Building a tool to overcome barriers in research-implementation spaces: the Conservation Evidence database

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Abstract

Conservation practitioners, policy-makers and researchers work within shared spaces with many shared goals. Improving the flow of information between conservation researchers, practitioners and policy-makers could lead to dramatic gains in the effectiveness of conservation practice. However, several barriers can hinder this transfer including lack of time, inaccessibility of evidence, the real or perceived irrelevance of scientific research to practical questions, and the politically motivated spread of disinformation. Conservation Evidence works to overcome these barriers by providing a freely-available database of summarized scientific evidence for the effects of conservation interventions on biodiversity. The methods used to build this database – a combination of discipline-wide literature searching and subject-wide evidence synthesis – have been developed over the last 15 years to address the challenges of synthesizing large volumes of evidence of varying quality and measured outcomes. Here, we describe the methods to enhance understanding of the database and how it should be used. We discuss how the database can help to expand multi-directional information transfers between research, practice and policy, which should improve the implementation of evidence-based conservation and, ultimately, achieve better outcomes for biodiversity.

Keywords: evidence-based conservation, evidence-based policy, evidence-based practice, Delphi technique, subject-wide evidence synthesis, research-implementation space

Word count: 7790

1. Introduction

Despite efforts to conserve it, biodiversity is being lost at an alarming and increasing rate (Dirzo et al., 2014; Ripple et al., 2017). Research on the effectiveness of conservation interventions is critical to ensure conservation efforts are beneficial, efficient, and not creating additional harms (Cardinale et al., 2012). The number of publications evaluating the impact of conservation-relevant interventions is growing annually, but the lessons learned are often not employed in management decisions or policy (Sutherland et al., 2004; Young and Van Aarde, 2011).

This problem has been widely conceptualized as a "research-implementation gap" (Anon, 2007; Knight et al., 2008; Westgate et al., 2018, see Glossary in Supplementary Material). More recently, it has been reconceptualized as an issue within a series of “research-implementation spaces”: arenas in which various stakeholders and interest groups interact, collaborate and learn together (Toomey et al., 2017). This concept explicitly recognizes the existing connections between research and practice rather than implying there are voids between research and practice that need to be filled, as well as the broader context in which scientific knowledge is produced and utilized.

Within research-practice and research-policy spaces, several clearly defined barriers limit collaboration and coproduction of knowledge (Roux et al., 2006; van Kerkhoff and Lebel, 2015; Table 1). These include communication barriers (e.g. length, linguistic and statistical complexity of scientific articles), financial barriers (e.g. studies hidden behind paywalls), relevance barriers (research often lacks direct relevance to practitioners or policy-makers), synthesis barriers (an overwhelming volume of unsynthesized scientific literature) and socio-political barriers (e.g. motivated skepticism of information that challenges existing worldviews).

Evidence synthesis is fundamental to overcoming some of these barriers, increasing the flow of ideas within research-implementation spaces, and ultimately helping researchers, practitioners and policy-makers navigate towards the common goal of conserving biodiversity. Evidence synthesis methods aim to locate, collate, and synthesize relevant information, usually from published literature. They range from unsystematic, ad hoc literature reviews, to comprehensive systematic reviews, and even reviews of reviews (Collins et al., 2015). However, these existing approaches have shortfalls. Traditional literature reviews can be subjective, liable to bias and methodologically opaque (Collins et al., 2015; Haddaway et al., 2015). Systematic reviews are designed to reduce those issues, but can be expensive and time-consuming (Borah et al, 2017; Haddaway and Westgate, 2019). Therefore, they are not always possible in conservation, where resources are limited (Soulé, 1985; Gerber, 2016). The intended audience of reviews and systematic reviews sometimes face communication barriers (e.g. Cochrane Clinical Answers are needed as a “readable, digestible” entry point to medical Cochrane Reviews; Cochrane Library, 2019) and financial barriers (e.g. paywalls, although *Environmental Evidence* provides open access systematic reviews).

To address these issues, we have developed a method to rapidly synthesize evidence across entire subject areas (comprising tens or hundreds of related review questions), whilst being transparent, objective and minimizing bias. Target end users (i.e. researchers, practitioners and policy-makers) are actively involved in the synthesis process. Uniquely, our subject-wide evidence syntheses (Sutherland and Wordley, 2018) are part of a broader discipline-wide project, pooling resources to increase speed and cost-effectiveness. The ultimate output of this process is the freely accessible, plain-English Conservation Evidence database, which contains evidence for the effects of conservation interventions. The database is complemented by other tools in the Conservation Evidence toolbox (e.g. the journal *Conservation Evidence* and Evidence Champions). Together, these tools are designed to overcome or lower barriers within research-implementation spaces, increasing the use of evidence in practical conservation and policy-making, and enabling practice and policy to influence research. Ultimately, we hope this will lead to more targeted conservation research and more effective conservation action.

In this paper, we focus on the Conservation Evidence database, describing the methods used to create it and how it helps to overcome barriers between conservation researchers, practitioners and policy-makers. Although aspects of the methods have been described previously (e.g. Dicks et al., 2016; Sutherland and Wordley, 2018), this paper provides the only complete and detailed overview of the methods currently used by Conservation Evidence. Through increasing methodological transparency and communicating what the database is (and is not) designed to do, we hope this paper will encourage effective and appropriate use of this tool. We also discuss the database in a broader context, acknowledging that published evidence is just one of a multitude of factors within research-implementation spaces that affect conservation decision making.

2. Building the Conservation Evidence Database

2.1. An overview of the Conservation Evidence database

The Conservation Evidence database gathers, organizes, and summarizes studies that quantify the effects of conservation interventions (i.e. actions that have been or could be used to conserve biodiversity) on any aspect of biodiversity (e.g. abundance of a focal species, survival rates of translocated individuals, use of nest boxes, extent of habitat) or human behavior related to biodiversity conservation (e.g. levels of hunting, or sales of products detrimental to biodiversity). Ultimately, the database will present the evidence for interventions across the entire discipline of biodiversity conservation. Four key types of information fall largely outside the scope of the database: qualitative data, unpublished practitioner experience, traditional or indigenous knowledge, and detailed information on social or ethical issues (see Section 3.4). At present our focus is restricted to quantitative data which provide objective information on the size and direction of effects.

