based reviews difficult to decipher because of a lack of expert knowledge of the subject matter or inexperience with the language and style of scientific writing.

2.4. Systematic maps

Systematic maps are a configurative approach to synthesis that document and catalogue the available literature on a specific topic (James et al., 2016). They use the same peer-review process and rigorous systematic approach to searching the literature employed by Cochrane-style reviews (see below). An advantage of a systematic map is that it provides a clear assessment of the evidence-base for a specific question, which can assist in revealing knowledge gaps and where to target more in-depth evidence synthesis (James et al., 2016). For example, the Farmland Synopsis was produced as a result of a systematic map (Dicks et al., 2013). Systematic maps do not extract data from studies (Dicks et al., 2014). Therefore, they can potentially capture a larger number of studies than could be included in a Cochrane-style systematic review or meta-analysis because they are not subject to the same data restrictions (Table 1). Systematic maps often include an appraisal of the methodological rigor of relevant studies (Dicks et al., 2014), such as by using an evidence hierarchy (Pullin and Knight, 2003) to classify the study design for studies that meet the inclusion criteria (e.g., McKinnon et al., 2016), similar to evidence summaries (see below). When such an appraisal is conducted, systematic maps provide a resource for practitioners seeking robust studies relevant to their decision context (James et al., 2016). As the name suggests, systematic maps provide a visual representation of the size and quality of the evidence-base, providing a useful summary at a glance (Fig. 2). Because they do not involve data extraction and analysis, systematic maps require fewer resources than other more comprehensive forms of evidence.

2.5. Rapid reviews

Methods for undertaking rapid reviews of environmental evidence have emerged, driven by the need to meet the practical requirements of decision-makers (Khangura et al., 2012; Webb et al., 2017). Despite the demand for this type of synthesis, there is currently no formally adopted definition or universally accepted standards for undertaking a rapid style of review. There is little published literature on rapid review methodologies for environmental evidence, making it difficult to appraise the validity and utility of emerging methods (Khangura et al., 2012). This is in direct contrast to other methods, such as Cochrane-style systematic reviews (see below), which have detailed, published guidelines for how they should be conducted (e.g., CEBC, 2013; Higgins and Green, 2011).

In reality, the distinction between more resource intensive systematic reviews and rapid reviews is often the comprehensiveness applied to the search strategy and inclusion criteria. Beyond that, there is great variability in the methods used and the presence of, or approach to, study quality assessment (Table 1, Appendix 1; Haddaway et al., 2015). The ways in which these elements of the synthesis process are conducted will determine where a rapid review falls on a continuum of confidence in the finding.

Rapid reviews can be a valuable form of evidence synthesis for a range of different contexts. They require fewer resources than more comprehensive synthesis approaches (Appendix 1), making them more accessible to decision-makers. They can be used to provide an assessment of the evidence that exists for a narrow and highly-focused question, similar to a systematic map (see above). In these cases, the narrow scope restricts the size of the evidence-base, reducing the work involved in all steps of the synthesis process, but can introduce bias. Some rapid review approaches, such as Eco Evidence, have documented methods, use systematic searches, have clear inclusion criteria and weight relevant studies by quality, which provides a robust, yet rapid review of the evidence for causal associations (Norris et al., 2012; Webb et al., 2015b).

2.6. Stand-alone meta-analysis

Meta-analyses are a set of statistical approaches that enable data from multiple studies to be combined to determine the overall support for a research question (Arnqvist and Wooster, 1995). Widely used in health care, this approach is gaining popularity in environmental studies, where it is particularly useful because study outcomes often vary in space and time making it difficult to make generalisations without formal analysis (Cadotte et al., 2012). Meta-analysis is an aggregative form of synthesis that provides a rigorous tool to combine the outcomes from many studies to increase the power to detect the effect of an intervention (Hedges et al., 1999). It also provides an opportunity to test hypotheses about potentially important sources of heterogeneity in study results (Arnqvist and Wooster, 1995). Often, meta-analyses are based on examining the average effect-size across all studies, which provides an overall measure weighted by sample size. While published meta-analyses often claim to be systematic reviews, generally there is no systematic literature search, or the search strategy is not reported (Table 1). Likewise, meta-analyses rarely have transparent inclusion criteria or a robust examination of study quality, which are strengths of other forms of evidence synthesis (Haddaway et al., 2015). Because meta-analysis involves combining replicates across many studies, the methods used in each study must be strictly comparable, such as using the same response variable (e.g., mortality rather than fecundity; Smith et al., 2011). This means that high quality evidence may need to be excluded because it does not meet the stringent requirements of the analysis (Cook et al., 2013b). Therefore, while the results of meta-analyses can be rigorous, they can also be narrowly focused on a subset of the available evidence and lack generality.

