An evidence assessment tool for ecosystem services and conservation studies

Anne-Christine Mupepele [1 2] & Jessica C. Walsh [3] & William J. Sutherland[3] & Carsten F. Dormann[1]

[1] Department of Biometry and Environmental System Analysis, University of Freiburg, Tennenbacherstr. 4, 79106 Freiburg, Germany
[2] anne-christine.mupepele@biom.uni-freiburg.de
[3] Department of Zoology, University of Cambridge, Downing Street, Cambridge, CB2 3EJ, UK.

Abstract

Reliability of scientific findings is important, especially if they directly impact decision making, such as in environmental management. In the 1990s, assessments of reliability in the medical field resulted in the development of evidence-based practice. Ten years later, evidence-based practice was translated into conservation, but so far no guidelines exist on how to assess the evidence of individual studies. Assessing the evidence of individual studies is essential to appropriately identify and synthesize the confidence in research findings. We develop a tool to assess the strength of evidence of ecosystem services and conservation studies. This tool consists of (1) a hierarchy of evidence, based on the experimental design of studies and (2) a critical-appraisal checklist that identifies the quality of research implementation. The application is illustrated with 13 examples and we suggest further steps required to move towards more evidence-based environmental management.

Keywords: governance - quality checklist - quantification - rigour - valuation

Conservation and ecosystem services studies are important scientific sources for decision-makers seeking advice on environmental management (Daily and Matson, 2008; Kareiva and Marvier, 2012). Their results potentially influence actions and it is therefore crucial to assess transparently the reliability of current research and its recommendations (Pullin and Knight, 2003; Boyd, 2013).

Evidence-based practice was introduced in the medical field aiming to assess the reliability of scientific statements and identify the best available information to answer a question of interest (Sackett *et al.*, 1996; GRADE Working Group, 2004; OCEBM Levels of Evidence Working Group, 2011, Cochrane Collaboration - www.cochrane.org). In conservation, evidence-based practice was first mentioned 15 years ago (Sutherland, 2000; Pullin and Knight, 2001). Today, the 'Collaboration for Environmental Evidence' (www.environmentalevidence.org) fosters the creation of systematic reviews to collate the strongest possible evidence (Petrokofsky *et al.*, 2011; Collaboration for Environmental Evidence, 2013, see also *Journal for Environmental Evidence*), together with 'Conservation Evidence' (www.conservationevidence.org), which focuses on the development of summaries and guidelines, and the communication of evidence to practitioners (Sutherland *et al.*, 2012; Dicks *et al.*, 2014). Summaries, contrary to systematic reviews, do not focus on a specific question but bring together information from a much broader topic, e.g. from a whole animal group, such as bees (Dicks *et al.*, 2010, 2014; Walsh *et al.*, 2015).

Systematic reviews and summaries compile individual studies and therefore require the evaluation of the evidence at the level of the individual study. In systematic reviews this is typically mentioned as one step of the critical appraisal. However, to date such critical appraisal is often implicit, based on criteria varying for every systematic review (Collaboration for Environmental Evidence, 2013; Carroll and Booth, 2015; Stewart and Schmid, 2015). We therefore introduce an evidence assessment tool providing a clear appraisal guideline to score the reliability of individual studies.

Evidence assessment tool

A well-defined terminology is essential for effective communication between practitioners and scientists. **Evidence** is the 'ground for belief' or 'the available body of information indicating whether a belief or proposition is true or valid' (Howick, 2011, OED Online, Oxford University Press, September 2015; Oxford Dictionaries: www.oxforddictionaries.com/definition/english/evidence). Evidence describes the knowledge behind a statement and expresses how solid our recommendations are (see also Higgs and Jones 2000, p.311; Rychetnik *et al.* 2001; Lohr 2004; Binkley and Menyailo 2005; Pullin and Knight 2005). The **strength of evidence** reflects the reliability of information and we can identify whether a statement is based on **strong or weak evidence**, i.e. very reliable or hardly reliable. Hence **evidence-based practice** means to *identify* the reliability of current knowledge, based on research integrated with expertise, and to *act* according to this best available knowledge. The collation and appraisal of the best available evidence follow strict criteria to ensure transparency and to reduce bias. A goal of evidence-based practice is to act on best available evidence while being aware of the strength of inference this evidence permits (Howick, 2011, p.15).

1. Setting question and context

The formulation of a clear research question and the purpose of investigation is highly emphasized throughout the evidence literature (Higgins and Green, 2011; Collaboration for Environmental Evidence, 2013, p.20-23). Questions should specify *which* ecosystem service, species or aspect of biodiversity will be investigated in *which* system, as this will help to determine the external validity of the answer provided in a study.