The database is split into subject areas, usually along taxonomic lines (e.g. bats, amphibians) with some taxa split by habitat (e.g. forest vegetation, shrubland vegetation). Subjects are distinct areas of research and practice, which we delimit according to (1) what we, and our advisory boards (Section 2.3.2), think would produce a useful synthesis for practitioners; (2) shared conservation challenges and relevance of interventions across the subject; (3) the abundance and distribution of literature, with a subject needing to be covered within a 1–3 year project and (4) aims and budgets of funders. For example, bat conservation is synthesized separately from conservation of other terrestrial mammals because chiropterologists form a distinct research and practice community, and because initial funding was limited. At the user interface, subject areas provide a rapid overview of the scope of the database, and coarse filters to focus on the most relevant information.

In each subject area, the database provides a comprehensive list of interventions. For each intervention, the database provides: background information such as the logic behind the intervention and how it might be carried out; standardized paragraphs summarizing individual scientific studies that have quantified the effects of that intervention; key messages that provide a narrative index to the combined evidence from all of those studies; and an overall effectiveness category based on an assessment of the evidence (effectiveness, certainty, and harm) by a panel of experts.

In the following sections, we outline the two levels of work involved in building the database and the steps therein (Figure 1). At a high level, *discipline-wide literature searches* identify publications that fall within the scope of the Conservation Evidence project. At a lower level, *subject-wide evidence syntheses* collate and summarize studies across subject areas.

2.2. Discipline-wide literature searches

2.2.1 Systematic manual searches

The main method used by Conservation Evidence to find relevant literature is discipline-wide, systematic, manual literature searching. This means identifying literature sources (e.g. academic journals, report series, organizational websites) that are likely to contain relevant information, then manually scanning the title and abstract (or summary) of every document in those sources. All documents meeting the general inclusion criteria (Section 2.1) are added to a discipline-wide repository, and tagged or filed by subject areas.

Sources with a broad, discipline-wide scope (e.g. *Journal of Applied Ecology*, *Biological Conservation*) are searched annually to keep the literature repository up to date. Specialist subject sources (e.g. *Journal of Mammalogy*, British Trust for Ornithology reports) are searched when the synthesis project for that subject is carried out (Section 2.3). Typically, sources are searched from their first publication date until a specified recent date. The list of sources and years screened is published alongside evidence synthesis products.

The key advantages of this method are that it does not depend on search term choice and can identify novel interventions not suggested a priori by the authors or advisory board for a synthesis (Sutherland and Wordley, 2018). It is also highly repeatable and transparent, notwithstanding some inevitable variation in the interpretation of inclusion criteria. We use Kappa tests (Cohen, 1960) to identify, and then correct, inconsistency between searchers. Because all relevant publications are added to a discipline-wide repository, each journal issue or block of reports only needs screening once. Each new synthesis or synthesis update can draw from (and contribute to) an existing repository rather than starting afresh (Figure 1), substantially increasing cost-effectiveness.

The disadvantages of the systematic manual search approach are that it requires a high initial outlay of time and money, cannot easily incorporate some sources that contain a large number of publications (e.g. mega-journals such as *PLoS ONE*), and cannot cover sources with a likely low yield of relevant publications. Thus, search terms are used instead of, or to complement, systematic manual searching in some specific cases (see Section 2.3.4). In the future, automated processes based on machine learning could reduce the cost of systematic source-by-source literature screening, whilst increasing coverage (Westgate et al., 2018).

2.2.2. Non-English and grey literature

A large proportion of the global scientific literature in conservation is not published in English (Amano et al., 2016). Conservation Evidence is creating a list of priority conservation journals in 20 different languages. Of these, 159 journals have been searched by fluent speakers of each language, with more searches underway. Results are being added to the discipline-wide literature repository (Figure 1), with titles and abstracts translated into English. Papers retrieved during these searches are being incorporated into the Conservation Evidence database as staff language skills permit. The aim is to reduce bias in the database towards evidence from English-speaking countries.

"Grey literature" refers to documents not controlled by commercial publishers, such as governmental and non-governmental reports, newsletters, conference proceedings, and theses (Farace and Schöpfel, 2010). Including grey literature in evidence syntheses may help to counteract the problem of publication bias, where studies reporting negative or non-significant findings are less likely to be written up and published in journals (McAuley et al., 2000; Dwan et al., 2013). Conservation Evidence is making a concerted effort to systematically search more grey literature sources (e.g. 687 reports from the British Trust for Ornithology and 945 from Scottish Natural Heritage were searched by 2017) and include relevant publications in the database.

2.3. Subject-wide evidence syntheses

2.3.1. Defining the subject and its scope

The detailed process of synthesizing evidence for the Conservation Evidence database is broken down into subject-focused work packages, or subject-wide evidence syntheses (Figure 1). The precise subject and scope of each synthesis is decided at an early stage in consultation with the advisory board (see Section 2.3.2). It is essential to define what each synthesis will include and exclude (Pullin and Stewart, 2006).

The subject is usually defined taxonomically, then sometimes further refined by habitat type (see Section 2.1). It is occasionally defined by other areas of interest, such as invasive species management or sustainable agriculture. The geographic scope is usually global. Conservation Evidence syntheses are focused on the effects of conservation interventions, so the question structure for review typically follows a PICO format (population, intervention, comparator, outcome). There is a separate review of the evidence for each intervention. Outcome measures are usually direct measures of effects on biodiversity, but may include less direct or intermediate outcomes (see Section 2.1). A synthesis-specific list of focal metrics may be constructed (e.g. abundance of certain indicator plant taxa) to guide consistent reporting of results from summarized studies. Synthesis-specific inclusion/exclusion criteria may also be defined. For example, laboratory and greenhouse studies are excluded for most interventions within vegetation-focused syntheses.

