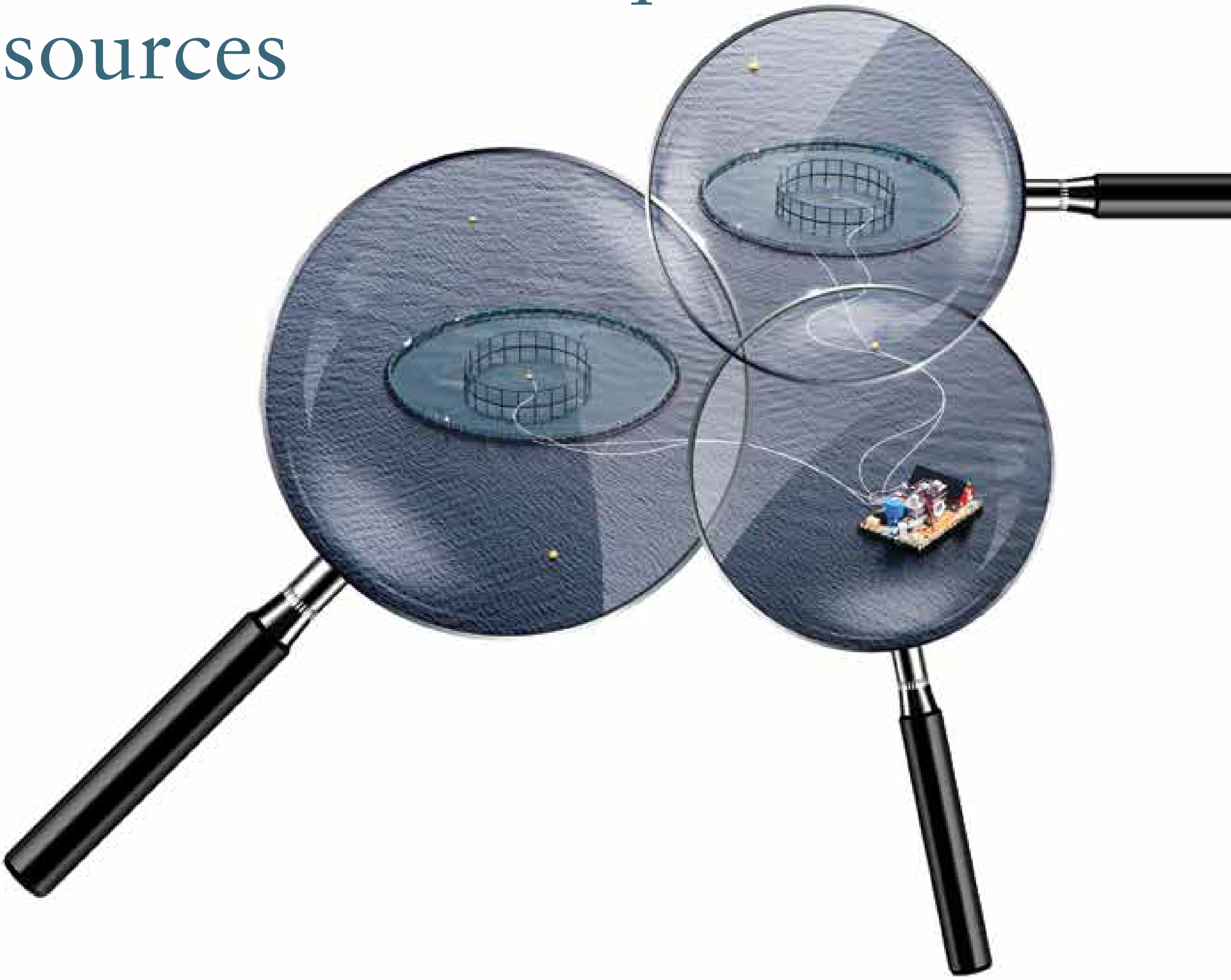
FEATURE

A Call for Evidence-Based Conservation and Management of Fisheries and Aquatic Resources



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Natural resource management agencies implement conservation policies with the presumption that they are effective and of benefit to aquatic ecosystems. However, it is often difficult to decide what management action to implement and what will be most effective. Here we call for natural resource management agencies to fully adopt and implement evidence-based management (EBM) for conservation and fisheries management. We support this call by providing a primer on systematic reviews, a core tool in evidence synthesis but one that is rarely used in the context of fisheries management. We highlight the benefits and challenges associated with implementing EBM, with a particular focus on the routine decisions and management actions undertaken by natural resource practitioners. We submit that by adopting EBM, practitioners would have access to the best available evidence on the effectiveness of various management and conservation interventions, while providing defensible and credible evidence to inform decision-making processes and policies.