We further recommend to determine the focus of the question, as either 'quantification', 'valuation', 'management' or 'governance'. **Quantification** studies measure the amount of an ecosystem service, species abundance, biodiversity or other conservation targets. Measures can be taken in absolute units or relative to another system. **Valuation** studies assess the societal value of ecosystem services. The most common way is monetary valuation. **Management** is the treatment designed to improve or benefit specific ecosystem services, target species or other conservation aspects. For example: leaving dead wood in forests to increase biodiversity, or reducing agricultural fertiliser to decrease nearby lake eutrophication. **Governance** is seen as the strategy or policy to steer a management intervention, such as REDD (Reducing Emissions from Deforestation and Forest Degradation), which aims to encourage forest protection and reforestation (Kenward *et al.*, 2011). The strategies used by policy makers include incentives (subsidiaries) or penalties (law/tax; see also Bevir, 2012). When the effectiveness of management and governance strategies is determined, evidence-based quantification or valuation is required to measure the outcome of the management or governance intervention. Acuña *et al.* (2013), for example, used valuation methods to determine success or failure of a management strategy while Walsh *et al.* (2012) quantified malleefowl abundance through monitoring survey data to assess the management impact of fox baiting. The distinction of four different foci is essential to assess the whole range of environmental management.

We have described how to set the context of questions that can be useful in environmental management. Once the question has been determined, and the investigation carried out, the strength of the resulting evidence should be assessed (Fig. 1).

2. Evidence assessment

The reliability of a study is characterized by its study design and the quality of its implementation. Both are evaluated in the evidence assessment.

2a. Evidence hierarchy

The study design refers to the set-up of the investigation, e.g. controlled or observational design (GRADE Working Group, 2004). These study designs are not equally compelling with respect to inferring causality. Differences in study designs typically translate into weak or strong evidence. To identify the reliability of a study, study designs can be ranked hierarchically according to a level-of-evidence scale, hence forth the evidence hierarchy (Fig. 2).

Systematic reviews (LoE1a) are at the top of the evidence hierarchy and provide the most reliable information. They summarize all information collated in several individual studies, have an *a priori* protocol on design and procedure, and are conducted according to strict guidelines (e.g. Collaboration for Environmental Evidence, 2013). If possible, they ideally include quantitative measures, i.e. a meta-analysis (see Koricheva *et al.*, 2013; Vetter *et al.*, 2013). All other, non-systematic and more **conventional reviews (LoE1b)** may also include quantitative analysis or are purely qualitative. Both types of review summarize the findings of several studies, but systematic reviews assess the completeness and reproducibility more carefully and strive to reduce bias by having transparent, thorough, pre-defined methods (Freeman *et al.*, 2006; Higgins and Green, 2011; Collaboration for Environmental Evidence, 2013; Haddaway and Bayliss, 2015; Haddaway and Bilotta, 2015).

The necessary condition for any review is that appropriate individual studies are available. The most reliable individual study design is **a study with a reference/control (LoE2)**. Typically, these are case-control or before-after control-impact studies **(LoE2a)** (Smith *et al.*, 2014). Investigations that cannot follow such a controlled design may alternatively seek to gain strong evidence through multiple lines of moderate evidence **(LoE2b)**. Multiple lines of evidence require at least two unrelated and consistent arguments to confirm the study conclusions, thereby forming a non-contradicting picture (see also Smith *et al.*, 2002). Illustrative examples are the valuation of ecosystem services (e.g. Mogas *et al.*, 2006), or long-term environmental processes that are difficult to control (e.g. Dorman *et al.*, 2015). Multiple lines of evidence can be collected in individual studies using different approaches within one study context (LoE2b, LoE3c) or in reviews (LoE1) including evidence from different studies.

Observational studies (LoE3) are individual studies without a control. These include studies employing inferential and correlative statistics **(LoE3a)**, e.g. testing for the influence of environmental variables on the quantity of an ecosystem service. Descriptive studies **(LoE3b)** imply data collection and representation without statistical testing (e.g. data summaries, ordinations, histograms, surveys). Multiple lines of weak evidence **(LoE3c)** can increase the evidence of LoE4 investigations; elicitation of independent expert opinions is a currently well-known example (Sutherland *et al.*, 2013; Morgan, 2014; Smith *et al.*, 2015; Sutherland and Burgman, 2015, see also Appendix).

The lowest level of evidence are statements **without underlying data (LoE4)**. These are usually individual expert opinions, often not distinguishable from randomness (Tetlock, 2005; Drolet *et al.*, 2015). Other statements without underlying data are reasoning based on mechanism. Mechanism-based reasoning involves an inferential chain linking an intervention to the outcome (Howick *et al.*, 2010; Howick, 2011). If this chain of mechanisms is not supported by data, there is no possibility to assess whether all relevant mechanisms linking the intervention to the outcome have been included. Mechanism-based reasoning without corroborative data provides only weak evidence. On the other hand, mechanism-based reasoning can result in a model that is validated and tested on real world data. With such a data validation, the model could reach moderate evidence or strong evidence, depending on the underlying study design.