2.3.2. Forming an advisory board

The advisory board for each synthesis is a panel of subject experts who can help to refine its scope (Section 2.3.1) as well as its structure and language (Section 2.3.7), identify interventions (Section 2.3.3) and identify key sources of evidence to search (Section 2.2.1). Advisors contribute to planning each synthesis as well as reviewing a near-final version. Since 2018, we have formalized the input of the advisory board to the planning stage by asking them to review a synthesis protocol. These protocols are registered on the Open Science Framework (https://osf.io/mz5rx/) and published ahead of each synthesis on the Conservation Evidence website. We have always used and reported standard methodologies that allow for robust evidence synthesis, but we now appreciate the added value of publishing protocols in advance (Haddaway and Macura, 2018).

Advisory boards are selected to provide expertise in diverse topics within the subject, represent the geographic range covered by the evidence synthesis, and to include a mix of academics, practitioners and policy-makers. Thus, anticipated users of the database contribute to its development, helping to ensure applicability to practice and to increase the likelihood of uptake. So far, advisory boards for Conservation Evidence syntheses have comprised a mean of 11.6 (± 6.9 SD, n = 15) subject experts. Of the 157 individual experts from a total of 28 countries across six continents, approximately 53% have been from institutes operating more within research domains, and 47% from organizations oriented more towards policy and practice domains.

2.3.3. Intervention scanning

Based on initial literature scans and consultation with the advisory board, a list of conservation interventions for the subject of the synthesis is created. The aim is to produce a comprehensive list of all interventions that have been tried or suggested for the subject of the synthesis and that could realistically be implemented. The intervention list can be modified, and added to, as the synthesis process proceeds. Including all possible interventions and then populating these with evidence forms the basis for identifying and mapping evidence gaps (see Section 2.3.6).

Interventions are grouped in a consistent manner across syntheses: primarily according to the IUCN threat category that they address (Salafsky et al., 2008) and, for interventions that tackle multiple threats, secondary categories based on IUCN action types. The naming and division of interventions are guided by both the existing literature and the advisory board. Where possible, interventions are described at a fine scale (for example "Set longlines at the side of the boat to reduce seabird bycatch" is a separate intervention from "Set lines underwater to reduce seabird bycatch"; Williams et al., 2013), so that they can be combined in multiple ways by the user to address larger closed questions (e.g. are longlines at the side of the boat more effective than setting lines underwater to reduce seabird bycatch?), or open questions (what is the state of knowledge on seabird bycatch reduction methods?).

As the evidence synthesis is constructed, background information is added to each intervention. This briefly explains the logic behind the intervention, key issues regarding practical implementation, any unavoidable technical terms used, and potential harms to society or the wider environment. This background information is not, for pragmatic reasons, based on systematic literature searches and is therefore not taken into account during expert assessment (Section 2.3.8).

2.3.4. Collating subject-relevant literature

The synthesis authors collate a repository of literature that is relevant to their synthesis, based on title and abstract/summary screening. The authors draw documents from the discipline-wide repository—which contains the results from screening sources with a discipline-wide focus and sources with a focus on other previously-synthesized subjects (Section 2.2.1)—but also search sources most relevant to their synthesis subject (e.g. herpetological journals for an amphibian-focused synthesis). Relevant sources are identified in collaboration with the advisory board. The documents extracted from these synthesis-specific searches in turn feed back into the discipline-wide repository. For example, searches of herpetological journals for the amphibian-focused synthesis will also return papers relevant to a synthesis for reptiles.

Conservation Evidence syntheses on a new subject area unlikely to retrieve many publications from the existing discipline-wide repository, or on a very specific subject (e.g. the control of a particular group of invasive species), may use search terms to query databases of scientific literature. In such cases, employing search terms can be a useful complement to, or replacement for, journal searching. If this approach is taken, records are kept and presented to show the databases searched, the terms used and the dates searches were carried out.

2.3.5. Summarizing relevant studies

Each publication retrieved through literature searches is screened at full-text by the synthesis authors. If the publication contains at least one study (i.e. conceptually distinct experiment or test of an intervention) that meets the general inclusion criteria as well as any specific criteria defined for that synthesis, then each study is summarized in a standardized paragraph. Reviews and meta-analyses are summarized as evidence if they provide new or collective data relevant to the synthesis.

Summary paragraphs consistently present the same key information from each study in the same order (see Figure A1. in Appendix). This includes: study design; years of study; habitat; location; conservation intervention; target species or habitat; whether there was a statistically significant effect of the intervention and the direction of any effect; quantitative data on the outcome of the intervention; and a brief overview of the methods and monitoring approach. Summary paragraphs are concise—typically around 150–200 words—and written in plain English, avoiding technical terms wherever possible. Although short, the aim is for summary paragraphs to include sufficient detail of the study context and methods to allow users to begin to assess its importance and relevance to their own system (e.g. location, length of monitoring, exactly how the intervention was done) and interpret simple context-dependencies in results.

Conservation Evidence does not follow a formal process for critically appraising studies: generally, all studies that meet inclusion criteria are summarized. However, the design and size of each study are reported to help the user—and expert assessors (Section 2.3.8)—judge its importance and reliability (internal validity). As a simple example, the reader might give more weight to results from reviews, and particularly systematic reviews, than to results from individual case studies. Major concerns (from the original authors or synthesis authors) over the study design are explicitly highlighted in summary paragraphs. Exceptionally, studies may not be summarized if they clearly involve invalid comparisons, or are missing key information that severely inhibits comprehension. These issues are noted in the subject-wide literature repository (Figure 1).

2.3.6. Key messages: an overview of the summaries

Summary paragraphs describing studies that test the same intervention are grouped together. "Key messages" provide a brief overview of the studies testing each intervention: usually some indication of the number of studies, their geographical distribution, and their reported effects on key outcome metrics. Key messages are intended to provide an index to the evidence, easing the user into summary paragraphs and helping them identify the most relevant studies to their situation, and to facilitate comparisons of studies.