INTRODUCTION

Aquatic ecosystems, including both freshwater and marine environments (Postel and Carpenter 1997; Barbier et al. 2011) and implicit fish populations (Holmlund and Hammer 1999; Lynch et al. 2016), provide important and diverse services to global life support processes. Economically speaking, such services include the support of fisheries-related livelihoods, as well as local and national economies, through the import and export of harvested product. Indeed, fish products and related resources are the most highly traded food items on earth (FAO 2010). Fisheries resources are also the main source of protein for approximately 3 billion people worldwide (Tacon and Metian 2013), including some of the most food insecure peoples (Youn et al. 2014). Many of the world's aquatic ecosystems have been dramatically altered, and the fish populations that they once supported are declining to such an extent that efforts to manage and maintain them have become a global priority. Threats to these often fragile systems are varied and numerous, including climate change, exploitation, land use change, pollution, invasive species, mismanagement, eutrophication, and impediments to connectivity, among others (see Dudgeon et al. [2006] for freshwater examples and Gray [1997] for marine examples). Despite these challenges, failure to conserve and manage resources effectively can be costly in ecological and economic terms (Worm et al. 2006) and have direct implications for the health of the world's aquatic ecosystems, as well as human nutrition and health (Pauly et al. 2005).

At a variety of scales, ranging from local, to national, to international (e.g., Food and Agriculture Organization of the United Nations), natural resource management agencies, along with their partners and various stakeholders, implement conservation and management policies and/or initiatives with the presumption that these efforts are effective and of benefit to aquatic ecosystems and fish populations. However, often it is unclear to what extent such management actions are actually doing "more good than harm" (Pullin et al. 2004). It can take considerable resources (e.g., time, money, personnel) and scientific capacity for managers to amass the necessary evidence to accurately determine the effectiveness of specific conservation management actions (Fazey et al. 2004). Further, managers often report difficulties in evaluating, synthesizing, and interpreting the credibility of the evidence in a consistent and practical manner (Milner-Gulland et al. 2010; Adams and Sandbrook 2013). These factors complicate the implementation of changes to policy, as managers are commonly faced with inadequate, overly complex, or conflicting information (Pullin and Knight 2004). In turn, these difficulties can often result in management plans being justified on the basis of the manager's experience, anecdotal evidence, and conventional wisdom rather than the best available evidence (Pullin and Knight 2004; Cook et al. 2010; Drolet et al. 2015). It is on this background that the Collaboration for Environmental Evidence (CEE) was created (see www.environmentalevidence.org)—an open community of scientists and practitioners engaged in evidence synthesis that provide a rigorous and transparent methodology to assess the impacts of human activity and effectiveness of policy and management interventions.

Here we call for agencies, organizations, and individuals responsible for the conservation and management of fisheries and aquatic resources to fully adopt and implement evidence-based management (EBM). In this article, we first provide a retrospective look at the EBM model, from its roots in the medical realm to its application in environmental management and conservation. Next, we provide a primer on systematic reviews (SRs), a core tool in evidence synthesis (see Box 1), and then provide several examples of where SRs and EBM have been applied in the context of aquatic conservation and management (see Box 2). Interestingly, a search of the American Fisheries Society journals database failed to identify any SRs published in its journals, emphasizing a current void and opportunity. We then highlight some of the benefits and challenges associated with implementing evidence-based aquatic and fisheries conservation and management. We conclude with identifying areas where we think efforts should be directed for future SRs. By adopting EBM, practitioners would be given access to the best available evidence on the effectiveness of various management and conservation interventions, while providing defensible and credible evidence to inform decision-making processes and policies (Pullin and Knight 2004). With dwindling financial resources to support aquatic and fisheries management, evidence-based approaches will ensure that limited resources are directed toward effective actions.