It is important to note that 'method' and 'design' should not be confused. Methods are the means used to collect or analyse data, e.g. remote sensing, questionnaires, ordination techniques. Design reflects how the study was planned and conducted, e.g. a case-control or observational design (GRADE Working Group, 2004). The same methods can be employed for different underlying designs. Remote sensing for example can be done purely descriptively (LoE3b) or with a reference such as ground-truthing or in a 'before-and-after' design (LoE2a). Analogously, models can represent theories without supporting data (LoE4), involve data input to determine parameters (LoE3b) or be tested and validated (LoE3a). To achieve strong evidence, model predictions have to be confirmed by several unrelated data sets forming a non-contradicting picture (LoE2b), or should be built on information derived from controlled studies unequivocally identifying the underlying causal mechanism (LoE2a; Kirchner, 2006).

2b. Critical appraisal

Study design alone is an inadequate marker of the strength of evidence (Rychetnik *et al.*, 2001). A study with a strong-evidence design may be poorly conducted. The critical appraisal assesses the implementation of the study design, specifically the methodological quality, the actual realization of the study design and its reporting (Higgins and Green, 2011). It identifies the study quality and may lead to a downgrading in the evidence hierarchy. **Quality**, in this context, is the extent to which all aspects of conducting a study can be shown to protect against bias, and inferential error (Lohr, 2004). Quality checklists can be used to detect bias and inferential error. Combining 30 published quality checklists, we provide the first quality checklist for conservation and ecosystem services (Appendix Table 1), that can be used to comprehensively assess the internal validity of a study, covering questions on data collection, analysis and the presentation of results. The checklist consists of 43 questions, of which some apply only to a specific context, e.g. for reviews or only studies focusing on valuation. All questions answered with ‘yes’ receive one point. In the case of non-reported issues, we advise the answer ‘no’ to indicate a deficient reporting quality. The percentage of points received can help to decide whether to downgrade the level of evidence (Appendix Table 2).

Reviews provide information at the highest level of evidence and their critical appraisal is different from other designs, because they are based on studies with weaker evidence (see Appendix Table 1: Review). Every single study included in the review can be assessed for its level of evidence, using the evidence hierarchy and the checklist for quality criteria. If only studies based on weak evidence were included, then the review should be downgraded, regardless of other quality criteria. In addition, a review can be assessed for other quality shortcomings using again the quality checklist.

The checklist should make the assessment more transparent, but we are aware that the process may not always be straightforward. Questions in the checklist can be subjective and depend on the judgment of the assessor. Cohen's kappa test was used to test the agreement in 13 exemplary studies between two different assessors (Appendix Table 3). It ranges from 0 to 1, representing random to perfect agreement. Our result revealed a moderate agreement (unweighted Cohen's kappa $= 0.49$; p-value < 0.001. Landis and Koch, 1977; Cohen, 1960; Gamer *et al.*, 2015). Depending on the context, the assessor may decide to give more weight to particular questions or add questions to the checklist. Although the procedure cannot be fully standardized, we are not aware of a better alternative, and we encourage the use of the checklist as a baseline that can be adapted for specific studies.

The combination of study design (Fig. 2) and quality criteria (Appendix Table 1) is the last step and identifies the strength of evidence supporting the study result (schematic representation in Fig. 1). The level of evidence derived by the study design should be downgraded depending on the quality score calculated from the quality checklist (Appendix Table 2).

Application of the evidence assessment tool

The suggested method was applied to assess the evidence of 13 studies (Appendix Table 3). They were selected to serve as examples and illustrate the applicability of the tool to the whole range of study designs and foci. The first example was a management-related systematic review of Mant *et al.* (2013), conducted according to the guidelines of the Collaboration for Environmental Evidence (2013). They investigated the effect of 'liming' rivers or lakes on fish and invertebrate populations. They found that liming increased fish abundances and acid-sensitive invertebrates, but may have a negative impact on the abundance of all invertebrate taxa combined. According to the critical appraisal the study achieved 21 out of 24 points (88%) and it therefore remained at the originally assigned LoE1a, the highest level of evidence (Appendix Table 3).

A second example tackles the question: 'How does adding dead wood to rivers influence the provision of ecosystem services?' (Acuña *et al.*, 2013). The authors investigated two ecosystem services (fishing and retention of organic and inorganic matter) in a river-forest ecosystem in Spain and Portugal and studied the effect of this management intervention. Their study design followed a before-after control-impact approach, equivalent to LoE2a. The critical appraisal revealed shortcomings, e.g. no blinding, no randomization and no probability sampling: only 17 out of 25 points (68%) were achieved. The level of evidence was downgraded by one level to LoE3a. We therefore conclude that the statement made by Acuña *et al.* (2013): 'restoration of natural wood loading in streams increases the ecosystem service provision' is based on moderate evidence (LoE3a).