The key messages also highlight knowledge clusters and gaps in relation to interventions, targets, outcomes, habitats and geographic locations – and thus help identify where further research is needed. For example, no studies were found testing the intervention "Leave unharvested cereal headlands within arable fields" for bird populations (Williams et al., 2013). Furthermore, whilst four studies tested the intervention "Leave standing deadwood/snags in forests" for amphibian populations, they were all carried out in the USA (three in Virginia) and all but one focused on salamanders (Smith and Sutherland, 2014). The key messages across all interventions in a synthesis map the distribution of evidence across the subject area. Ultimately, key messages across the entire Conservation Evidence database will provide a "mega-map" of evidence for the whole conservation discipline.

We realize our key messages may be interpreted as an invitation to vote count (i.e. draw conclusions based on the number of studies showing positive vs negative results), which is usually a misleading method of synthesis (Stewart and Ward 2019). This is not the intended use. Key messages include information about study designs to suggest that the value of evidence varies between studies. Online, they link directly to the summary paragraphs that contain data to indicate the magnitude of any effects. We have added an explicit warning about vote counting to key messages on the Conservation Evidence website, and are considering alternative ways to provide an overview of the evidence base.

2.3.7. External review of synthesis

Once the evidence has been summarized, the draft synthesis is reviewed by the advisory board. They identify problems with language and structure, and suggest further relevant publications not retrieved through literature searches (Sections 2.2.1 and 2.3.4). The synthesis authors then include relevant studies and rectify any problems.

2.3.8. Expert assessment

Expert assessment is an important final step in synthesizing and presenting the evidence (Figure 1). The aim is to consider studies holistically and generate a generalized, overall effectiveness category for each intervention. This provides users with a supplementary decision-support tool, alongside the key messages and individual study summaries.

For a Conservation Evidence synthesis, the evidence for each intervention is assessed using a modified Delphi technique (Mukherjee et al., 2015). This involves a panel of experts—academics, practitioners and policy-makers from across the geographic range of the synthesis—carrying out several rounds of scoring for each intervention. The experts score the effectiveness, certainty and harm of each intervention, based on the evidence presented in the synthesis. Anonymized scores and comments are shared within the expert panel between rounds of scoring, to be used as a basis for refining scores. After 2–3 rounds, final median scores are used to assign an overall effectiveness category for each intervention (Sutherland et al., 2018; Table A1 in Appendix).

Effectiveness is scored by considering whether the intervention produces a desirable outcome in the summarized studies, and the magnitude of that outcome (0% = not effective, 100% = highly effective). *Certainty* is a measure of how confident assessors are that the effectiveness score applies across all appropriate contexts. The certainty score incorporates (1) the strength or reliability of the evidence as a whole, based on the number of studies and their quality (internal validity e.g. study design, replication, bias); and (2) how generalizable the results of these studies are, which will depend on the taxonomic/habitat/geographical coverage of studies (external validity). Certainty is scored from 0% (no evidence) to 100% (lots of high quality evidence, high generalizability). An intervention could be scored as having high effectiveness if it is supported by many studies showing strong desirable outcomes, but low certainty if those studies use low quality study designs or only consider a specific local context. *Harm* is scored by rating the magnitude of undesirable effects on the subject of the synthesis from undertaking the intervention (0% = no undesirable effects, 100% = major undesirable effects). The harm score is important to distinguish interventions that lack desirable effects from those that have undesirable effects: such interventions could receive identical effectiveness (and certainty) scores.

Currently, the Conservation Evidence database presents the overall effectiveness categories and the percentage scores for their three components (effectiveness, certainty, and harms). Whilst the percentage scores are useful for giving assessors flexibility and to generate medians across all assessors, we realize they could give a false sense of precision to database users. Thus, in the future, we may move towards categorical groupings to present scores for the three components.

Combining evidence from disparate locations, of varying rigor, and reporting different output metrics, is a challenge. Conservation Evidence uses expert assessment rather than meta-analyses to synthesize studies testing the same intervention, but reporting very different metrics, into an overall effectiveness category. For example, expert assessment can combine studies reporting the appearance of *Sphagnum* moss species on bogs following rewetting (a desirable change) and studies reporting a decrease in tree cover on bogs following rewetting (also a desirable change) to give an overall assessment that the intervention is effective. Meta-analyses tend not to combine different metrics because the resulting effect size would not be linked to any metric and would therefore lose some meaning. Some studies that can be considered by expert assessment also lack sufficient detail for the calculations involved in meta-analysis (Haddaway and Verhoeven, 2015). Conservation Evidence highlights (e.g. in synopsis introductions) interventions or groups of interventions where we think conducting a meta-analyses would be worthwhile as a more robust alternative to expert assessment.

2.4. Accessing the database

Outputs from each subject-wide evidence synthesis (interventions, summary paragraphs, key messages, expert assessments) are freely available within the searchable online database, www.conservationevidence.com. Users can search and filter the database in multiple ways, including by taxon, habitat, intervention and threat. Synopses capture most of each subject-wide evidence synthesis (interventions, summarized paragraphs and key messages) in a free-to-download pdf, and in some cases as a printed book. An annual publication, *What Works in Conservation* (e.g. Sutherland et al., 2018), presents the key messages and expert assessment for interventions reviewed so far, as a rapid overview and gateway into the online database (via hyperlinks).

2.5. Updates

The Conservation Evidence database is designed to allow the regular incorporation of new evidence. Updating each subject-wide evidence synthesis involves searching new volumes, issues, or documents within the originally-searched literature sources; searching additional literature sources; and adding new interventions or adjusting existing ones (e.g. where new literature suggests actions could be divided into multiple interventions). Further documents suggested by users since the publication of the original synthesis can also be included. Thus, all users can contribute studies to evidence syntheses through publishing their own articles and/or highlighting articles published by others. Key messages are updated and expert assessments repeated for any interventions where new evidence was added. Conservation Evidence has started to update existing syntheses and, in the short term, aims to produce updates every few years. In the longer term, we envisage updating the database in near-real time as new evidence is published, perhaps with the help of artificial intelligence to find publications and/or extract data (Westgate et al. 2018).