A BRIEF HISTORY OF THE EBM MODEL IN MEDICINE

Three decades ago, medical practitioners developed EBM as a result of growing recognition that many of the common medical procedures and practices being used were not well standardized and were not always the most effective (Sacket and Rosenberg 1995). This vast discrepancy between practice and evidence led to the development of "evidence-based medicine" or, simply, using the best available evidence to help guide clinical decision making. Modern medicine has since been revolutionized and this practice has since been adopted by many other applied disciplines (Dopson et al. 2003). Today, the field of medicine has rigorous standards and protocols in place, with groups around the world dedicated to the development of SRs and the dissemination of evidence that follow strict guidelines, including peer review, to ensure the highest standards are met (Kahn et al. 2011). These groups are also effectively linked by networks such as the Cochrane Collaboration (www.cochrane.org), facilitating the dissemination of evidence-based information to a global audience. Most important, evidence-based medicine has led to an obvious cultural reform within medicine and how practitioners perceive and use medical information.

IMPLEMENTING EVIDENCE-BASED AQUATIC CONSERVATION AND MANAGEMENT

Over a decade ago, Pullin and Knight (2004) and Sutherland et al. (2004) recognized that the fields of conservation and environmental management faced many issues that mirrored those of medicine in decades past and, as such, could benefit greatly from implementing an EBM approach. Though the basic framework for EBM from the medical field remains intact, the guidelines for conducting SRs have been adapted to reflect some of the unique challenges posed by conservation management (Pullin and Stewart 2006; CEE 2013). In the context of this article, we submit that the adoption of evidence-based fisheries conservation and management (EBFCM), through the production of SRs to assess the effectiveness of alternative interventions for the conservation and management of fisheries, would improve outcomes and ensure that we are doing more good than harm.

The CEE is the main group of scientists and managers working toward promoting the adoption of SRs to support the conservation of biodiversity globally (CEE 2013). Members of CEE work together to facilitate the conduct of SRs around the world, including through capacity building and monitoring standards through the peer-review process. Completed SRs are available to anyone (i.e., practitioners, managers, the general public) through its flagship open-access journal *Environmental Evidence* (www.environmentalevidencejournal.org), although other journals (e.g., *Biological Conservation, Environmental Reviews, Ecological Applications*) have a track record of publishing SRs related to conservation and resource management. The general process of completing a SR is described below.

Step 1 is to identify a specific, practical, environmental management question that addresses relevant management objectives. This step is often very difficult, especially given broad management objectives that need to be focused into a single, defined question that can be addressed by a review. This process is often done in collaboration with managers, practitioners, and stakeholders so that the most relevant questions are being addressed (Thorson et al. 2015). For example, in their SR protocol document on marine protected areas (MPAs), Sciberras et al. (2009) asked the question: "Is there a relationship between the level of protection from anthropogenic extractive activities and the magnitude of the effect of the MPA intervention on biological measures?" (p. 4). In this case, the authors wanted to assess the effects of MPAs by examining various reported biological measurements (density, biomass, species richness, and body size of fish and invertebrate populations) within areas that provided full, partial, and no protection. Conservation managers, planners, and practitioners needed to better understand the biological consequences of each level of protection to know when and where to best implement each type. Typically, practical or policy concerns can be broad, leading to open questions, whereas SRs work best for focused questions. Important discussions are needed at the outset to ensure that the question is closed and well defined.

After identifying and refining a suitable question, a review protocol is developed outlining the proposed methodology, including an explicit search strategy with defined inclusion and exclusion criteria. This process ensures that the review is as rigorous, explicit, and transparent as possible. Such transparency is crucial because the repeatability of search methods is a key aspect of the systematic review process (Fazey et al. 2004). Information also needs to be gathered from multiple sources, including both traditional academic research (i.e., those in commercial academic journals) and noncommercial documents and reports (termed "gray literature" and including organizational reports, conference proceedings, government papers and theses; Haddaway and Bayliss 2015) to minimize potential publication bias (Pullin and Stewart 2006). When an SR is registered with CEE, the protocol document is submitted to CEE for peer review, allowing for members of the scientific community (both subject and methodology experts) to provide feedback, advice, and insights on the established protocols. Following the peer-review process, the accepted protocol is made publicly available online by CEE in the open-access journal *Environmental Evidence (*see Sciberras et al. 2009 as example).