We provide further examples in the Appendix (Appendix Table 3 and 4, GitHub: https://github.com/biometry/EvidenceAssessmentTool/blob/master/Examples.xlsx). All but one study revealed quality shortcomings and had to be downgraded. Most were scored as LoE3 or LoE4.

Relevance for different user groups

In the previous section it was elaborated *how* to assess the strength of evidence for individual studies and reviews. Now we provide a few notes on *who* should use it:

1. Scientists conducting their own studies have to be aware of how to achieve strong evidence, particularly during the planning phase. Choosing a study design that provides strong evidence and respects the quality criteria will substantially increase the potential contribution to our knowledge.

2. Scientists advising decision-makers should be explicit about the strength of evidence of information they include in their recommendations. Weighting all scientific information equally, or subjectively, runs the risk of overconfidence and bias.

3. Decision-makers receiving information from scientists should demand a level-of-evidence statement for the information provided. Alternatively, they can assess the strength of evidence themselves. However, this may be difficult as it takes time and requires some scientific training to identify the study design and evaluate the quality questions.

4. We further encourage **consortia, international panels and learned societies**, such as the Intergovernmental Platform on Biodiversity & Ecosystem Services (IPBES), the Ecological Societies (ESA, BES, GFÖ and others), the Society for Conservation Biology (SCB) and the Ecosystem Services Partnership (ESP) to support the development of guidelines, that include an evidence assessment (Graham *et al.*, 2011; Sutherland *et al.*, 2015). These 'best-practice guides' are based on the collection of scientific evidence synthesized and judged by a group of experts. They provide recommendations on how to best quantify, value, manage or govern a desired ecosystem service or conservation target, giving decision-makers transparent advice with an emphasis on the strength of the evidence available (for examples of equivalent Clinical Guidelines see www.guideline.gov (USA), www.ncgc.ac.uk (UK), www.awmf.org/leitlinien (Germany)).

Discussion

We have outlined an evidence assessment tool for ecosystem services and conservation studies, encompassing a hierarchy to judge the available evidence based on study design and a quality checklist to facilitate critical appraisal. We have further illustrated with examples how to apply the tool (see also Appendix Table 3 and 4).

Evidence-based practice seeks to complement existing management frameworks, by emphasizing the importance of systematically collating the existing scientific evidence and assessing it for its reliability and relevance. The IPCC report, for example, uses a combined measure of evidence and level of agreement (Mastrandrea *et al.*, 2010; Spiegelhalter and Riesch, 2011). Our suggested approach is more detailed, describing *how* one can actually assess the evidence.

Evidence-based practice has faced criticism of its evidence hierarchies, claiming that controlled trials are not always more reliable than observational studies. A main argument against hierarchies is that they are rigid and only consider the study design to assign a level of evidence (Petticrew and Roberts, 2003; Adams and Sandbrook, 2013; Stegenga, 2014). With our quality checklist we emphasize the critical appraisal to check for an appropriate implementation and methodological quality of study designs. The proposed assessment therefore does not overestimate the results of deficiently implemented meta-analyses and controlled studies. Some science sectors have to rely on observational studies, because their study units cannot be controlled. This usually applies to environmental governance, conservation biology of rare species, or global theories that lack a second earth as a control. Multiple lines of evidence can lead to strong evidence using only observational study designs (Fig. 2, LoE2b). However, a central task of natural science is to determine causal relationships, and observational studies do not have the same strength to determine causal relationships than replicated and randomized case-control studies (Holland, 1986; Grimes and Schulz, 2002; Illari *et al.*, 2011). We should acknowledge that in some areas of science causality cannot be established, and hence the reliability achieved remains lower than in areas where it can.

Other criticism has been directed towards the fact that every system is unique and the external validity of studies is low. We are aware that generalizability of results is problematic in ecosystems, where many different drivers take influence at the same time and hence the general evidence may not apply due to particular circumstances. At this point the judgment of experts on the external validity of the currently best available evidence is irreplacable (Karanicolas *et al.*, 2008; Howick, 2011). Evidence-based practice means integrating individual expertise with the best available evidence from systematic research (Sackett *et al.*, 1996; Straus *et al.*, 2010). More reflection and responses to criticism of evidence-based practice can be found in Mullen and Streiner (2004), Sutherland *et al.* (2004, 2005) and Haddaway and Pullin (2013).

Despite the criticism raised against evidence-based practice the benefits are clear (Gilbert *et al.*, 2005; Howick, 2011; Walsh *et al.*, 2014, 2015). Rating the strength of evidence matters as it clarifies the reliability of research results and, thus, the strength of conclusions, decisions, or recommendations drawn from that research (Lohr, 2004).

Reliable scientific evidence in environmental management is pivotal, and its use (or misuse) can have immense impacts on environmental outcomes and the society. It is essential that scientists and decision makers consider the strength of evidence when conducting studies, provding advice and taking decisions. In the interest of responsible use of environmental resources and processes, we strongly encourage embracing evidence-based practice as a paradigm for all research contributing to environmental management.