3. Discussion

3.1. Synthesizing complex evidence at scale

The methods developed to build the Conservation Evidence database allow for the synthesis of complex evidence across broad subjects and ultimately across whole disciplines. Using discipline-wide searches and subject-wide syntheses, we can efficiently synthesize evidence for both major and obscure topics, with a large or limited evidence base, respectively. Through a combination of summary paragraphs, key messages and expert assessment, we can present a general overview of the evidence incorporating a diversity of metrics, whilst allowing users to drill down to the evidence most relevant to their situation. Key messages and expert assessment can also highlight knowledge gaps and clusters for subjects and interventions. Finally, by using short summary paragraphs in plain English, we produce a user-friendly end product. We believe the truly unique feature of our methods is the combination of subject-wide synthesis and discipline-wide searches: we are not aware of any other synthesis projects that work across entire subjects and simultaneously collate literature for future syntheses within the discipline. We suggest these methods could be used to synthesize evidence for other themes within biodiversity conservation, such as threats or monitoring methods.

The Conservation Evidence database complements other systematic evidence synthesis outputs. The Conservation Evidence database provides syntheses of evidence over a broad range of topics, for which the investment in a systematic review is not (yet) justified but something more than just a map of the evidence would be useful. Systematic reviews, which favor depth of review over breadth of topics reviewed, are desirable for interventions with a large evidence base, where studies present contrasting results, for contentious topics, or where the risks posed by an incorrect conclusion are severe (Collaboration for Environmental Evidence, 2013; Collins et al., 2015). Systematic maps provide a rapid and inexpensive overview of the state of evidence in a broad subject or topic, without detailing what the evidence finds. They are most useful for identifying knowledge gaps and clusters, which can help direct research effort where it is most needed (Haddaway et al. 2016). All of these systematic outputs—including the Conservation Evidence database—are clearly organized, permanent, searchable and designed to minimize several key sources of bias, especially compared to other communication methods such as traditional literature reviews, notes from conference presentations, or word of mouth.

3.2. How the Conservation Evidence database helps to overcome barriers in research-implementation spaces

The Conservation Evidence database is designed to overcome some of the barriers between conservation research, practice and policy (Table 1), facilitating the flow of information between (and within) these domains. For example, the scientific literature is vast and ever-expanding, yet only a fraction of it is directly relevant to practitioners or policy-makers (Westgate et al. 2018). The Conservation Evidence database helps to overcome this barrier by presenting a relevant subset of the literature, containing quantitative information about the effects of conservation interventions—which can be a key factor in making robust conservation decisions (Adams and Sandbrook 2013; see also Section 3.4). Furthermore, the database is categorized at multiple levels (subjects, interventions, individual studies), allowing users to quickly drill down to relevant information, and combine it within and across levels to generate a custom evidence synthesis. We are currently developing an online tool that allows users to formally generate custom evidence syntheses.

A key feature of the Conservation Evidence database is its breadth, synthesizing evidence for a large number of questions (interventions). Since the first Conservation Evidence synthesis began in 2010, we have reviewed over 1,800 interventions (Sutherland et al., 2018) for 15 subjects. The aim is to synthesize the evidence for the effects of all interventions, for all taxa and all habitats, everywhere in the world.

Clearly there is a trade-off between breadth and depth of the database, so we cannot claim to have captured all of the available evidence for each intervention. The assumption is that users benefit from a synthesis of the evidence in the sources we search, as long as that is based on an unbiased sample of the available evidence, and users understand that the evidence base might be incomplete. A similar assumption implicitly, or explicitly, supports the use of other forms of rapid evidence assessment (e.g. Collins et al., 2015). As we have already included studies from over 280 journals and grey literature sources in the database, we think we have captured a substantial proportion of the relevant literature. We reduce publication and geographic biases by searching grey and non-English literature.

We acknowledge that even if all the available journals and grey literature were screened in multiple languages, a substantial amount of conservation-relevant knowledge would not be captured and a knowledge-accessibility barrier remains. Many reports remain as internal documents and are not publicly accessible. Moreover, some data on the effects of conservation interventions are not formally reported and remains as case experience in minds and notebooks. Although it may be possible to include case experience in the Conservation Evidence database, for example through the use of interviews, it can be difficult to capture in a systematic fashion and is likely subject to behavioral, social and cognitive biases that can be difficult for third parties to assess. As such, we have decided not to include it in the database at present. Still, such experiential and tacit knowledge should be used to complement the Conservation Evidence database when making conservation decisions (Section 3.3).

Suggested barriers between conservation research and practice/policy	**Example references**	**How the Conservation Evidence database helps to overcome or lower this barrier**

Research produces fragmented information that often does not address questions or problems relevant to conservation practice/policy.	McNie, 2007; Roux et al., 2006; Knight et al., 2008 ; Bainbridge, 2014; Gossa et al., 2015; Rose et al., 2018	Practitioners/policy-makers suggest interventions to be included in the database. Interventions with little evidence are highlighted for researchers. Thus, the database can act as a source of inspiration for practice/policy-relevant research. The database includes practice/policy-relevant research e.g. published in the journal *Conservation Evidence* or reports from conservation organizations.
Practitioners/policy-makers need answers more quickly than they can be produced by research, or even reviews of existing research.	Bainbridge, 2014; Gossa et al., 2015	Database is created proactively, reviewing the evidence for all interventions before a specific request from practitioners/policy-makers. Evidence synthesis prioritizes breadth of interventions covered over depth of review for each intervention to provide some synthesized evidence for all interventions, rather than detailed synthesis for few interventions.

Locating and accessing relevant primary literature is often too time-consuming (due to the large volume of published literature, including much that is not relevant to practitioners/policy-makers)	Pullin and Knight, 2005; Gossa et al., 2015; Westgate et al., 2018	Database can be queried using search terms or with various filters (subjects, countries, threats, actions). Evidence within each subject is organized in a consistent way (interventions grouped under threat and action categories).
Even when primary literature is located, reading papers can be time consuming, as much research is not streamlined for practitioners/policy-makers.	Pullin and Knight, 2005; Bainbridge, 2014; Westgate et al., 2018	Database contains short, summaries (usually <200 words) of each study, plus key messages to guide users through the summary paragraphs.
Much of the primary literature is technical and difficult to interpret for non-specialists. Research is often not communicated effectively for non-scientists.	Pullin and Knight, 2005; Roux et al., 2006; Bainbridge, 2014; Rose et al., 2018	Content of database is in plain English, avoiding jargon where possible (and explaining it otherwise).
Primary literature may be in a foreign language.	Arlettaz et al., 2010; Gossa et al., 2015	Summaries are written in English, even for primary articles not in English. We appreciate this introduces language barriers for users for whom English is a foreign language.