2.7. Causal criteria analysis

Causal criteria analysis is an aggregative approach to synthesis used to assess evidence for causation in the absence of strong experimental evidence (Hill, 1965; Tugwell and Haynes, 2006; Weed, 1997). It was originally developed by epidemiologists who must conduct research without true experiments, in the presence of confounding factors, and with limited replication of sampling units. It is built on the premise that individual pieces of evidence alone may be weak, but when combined and considered along with multiple ‘lines of evidence’ can build a strong argument for causality (Downes et al., 2002; Norris et al., 2005). For example, if different researchers, operating in different places, using different assessment approaches, consistently observe the same

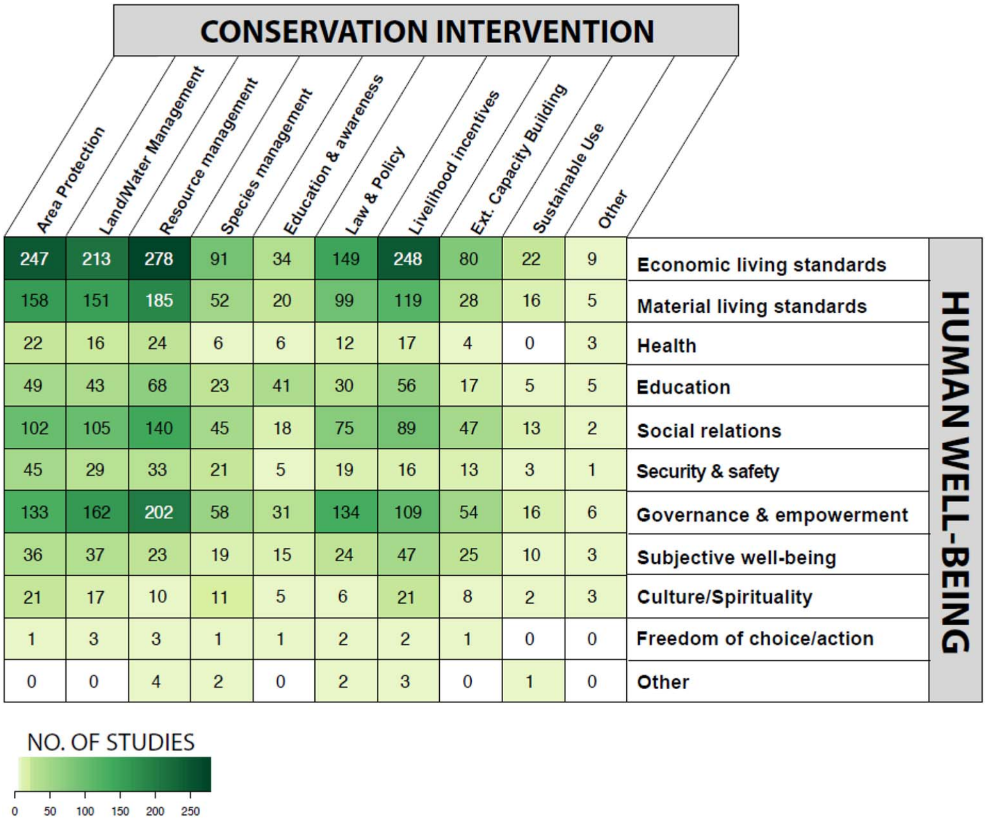

Fig. 2. An example of a systematic map output assessing the effects of nature on human well-being.
(Reproduced from McKinnon et al. (2016).)

association between two variables, then it is more likely to be causal (i.e., Consistency of Association; Hill, 1965).

