Environmental Modelling & Software 64 (2015) 72–79

Contents lists available at ScienceDirect

Environmental Modelling & Software

journal homepage: www.elsevier.com/locate/envsoft

An online database and desktop assessment software to simplify systematic reviews in environmental science

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ARTICLE INFO

Article history:
Received 17 March 2014
Received in revised form
6 November 2014
Accepted 14 November 2014
Available online

Keywords:
Eco Evidence
Evidence-based practice
Literature
Software
Systematic review
Environmental management

ABSTRACT

We describe software to facilitate systematic reviews in environmental science. Eco Evidence allows reviewers to draw strong conclusions from a collection of individually-weak studies. It consists of two components. An online database stores and shares the atomized findings of previously-published research. A desktop analysis tool synthesizes this evidence to test cause–effect hypotheses. The software produces a standardized report, maximizing transparency and repeatability. We illustrate evidence extraction and synthesis. Environmental research is hampered by the complexity of natural environments, and difficulty with performing experiments in such systems. Under these constraints, systematic syntheses of the rapidly-expanding literature can advance ecological understanding, inform environmental management, and identify knowledge gaps and priorities for future research. Eco Evidence, and in particular its online re-usable bank of evidence, reduces the workload involved in systematic reviews. This is the first systematic review software for environmental science, and opens the way for increased uptake of this powerful approach.

Software/data availability

Eco Evidence was developed by researchers and programmers at the eWater Cooperative Research Centre, Australia. It was publicly released in December 2012. The Eco Evidence Analyser (v1.1.1) software can be downloaded from www.toolkit.net.au/tools/eco-evidence, and the Eco Evidence Database is also accessible at this address using any web browser. New users must register with the Toolkit website, but there is no charge for registration or subsequent use of Eco Evidence. The Eco Evidence Database has an ASP.NET web interface driven by a Microsoft SQL Server database. Users must go through a self-approval process before they can add new citations and evidence items. The database is highly scalable and was designed to be accessed by multiple concurrent users. All records are associated with the user who enters/edits them, with the latest edit being kept. The relational database schema uses an entity–attribute–value data model to store the evidence information. This allows the structure of an evidence item to be changed without requiring additional software development work. The database schema is highly normalized and only requires the storage of basic data types (i.e. numbers, strings), so the storage requirements are minimal. The Eco Evidence Analyser software was written in C#.NET and runs on Microsoft Windows (requires.NET 4.0 framework). The installer file is 4.15 MB in size. Projects (including the local databases contained therein) are saved in XML format and the standardized report is HTML.

1. Introduction

Environmental studies are often carried out under conditions that make it difficult or impossible to infer with confidence that one thing actually causes another (Beyers, 1998). For many large-scale investigations, treatments cannot be randomly allocated to experimental units, replication (and hence statistical power) is low, and we are faced with the presence of confounding environmental gradients (e.g. variation in rainfall). When investigating environmental impacts, the suspected cause has often occurred years or

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http://dx.doi.org/10.1016/j.envsoft.2014.11.011
1364-8152/

decades earlier, meaning we have no 'before' data against which to compare present-day conditions.

However, demonstrating causality is important, both for advancing our state of ecological understanding and helping to develop theory, and also for using this knowledge in evidence-based management of natural and impacted environments. This latter consideration is especially important in contested decision spaces, where the relative benefits of natural and human uses of environments must be weighed when making management decisions (e.g. Poff et al., 2003). If individual studies cannot make strong inferences about ecological causes and effects, then more evidence is needed from elsewhere (Downes et al., 2002).

Like many scientific disciplines, environmental science has seen a recent explosion in the amount of literature available (e.g. Stewardson and Webb, 2010). It has even been hypothesized that this information deluge has reached the point where it is holding back scientific progress, rather than aiding it (Attwood et al., 2009). Methods and tools are required to help make sense of this mountain of literature. *Systematic reviews* are one way to analyse the knowledge contained within a large body of literature. A systematic review explicitly treats the literature as data (Khan et al., 2003). They commonly employ statistical analyses, and use transparent and repeatable methods to test specific hypotheses across sets of papers. This approach brings a level of discipline and focus to a review far greater than that usually seen in the *narrative* reviews that dominate environmental science. Narrative reviews use written descriptions to summarize a large body of research, but seldom seek to test whether there is or is not enough evidence to support or refute an ecological hypothesis. The short narrative reviews found in the introductions of most journal papers are often poorly executed and do little to argue for the importance of the research that follows (Maier, 2013). Systematic reviews are common in several other scientific disciplines, most notably medical research and patient management (Keene and Pullin, 2011). However, despite calls for their increased use in ecology and environmental science (Pullin et al., 2009; Sutherland et al., 2004), they are not yet widely used. This lack of uptake might be explained by the related observations that systematic reviews can be laborious (CEBC, 2010), and that to date there have been no tools specifically designed to reduce this workload to a manageable level.