Financial barriers can be prohibitive (journal articles are often hidden behind paywalls, which can be too expensive for conservation practitioners/policy-makers; books can also be too expensive).	Arlettaz et al., 2010; Gossa et al., 2015	Database and related outputs are free to access.
Practitioners/policy-makers do not trust that the research, or synthesis, is credible.	Bainbridge, 2014	Summary paragraphs include key information (e.g. study design, raw data, major reported caveats) to allow users to make some judgement about study quality (internal validity). Methods used to produce synthesis are reported alongside the database.
The uptake of evidence is often undermined by socio-political agendas, whereby practitioners/policy makers tend to accept information—or disinformation—that confirms pre-existing worldviews but be critical of evidence in conflict.	Hameleers et al. 2019; Ecker et al 2019.	A small contribution: the Conservation Evidence database serves as an independent fact-checking resource to help debunk disproven or unfounded claims.

The Conservation Evidence database aims to present scientific information in a format relevant to practitioners and policy-makers who often struggle with the technical language, statistical analyses and length of scientific articles (Pullin and Knight 2005)—including systematic reviews (Tricco *et al*. 2016). The database uses short paragraphs in plain English. The content is also edited/reviewed by practitioners and policy-makers who sit on the synthesis advisory boards. In addition, interventions are tagged (grouped) according to the IUCN universal classification schemes of threats and actions (Salafsky et al., 2008), which were developed with input from practitioners and therefore reflect their thought processes.

The database breaks down some language barriers by summarizing some articles originally published in languages other than English, making them more accessible to English speakers (and at least all in a common language). We take opportunities to translate syntheses into alternative languages where possible (e.g. Hebrew for bee conservation), and have incorporated Google Translate into our website for “on the fly” translation. We appreciate that we still have work to do to break down language barriers for non-English-speaking users of the Conservation Evidence database.

In many cases, the knowledge transfer barriers in the research-implementation space arise upstream of evidence synthesis: there are often no (or few) scientific studies relevant to practitioners or policy-makers. For example, scientists may focus on global analyses, complex statistics and studies that push the boundaries of fundamental scientific knowledge to generate publications with a high academic impact—but which are of little use to practitioners and policy-makers (McNie, 2007; Hulme, 2011; Braunisch et al., 2012). To overcome this barrier, practitioners and policy-makers contribute to shaping the interventions included in the Conservation Evidence database. Furthermore, the database highlights knowledge gaps (i.e.

which interventions are supported by no, little or low quality evidence) and clusters (e.g. in certain locations or habitat types). Thus, researchers can see which questions are of interest to practitioners and policy-makers, and which are lacking evidence-based answers. Being able to demonstrate a knowledge gap for a practice- or policy-relevant question may help researchers justify research funding.

There may also be psychological barriers limiting the flow of information between research, practice and policy. For example, if institutionalized methods and relationships do not currently involve interactions between research and practice, a certain degree of activation energy will be needed to change habits (van Kerkhoff and Lebel, 2015). Further, scientific evidence is often discounted when it challenges people's pre-existing values or worldviews, especially when they are strongly connected to defined social identities (Roux et al., 2006; Newell et al., 2014). Related to this, there is a growing availability of highly visible and accessible, but often unreliable, information—especially on social media—which can “crowd out” reliable sources of evidence (Ladle et al., 2005). Whilst many solutions to these problems are largely outside of the scope of the Conservation Evidence project (e.g. detecting and removing disinformation on social media platforms), we suggest that the Conservation Evidence database may indirectly help to combat the spread of disinformation by increasing the accessibility and visibility of verifiable research evidence (see also Section 3.4 on Evidence Champions) and may help to reduce the impact of politically motivated disinformation by providing an open, objective, independent fact-checking resource for practitioners (Ecker, et al., 2019; Hameleers and van der Meer, 2019).

In an attempt to normalize use of the Conservation Evidence database, and reduce the psychological barrier of using a new tool, the database is integrated into an increasing number of practitioner-focused resources and decision-support software tools. It complements existing information on the websites of the IUCN Red List (https://www.iucnredlist.org), the National Biodiversity Network (https://nbn.org.uk), the British Trust for Ornithology (https://www.bto.org), and the UNEP-Agreement on the Conservation of African-Eurasian Migratory Waterbirds (https://www.unep-aewa.org/). The database is embedded in the Conservation Management System software (https://www.software4conservation.com/cmsi-software) used by Natural England and 10 other organizations to plan land management. The Cool Farm Tool (https://coolfarmtool.org/) is used by major grocery retailers to help farmers choose practices that reduce greenhouse gas emissions and, through the integration of the Conservation Evidence database, could be beneficial for biodiversity.

Unfortunately, we currently have limited data about the effectiveness of Conservation Evidence at breaking down barriers. Empirical evidence that the database can improve the effectiveness of conservation when used is limited to one study. Walsh et al. (2014) demonstrated that information synthesized by Conservation Evidence (on the effectiveness of various interventions to control predators for bird conservation) changed practitioners' stated choices of management in favor of more effective interventions, and away from interventions that were likely to be ineffective or even harmful. Data on whether the Conservation Evidence database increases the effectiveness of conservation in practice are difficult to collect, but we are seeking research funding to do so (and encourage others to take up the challenge too).

We do know that the website is well used: it received an average of 29,000 page views per month between January and May 2019, by an average of 11,700 visitors per month from over 220 countries and overseas territories. About 25% of visitors have used the website more than once. Copies of *What Works in Conservation* have been read online or downloaded almost 39,000 times as of June 2019.