The best known set of causal criteria was proposed by Hill (1965). These included: Strength of Association (the effect size in an association is large); Consistency of Association (defined above); Specificity of Association (the observed effect is only associated with the hypothesised cause); Biological Gradient (dose-response – where a change in one variable – the hypothesised cause – leads to a predictable change in the other variable – observed effect); and Biological Plausibility (the existence of a sensible conceptual model linking cause to effect). Over time, researchers have added and deleted criteria from the list, and argued for different levels of importance among them (Adams, 2005; Susser, 1991). Some of these criteria can be used to aggregate the evidence for causation using a modified vote counting approach that weights studies by inferential power (Table 1; Norris et al., 2012).

2.8. Evidence synopses and summaries

Evidence synopses are another form of evidence synthesis with roots in the health sciences, providing brief, plain language descriptions of the results of a study, or a systematic review, targeted at decision-makers (Dicks et al., 2014). When aggregated for an area of practice, synopses can form the basic units for evidence summaries, presenting evidence across the range of possible management interventions relevant to a particular type of management decision (e.g., farmland conservation; Dicks et al., 2013) or taxonomic group (e.g., birds; Williams et al., 2012). Generally, summaries involve a systematic search of the literature, clear inclusion criteria for studies and a classification of the study method (e.g., before-and-after trial) (Smith and Sutherland, 2014). While there are no published methodological guidelines in conservation, such as those that exist for public health (Graham et al., 2011), the synopses and summaries developed by Conservation Evidence (www.conservationevidence.com) each follow their own predefined method, which is described within the document. Summaries have been criticised for having gaps and geographic biases in the literature they include, which can risk oversimplifying the results of studies and failing to place results from single studies in the context of other contributing factors (Nisbet, 2013).

The broad scope of evidence summaries means they require significant time (1–5 years) and money (US$70,000–750,000) to prepare (Dicks et al., 2014). However, they provide the advantage of being a reference guide for decision-makers, highlighting a comprehensive range of management options available for a problem, and the evidence for or against their effectiveness, which can lead decision-makers to consider different approaches to management (Walsh et al., 2015).

Summaries are aggregative approaches, compiling the findings of individual studies and systematic reviews (Dicks et al., 2014). Within summaries, relevant studies and systematic reviews are briefly described (synopses), providing a tally of studies with evidence for or against its effectiveness, similar to a vote counting approach (see above). Because summaries are not focused on a single intervention, and do not aggregate studies using meta-analysis, they are able to capture a wider range of evidence than Cochrane-style systematic reviews. Summaries can be combined into books, which include all synopses produced across different conservation topics (Sutherland et al., 2017). These books include an additional process of using best-practice elicitation to capture and document expert opinion on the effectiveness of each technique reviewed (Dicks et al., 2016). However, the broad scope of summaries mean that they require more resources to complete (Dicks et al., 2014). Although existing summaries provide a source of reference material, in our experience new summaries can be challenging to fund and so beyond the reach of many conservation agencies.

2.9. Cochrane-style systematic reviews

The Cochrane method of systematic review is an aggregative method that involves a rigorous protocol designed to minimise bias and improve the transparency of findings through explicit procedures to collate (systematically search for literature), filter (identify relevant and credible sources of evidence), synthesise (analyse the body of evidence through meta-analyses to determine the overall effect of an intervention), and disseminate evidence to practitioners (Higgins and Green, 2011). The success of this model in medicine (e.g., the Cochrane Collaboration; Higgins and Green, 2011) led to systematic reviews being adopted by social science (e.g., the Campbell Collaboration; CC, 2015) and environmental science (e.g., the Collaboration for Environmental Evidence; CEBC, 2013). Such systematic reviews are often seen as the gold-standard for evidence synthesis (Haddaway et al., 2015).