Our aim in this paper is to introduce the Eco Evidence software package. To assist new and potential users to learn how to use the software, we provide examples of its use. The software implements the systematic review method developed by Norris et al. (2012), and fully described therein. It is not our purpose here to explain the previously-published method, nor justify its logical basis. However, briefly, the Eco Evidence method has its basis in the epidemiological method of causal criteria analysis. Faced with similar issues of weak inference as those described above, epidemiologists developed causal criteria as a means of building a strong argument for causality from a collection of otherwise individually-weak pieces of evidence (Hill, 1965; Tugwell and Haynes, 2006). In Eco Evidence, the individual pieces of evidence are bivariate associations (e.g. fish diversity associated with flow seasonality; discussed below) that are drawn from the literature. The key aspects of Eco Evidence are: an open-access online database for permanent storage and sharing of the 'evidence items' used in systematic reviews, allowing future re-use of the evidence by the same or other reviewers; an analysis package that guides users through the 8-step method of Norris et al. (2012), thereby providing a standardized approach for synthesizing literature evidence; and the provision of a standard report, which provides complete transparency of the review undertaken.

The Eco Evidence package can facilitate ecological systematic reviews in the same way, for example, that the RevMan package (http://ims.cochrane.org/revman) has aided medical reviews. Moreover, the database component of Eco Evidence is the first such publicly-available evidence database in any discipline that uses systematic reviews. More fundamentally, Eco Evidence has the potential to improve the standard of reviews in environmental science, answering questions across a body of literature and identifying the knowledge gaps that need to be filled by new research (sensu Maier, 2013).

2. The Eco Evidence software

Eco Evidence consists of two components: the online database for storing and sharing evidence items, and a desktop analysis tool to guide users through the Norris et al. (2012) framework to assess the level of support for causal hypotheses. The Eco Evidence Analyser (v1.1.1) software can be downloaded from www.toolkit.net.au/tools/eco-evidence, and the Eco Evidence Database is also accessible at this address using any web browser. New users must register with the Toolkit website, but there is no charge for registration or subsequent use of Eco Evidence.

2.1. Eco Evidence Database (EED)

The Eco Evidence Database (hereafter EED) is an online database for storing and sharing evidence items. It provides a permanent repository for environmental evidence and allows users to access and use evidence items entered by other users. It is accessible via any web browser and requires no installation or system customization.

2.1.1. Data entry

Registered users can add citations and evidence items to the database. Changes made to the database are tagged with the user name as a basic means of quality control. Basic users are able to create and edit only their own contributions, while 'power' users are able to edit all contributions (Webb et al., 2011). When adding a new citation (e.g. journal paper), the database first tests for the presence of duplicates. Once the citation is created, the user can add evidence items to it. Users can also add new evidence items to existing citations. To add evidence, the user must first extract it from the citation, a process explained below. We refer to this user as the 'extractor' for clarity in the following sections.

2.1.2. Data structure

The key data items managed in the EED are citations and evidence items. For each citation, the database contains standard bibliographic information (author, title, source, abstract, keywords). It also contains basic study characteristics (region in which the study took place, climatic classification, ecosystem type, spatial and temporal scale of the study, broad class of study type), which are selected by the extractor from dropdown menus and are used to facilitate searching through large collections of studies. Attached to each citation are one or more evidence items.

The evidence item consists of a set of database fields that collectively describe the hypothesized cause–effect association reported in the citation (Table 1). These fields have been determined through user input, data usage, and discussions with users and collaborators. Only a small subset of the 34 fields is compulsory, but a number (9) are necessary if the evidence item is to be used in a subsequent analysis using the Eco Evidence Analyser tool. Inputs to many of the fields are restricted through the use of control elements (radio buttons, tick boxes, drop-down lists) to ensure consistent data entry. Free-text fields allow the extractor to describe the evidence more fully.

At the core of an evidence item is the basic putative cause–effect association. It consists of a standard term for the cause, a standard

Table 1
The fields in an evidence item. Each set of rows separated by horizontal lines is a 'field group', which contains fields of multiple types (see Field type) to describe that feature of the evidence item (e.g. a 'cause'). Two right hand columns illustrate whether the field is Compulsory to enter into the database, and whether the information is Necessary for an Eco Evidence analysis or whether it is Optional (i.e. not necessary, but will be used if provided).