Evidence Champions (see section 3.4) and others have provided feedback that the database has helped their decision-making. For the AEWA (Agreement on the Conservation of African-Eurasian Migratory Waterbirds) Secretariat, "it was a very helpful source, as we could use it as a good reference and depending on the case also as a source for good examples on the ground." The Rufford Foundation, who ask grant applicants to reference Conservation Evidence in their applications, said, "I think that it has been valuable as a way of encouraging those designing projects to look further afield to see if techniques they plan to use have been tried before and, if yes, with what result. All of this has certainly helped our reviewers. Overall, Conservation Evidence has… greatly improved the quality of the applications we receive."

The Conservation Evidence database has been recognized in the political sphere. An example from the Conservation Evidence database, publicized by Sutherland and Wordley (2017), was used by Lord John Krebs to ask the UK government to ensure the government's 25 year environment plan would be evidence-based. The database has also been referred to in multiple policy briefs and government documents, such as Defra's *Consultation on the National Pollinator Strategy* (2014), The Scottish Government's *Consultation on the Scotland Rural*

Development Programme (SRDP) 2014–2020, and The New Zealand Government's *Improvements to Biodiversity Assets Systems and Processes* (2014).

3.3. Other tools in the Conservation Evidence toolbox that help overcome the barriers in research-implementation spaces

The database is a core part of the wider Conservation Evidence project, which contains other tools to help overcome barriers between conservation researchers, practitioners and policy-makers. We briefly discuss these here.

The journal *Conservation Evidence* publishes research, monitoring results, and case studies on the effects of conservation interventions. There is no requirement for novelty, complex statistical analyses, or technical discussions. It is designed specifically to encourage practitioners to submit their quantitative data and make them accessible to all. By converting unpublished reports, internal documents and data from field notebooks into open access publications, this journal helps overcome the knowledge-accessibility barrier discussed above (Section 3.2). Providing an outlet for sharing robust, conservation-relevant primary research could also encourage greater collaboration between researchers and practitioners.

Since 2017 we have worked with a group of designated Evidence Champions. These are organizations committed to using evidence (particularly the Conservation Evidence database) when planning, funding, or publishing practical conservation actions, and/or testing a certain number of interventions each year and publishing the results. These techniques are intended to address some of the psychological barriers to the use of evidence (Section 3.2) by making a balanced assessment of evidence a routine and expected part of conservation planning. Evidence Champions are supported through training in evidence interpretation and generation techniques.

We also run more general workshops to explain what the Conservation Evidence database is and how it can be used, or how practitioners can best carry out research to feed into the database. Again, these can help to reduce behavioral or psychological barriers to the use or production of conservation-relevant evidence.

3.4. Conservation in practice: other factors and actors in research-implementation spaces

The Conservation Evidence database is built within the collaborative spaces occupied by conservation researchers, practitioners and policy-makers. When the database is used to make practical or policy conservation decisions, other actors (e.g. NGOs, governments, landowners, farmers, indigenous communities, activists), issues (e.g. spiritual and cultural values, financial resources, political), and information (e.g. the basic biology, distribution and status of species and habitats, the presence and degree of threats, local knowledge and practical experience) are introduced to these arenas (Roux et al., 2006; Toomey et al., 2017; Evans et al., 2018). Conservation decisions are not made based on scientific evidence alone; socially acceptable decisions must balance the needs of nature and people. In particular, the quantitative data from the Conservation Evidence database will need to be combined with qualitative data, for example derived from interviews or focus groups, to capture relevant tacit knowledge and values and ultimately design effective conservation strategies (Roux et al., 2006; Sutherland et al. 2018).

Similarly, the Conservation Evidence database cannot tell practitioners or policy-makers when or how to intervene. This decision will be influenced by site-specific issues and information mentioned above, as well as assessments of the focal site's history and desired future for all stakeholders. We recognize the potential that a list of interventions—some assessed as beneficial to species or habitats—might encourage unnecessary active intervention. In some cases, particularly in relatively intact sites, interventions may not be required to reach a desired state and might do more harm than good to biodiversity. Thus, we caution against assuming that intervening is always better than not intervening. To this end, we also include some passive interventions in our syntheses (e.g. 'Allow shrubland to regenerate without active management) to highlight that doing nothing is a management option to consider.

3.5. Conclusion and Recommendations

The Conservation Evidence database is assembled through a systematic, repeatable process, with input from conservation researchers, practitioners and policy-makers. It is a powerful and pragmatic tool to improve the use of scientific evidence by practitioners and policy-makers, and encourage new research that is guided by practice and policy needs. The database aims to complement existing evidence synthesis methods, and is complemented by other tools within the Conservation Evidence toolbox, helping to create interactive spaces where researchers, practitioners and other key stakeholders can collaboratively pursue evidence-based conservation.

Several concrete recommendations arise from our work building the Conservation Evidence database and this article reflecting on the methods used to build it. Conservation researchers, practitioners and policy-makers should consult the database when making conservation decisions, to ensure those decisions are informed by evidence alongside expert opinion, experience, local knowledge and values. Second, conservation intervention projects should be monitored and the results published, whether or not successful and/or novel, in order to strengthen the evidence base. Third, conservationists should engage with the Conservation Evidence project, offer constructive feedback and help us to make the database as useful as possible for you. Finally, the database should, and will, be constantly growing and evolving as it incorporates new evidence, methodological improvements and technological developments.

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Figure 1. An overview of the methods used to build the Conservation Evidence database (discipline-wide literature searches and subject-wide evidence synthesis), and how a range of end users are incorporated into the construction process. *Rectangles* represent processes, and *rhomboids* represent outputs. *Numbers* indicate section of text where item is explained.

Table 1: Some barriers that inhibit interaction between research and practice/policy, and how the Conservation Evidence database helps to overcome or lower these barriers.

Appendix

General format for Conservation Evidence summary paragraphs:

A [TYPE OF STUDY[1]] in [YEARS X–Y] in [HOW MANY SITES] in/of [HABITAT] in [REGION and COUNTRY] [REFERENCE] found that [INTERVENTION] [SUMMARY OF ALL KEY RESULTS[2]] for [SPECIES/HABITAT TYPE]. [DETAILS OF KEY RESULTS, INCLUDING DATA[2]]. In addition, [EXTRA RESULTS, IMPLEMENTATION OPTIONS, CONFLICTING RESULTS]. The [DETAILS OF EXPERIMENTAL DESIGN, INTERVENTION METHODS and KEY DETAILS OF SITE CONTEXT[3]]. Data was collected in [DETAILS OF SAMPLING METHODS].

