Behavioral Ecology

The official journal of the
ISBE
International Society for Behavioral Ecology

Behavioral Ecology (2019), 30(1), 1–8. doi:10.1093/beheco/ary130

Invited Review

Systematic reviews and maps as tools for applying behavioral ecology to management and policy

Oded Berger-Tal,[a,*,†] Alison L. Greggor,[b,*] Biljana Macura,[c] Carrie Ann Adams,[d] Arden Blumenthal,[e] Amos Bouskila,[a,f] Ulrika Candolin,[g] Carolina Doran,[h] Esteban Fernández-Juricic,[e] Kiyoko M. Gotanda,[i] Catherine Price,[j] Breanna J. Putman,[k,l] Michal Segoli,[a] Lysanne Snijders,[h] Bob B.M. Wong,[m] and Daniel T. Blumstein[l]

[a]Mitrani Department of Desert Ecology, Ben-Gurion University of the Negev, 8499000 Midreshet Ben Gurion, Israel, [b]Institute for Conservation Research, San Diego Zoo Global, Escondido, CA, USA, [c]Mistra EviEM, Stockholm Environment Institute, 87D Linnégatan, Stockholm 10451, Sweden, [d]Department of Biological Sciences, University of Alberta, Edmonton, AB, Canada, [e]Department of Biological Sciences, Purdue University, West Lafayette, IN, USA, [f]Department of Life Sciences, Ben-Gurion University of the Negev, 8410501 Beer-Sheva, Israel, [g]Department of Biosciences, University of Helsinki, 00014 Helsinki, Finland, [h]Department of Biology and Ecology of Fishes, Leibniz-Institute of Freshwater Ecology and Inland Fisheries, Müggelseedamm 310, 12587 Berlin, Germany, [i]Department of Zoology, University of Cambridge, Cambridge, United Kingdom, CB2 3EJ, [j]School of Life and Environmental Sciences, University of Sydney, New South Wales, 2006, Australia, [k]Section of Herpetology and Urban Nature Research Center, Natural History Museum of Los Angeles County, 900 Exposition Boulevard, Los Angeles, CA 90007, USA, [l]Department of Ecology and Evolutionary Biology, University of California, Los Angeles, CA, USA, and [m]School of Biological Sciences, Monash University, Victoria, 3800, Australia

Lysanne Snijders is now at Leibniz-Institute for Zoo and Wildlife Research, Alfred-Kowalke-Straße 17, 10315 Berlin, Germany.

Received 24 May 2018; revised 1 August 2018; accepted 18 September 2018.; editorial decision 30 August 2018; Advance Access publication 8 October 2018

Although examples of successful applications of behavioral ecology research to policy and management exist, knowledge generated from such research is in many cases under-utilized by managers and policy makers. On their own, empirical studies and traditional reviews do not offer the robust syntheses that managers and policy makers require to make evidence-based decisions and evidence-informed policy. Similar to the evidence-based revolution in medicine, the application of formal systematic review processes has the potential to invigorate the field of behavioral ecology and accelerate the uptake of behavioral evidence in policy and management. Systematic reviews differ from traditional reviews and meta-analyses in that their methods are peer reviewed and prepublished for maximum transparency, the evidence base is widened to cover work published outside of academic journals, and review findings are formally communicated with stakeholders. This approach can be valuable even when the systematic literature search fails to yield sufficient evidence for a full review or meta-analysis; preparing systematic maps of the existing evidence can highlight deficiencies in the evidence base, thereby directing future research efforts. To standardize the use of systematic evidence syntheses in the field of environmental science, the Collaboration for Environmental Evidence (CEE) created a workflow process to certify the comprehensiveness and repeatability of systematic reviews and maps, and to maximize their objectivity. We argue that the application of CEE guidelines to reviews of applied behavioral interventions will make robust behavioral evidence easily accessible to managers and policy makers to support their decision-making, as well as improve the quality of basic research in behavioral ecology.

Key words: **applied animal behavior, conservation behavior, evidence-based management, literature review, meta-analysis, policy impact, systematic maps.**

Address correspondence to O. Berger-Tal. E-mail: bergerod@bgu.ac.il.
*Equal first authors.

INTRODUCTION

Behavioral ecology can help provide applied solutions to many pressing real-world problems. Most notably, behavioral research can assist in the development of effective interventions for wildlife conservation and management (Blumstein and Fernández-Juricic 2010; Berger-Tal and Saltz 2016; Greggor et al. 2016), such as attracting endangered birds to specific breeding sites using conspecific calls (Ward and Schlossberg 2004), or training predators to avoid a toxic invasive prey to reduce the detrimental impacts of the invasive species (Price-Rees et al 2013). However, similar to other subfields of behavioral ecology, the field of conservation behavior continues to lag behind its promises of contributing to real-world application (Caro 2007; Caro and Sherman 2013; but see Buchholz (2007) and Fernández-Juricic and Schulte (2016)). Clearly, the sheer number of conservation interventions required to mitigate threats to biodiversity worldwide, combined with the limited resources available for conservation, rules out the option of conducting system-specific studies for every case. However, tapping into the vast amount of knowledge and evidence that has accumulated on particular interventions across species can provide extremely useful guidance (Sutherland et al. 2004). Regrettably, behavioral knowledge is not often considered when designing management interventions, even with conservation problems that require key behavioral insights, such as animal reintroduction programs (Berger-Tal et al. 2015). One barrier to the application of behavior is that the efficacy of behavior-based solutions has not been collectively evaluated, nor have the contextual constraints of such solutions been properly articulated (Greggor et al. 2014; Greggor et al. 2016). This same issue is expected to arise when dealing with other applications of behavior, such as the development of behavioral welfare indicators for zoo, laboratory, and farmed animals (Broom and Fraser 2015). We cannot expect managers and policy makers to have the time and resources to discover, integrate, interpret, and apply behavioral research without assistance. Rather, the available scientific evidence must be collated, critically appraised, and synthesized in a comprehensive, transparent, and verifiable way to become a reliable support tool in policy and practice. Here we describe why and how systematic reviews can be a vital tool for those who wish to apply insights from behavioral ecology research to real-world problems. In doing so, we explain a number of methodological steps which are broadly valuable to any behavioral ecologist wishing to add rigor to their research.