Acknowledgements

We thank Andrew Pullin, Sven Lautenbach and Ian Bateman for valuable comments on earlier versions of the manuscript. This work was supported by the 7th framework programme of the European Commission in the project OPERAs (grant number 308393, www.operas-project.eu).

References

Acuña V, Díez JR, Flores L, *et al.* 2013. Does it make economic sense to restore rivers for their ecosystem services? *Journal of Applied Ecology* **50**: 988–997.

Adams WM and Sandbrook C. 2013. Conservation, evidence and policy. *Oryx* **47**: 329–335.

Bevir M. 2012. Governance: A Very Short Introduction. Oxford University Press.

Binkley D and Menyailo O. 2005. Gaining insights on the effects of tree species on soils. In: Tree Species Effects on Soils: Implications for Global Change, chapter 1, 1–16. Dordrecht: Kluwer Academic Publishers.

Boyd I. 2013. A standard for policy-relevant science. *Nature* **501**: 159–160.

Carroll C and Booth A. 2015. Quality assessment of qualitative evidence for systematic review and synthesis: Is it meaningful, and if so, how should it be performed? *Research Synthesis Methods* **6**: 149–154.

Cohen J. 1960. A coefficient of agreement for nomial scales. *Educational and psychological measurement* **20**: 37–46.

Collaboration for Environmental Evidence. 2013. Guidelines for Systematic Review and Evidence Synthesis in Environmental Management. Version 4.2. Environmental Evidence. URL www.environmentalevidence.org/Documents/Guidelines/Guidelines4.2.pdf.

Daily GC and Matson PA. 2008. Ecosystem services: from theory to implementation. *Proceedings of the National Academy of Sciences* **105**: 9455–9456.

Dicks LV, Showler DA, and Sutherland WJ. 2010. Bee conservation: evidence for the effects of interventions. Pelagic Publishing.

Dicks LV, Walsh JC, and Sutherland WJ. 2014. Organising evidence for environmental management decisions: a '4S' hierarchy. *Trends in Ecology & Evolution* **29**: 1–7.

Dorman M, Svoray T, Perevolotsky A, *et al.* 2015. What determines tree mortality in dry environments? a multi-perspective approach. *Ecological Applications* **25**: 1054–1071.

Drolet D, Locke A, Lewis MA, and Davidson J. 2015. Evidence-based tool surpasses expert opinion in predicting probability of eradication of aquatic nonindigenous species. *Ecological Applications* **25**: 441–450.

Freeman SR, Williams HC, and Dellavalle RP. 2006. The increasing importance of systematic reviews in clinical dermatology research and publication. *The Journal of investigative dermatology* **126**: 2357–2360.

Gamer M, Lemon J, Fellows I, and Singh P. 2015. The irr package for R: various coefficients of interrater reliability and agreement.

Gilbert R, Salanti G, Harden M, and See S. 2005. Infant sleeping position and the sudden infant death syndrome: systematic review of observational studies and historical review of recommendations from 1940 to 2002. *International Journal of Epidemiology* **34**: 874–87.

GRADE Working Group. 2004. Grading quality of evidence and strength of recommendations. *BMJ* **328**: 1–8.

Graham R, Mancher M, Wolmann DM, *et al.* 2011. Clinical Practice Guidelines We Can Trust. Washington, DC: The National Academies Press.

Grimes DA and Schulz KF. 2002. Descriptive studies: what they can and cannot do. *Lancet* **359**: 145–149.

Haddaway NR and Bayliss HR. 2015. Clarification on the applicability of systematic reviews. *Frontiers in Ecology and the Environment* **13**: 129–129.

Haddaway NR and Bilotta GS. 2015. Systematic reviews: Separating fact from fiction. *Environment International* **(in press)**.

Haddaway NR and Pullin AS. 2013. Evidence-based conservation and evidence-informed policy: a response to Adams & Sandbrook. *Oryx* **47**: 336–338.

Higgins JPT and Green S. 2011. Cochrane Handbook for Systematic Reviews of Interventions. Version 5.1.0. [updated March 2011]. The Cochrane Collaboration.

Higgs J and Jones M. 2000. Will evidence-based practice take the reasoning out of practice? In: Higgs J and Jones M (Eds.) Clinical Reasoning in the Health Professionals, 307–315. Oxford: Butterworth Heineman, 2 edition.

Holland PW. 1986. Statistics and causal inference. *Journal of the American Statistical Association* **81**: 945–960.

Howick J. 2011. The Philosophy of Evidence-Based Medicine. Oxford, UK: Wiley-Blackwell.

Howick J, Glasziou P, and Aronson JK. 2010. Evidence-based mechanistic reasoning. *Journal of the Royal Society of Medicine* **103**: 433–441.