Field group	Fields	Field type	Compulsory?	EEA?
Cause	Trajectory	Radio buttons		Necessary
	Term & attribute	Standard list	Yes	Necessary
	Description	Free text	Yes	
Effect	Trajectory	Radio buttons		Necessary
	Term & attribute	Standard list	Yes	Necessary
	Description	Free text	Yes	
Design & replication	Type of design	Drop-down list	Yes	Necessary
	Number of impact sampling units	Numeric		Necessary
	Number of control sampling units	Numeric		Necessary
	Description of design	Free text		
	Are samples random?	Drop-down list		
	Are sample independent?	Drop-down list		
Association	Type of association	Drop-down list		Necessary
	Description of association	Free text		
	Presence of dose–response relationship	Drop-down list		Optional
	Form of dose–response relationship	Drop-down list		
	Description of dose–response	Free text		
Analysis	Is the analysis appropriate?	Boolean		Necessary
	Description of analysis	Free text		
	Evidence of the cause in biota?	Boolean		Optional
	Paper contains information suitable for meta-analysis?	Boolean		
Strength of association	Classification of strength	Drop-down list		
	Effect size	Numeric		
	Variability	Numeric		
	Description	Free text		
Time order	Does cause precede effect?	Drop-down list		
	Description	Free text		
Coherence	Classification of coherence	Drop-down list		
	Description	Free text		
Description of predictive performance		Free text		
Information for other users	Design pp	Numeric		
	Results pp	Numeric		
	Discussion pp	Numeric		
	Question asked	Free text		

term for the effect, and the nature of the association between them. This construction is functionally equivalent to the subject–predicate–object construction used by the OWL (Web Ontology Language) standard for developing ontologies on the internet (http://www.w3.org/TR/owl2-overview/). The standardized list of causes and effects presently consists of 229 items that cover the scope of applications to which Eco Evidence has already been applied (mostly aquatic ecology). It is open to further revision and expansion as new use cases arise. Entries in the list consist of a Term (an entity) and an Attribute (a property of the entity), structured as 'term (attribute)' – e.g. 'fish (abundance)'. There are also term-only entries – e.g. 'fish'. For each of the entries in the standardized list, a definition is presented to help the extractor classify cause and effect for a new evidence item. The list and definitions reduce the impact of semantic differences between individual extractors on classification of evidence, and increase subsequent search power.

2.1.3. Search and export

Users can search for evidence items using any or all of the following criteria: bibliographic information from the original citation; multiple causes and/or effects chosen from the standard terms list; the question to which the evidence item refers, as recorded by the original extractor; and the 'study characteristics' described above (e.g. region). Users can search the entire database or only within evidence items they have previously entered or modified (Appendix A, Fig. A1). Results from a search can be exported to a .csv (comma separated values) text file. When exporting evidence, a 'shopping cart' is available for users to build up lists of relevant evidence items and citations to export for different questions, search types, etc. Evidence can also be retrieved by running cause–effect searches from the Eco Evidence Analyser tool.

2.2. Eco Evidence Analyser (EEA)

The Eco Evidence Analyser (hereafter EEA) is a Windows-based software tool that uses a wizard-style interface to guide users through the Eco Evidence framework (Fig. 1). Early stages of analysis consist of: defining the overall question, the environmental context in which it is being asked, and developing a conceptual model of the hypothesized cause–effect linkages. The EEA has free-text fields and an option to import graphics to assist with completing these steps. Users are free to use any means or tools to