Behavioral ecologists commonly use traditional review methodology and formal meta-analyses to summarize evidence (e.g., Arct et al. (2015)). However, evidence collected this way can be highly susceptible to bias at various stages of the review process (Haddaway et al. 2015; Haddaway and Macura 2018). Traditional reviews (see Glossary) often only search for and include academic publications—where results with negative or no effect are less likely to be published—which introduces publication bias into review findings (Sterne et al. 2001; Jennions and Møller 2002; Cassey et al. 2004, Jennions et al. 2013). Moreover, by including studies based on subjective decisions, such as including only highly cited research, or conducting the search using keywords that may be popular in some disciplines but not in others (see Berger-Tal and Bar-David (2015) for an example), traditional reviews and meta-analyses might suffer from selection bias (Haddaway and Watson 2016). Finally, at the synthesis stage, traditional reviews often assign equal weight to all studies, regardless of their methodological rigour or sample size, often focusing only on statistical significance of the effect (Haddaway et al. 2015, Haddaway and Macura 2018). This is also known as "vote-counting." Although meta-analyses avoid "vote-counting" by providing statistical tools for investigating data collected during the process of a review (Arnqvist and Wooster 1995; Koricheva et al. 2013), their conclusions are only as valid as the collection of studies they analyze. Together, biases at different stages of the review process can influence the reliability of review conclusions and lead to the deployment of a flawed intervention in practice. Unsurprisingly, numerous examples exist of different reviews reporting conflicting results on the same topic (Berlin and Golub 2014). Without a credible and consistent method for evidence synthesis (Figure 1), not all reviews can be considered equally reliable, which is particularly problematic when the goal is to craft effective policy and design successful management interventions. Implementing systematic reviews and maps methodology addresses all of the abovementioned biases (Pullin and Stewart 2006; Collaboration for Environmental Evidence 2018a).

Evolutionary and behavioral ecologists were early adopters of meta-analyses in the mid-1990s (e.g., Arnqvist and Wooster (1995)). By 2010, behavioral ecologists fully embraced meta-analytic methods (e.g., Nakagawa and Poulin (2012), Koricheva et al. (2013), Arct et al. (2015), Dougherty and Shuker (2015), Moore et al. (2016), and Gurevitch et al. (2018)). But these were largely aimed to test theoretical predictions in the literature, rather than to apply them

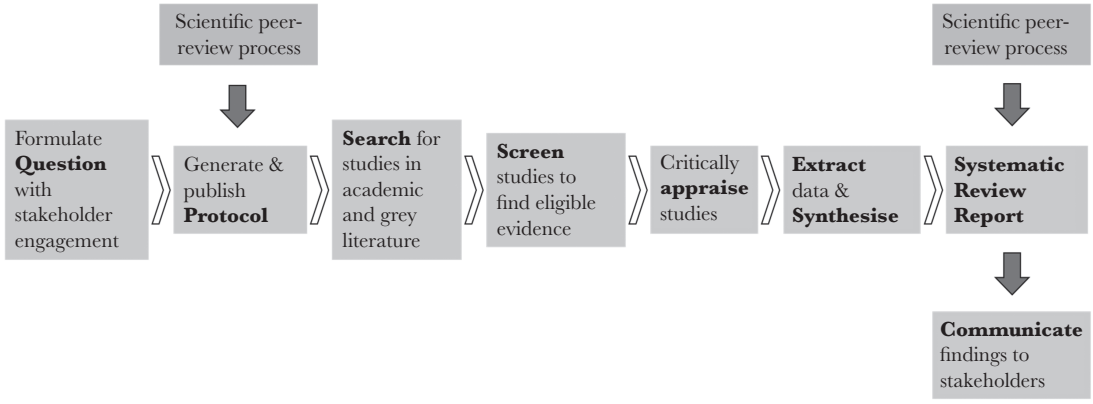

Figure 1
Flow diagram detailing the systematic review process.

in areas such as conservation and management, which require different methods for gathering literature and engaging with stakeholders. Systematic reviews are not a new concept either. In the 1990s, the field of medicine was revolutionized through the use of evidence-based treatments that turned to formal systematic reviews to improve health outcomes (Sackett 1997; Cochrane 2011). What followed was the development of Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA; Moher et al. 2009)—a set of reporting standards for systematic reviews and meta-analyses, developed for syntheses in public health (but also used in other fields, e.g., education). However, PRISMA reporting standards are not optimal for the environmental field as they lack necessary detail, do not accommodate for the latest methodological developments (such as systematic maps), focus only on internal validity during the critical appraisal, etc. Therefore, to retain high transparency of reporting and support the methodological strength of systematic reviews and maps, the RepOrting standards for Systematic Evidence Syntheses (ROSES) was designed specifically for the field of conservation and environmental management (Haddaway et al. 2018).