Illari PM, Russo F, and Williamson J. 2011. Causality in the Sciences. Oxford University Press.

Karanicolas PJ, Kunz R, and Guyatt GH. 2008. Evidence-based medicine has a sound scientific base. *CHEST* **133**: 1067.

Kareiva P and Marvier M. 2012. What is conservation science? *BioScience* **62**: 962–969.

Kenward RE, Whittingham MJ, Arampatzis S, *et al.* 2011. Identifying governance strategies that effectively support ecosystem services, resource sustainability, and biodiversity. *Proceedings of the National Academy of Sciences* **108**: 5308–5312.

Kirchner JW. 2006. Getting the right answers for the right reasons: linking measurements, analyses, and models to advance the science of hydrology. *Water Resources Research* **42**: 1–5.

Koricheva J, Gurevitch J, and Mengersen K. 2013. Handbook of Meta-analysis in Ecology and Evolution. Princeton University Press.

Landis JR and Koch GG. 1977. The measurement of observer agreement for categorical data. *Biometrics* **33**: 159–174.

Lohr KN. 2004. Rating the strength of scientific evidence: relevance for quality improvement programs. *International Journal for Quality in Health Care* **16**: 9–18.

Mant RC, Jones DL, Reynolds B, *et al.* 2013. A systematic review of the effectiveness of liming to mitigate impacts of river acidification on fish and macro-invertebrates. *Environmental Pollution* **179**: 285–293.

Mastrandrea M, Field C, Stocker TF, *et al.* 2010. Guidance note for lead authors of the IPCC fifth assessment report on consistent treatment of uncertainties.

Mogas J, Riera P, and Bennett J. 2006. A comparison of contingent valuation and choice modelling with second-order interactions. *Journal of Forest Economics* **12**: 5–30.

Morgan MG. 2014. Use (and abuse) of expert elicitation in support of decision making for public policy. *Proceedings of the National Academy of Sciences* **111**: 7176–7184.

Mullen EJ and Streiner DL. 2004. The evidence for and against evidence-based practice. *Brief Treatment and Crisis Intervention* **4**: 111–121.

OCEBM Levels of Evidence Working Group. 2011. The Oxford Levels of Evidence 1. URL http://www.cebm.net/index.aspx?o=5653.

Petrokofsky G, Holmgren P, and Brown ND. 2011. Reliable forest carbon monitoring-systematic reviews as a tool for validating the knowledge base. *International Forestry Review* **13**: 56–66.

Petticrew M and Roberts H. 2003. Evidence, hierarchies, and typologies: horses for courses. *Theory and Methods* **57**: 527–529.

Pullin AS and Knight TM. 2001. Effectiveness in conservation practice: pointers from medicine and public health. *Conservation Biology* **15**: 50–54.

Pullin AS and Knight TM. 2003. Support for decision making in conservation practice: an evidence-based approach. *Journal for Nature Conservation* **11**: 83–90.

Pullin AS and Knight TM. 2005. Assessing conservation management's evidence base: a survey of management-plan compilers in the United Kingdom and Australia. *Conservation Biology* **19**: 1989–1996.

Rychetnik L, Frommer M, Hawe P, and Shiell A. 2001. Criteria for evaluation evidence on public health interventions. *Journal of Epidemiology and Community Health* **56**: 119–127.

Sackett DL, Rosenberg WMC, Gray JAM, *et al.* 1996. Evidence based medicine: what it is and what it isn't. *Clinical Orthopaedics and Related Research* **455**: 3–5.

Smith EP, Lipkovich I, and Ye K. 2002. Weight-of-Evidence (WOE): quantitative estimation of probability of impairment for individual and multiple lines of evidence. *Human and Ecological Risk Assessment: An International Journal* **8**: 1585–1596.

Smith RK, Dicks LV, Mitchell R, and Sutherland WJ. 2014. Comparative effectiveness research: the missing link in conservation. *Conservation Evidence* **11**: 2–6.

Smith SDP, McIntyre PB, Halpern BS, *et al.* 2015. Rating impacts in a multi-stressor world: a quantitative assessment of 50 stressors affecting the Great Lakes. *Ecological Applications* **25**: 717–728.

Spiegelhalter DJ and Riesch H. 2011. Don't know, can't know: embracing deeper uncertainties when analysing risks. *Philosophical Transactions of the Royal Society A* **369**: 4730–50.

Stegenga J. 2014. Down with the hierarchies. *Topoi* **33**: 313–322.

Stewart GB and Schmid CH. 2015. Lessons from meta-analysis in ecology and evolution: the need for trans-disciplinary evidence synthesis methodologies. *Research Synthesis Methods* **6**: 109–110.

Straus SE, Glasziou P, Richardson WS, and Haynes RB. 2010. Evidence-Based Medicine: How to Practice and Teach It, 4e (Straus, Evidence-Based Medicine). Churchill Livingstone.