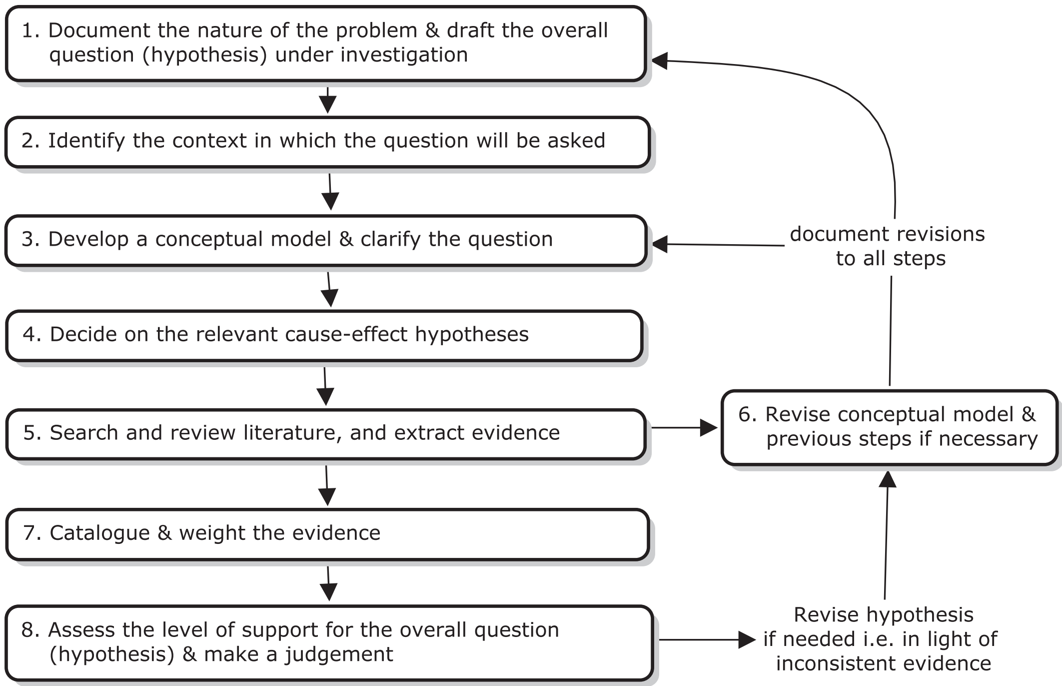

Fig. 1. Workflow for the Eco Evidence method and Analyser software. Reproduced from Norris et al. (2012).

develop the conceptual model prior to importing it to the EEA. For example, the eWater CRC tool Concept, also available from the toolkit website, is specifically designed to assist with developing graphical conceptual models. The conceptual model needs to contain links between hypothesized causes and observed or putative effects; these form the basis for the cause–effect hypotheses to be tested by the Eco Evidence analysis. Such linkages might be direct representations of ecological processes, or they may be empirical relationships between 'higher-level' causes and effects. The most important consideration for the conceptual model is that it can be used to develop these hypotheses, and that it be sufficiently clear so that a reader could determine whether any important linkages have been omitted.

The analysis then focuses on evaluating the evidence for one or more of the cause–effect hypotheses detailed in the conceptual model, with the evidence items for each hypothesis providing the data for the assessment. To set a hypothesis, the reviewer chooses hypothesized cause and effect from the standard list, and their trajectories (e.g. an *increase* in 'surface water (volume)' will cause a *decrease* in 'vegetation (growth)'). The EEA then connects remotely to the EED and retrieves all evidence items with that cause–effect combination. The reviewer may also define their own terms for cause and effect, allowing them to reclassify database terms for individual reviews. The evidence items retrieved from the EED provide most of the information required for the analysis. However, the user is required to confirm whether each evidence item retrieved is relevant to their hypothesis. Once this is completed, a weight is determined for each relevant evidence item based on study type and sample replication. Study weights range from 1 to 10, with stronger studies (i.e. those less likely to be reporting spurious results because of low replication, poor control of confounding influences, etc.) being assigned higher weights (see Norris et al., 2012 for full details). The EEA allows users to define their own evidence weights if the default settings are inappropriate (e.g. Grove et al., 2012), and has a free text field to record the justification for any changes made.

After the evidence has been collated and weighted, the software automatically compares the trajectories of the evidence items to those of the cause–effect hypothesis. Based on this comparison, each item of evidence contributes to either supporting or rejecting the hypothesis. The weighted values for each study that supports the hypothesis are summed, as are the weighted values for those studies that do not support the hypothesis. A comparison of these two sums to a threshold value (default value of 20 points) is used to reach one of four conclusions: Support for hypothesis, Support for Alternate hypothesis, Insufficient evidence, Inconsistent evidence (see Norris et al., 2012 for full details). The Eco Evidence Analyser undertakes the weighting and summation automatically, allowing the reviewer to focus on interpreting the evidence.

Finally, the software produces a standardized report that presents the information input by the user (question, context, conceptual model, search strategies), the findings for each cause–effect hypothesis, the evidence used to reach those conclusions, the sources of that evidence, and the overall conclusion of the analysis. This report provides complete transparency for the causal assessment, and means that any bias or omission (either deliberate or inadvertent) will be more easily detected than with a traditional literature review.

3. Illustrative examples

3.1. Extraction

Extracting evidence from a publication necessitates a different approach to reading papers compared to that used by many environmental scientists. Specifically, the extractor focuses primarily on the methods and results, rather than the author's own interpretation in the discussion. To illustrate the process, we use a recent paper. Mims and Olden (2012) described associations between fish life history strategies and hydrologic indices. Although this paper, like most others, could provide several pieces of evidence for different cause–effect hypotheses, here we extract the evidence relevant to the hypothesis, 'increased flow seasonality will cause changes in the structure of fish assemblages towards periodic strategist species'. This is an extremely specific hypothesis, but one that may be relevant to one part of a review considering (for example) the environmental impacts of water resource development for irrigation. Much less specific hypotheses can also be used to investigate general environmental issues (e.g. Webb et al., 2013). The extracted evidence item from Mims and Olden (2012) is available for registered users on the Eco Evidence Database (http://www.toolkit.net.au/Tools/Online/EE/Evidence/Item.aspx?EID=19210), and the marked up paper is also available as supplementary material (Appendix B). Like all other evidence in the database, this item is now available for any user to view and/or include in a review.