1. Type of study is described using standard terms, available alongside the Conservation Evidence database and in synopses.

2. Results (e.g. difference between groups, changes over time) are statistically significant, unless specifically stated (e.g. with the sentence "These results were not tested for statistical significance").

3. For the sake of brevity, only nuances essential to the interpretation of the results can be included. The reader is always encouraged to read the original source to get a full understanding of the study site (e.g. history of management, physical conditions).

For example:

A replicated, controlled study in 2001 of bottomland hardwood forest in Georgia, USA (1) found that prescribed burning had no significant effect on abundance, diversity or richness of amphibians. Abundance did not differ significantly at burned and unburned sites for all amphibians (burned: 43; unburned: 62), salamanders (2 vs 6) or frogs and toads (39 vs 50). The same was true for species richness overall (burned: 8; unburned: 8 species), for salamanders (2 vs 2) and frogs and toads (6 vs 6). The volume of coarse woody debris was similar in burned (60 m^3/ha) and unburned stands (128 m^3/ha). Amphibians were monitored in three winter-burned and unburned stands from July to October 2001. Drift-fencing with pitfall traps, artificial cover boards and PVC pipe refugia were randomly placed within each site.

(1) Moseley K.R., Castleberry S.B. & Schweitzer S.H. (2003) Effects of prescribed fire on herpetofauna in bottomland hardwood forests. *Southeastern Naturalist*, 2, 475–486.

Figure A1. The general format for Conservation Evidence summary paragraphs with an example.

Table A1. Overall effectiveness categories, with colors as used in Sutherland et al. *(2018). Reproduced with permission from Sutherland* et al. *(2018).*

Category	Description	General criteria	Thresholds
Beneficial	Effectiveness has been demonstrated by clear evidence. Expectation of harm is small compared with the benefits	High median benefit score High median certainty score Low median harm score	Effectiveness: >60% Certainty: >60% Harm: <20%
Likely to be beneficial	Effectiveness is less well established than for those listed under 'effective' **OR** There is clear evidence of medium effectiveness	High benefit score Lower certainty score Low harm score **OR** Medium benefit score High certainty score Low harm score	Effectiveness: >60% Certainty: 40–60% Harm: <20% **OR** Effectiveness: 40–60% Certainty: ≥40% Harm: <20%
Trade-off between benefit and harms	Interventions for which practitioners must weigh up the beneficial and harmful effects according to individual circumstances and priorities	Medium benefit and medium harm scores **OR** High benefit and high harm scores High certainty score	Effectiveness: ≥40% Certainty: ≥40% Harm: ≥20%
Unknown effectiveness (limited evidence)	Currently insufficient data, or data of inadequate quality	Low certainty score	Effectiveness: Any Certainty: <40% Harm: Any
Unlikely to be beneficial	Lack of effectiveness is less well established than for those listed under 'likely to be ineffective or harmful'	Low benefit score Medium certainty score and/or some variation between experts	Effectiveness: <40% Certainty: 40–60% Harm: <20%
Likely to be ineffective or harmful	Ineffectiveness or harmfulness has been demonstrated by clear evidence	Low benefit score High certainty score (regardless of harm) **OR** Low benefit score High harm score (regardless of certainty of effectiveness)	Effectiveness: <40% Certainty: >60% Harm: Any **OR** Effectiveness: <40% Certainty: ≥40% Harm: ≥20%

Glossary

Definitions of terms as used by Conservation Evidence and in the main article text.

Discipline: A research field of a size that could be taught as a standalone undergraduate degree course, such as biodiversity conservation. Contains multiple subject areas.

Evidence synthesis: The process of combining multiple sources of evidence addressing a particular area or question (verb) or any product arising from this process (noun).

Expert assessment: Using multiple experts to assess the effectiveness, associated certainty and harm of an intervention, to produce a generalized overall effectiveness category for the intervention.

Intervention: A conservation action or management option that is currently used, or could be used, with the intention of benefitting biodiversity. For example, 'Use streamer lines to reduce seabird bycatch on longlines' or 'Legally protect habitat'.

Key messages: In the Conservation Evidence database, these provide an overview of the studies that tested a particular intervention. Intended to guide users to the more detailed study summaries.

Practitioner: Decision-maker whose main occupation is not research, but the implementation of actions in the field, for example conservation actions to protect and manage natural resources (Gossa et al., 2015).

Policy-maker: Decision-maker whose main occupation is not research, but defining plans and legislation, for example to protect and sustainably manage natural resources.

Research-implementation gap: A conceptual division or void between research and practice or policy, whereby interaction or flow of information between these groups is limited. Encourages a focus on linear transfer of absolute truth from science to practice and policy, rather than recognizing the complex and multi-directional interactions between these groups (Toomey et al., 2017).

Research-implementation space: A conceptual arena in which researchers, practitioners and/or policy-makers interact and work. Barriers within this space can hinder interactions and knowledge transfer. Research-implementation spaces may also overlap with factors such as local knowledge, beliefs and societal values, and these factors should be considered when making conservation decisions.

Study summary: A paragraph summarizing the conceptually distinct part (or the whole) of a paper, report or other source of evidence. Written using a structured methodology to present the main methods and results.

Subject: A large area within a discipline, big enough to comprise multiple (usually hundreds) of related review questions. Subjects within the Conservation Evidence project include bird conservation, conservation of forest vegetation, and management of aquatic invasive species.

Subject-wide evidence synthesis: A systematic method of evidence synthesis that reviews closed review questions across entire subject areas at once (verb) or any product arising from this process (noun). Necessitates trading-off depth of each review for breadth of topics covered. Will usually focus on one type of review question within the subject e.g. effects of interventions, impacts of threats, comparison of methods.

Synopsis: A document capturing the synthesized evidence for an entire subject (e.g. bird conservation). Conservation Evidence synopses contain the list of interventions, study summaries, key messages and background information and are published as pdfs and/or books.

References

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