Systematic reviews were introduced to the field of environmental conservation and management in the early 2000s (Fazey et al. 2004; Sutherland et al. 2004; Pullin and Knight 2009; Collaboration for Environmental Evidence 2013) and remain effective in facilitating the use of scientific evidence in management and policy decisions (Walsh et al. 2015). The growing use of systematic reviews as a tool for policy-makers has spurred the creation of coordinating bodies, such as the Collaboration for Environmental Evidence (CEE) (Collaboration for Environmental Evidence 2018b), which support the methodological development and conduct of evidence-based reviews through rigorous guidelines that help us to maintain the integrity of the review process. A growing number of mainstream journals (e.g., *Biological Conservation* and *Proceedings of the Royal Society B*) have also started publishing systematic reviews and evidence syntheses, although the review standards may vary by journal. With the increasing acknowledgement that scientific evidence should be part of sound management and policy, and the increasing number of tools available for conducting systematic reviews, conditions are now ideal for the field of behavioral ecology to directly support evidence-informed policy and practice.

Here, we propose adopting the rigorous standards of systematic evidence syntheses for behavioral ecology. We describe the well-tested methods and work-flow process of systematic reviews and maps, and explain why and how these methods can be adopted to collate, describe, critically appraise, and synthesize behavioral research. We focus on conservation behavior as an example, yet the lessons learned are equally relevant to other areas of applied animal behavior, such as zoo, farm, laboratory, and companion animal management (Mason et al. 2001; Hinde et al. 2014), as well as for the review of theoretic behavioral ecology topics.

WHAT IS A SYSTEMATIC REVIEW AND SYSTEMATIC MAP?

Systematic reviews and maps are rigorous, transparent, and repeatable methods for cataloguing, collating, and synthesizing all available documented evidence on a topic of interest (CEE 2018a). These methods are used across various fields, from medicine, education, and international development to conservation and environmental management (Petticrew and Roberts 2006; Higgins and Green 2011; Campbell 2017; CEE 2018a). They strive to maximize objectivity and minimize the influence of various sources of bias in the synthesis process (Haddaway et al. 2015; CEE 2018a; Haddaway and Macura 2018).

Systematic reviews differ from traditional reviews in that they are typically conducted through well-established, rigorous, and standardized methods (Figure 1), including 1) question formulation with stakeholder engagement, 2) peer-reviewed protocol development (a detailed methodological plan of the review process, which is published before the review takes place, e.g., Doerr et al. (2014)), 3) comprehensive search for evidence, 4) careful eligibility screening of literature, 5) coding and data extraction, 6) critical appraisal of study validity, 7) synthesis, 8) reporting of findings in a peer-review, open-access publication, and 9) communication of results (CEE 2018a). Systematic reviews have been used to evaluate the effectiveness of management interventions, or the effects of exposure to unintended actions, all of which can influence conservation practice and policy (Sutherland et al. 2004; Pullin and Stewart 2006). For example, a systematic review on the effectiveness of urban "greening" on reducing UV exposure and the capacity for cities to overheat (Bowler et al. 2010) was used by the UK government in crafting their Heatwave Plan (T. Knight, personal communication). However, currently very few systematic reviews exist that rely on behavioral knowledge to inform conservation policy or management decisions.

In contrast to the highly specific nature of systematic reviews, systematic maps are comprehensive catalogues of the literature on a broad topic of interest (James et al. 2016). They follow the same step-wise process as systematic reviews (Figure 1), but they tackle broader questions, do not require critical appraisal of study validity (although authors may choose to conduct some form of appraisal), and include no synthesis of study findings. The final output of the systematic mapping exercise is a peer-reviewed narrative report and a searchable catalogue of the literature that can be used to identify areas where evidence is lacking or is under-represented (knowledge gaps), or areas with sufficient evidence to conduct full synthesis (knowledge clusters) (McKinnon et al. 2015; Haddaway et al. 2016; James et al. 2016). Systematic maps can also result in an interactive geographic map of the findings (this is called an evidence atlas), which can show the geographical spread of the evidence within the literature (e.g., see evidence atlas of systematic map on road-side management effects on biodiversity, Bernes et al. (2017): https://maps.esp.tl/maps/_Locations-of-included-roadside-studies/pages/map.jsp?geoMapId=279574&TENANT_ID=175644).

A critical stage of every systematic review or map is the formation of the review question (CEE 2018a). This question is carefully crafted, often with stakeholder input, and formulated around specific elements: the target population (P), the intervention (I) or exposure (E), the comparison (C), and the outcome (O) (i.e., PICO or PECO elements). For example, rather than posing an open-ended or vaguely focused question, such as "*How does human activity influence animal behavior?*" a systematic review requires a more narrowly defined question, such as "*What are the fitness consequences of cage diving operations to sharks?*" (PECO question—assessing impact of exposure to human activities), or "*What type of olfactory lures are most effective for attracting invasive mammalian predators in the tropics?*" (PICO question—assessing effectiveness of an intervention). In contrast to reviews, systematic maps often have broader and less focused questions, such as "*What evidence exists on the effects of anthropogenic noise on the courtship behavior of city-dwelling animals?*" (PIO or PO—describing the nature and quantity of evidence on a given subject (Haddaway et al. 2016; James et al. 2016).