When entering Mims and Olden (2012) as a citation, in addition to the paper's basic bibliographic data, we recorded the study characteristics as: Study classification – analysis of routine monitoring data; Study region – North America; Spatial extent – continental; Temporal extent – static; Climate type – multiple; Ecosystem type – upland and lowland (Appendix A, Fig. A2). We were able to determine these characteristics solely from reading the paper's abstract.

We then added an evidence item to the citation. From the list of standard terms, we used 'surface water (seasonality)' as the putative cause, and 'fish (assemblage)' as the effect. We assigned 'increasing' trajectories for both of these, and used the free text fields 'Detailed cause' and 'Detailed effect' to describe these choices in greater detail. The study design was assigned as 'spatial gradient' with 109 sampling units, again with further information provided to explain design (Appendix A, Fig. A3). The study described a positive statistical association between flow seasonality and the prevalence of periodic strategists, and we classified this association as showing a weak dose–response relationship. We concluded that the statistical methods chosen and interpretation of the results was appropriate (Appendix A, Fig. A4). We also filled out the other fields in the evidence item, but these are not currently used by the EEA software (Table 1).

3.2. Analysis

A complete systematic review using Eco Evidence is a full research paper in its own right, and so to illustrate the analysis process we use an abbreviated example from a recent systematic review (Miller et al., 2013). Other fully-developed case studies are also available for interested readers (Greet et al., 2011; Grove et al., 2012; Webb et al., 2013, 2012b). This section is organized according to the 8 steps of the Eco Evidence framework (Norris et al., 2012).

3.2.1. Step 1 – the question & step 2 – the context

Many regulated rivers suffer from encroachment of terrestrial vegetation into the channel. Environmental flow assessments commonly predict that restoring a more natural level of base flow in winter/spring and/or re-instating higher flow events will reduce encroachment. We used Eco Evidence to examine the evidence for the question, "Will increased winter/spring base flows and more frequent high flow events reduce terrestrial plant encroachment into river channels?" For this case study, we were interested in generalizing conclusions to lowland regulated rivers in south-eastern Australia. However, evidence from similar systems globally was used.

3.2.2. Step 3 – conceptual model & step 4 – identify causes and effects

Increased base flows and increased frequency of high flow events will lead to increased inundation of channel features colonized by terrestrial vegetation. Reduced encroachment may be achieved by reduced germination of terrestrial propagules within the channel, dieback of existing vegetation within the channel, or physical removal of such vegetation from the channel through flows that scour the bed (Fig. 2). These individual linkages within the conceptual model form the specific cause–effect hypotheses, with cause and effect terms chosen from the standard terms list in Eco Evidence or defined specifically for this study (Scour and Inundation; Table 2).

3.2.3. Step 5 – conduct literature search and review

For this application, there were no previously-entered relevant evidence items already in the database. We searched Thompson ISI's 'Web of Science' using a pre-defined set of search terms (Appendix C) and all combinations of cause and effect terms. The search and subsequent screening of the initial results resulted in 58 relevant evidence items (Miller et al., 2013). These were added to the Eco Evidence Database, and the evidence was subsequently retrieved by the EEA software for analysis.

3.2.4. Step 6 – revise conceptual model if necessary

Many of the evidence items were from empirical studies that linked inundation of channel features directly to reduced abundance of terrestrial vegetation, and so this was added as an additional link to be tested (bold line, right hand side of Fig. 2).

3.2.5. Step 7 – catalogue and weight the evidence

The EEA software makes this step implicit. As soon as an evidence item is deemed relevant to a hypothesis during Step 5, its evidence weight is recorded either in support of that hypothesis or against it. We used the default evidence weights and threshold (Norris et al., 2012), but if a user wished to change these, they would do so at this stage and provide justification.

3.2.6. Step 8 – the judgement

There was insufficient evidence to reach a conclusion regarding the effect of increased inundation on terrestrial plant reproduction. Regarding the effects of increased inundation on germination, the evidence supported the alternate hypothesis to that posed (i.e. increased inundation would either have no effect on germination rates, or could lead to an increase). The other hypotheses were supported (Table 2). The final judgement in an Eco Evidence analysis regarding the overall question developed at Step 1 requires synthesis of the conclusions for each individual hypothesis (Norris et al., 2012). While not all of our individual hypotheses were supported, our overall assessment was that there was sufficient evidence to conclude that increased flows should prevent encroachment of terrestrial vegetation (Miller et al., 2013).