The rigor associated with a Cochrane-style systematic review provides a major advance on forms of evidence synthesis that lack transparency and processes to minimise bias (Haddaway et al., 2015; Roberts et al., 2006). The meta-analysis used to combine results from multiple studies allows for effect modifiers to be evaluated, potentially revealing the circumstances under which an intervention is or is not effective (Pullin and Stewart, 2006). Under the right circumstances, Cochrane-style systematic reviews can provide a source of information on both the relevance of the available evidence-base for management decisions, and the areas in which this evidence-base is lacking or not of sufficient quality to be trustworthy (Cook et al., 2013b; Higgins and Green, 2011). Within environmental (Cook et al., 2013b) and social (Hansen and Rieper, 2009) contexts, the evidence-base is often of insufficient size, quality and consistency to draw conclusions from a Cochrane-style review. While a lack of relevant evidence is a common impediment to most evidence synthesis, the stringent requirements of meta-analyses conducted as part of a Cochrane-style systematic review, the need for a common outcome measure and the requirement of adequate experimental controls, means credible evidence is often excluded from Cochrane-style reviews (Cook et al., 2013b). Another problem for meta-analysis is the need for studies to report summary statistics, such as means, variance and sample size to allow the calculation of a standardized effect size, which are frequently missing from published studies, along with bias associated with selective reporting of results (Parker et al., 2016). Studies have found that, up to 50% of otherwise relevant studies fail to report the information required for inclusion in meta-analyses, both in medical (Bekkering et al., 2008) and ecological (Greet et al., 2011) settings.

The stringent methods used in this type of review usually mean a significant investment of resources is needed, both of time (6 to 36 months) and money (US$30,000–300,000) and technical expertise (Dicks et al., 2014; Haddaway et al., 2015). Therefore, Cochrane-style systematic reviews are best suited to evaluating management interventions with high policy relevance, a requirement for strong confidence in the findings (e.g., issues with serious consequences or that are politically sensitive in nature), and where there is a strong evidence-base of high quality studies that can be directly compared. Nevertheless, the level of resources required may place this form of review outside the current expectations of decision-makers even for the most significant environmental issues.

3. Selecting the most appropriate method

The methods described above have different features (Table 1; Appendix 1) that could be viewed as strengths or weaknesses depending on the purpose of, and constraints on, the evidence synthesis process. We provide a decision tree (Fig. 3) that classifies methods according to these attributes. The decision tree, like all classifications is imperfect, but is intended to guide and assist users rather than constrain thinking.

In selecting the most appropriate method, the first question that must be answered is whether the purpose of the evaluation is to test or generate hypotheses. This will determine whether aggregative or configurative methods are most appropriate. Given the importance of resource constraints on decision-makers, an important consideration is the level of resources available, including time, money and expertise (Appendix 1). Compared to disciplines for which Cochrane-style reviews are the standard approach to evidence synthesis (e.g. health sciences), environmental science decisions must generally be made with far fewer resources (Ziegler et al., 2015). The range of approaches we outline covers a broad spectrum, providing options within the reach of most decision-makers, even when they are acting under multiple constraints. However, there is a trade-off between the resources required and the level of confidence in the findings (i.e., high confidence is unlikely to be achieved when resources are low), often related to the measures used to increase rigor. This trade-off means that decision-makers must carefully consider whether the approach will provide the necessary level of confidence for the management issue being addressed.

For aggregative approaches, it is important to consider the scope of the question that evidence synthesis must address (e.g., narrow versus broad management area). By considering these questions, those commissioning or conducting evidence syntheses should be able to narrow down the available approaches to one that will achieve a level of certainty that is appropriate within the existing constraints. Depending on the topic for synthesis, methods that have high levels of transparency (i.e., clear articulation of the methods, such as specific search strings) that can facilitate repeatability and products being updated, could be prioritised.

4. Applying the decision tree

We illustrate the use of the decision tree with three examples of evidence synthesis in different contexts. The examples illustrate different pathways taken through the decision tree, depending on the different circumstances of the three cases.