Another unique aspect of systematic reviews and maps is that they are preceded by a peer-reviewed protocol (CEE 2018a). The protocol is a methodological plan describing the review process in detail: the review question, search strategy (including search string, sources of academic and grey literature), eligibility criteria, study validity assessment, coding and data extraction and, for a systematic review, a method for data synthesis. The process of protocol formulation can also assist in sharpening the conceptual framework of the review beforehand (e.g., which potential sources of heterogeneity [effect modifiers] to include, which species/taxa to focus on, which intervention subtypes), which is why protocol formation requires careful planning, stakeholder engagement, and pilot-studying of all review stages. The protocol facilitates transparency and repeatability of the review process, and makes sure the review stays on track. It also makes it easier to conduct a review update. So far, the CEE journal *Environmental Evidence* is one of the only venues for publishing review protocols. Regardless of whether the protocol is published, once the protocol has been developed, a comprehensive search for evidence follows.

A comprehensive literature search is a crucial step in systematic evidence syntheses. The searching authors must use an iterative process to develop a comprehensive search strategy built around the PI/EO elements of the review question (including synonyms and alternative spellings of search terms or phrases). The search normally covers multiple databases and includes the grey literature, because not all scientific findings are necessarily published in the peer-reviewed academic journals. A lack of standardized keywords in behavioral publications will usually necessitate a balance between sensitivity and specificity (i.e., the use of both general and specific search terms) to capture relevant literature (CEE 2018a). Coming up with effective search strings for the specific question of interest that is both precise and broad is challenging and may require experimentation through trial and error.

Once searches are completed, the search results are screened for eligibility at the title, abstract, and full text stages. In some cases, where, for example, the existence of homonyms can make the screening process extremely taxing, it may be possible to train machine learning algorithms to undertake the initial screening (Cheng et al. 2018; Roll et al. 2018). Additionally there are online open source tools available for organizing and streamlining the screening process (Kohl et al. 2018). Following the screening stages, studies that are found eligible are coded according to predetermined categories. At this stage, a systematic map can be created to outline the existing evidence available in the field (McKinnon et al. 2015; Haddaway et al. 2016). If sufficient studies exist on the topic in question, then data can be extracted and critically appraised based on internal and external validity (including criteria such as presence of confounding factors, level of replication, type of study design, and baseline data). Findings are then synthesized through narrative (qualitative) and quantitative synthesis (i.e., a meta-analysis, if appropriate). If there is sufficient evidence to warrant a meta-analysis, many of the analytical tools familiar to behavioral ecologists are relevant at this stage (e.g., Arnqvist and Wooster 1995; Koricheva et al. 2013). Finally, results are communicated with stakeholders, according to a predetermined communication plan.

A systematic review may require a large amount of time to complete. The exact amount of time will depend on various factors such as the scope of the question, the number of people working on the review, and the amount of time they dedicate to it. A new online tool (predicter.org) can assist in estimating the time that will be needed to complete a review. Publishing a systematic review may require that the authors pay the cost of an open access publication (which can easily exceed USD 3000). For these reasons, conducting a systematic review should not be embarked upon without serious consideration. A systematic review is not needed on topics that have already been recently comprehensively reviewed, or on questions where most studies draw similar conclusions (Haddaway et al. 2015). In the cases where a suitable question exists, but the researcher simply lacks the resources to conduct a formal systematic review, it is still worthwhile to adopt many of the principles of the systematic review process (such as transparently documenting all stages of the review process to allow for repeatability, including a grey literature search, or avoiding vote-counting) to improve the quality of a traditional literature review (Haddaway et al. 2015). However, where a review must be both comprehensive and transparent, or where scientific evidence is contradictory, systematic reviews can provide a source of the best available evidence for managers and decision makers in policy.

IMPROVING THE QUALITY AND RELEVANCE OF BEHAVIORAL ECOLOGY

The goal of conservation behavior research, like any field of science, is to produce credible findings. Such findings advance theory and can be trustworthy sources of evidence. Credible science has some widely acknowledged criteria: it should be systematic and objective as possible so as to be reliable, reproducible, and replicable (Ihle et al. 2017). By adopting the systematic reviews approach, which includes critical appraisal of the evidence, we can build a comprehensive evidence base for gaining insights into behavioral ecology theory as well as for its application. Systematic reviews are therefore not only useful for translating scientific findings into policy and practice, but can also be used to advance and develop conceptual ideas and theories within our discipline.

The incorporation of the grey literature into systematic reviews may also help push the field of behavioral ecology forward. Grey literature often provides important insights for the effectiveness of different behavioral interventions and does not necessarily lack rigor, despite not being published in academic journals (Blackhall 2007). Moreover, PhD and MSc theses, government-threatened species recovery reports, and reports from nongovernmental organizations, such as the IUCN or WWF, might be the only sources of information on the applications of behavioral theory in conservation translocations or other behavioral interventions on threatened species. This is especially true when the outcome of the intervention is overall negative or unclear, since the academic literature is heavily biased towards publishing positive results (McAuley et al. 2000). In some cases, patents may provide evidence for successful application of tools such as deterrents or attractants of animals, which is key for many conservation and management issues, such as human-wildlife conflict interventions, protected areas management, or invasive species control. Additionally, by including a greater variety of species, grey literature can provide us with important data about the specificity or generalizability of common behavioral theories beyond common academic model species. Of course, it is essential to critically appraise and evaluate grey literature before including them in the synthesis (see Supplementary Material for a list of behaviorally relevant grey literature sources).