4. Discussion

Like many scientific disciplines, environmental science is struggling under the weight of a rapidly increasing literature base. Tools are urgently required to summarize the findings of this vast volume of research. The Eco Evidence method and software were developed to perform this function for ecology and environmental science, facilitating systematic review of the literature. Systematic review has been heavily promoted as a valuable tool for research and management in ecology and environmental science (Pullin et al., 2009), but relatively few have been undertaken and published (Pullin and Stewart, 2006). Eco Evidence is the first software developed to aid systematic reviews in environmental science, and the availability of such a tool may encourage researchers and managers to adopt this powerful research method.

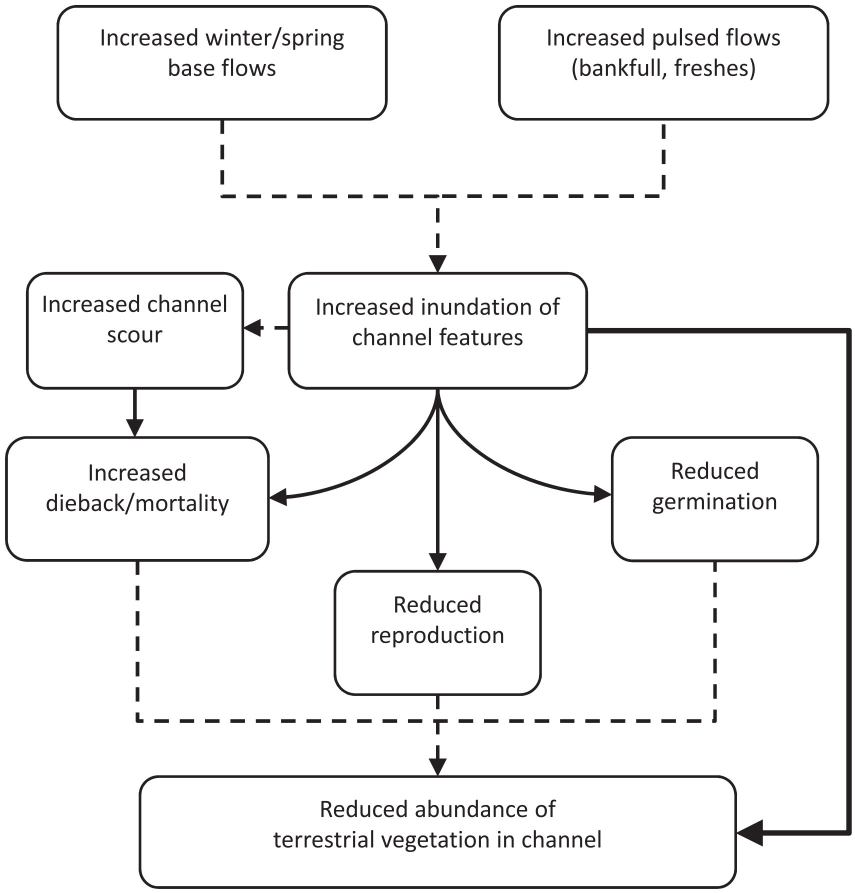

Fig. 2. Conceptual model of the relationship between environmental flows and the reduction of encroachment of riparian vegetation into channels. Our literature review focussed on testing the five cause–effect hypotheses indicated with solid lines. Broken lines represent implied links that were not tested. Reproduced from Miller et al. (2013).

Eco Evidence can be used for both pure and applied purposes; any question of cause and effect in environmental science is suitable for analysis. Indeed, we believe that the set of fields that comprise an evidence item can be used to describe an empirical relationship between a pair of entities in *any* research field. However, to date published reviews have studied ecological responses to human-induced environmental change, mostly ecological impacts of changing riverine and wetland water regimes. In a pure ecology setting, Eco Evidence could be used to test the state of knowledge prior to undertaking experimental research, and can specifically identify knowledge gaps needing to be filled by such research. Conversely, in an applied setting, Eco Evidence could be used to evaluate the evidence for the effectiveness of various management alternatives before making a decision. Such an approach would facilitate the move towards 'evidence-based' management of natural environments.

Table 2
Results of the Eco Evidence analysis of each cause–effect linkage from our conceptual model. Modified from Miller et al. (2013). The summed totals of evidence points that support and refute each hypothesis determine the conclusion. ↑ = 'increased', ↓ = 'decreased'.