Sutherland WJ. 2000. The Conservation Handbook: Research, Management and Policy. Blackwell Science Ltd.

Sutherland WJ and Burgman MA. 2015. Use experts wisely. *Nature* **526**: 317.

Sutherland WJ, Dicks LV, and Smith RK. 2015. What Works in Conservation? Lessons from Conservation Evidence. OpenBooks, Cambridge.

Sutherland WJ, Gardner TA, Haider LJ, and Dicks LV. 2013. How can local and traditional knowledge be effectively incorporated into international assessments? *Oryx* **48**: 1–2.

Sutherland WJ, Mitchell R, and Prior SV. 2012. The role of 'Conservation Evidence' in improving conservation management. *Conservation Evidence* **9**: 1–2.

Sutherland WJ, Pullin AS, Dolman PM, and Knight TM. 2004. Response to Griffiths. Mismatches between conservation science and practice. *Trends in Ecology & Evolution* **19**: 565–566.

Sutherland WJ, Pullin AS, Dolman PM, and Knight TM. 2005. Response to Mathevet and Mauchamp: Evidence-based conservation: dealing with social issues. *Trends in Ecology & Evolution* **20**: 424–425.

Tetlock PE. 2005. Expert Political Judgment: How Good Is It? How Can We Know? Princeton University Press.

Vetter D, Rücker G, and Storch I. 2013. Meta-analysis: A need for well-defined usage in ecology and conservation biology. *Ecosphere* **4**.

Walsh JC, Dicks LV, and Sutherland WJ. 2014. The effect of scientific evidence on conservation practitioners' management decisions. *Conservation Biology* **00**: 1–11.

Walsh JC, Dicks LV, and Sutherland WJ. 2015. The effect of scientific evidence on conservation practitioners management decisions. *Conservation Biology* **29**: 88–98.

Walsh JC, Wilson KA, Benshemesh J, and Possingham HP. 2012. Integrating research, monitoring and management into an adaptive management framework to achieve effective conservation outcomes. *Animal Conservation* **15**: 334–336.

Appendix A

The appendix provides details and examples for the application of the evidence assessment tool. The quality checklist is given in Table 1. Table 2 guides the downgrading of the level of evidence according to the quality score. We further present the evidence assessment of all 13 examples, together with the detailed quality checklist filled in for each study (also available on GitHub: https://github.com/biometry/EvidenceAssessmentTool/blob/master/Examples.xlsx).

Figure Legends

Figure 1: Schematic representation of the evidence assessment tool: 1. Identification of study question, design and outcome. 2. Assessing a level of evidence based on the underlying study design and calculating the quality score based on the quality checklist. 3. Determine the final level of evidence supporting the outcome by downgrading the originally assigned level of evidence according to the quality score.

Figure 2: Level-of-evidence (LoE) hierarchy ranking study designs according to their evidence. Very strong evidence (LoE1) to weak evidence (LoE4) with internally ranked sublevels a, b and c.