Although they can be a useful tool for any behavioral ecologist, systematic reviews and maps are particularly relevant to conservation behavior in several ways. In the context of conservation

and management, it is important to not only understand whether an intervention is successful, but also why. Behavior is often the mechanism that links the intervention with the outcome, but this outcome can vary depending on the context (Berger-Tal et al. 2011; Berger-Tal and Saltz 2016). For example, the success of captive breeding programs often hinges on management of the animals' social environment, which varies greatly depending on the species' natural social system (Snijders et al. 2017). Systematic reviews, similar to meta-analyses, can provide a powerful tool for teasing out the source of this heterogeneity in study findings by analyzing the evidence gathered for each specific social system or for different types of captive breeding environments. Even empty reviews (syntheses that find no evidence on a subject, see Yaffe et al. (2012)) can be useful to highlight a lack of scientific evidence. Many fields within conservation behavior have been researched unevenly, with certain "hot topics" and other under-researched areas (Berger-Tal et al. 2015). Systematic reviews and maps can highlight these knowledge gaps and guide primary research within our field.

As a group, we, the authors, have begun the process of conducting our own systematic evidence syntheses on conservation behavior topics, precipitated by a CEE training workshop (October 2017) aimed specifically at behavioral ecologists. With the engagement of stakeholders, we are currently tackling a range of review questions that can be generally clustered into 3 categories (see Supplementary Material for the full range of the review questions): 1) using animal behavior to improve the outcomes of conservation translocations, 2) detrimental effects of noise and light pollution on wildlife populations, and 3) using behavioral cues to attract animals for conservation purposes. All of these topics have recently been flagged as being of particular importance to conservation (Greggor et al. 2016). Not only has this opportunity allowed us to better see the value of systematic reviews and maps for connecting researchers to managers and policy makers, but has also highlighted areas where more rigorous methods can improve the scientific rigor of behavioral ecology.

CONNECTING RESEARCHERS AND PRACTITIONERS: INCREASING UPTAKE OF FINDINGS

Stakeholders can be generally defined as any organization or person who can affect or be affected by the review conduct and findings (Keown et al. 2008; Rees and Oliver 2012; Haddaway et al. 2017). These include reviewers, researchers, experts, the general public, government bodies, funding agencies, land managers, NGOs, land owners, community groups, citizens living or visiting the areas relevant to the studies, as well as farmers and hunters operating in these areas. Reviews should be embedded in a larger process of linking the research community to other stakeholders, including decision makers in policy and practice (Sutherland and Wordley 2017). Making systematic reviews' findings freely and easily available in open access platforms is an essential part of systematic reviews; however, simply publishing systematic reviews or maps in such platforms will not in itself ensure that the evidence is understood and used.

To increase the chances that evidence will be used in policy or management decision making, stakeholders should be involved at various stages throughout the review process, and especially in the review question formulation stage (Land et al. 2017). Other than facilitating a wider dissemination and uptake of the research findings, there are several additional benefits to stakeholder engagement, such as identifying and prioritizing the review questions, getting pragmatic feedback on the research protocol, and providing additional literature sources (Cottrell et al. 2014).

From our personal experience, finding stakeholders and getting them involved in the review process may be a considerable challenge. Sometimes identifying relevant stakeholder can be geographically limited (at the local state level) simply because of the extent of existing networks and accessibility. In other times, it can be hard to get the stakeholders to be active participants in the discussion. Even after a diverse group of stakeholders has formed, additional challenges may follow (e.g., Fish (2011)). These might include forming a representative and balanced group of stakeholders, managing conflicts among them, and retaining their engagement throughout the whole review process (Taylor et al. 2017). Clear communication between researchers and stakeholders throughout the review process is important, and the expectations for the review outcomes must be set in advance. For example, stakeholders might expect recommendations for specific actions, but systematic reviews generally focus on presenting the evidence in a transparent and unbiased way, rather than crafting explicit recommendations. In any case, any undue influence of stakeholders during the review conduct must be avoided (Haddaway et al. 2017). Despite all of the above-mentioned challenges, having stakeholders involved throughout the review process is a key aspect of systematic reviews and maps that maximized their contribution.

Once the review is complete, several avenues exist that can be used to disseminate key results to various stakeholders and a wider network of decision makers in policy and practice (Quinn et al. 2014). The communication strategy can be carefully tailored for different types of stakeholders and may include fact sheets, policy briefs, and press releases. Additionally, visual media can be effective communication tools, especially through social media, such as short videos (e.g., https://www.youtube.com/watch?v=rRC9vreAkD4&feature=youtu.be communicating the results of Land et al. (2016)), public seminars, and lectures at meetings or conferences of managers and policy makers.

THE IMPORTANCE OF FORMAL TRAINING IN SYSTEMATIC EVIDENCE SYNTHESIS METHODS

Making systematic evidence synthesis training part of the education process for graduate students and early career researchers (behavioral ecologists and others) can provide scientists with comprehensive knowledge of the evidence surrounding a specific topic, equip them with a set of tools to engage more effectively with other scientists and practitioners, and increase the validity of their own research. These practical and enriching skills include how to devise comprehensive search strategies, as well as how to critically appraise experimental designs and results.

Apart from training in systematic review methods, students and researchers should receive training on science policy and scientific communication (including lessons on how to identify and engage with stakeholders and codesign and coproduce research). Unfortunately, such skills are rarely regarded as something that graduate students and early-career scientists should consider (Besley and Tanner 2011), but competence in this area is essential for developing impactful research questions and subsequently translating research outcomes into effective policy and management.

CONCLUSIONS

Sadly, many conservation interventions are implemented with little or no evidence of their success (Sutherland et al. 2004). As scientists, we have the power to change the prevalence of "evidence complacency" in our applied fields (Sutherland and Wordley 2017). Publications of empirical behavioral ecology studies increasingly contain insights as well as suggestions and recommendations that have concrete implications for management and policy. However, such statements are unlikely to reach the managers they hope to target, especially if they remain within the confines of *pay*-walled academic journals (McKinnon et al. 2015). For those of us who wish to integrate insights from studies of behavior with management and policy, publishing open-access systematic reviews and maps might offer an opportunity for true impact beyond the pursuit of fundamental knowledge.