The first relates to assessing the effectiveness of high flows in rivers at reducing the encroachment of terrestrial vegetation into river channels (Miller et al., 2013b). The primary purpose of the review was to inform the development of conceptual and statistical models of terrestrial vegetation encroachment (Webb et al., 2015a). It was therefore an aggregative synthesis based around a set of hypotheses. The review was commissioned by several Catchment Management Authorities (river managers) in Australia and formed a small component of a larger research project. This context meant that while the time and money available for the case study were limited, the moderate technical expertise required to undertake the synthesis was available. The knowledge gap to be filled was not urgent, nor threatening life or property. However, it would inform local and state-level river management decisions, and so the confidence required in the findings of the review were moderate. The large number of stakeholders with an interest in water management meant that the Government was seeking a high to moderate level of transparency in the synthesis process, and the ability to update the product as new evidence become available. Therefore, Eco Evidence (Norris et al., 2012), a form of rapid review, with elements of causal criteria analysis, was selected as the method to conduct the review. The analysis showed support for three hypotheses regarding specific mechanisms for reducing terrestrial vegetation encroachment, but a hypothesis that increased inundation would decrease germination was falsified, and one regarding effects of inundation on reproduction found insufficient evidence to reach a conclusion.

The second example is a topic where a configurative synthesis approach was more appropriate, exploring the evidence-base for environmental accounting in relation to landscape vegetation connectivity (BOM, 2016). To explore the multiple possible cause and effect relationships that relate landscape connectivity to ecosystem function, an evidence-based conceptual model formed the core of the synthesis. The review commissioner, the Australian Bureau of Meteorology, had only a moderate budget available for the review. Given the review was preliminary, it was agreed that the appropriate compromise between resources (moderate) and confidence could be achieved through a conceptual model with a limited search strategy resulting in moderate confidence in the review findings.

The third example is a topic with significant impact on the water resources of populations living downstream of Himalayan glaciers