Hypothesis tested		Number of evidence items	Summed evidence weights		Conclusion
Cause (flow)	Effect (vegetation)		Supporting hypothesis	Refuting hypothesis	
↑ Scour	↑ Mortality	12	28	10	Support
↑ Inundation	↑ Mortality	10	41	7	Support
↑ Inundation	↓ Reproduction	5	11	10	Insufficient
↑ Inundation	↓ Germination	11	13	24	Alternate
↑ Inundation	↓ Abundance	20	60	13	Support

A key feature of Eco Evidence is the re-usable evidence bank contained within the online database. Evidence extraction is time consuming (Webb et al., 2012a), and the database was developed to reduce the burden of evidence extraction for researchers undertaking reviews. Once an evidence item is entered into the database, it is available for use by any registered user. Applications include updated reviews on a topic previously researched, or use in another review looking at different questions but with some conceptual overlap. The database already contains a valuable collection of evidence items from the set of published (and in preparation) reviews done to date (~1400 evidence items extracted from ~600 citations). For example, the 200 items banked as part of a recent analysis (Webb et al., 2013) of evidence within a previously-published (and extremely influential) review of ecological responses to changes in flow regimes (Poff and Zimmerman, 2010), could be re-used in any updated review of this topic of global significance.

However, for the evidence database to become an immediately useful resource for new reviews over a wide range of topic areas, it needs to be populated to a much greater degree. Currently, evidence is entered by researchers working on specific questions, and so existing database content, and the standard cause–effect terms under which content is organized, are both heavily focused upon specific issues. For new applications, users can request to have new standard terms added to the database, as was first done for Grove et al. (2012). For the actual addition of evidence, we see two main pathways for the larger-scale population of the database (see Ziegler et al., submitted for publication for greater detail).

First, peer production/crowd-sourcing, where study authors and others enter, evaluate, and edit the evidence. Study authors are ideally placed to enter evidence, as they have immediate knowledge of how the study was conducted. Authors (and journals) would be motivated to enter evidence into the database, expecting that such evidence may be used in systematic reviews, thus leading to increased citation of the original paper. Journals may even mandate entry of a paper's evidence into the database, in the same way that an increasing number of journals require authors to publicly archive the data upon which their paper is based. While study authors will easily be able to enter evidence from their own papers, this will be more difficult for others. How much expertise is required to be able to extract evidence from a paper and enter it into the database? Our applications to date have been done by researchers with at least an undergraduate (but more often postgraduate) science degree. However, specific subject expertise has not been necessary in order to adequately extract evidence. Also, anecdotal information from two postgraduate teaching exercises suggests that students are quickly (within an hour of first exposure to the concepts) able to extract coherent evidence on experimental design and replication from publications in completely unfamiliar research domains, and also to use the assessment software.

Second, natural-language-processing (NLP) computer software can ‘read’ text to extract information from papers (Joshi, 1991). NLP is already used for extracting information from medical research literature to improve patient management (Demner-Fushman et al., 2009), and preliminary results suggest that at least some of the information required for an evidence item might be able to be automatically extracted from environmental science literature (Willet et al., 2012, 2013). Individually and working in concert, these techniques would build the Eco Evidence Database through the emerging phenomenon of ‘social computing’ (Fraternali et al., 2012).

Even if the database does grow much larger, we still recommend that users should use it to supplement literature searches conducted outside of Eco Evidence, rather than replacing them. New research is always appearing, and the imprecision of keyword searches of bibliographic databases ensures that a search will not locate every single study relevant to a particular topic (Webb et al., 2012b). Concurrent searches of the Eco Evidence Database and a literature database would show that some percentage of the relevant studies was already in the Eco Evidence Database, and that evidence extraction did not need to be repeated for these papers. The user could then extract evidence from the remaining papers and add it to the database, further building the shared resource for future users. However the database is populated, quality control of the evidence it contains is critical. Different people can have different interpretations of any given evidence item. If this occurs, a user can duplicate an existing evidence item and then revise those fields that he/she disagrees with in the new copy. However, our preliminary assessment of the effect of differing interpretations suggests that it has only a small effect in an Eco Evidence analysis (Webb et al., 2012a). To improve quality control, evidence items in the database could receive user ratings, similar to those on many social media and e-commerce sites. Similarly, management agencies using evidence items might certify those items that have passed some test for quality. Regardless of the methods used, we strongly recommend that anybody undertaking a review check that the evidence they use from the database is an accurate summary of the original research papers.

Readers trust reviews to provide a comprehensive and non-biased summary of the literature on a specific topic. However, there are several ways that reviews can inadvertently provide a misleading view. Several features of Eco Evidence can reduce these potential impacts, and we use two disparate features here as examples. First, by requiring the development of a conceptual model to elucidate testable hypotheses, the reviewer explicitly illustrates the complete context of the system under consideration. Any inadvertent or deliberate omissions (i.e. potential causal hypotheses, important modifying influences) that could bias the outcomes will be visible to a reader. Second, in an evolving research area, novel hypotheses often have little research to support (or refute) them. In an Eco Evidence analysis, such a hypothesis will return a finding of Insufficient Evidence, identifying a lack of knowledge and consequent need for research, rather than being dismissed entirely, something that would be more likely with a traditional review.