Systematic reviews and maps provide 4 important advantages for our field over traditionally conducted literature reviews and meta-analyses. First, they maximize objectivity, transparency, and comprehensiveness and attempt to minimize the bias at all stages of the review process (Haddaway et al. 2015). Second, the incorporation of grey literature into the review adds a potentially vast reservoir of valid research evidence (that most traditional reviews disregard), which decreases susceptibility to publication bias. Third, the structured investigation of sources of heterogeneity by these syntheses helps interpret apparent conflicting conclusions drawn from studies on the same subject. Fourth, the involvement of stakeholders—key individuals and organizations who can help formulate questions, as well as inform, endorse, and legitimize the review process—facilitates the uptake of these findings by managers and policy makers.

SUPPLEMENTARY MATERIAL

Supplementary material can be found at http://www.beheco.oxfordjournals.org/.

Acknowledgments. This paper is the product of an international training workshop by the Collaboration for Environmental Evidence specifically tailored for behavioral ecologists and held at the Jacob Blaustein Institutes for Desert Research, Ben-Gurion University of the Negev, Israel. We thank MISTRA-EviEM and Stockholm Environment Institute, Sweden for allocating time to Biljana Macura for running the training workshop and contributing to this paper. The workshop was made possible through collaboration between Ben-Gurion University and Monash University, Australia, as well as generous support from the Jacob Blaustein Center for Scientific Cooperation, The Swiss Institute for Dryland Environmental and Energy Research, Mitrani Department of Desert Ecology, and Ben-Gurion University of the Negev. We thank Uri Roll and Yael Kaplan for their instrumental role in making the workshop happen. We thank Shinichi Nakagawa, Gavin Stewart, and an anonymous reviewer for constructive comments on a previous version of this manuscript. This is publication number 985 of the Mitrani Department of Desert Ecology.

Forum editor: Leigh Simmons

GLOSSARY

Conservation intervention: An intentional (management) action with the goal to change a specified conservation outcome. Systematic reviews can be conducted to evaluate the effectiveness of such interventions.

Critical appraisal: An essential component of a systematic review (sometimes termed study validity assessment). Critical appraisal is the process by which individual studies are assessed for external (generalizability) and internal (susceptibility to bias) validity. Factors to be considered might include: (true) replication level, presence and appropriateness of control, study design (e.g., BACI = Before After Control Impact, RCT = Randomized Control Trial), and the presence of confounding factors. These factors can be integrated in the review process via the attribution of a basic categorical score to each study (e.g., unclear, low, medium, or high validity). These scores can subsequently be used by reviewers in quantitative synthesis. Checklist for assessment of validity can be used too.

Scientific evidence: Information gathered from scientific research using a scientific method to derive repeatable and reproducible findings countering or supporting a hypothesis or a theory.

Meta-analysis: A set of statistical tools for combining the magnitudes of the outcomes across different datasets addressing the same research question.

Systematic map: Systematic mapping does not attempt to answer a specific question as do systematic reviews, but instead collates, describes, and catalogues available evidence relating to a topic or question of interest. The included studies can be used to identify evidence for policy-relevant questions, knowledge gaps (to help direct future primary research), and knowledge clusters (sub-sets of evidence that may be suitable for secondary research, e.g., systematic review) (James et al. 2016).

Systematic review: An evidence synthesis method that aims to answer a specific question as precisely as possible in an unbiased way. The method collates, critically appraises, and synthesizes all available evidence relevant to the question. Reviewers use predefined methods to identify risks of bias in the evidence itself, and to minimize bias in the way evidence is identified and selected, and thus provide reliable findings that could inform decision making.

"Traditional" literature review: A textual summary of a broad topic using published materials that provides examination of recent or current literature. Traditional reviews can cover a wide range of subjects at various levels of completeness and comprehensiveness.

REFERENCES

Arct A, Drobniak S, Cichoń M. 2015. Genetic similarity between mates predicts extrapair paternity—a meta-analysis of bird studies. Behav. Ecol. 26:959–968.

Arnqvist G, Wooster D. 1995. Meta-analysis: synthesizing research findings in ecology and evolution. Trends Ecol Evol. 10:236–240.

Berger-Tal O, Bar-David S. 2015. Recursive movement patterns: review and synthesis across species. Ecosphere. 6:149.

Berger-Tal O, Blumstein DT, Carroll S, Fisher RN, Mesnick SL, Owen MA, Saltz D, St Claire CC, Swaisgood RR. 2016. A systematic survey of the integration of animal behavior into conservation. Conserv Biol. 30:744–753.

Berger-Tal O, Polak T, Oron A., Lubin Y, Kotler BP, Saltz D. 2011. Integrating animal behavior and conservation biology: a conceptual framework. Behav Ecol. 22:236–239.

Berger-Tal O, Saltz D. 2016. Conservation behavior: applying behavioral ecology to wildlife conservation and management. Cambridge (UK): Cambridge University Press.

Berlin JA, Golub RM. 2014. Meta-analysis as evidence: building a better pyramid. JAMA. 312:603–605.

Bernes C, Bullock JM, Jakobsson S, Rundlöf M, Verheyen K, Lindborg R. 2017. How are biodiversity and dispersal of species affected by the management of roadsides? A systematic map. Environ Evid. 6:1–16.