518 **Figure 1**

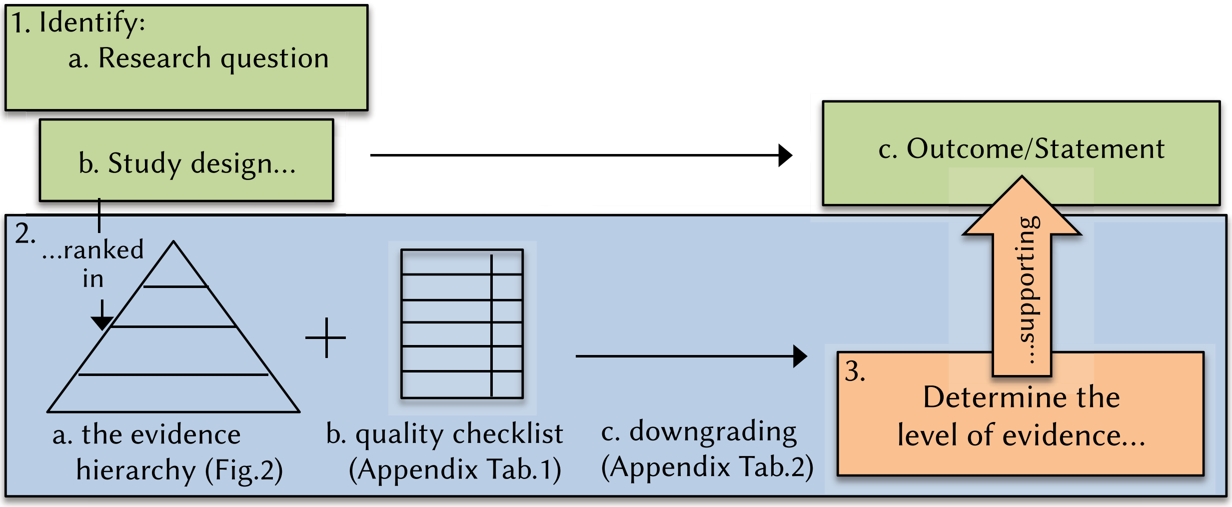
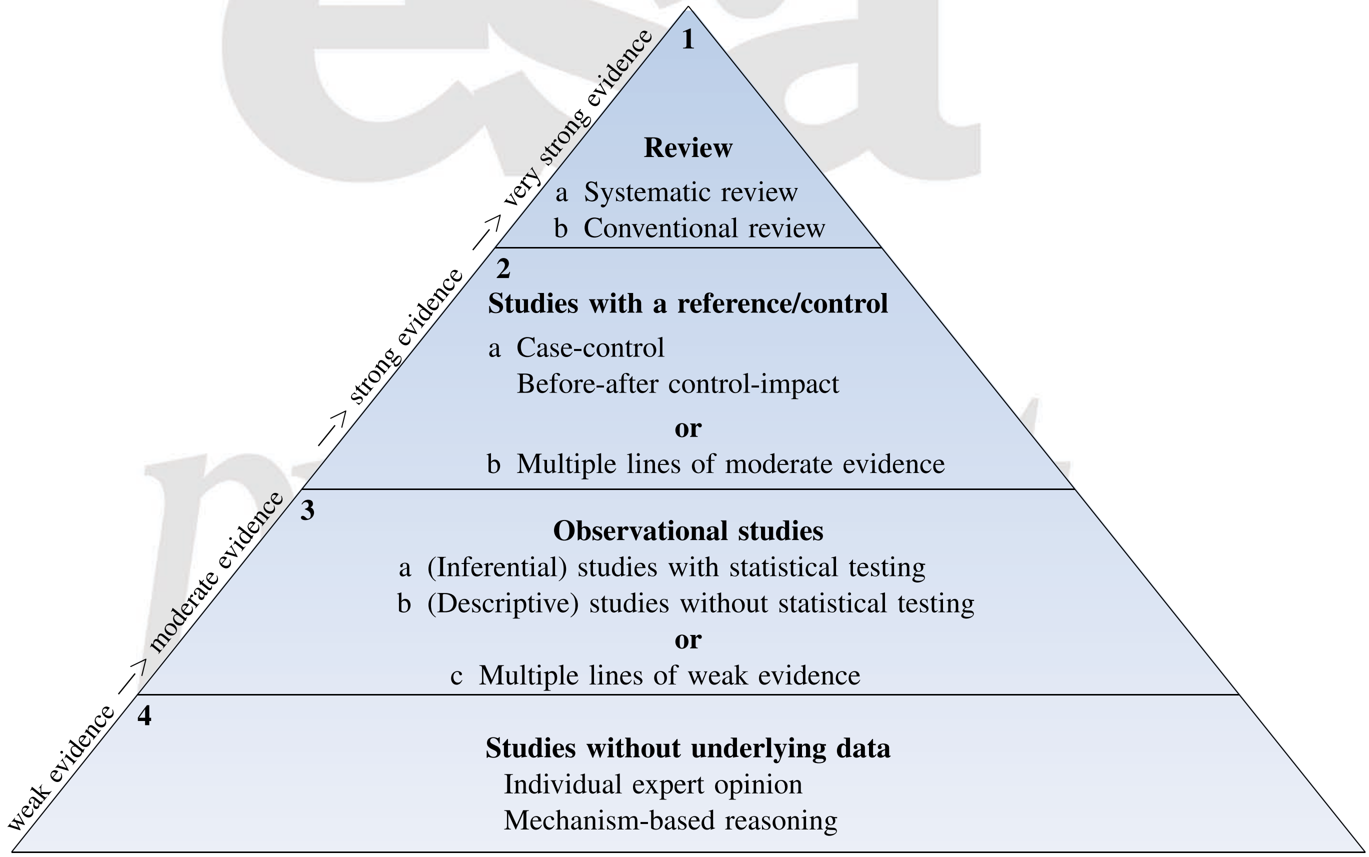

1. Identify:
a. Research question
b. Study design...
c. Outcome/Statement
2.
...ranked in
a. the evidence hierarchy (Fig.2)
b. quality checklist (Appendix Tab.1)
c. downgrading (Appendix Tab.2)
...supporting
3.
Determine the level of evidence...

Figure 2


weak evidence —> moderate evidence —> strong evidence —> very strong evidence
1
Review
a Systematic review
b Conventional review
2
Studies with a reference/control
a Case-control
Before-after control-impact
or
b Multiple lines of moderate evidence
3
Observational studies
a (Inferential) studies with statistical testing
b (Descriptive) studies without statistical testing
or
c Multiple lines of weak evidence
4
Studies without underlying data
Individual expert opinion
Mechanism-based reasoning