Comparisons of Eco Evidence with meta-analysis are inevitable. Meta-analysis is currently seen as the ‘gold standard’ for systematic reviews (CEBC, 2010; Gurevitch and Hedges, 2001). Eco Evidence does not produce an estimate of overall effect size in the same way as meta-analysis, but neither does it require the extraction and standardization of effect size information from the studies assessed. This reduces the workload involved per evidence item used, means that evidence can be extracted and synthesized by users with less experience and training than required by meta-analysis, and also approximately doubles the number of studies that can be included in a review (by allowing the inclusion of studies that do not present the summary statistics necessary for meta-analysis; Greet et al., 2011). In its current form, Eco Evidence formalizes the ‘narrative synthesis’ (CEBC, 2010) of a systematic review, but has fewer limitations and restrictions than meta-analysis.

The release of Eco Evidence Version 1 is expected to drive further development. Existing case studies (Greet et al., 2011; Grove et al., 2012; Webb et al., 2012b) have generated ideas for improving both method and software. With the public release, this list is expected to grow. Potential short-term changes to the software include: an ability to write back to the database from the desktop EEA; an online repository of Eco Evidence reports similar to the library of systematic reviews available from the Collaboration for Environmental Evidence (www.environmentalevidence.org); storing working analysis projects online, allowing multiple users to collaborate on a systematic review, similar to the USEPA's Interactive Conceptual Diagram tool (www.epa.gov/caddis/cd_icds_intro.html); and developing plug-ins to allow the software to download from and export to bibliographic databases and reference management software. Several of these changes would be facilitated by developing a web-based version of the Eco Evidence Analyser, moving away from the desktop-based system. Another option would be to add an application programming interface (API) to the Eco Evidence Database, allowing users to develop their own workflows and ways of interacting with the evidence it contains. Interoperability of the Eco Evidence Database with other databases would also greatly increase the amount of information available to users. The EED already uses a set of database fields in common with those used on the USEPA's ‘CadLit’ evidence database. Moreover, the two databases also use the same standard terms within these fields. This prototype ‘Ecological Exchange Language’ potentially allows evidence exchange between the two databases, opening up the possibility of distributed databases across the world contributing evidence to an assessment (Ziegler et al., submitted for publication). Beyond this, we see the possibility of the simple two-layer standard terms for cause and effects being replaced in future by more nuanced descriptors of cause and effect contained in published ecological ontologies (Madin et al., 2008).

Greater uptake of systematic review methods would be a major change in practice for environmental science, where most reviews are currently written in the narrative format. We do not recommend that systematic reviews are the only type of review that should be done (c.f. Khan et al., 2003). For example, reviews that seek to summarize the state of knowledge on a topic will be more informative if written in the narrative style. However, any review that seeks to test specific hypotheses will benefit from using a systematic method like Eco Evidence.

5. Conclusion

In summary, Eco Evidence provides a method and toolset for ecologists and environmental scientists to summarize and synthesize the literature – specifically to test cause–effect hypotheses. Eco Evidence has thus far been used for applied purposes, but can also potentially be used for pure research questions. This is the first software designed to facilitate systematic reviews in ecology and environmental science. The open-access evidence database provides a unique resource designed to reduce the burden of evidence extraction for users, and the analysis module provides a standardized framework for synthesizing the evidence to reach conclusions. We expect both method and software to evolve over time, but the existing version is sufficiently well developed for immediate use.

Acknowledgements

We salute the pioneering efforts of the late Professor Richard Norris in the development of the Eco Evidence method. Development of the Eco Evidence software was funded by the eWater Cooperative Research Centre (projects B1 'Multiple drivers of river ecosystems', R2 'Ecological modelling platform', and 'Ecological management'), with most of the programming for the Eco Evidence Analyser completed by Patrick Lea. This paper was funded by Australian Research Council project LP100200170 and the MDBfutures Collaborative Research Network project 'Using an evidence-based approach in the optimisation of water allocation decisions'). Author contributions: J.A.W., M.J.S., S.J.N developed the Eco Evidence method. S.R.W. developed the Eco Evidence Database and the workflow therein, and contributed to programming of the Eco Evidence Analyser. J.A.W. led writing of the manuscript, with K.A.M. providing the case-study application of Eco-Evidence and S.C.dL providing the section on the Eco Evidence Database. All authors contributed to the final version.

Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.envsoft.2014.11.011.

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