Besley JC, Tanner AH. 2011. What science communicators think about training scientists to communicate. Sci Commun. 33:239–263.

Blackhall K. 2007. Finding studies for inclusion in systematic reviews of interventions for injury prevention the importance of grey and unpublished literature. Inj Prev. 13:359.
Blumstein DT, Fernández-Juricic E. 2010. A Primer on conservation behaviour. Sunderland (MA): Sinauer.
Bowler D, Buyung-Ali L, Knight T, Pullin AS. 2010. How effective is "greening" of urban areas in reducing human exposure to ground level ozone concentrations, UV exposure and the "urban heat island effect"? CEE review 08-004 (SR41). Environ. Evid.
Broom D, Fraser A. 2015. Domestic animal behaviour and welfare. 5th ed. Tarxien, Malta: Gutenberg Press.
Buchholz R. 2007. Behavioural biology: an effective and relevant conservation tool. Trends Ecol Evol. 22:401–407.
Caro T. 2007. Behavior and conservation: a bridge too far? Trends Ecol Evol. 22:394–400.
Caro T, Sherman PW. 2013. Eighteen reasons animal behaviourists avoid involvement in conservation. Anim Behav. 85:305–312.
Cassey P, Ewen JG, Blackburn TM, Møller AP. 2004. A survey of publication bias within evolutionary ecology. Proc Biol Sci. 271(Suppl 6):S451–S454.
Cheng SH, Augustin C, Bethel A, Gill D, Anzaroot S, Brun J, DeWilde B, Minnich RC, Garside R, Masuda YJ, et al. 2018. Using machine learning to advance synthesis and use of conservation and environmental evidence. Conserv Biol. 32:762–764.
Campbell Collaboration. 2017. Campbell systematic reviews: policies and guidelines. In: Campbell policies and guidelines, Series No.1.
Cochrane Collaboration. 2011. Cochrane handbook for systematic reviews of interventions. In: Higgins J, Green S, editors. Version 5.1.0.
Collaboration for Environmental Evidence. 2013. Guidelines for systematic review and evidence synthesis in environmental management. Version 4.2. Environmental Evidence: https://www.environmentalevidence.org/Documents/Guidelines/Guidelines4.2.pdf.
Collaboration for Environmental Evidence. 2018a. Guidelines and standards for evidence synthesis in environmental management. In: Pullin AS, Frampton GK, Livoreil B, Petrokofsky G, editors. Version 5.0. https://www.environmentalevidence.org/information-for-authors.
Collaboration for Environmental Evidence. 2018b. About us. http://www.environmentalevidence.org/ (Accessed 27 September 2018).
Cottrell E, Whitlock E, Kato E, Uhl S, Belinson S, Chang C, Hoomans T, Meltzer D, Noorani H, Robinson K, et al. 2014. Defining the benefits of stakeholder engagement in systematic reviews. Research White Paper. Rockville (MD): Agency for Healthcare Research and Quality (US).
Doerr ED, Doerr VAJ, Davies MJ, McGinness HM. 2014. Does structural connectivity facilitate movement of native species in Australia's fragmented landscapes? A systematic review protocol. Evironmental Evid. 3:9.
Dougherty LR, Shuker DM. 2015. The effect of experimental design on the measurement of mate choice: a meta-analysis. Behav Ecol. 26:311–319.
Fazey I, Jalisbury J, Lindenmayer D, Maindonald J, Douglas R. 2004. Can methods applied in medicine be used to summarize and disseminate conservation research? Environ Conserv. 31:190–198.
Fernández-Juricic E, Schulte BA. 2016. Conservation behaviour: continued application, development and expansion. Anim Behav. 120:195–196.
Fish RD. 2011. Environmental decision making and an ecosystem approach: Some challenges from the perspective of social science. Prog Phys Geogr. 35: 671–680.
Greggor AL, Berger-Tal O, Blumstein DT, Angeloni L, Bessa-Gomes C, Blackwell BF, St Clair CC, Crooks K, de Silva S, Fernández-Juricic E, et al. 2016. Research priorities from animal behaviour for maximising conservation progress. Trends Ecol Evol. 31: 953–964.
Greggor AL, Clayton NS, Phalan B, Thornton A. 2014. Translating cognitive insights into effective conservation programs: reply to Schakner et al. Trends Ecol Evol. 29:652–653.
Gurevitch J, Koricheva J, Nakagawa S, Stewart G. 2018. Meta-analysis and the science of research synthesis. Nature. 555:175–182.
Haddaway NR, Bernes C, Jonsson BG, Hedlund K. 2016. The benefits of systematic mapping to evidence-based environmental management. Ambio. 45:613–620.
Haddaway NR, Kohl C, da Silva NR, Schiemann J, Spok A, Stewart R, Sweet JB, Wilhelm R. 2017. A framework for stakeholder engagement during systematic reviews and maps in environmental management. Environ Evid. 6:11.
Haddaway NR, Macura B, Whaley P, Pullin AS. 2018. ROSES reporting standards for systematic evidence syntheses: pro forma, flow diagram and descriptive summary of the plan and conduct of environmental systematic reviews and systematic maps. Environ Evid. 7:4–11.
Haddaway NR, Watson MJ. 2016. On the benefits of systematic reviews for wildlife parasitology. Int J Parasitol Parasites Wildl. 5:184–191.
Haddaway NR, Woodcock P, Macura B, Collins A. 2015. Making literature reviews more reliable through application of lessons from systematic reviews. Conserv Biol. 29:1596–1605.
Hinde K, Carpenter AJ, Clay JS, Bradford BJ. 2014. Holsteins favor heifers, not bulls: biased milk production programmed during pregnancy as a function of fetal sex. PLoS One. 9:e86169.
Ihle M, Winney IS, Krystalli A, Croucher M. 2017. Striving for transparent and credible research: practical guidelines for behavioral ecologists. Behav Ecol. 28:348–354.
James KL, Randall NP, Haddaway NR. 2016. A methodology for systematic mapping in environmental sciences. Environ Evid. 5:7.
Jennions MD, Lortie CJ, Rosenberg MS, Rothstein HR. 2013. Publication and related biases. In: Koricheva J, Gurevitch J, Mengersen K, editors. Handbook of meta-analysis in ecology and evolution, Princeton (NJ): Princton University Press.
Jennions MD, Møller AP. 2002. Publication bias in ecology and evolution: an empirical assessment using the 'trim and fill' method. Biol Rev Camb Philos Soc. 77:211–222.
Keown K, Van Eerd D, Irvin E. 2008. Stakeholder engagement opportunities in systematic reviews: knowledge transfer for policy and practice. J Contin Educ Health Prof. 28:67–72.
Kohl C, McIntosh EJ, Unger S, Haddaway NR, Kecke S, Schiemann J, Wilhelm R. 2018. Online tools supporting the conduct and reporting of systematic reviews and systematic maps: A case study on CADIMA and review of existing tools. Environ Evid. 7:1–17.
Koricheva J, Gurevitch J, Mengersen K. 2013. The handbook of meta-analysis in ecology and evolution. Princeton: Princeton University Press.
Land M, Graneli W, Grimvall A, Hoffmann CC, Mitsch WJ, Tonderski KS, Verhoeven JTA. 2016. How effective are created or restored freshwater wetlands for nitrogen and phosphorus removal? A systematic review. Environ Evid. 5:9.
Land M, Macura B, Bernes C, Johansson S. 2017. A five-step approach for stakeholder engagement in prioritisation and planning of environmental evidence syntheses. Environ Evid. 6:25.
Mason GJ, Cooper J, Clarebrough C. 2001. Frustrations of fur-farmed mink. Nature. 410:35–36.
McAuley L, Pham B, Tugwell P, Moher D. 2000. Does the inclusion of grey literature influence estimates of intervention effectiveness reported in meta-analyses? Lancet. 356:1228–1231.
McKinnon MC, Cheng SH, Garside R, Masuda YJ, Miller DC. 2015. Sustainability: Map the evidence. Nature. 528:185–187.
Moher D, Liberati A, Tetzlaff J, Altman DG, Group P. 2009. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. Ann Intern Med. 151:264–270.
Moore FR, Shuker DM, Dougherty L. 2016. Stress and sexual signaling: a systematic review and meta-analysis. Behav Ecol. 27:363–371.
Nakagawa S, Poulin R. 2012. Meta-analytic insights into evolutionary ecology: an introduction and synthesis. Evol Ecol. 26:1085–1099.
Petticrew M, Roberts H. 2006. Systematic reviews in the social sciences: a practical guide. Oxford: Blackwell Publishing.
Price-Rees SJ, Webb JK, Shine R. 2013. Reducing the impact of a toxic invader by inducing taste aversion in an imperilled native reptile predator. Anim Conserv. 16:386–394.
Pullin AS, Knight T. 2009. Doing more good than harm – Building an evidence-base for conservation and environmental management. Biol Conserv. 142:931–934.
Pullin AS, Stewart GB. 2006. Guidelines for systematic review in conservation and environmental management. Conserv Biol. 20:1647–1656.
Quinn E, Huckel-Schneider C, Campbell D, Seale H, Milat AJ. 2014. How can knowledge exchange portals assist in knowledge management for evidence-informed decision making in public health? BMC Public Health. 14:443.
Rees R, Oliver SI. 2012. Stakeholder perspectives and participation in reviews. In: Gough D, Oliver S, Thomas J, editors. An introduction to systematic reviews. London: Sage Publications. p. 17–34.
Roll U, Correia RA, Berger-Tal O. 2018. Using machine learning to disentangle homonyms in large text corpora. Conserv Biol. 32: 716–724.
Sackett DL. 1997. Evidence-based medicine. Semin Perinatol. 21:3–5.