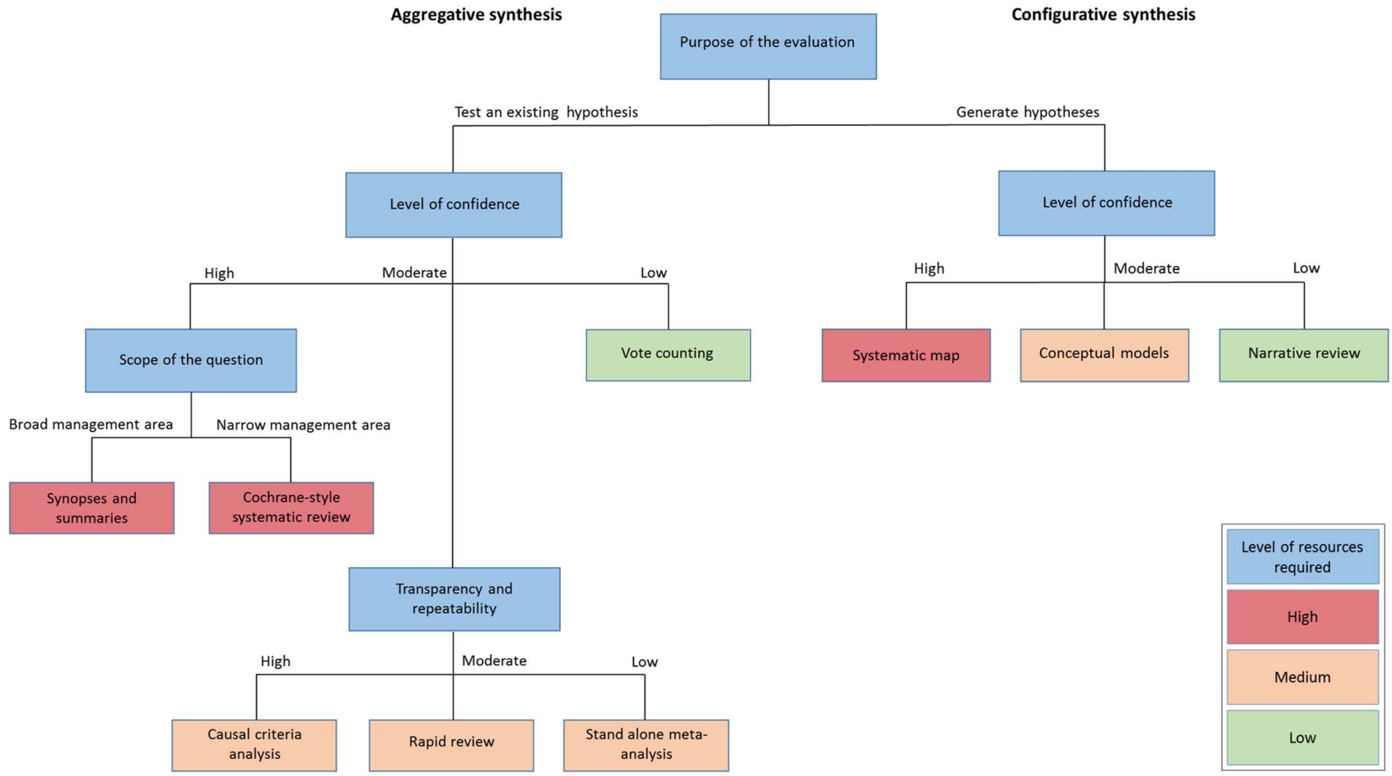

Fig. 3. A decision tree to help identify which types of synthesis might be most appropriate given the needs and constraints on decision-makers. Level of resources required is determined based on the time, money and technical expertise. This classification is advisory and intended to help guide thinking rather than be prescriptive. See Appendix 1 for details about methods.

(Miller et al., 2013a). Scientists have been concerned by claims that these glaciers are shrinking at an alarming rate with no clear understanding of how glacier shrinkage across the region hinders the development of well informed decision and policy-making. The purpose of the synthesis was to test this existing hypothesis, requiring an aggregative synthesis method. The level of confidence required for this internationally significant threatening process is very high, and significant resources have been committed to answer the single question about glacier retreat. The scope of the question is sufficiently narrow, so a Cochrane style systematic review is a suitable choice in this case.

5. Conclusions

The diversity of approaches to evidence synthesis provides a wide range of options suited to different decision-making contexts. While the array of methods may seem daunting at first, it is perhaps best viewed as a toolbox from which the most appropriate approach can be selected by reviewers or those commissioning reviews. Our decision tree provides a valuable heuristic tool to select a method that is fit-for-purpose based on the level of resources (time, money and technical expertise) involved and the level of certainty they provide in the outcome (Fig. 3). Decision-makers wishing to explore the available evidence-base have several configurative approaches available to them (e.g., systematic maps, conceptual models and narrative reviews) while those wishing to test hypotheses can select an aggregative approach (e.g., synopses and summaries, causal criteria analysis, Cochrane-style reviews; Table 1). While constraints such as the level of resources available for the review are an important consideration, decision-makers should also consider the scope and type of question that will frame the synthesis. Many aggregative approaches are suited to evaluating the effectiveness of a small number of interventions or assessing the support for a specific causal association (Table 1). Other methods offer an approach to aggregating studies and systematic reviews across a broad area of management practice (Dicks et al., 2014).

The level of certainty required from the synthesis should be a primary consideration for decision-makers. The range of evidence synthesis approaches outlined here span different levels of certainty that decision-makers may accept, depending on the management context. In general, achieving high-levels of certainty requires more stringent methods that help to reduce bias or confounding, which in turn require more time, money and expertise (Table 1; Appendix 1). In classifying the level of confidence in the outcomes of the evidence synthesis process, we have drawn on the ways in which these syntheses are commonly conducted. However, we recognise that there is flexibility in how different methods can be applied, which can lead to more or less rigorous outcomes. For example, narrative reviews could employ a systematic and well-documented search of the peer reviewed and grey literature. Nevertheless, this is rarely done despite urging for reform from within the environmental literature to increase their reliability (Haddaway et al., 2015). The safeguards that produce greater reliability come through greater transparency, repeatability and methods to minimise bias, but inevitably they increase the resources required.

In offering this decision tree, we hope that those considering commissioning or conducting an evidence synthesis will be encouraged to carefully consider the purpose and decision-making context for the review to ensure the most appropriate method is selected and the outcome is fit for purpose. As the volume of products from evidence synthesis grow, the toolkit we provide could be used in conjunction with evidence hierarchies (e.g., Dicks et al., 2014) to help decisions-makers select among existing syntheses to identify the most appropriate products for their needs. The classification we provide can function as a working hypothesis and the next steps are to see how well it works in practice through interaction with end users. In presenting the wide range of methods now available for evidence synthesis that can accommodate the multiple constraints on decision-makers, we hope that synthesis will become an increasingly common aspect of policy making to increase evidence-based management.

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