Snijders L, Blumstein DT, Stanley CR, Franks DW. 2017. Animal social network theory can help wildlife conservation. Trends Ecol Evol. 32:567–577.
Sterne JA, Egger M, Smith GD. 2001. Systematic reviews in health care: Investigating and dealing with publication and other biases in meta-analysis. BMJ. 323:101–105.
Sutherland WJ, Pullin AS, Dolman PM, Knight TM. 2004. The need for evidence-based conservation. Trends Ecol Evol. 19:305–308.
Sutherland WJ, Wordley CFR. 2017. Evidence complacency hampers conservation. Nat Ecol Evol. 1:1215–1216.
Taylor JJ, Rytwinski T, Bennett JR, Cooke SJ. 2017. Lessons for introducing stakeholders to environmental evidence synthesis Neal Haddaway, Sally Crowe. Environ Evid. 6:4–7.
Walsh JC, Dicks LV, Sutherland WJ. 2015. The effect of scientific evidence on conservation practitioners' management decisions. Conserv Biol. 29:88–98.
Ward M, Schlossberg S. 2004. Conspecific attraction and the conservation of territorial songbirds. Conserv Biol. 18:519–525.
Yaffe J, Montgomery P, Hopewell S, Shepard LD. 2012. Empty reviews: a description and consideration of Cochrane systematic reviews with no included studies. PLoS One. 7:e36626.