Following completion of the protocol document, the search begins. Systematic searches for evidence involve examining multiple databases to comprehensively collate the evidence base as much as possible (Bayliss and Beyer 2015). This evidence is then screened for relevance against the predefined inclusion criteria by checking for consistency within the review team at title, abstract, and, finally, full-text levels. Relevant studies are subsequently critically appraised to determine the level of confidence that can be placed in each study (Bilotta et al. 2014). Qualitative study descriptors (codes) are noted and quantitative metrics (study findings, typically as means and standard errors) are gathered from each study. Studies with an appropriate experimental design (such as randomization, replication, measurement methods, and spatial scale) are assigned greater weight in the synthesis, and studies with unacceptably inferior methodology may be included in the SR but excluded from any meta-analysis (Pullin et al. 2004; Sutherland 2004; Pullin and Stewart 2006).

After data are gathered and evaluated, they are described in detail in the review report. Synthesis can be narrative, quantitative, and/or qualitative. Qualitative syntheses collate qualitative research data. Though these syntheses are often sufficient in drawing important conclusions, including knowledge gaps, their findings can also be supported by quantitative research data and evidence that can require quantitative synthesis through meta-analysis (Thorson et al. 2015). Meta-analysis is a powerful quantitative tool because it uses weighted information from multiple studies to test a hypothesis, allowing each study to be judged on its scientific merit. It also allows for data from multiple studies to be combined, to provide stronger analytical support for (or against) a management intervention (Haddaway 2015). Meta-analyses have been undertaken for several different topics within fisheries science, including recruitment studies, population viability/extinction, habitat-specific vital rates, life history parameters, and evaluating the effectiveness of MPAs (Thorson et al. 2015). For example, Babock et al. (2010) used meta-analysis of MPAs to determine their effectiveness, finding that they had rapid direct effects on the abundance of target species and slower effects on the abundance of nontarget species. Subgroup analysis, metaregression, and sensitivity analysis allow reviewers to investigate the impacts of other explanatory variables within the study system (Gurevitch et al. 2001), despite these variables having not been explicitly examined within any of the individual research studies.

Following data syntheses, the completed comprehensive report, which includes a suite of supplementary information that documents, in detail, all activities undertaken within the review, is submitted to a peer-reviewed journal. This high level of transparency is key to ensuring that the review can be readily verified and repeated (or updated) as more research becomes available. The CEE is well placed to review and publish SRs because of its large community of subject and methodology experts, and its journal *Environmental Evidence* is the only dedicated publisher of SRs. The open-access nature of this journal allows for the find-

Box 1. How Do Systematic Reviews Differ from Traditional Literature Reviews and Meta-Analyses?

Review Type	Benefits	Limitations
"Traditional" literature review	Compilation of references on a single topic of interest	Typically subject to bias, such as selection bias and publication bias Varying comprehensiveness depending on resources chosen Study quality typically not described, rarely assessed systematically
Synopsis of evidence	Compilation of conservation interventions and supporting references Conservation oriented	No quantitative synthesis No assessment or study reliability
Meta-analyses	Quantitative analysis Effects modifiers can be examined Can test for publication bias	Only as good as the studies included: unreliable studies yield unreliable meta-analysis May be subject to bias, such as selection bias Varying comprehensiveness depending on resources chosen
Systematic review	Transparent, objective, repeatable Readily updateable as new studies are made available Robust to criticism Minimize bias Critical appraisal of the reliability (internal and external validity) of all evidence	Need well-definited, focused question Need access to grey literature

ings of the SRs to be widely accessible, increasing the breadth and impact of the study findings. All SR protocols and completed SRs are updated on the CEE website and social media platforms in real time, allowing for the best available evidence to be disseminated to the public as quickly as possible. Typically, systematic reviewers also invest considerable resources in communicating the results of their review to stakeholders as summaries and/or factsheets, which are commonly of greater use to decision makers.

The processes outlined above, if undertaken with a high degree of rigor as required by CEE, can result in the provision of the best available evidence for a particular environmental question. However, for fields such as fisheries conservation, the EBM calls for more than just the production and dissemination of SRs. First, policies need to be implemented that require conservation actions to be evidence based and scientifically justified. Second, there needs to be active monitoring of current and future conservation plans, both to add data for future reviews and to ensure plan effectiveness. There also needs to be active identification of priority areas and questions for SRs, as well as identification of research gaps through the review process, prioritizing these for future research (Pullin and Knight 2004; Cooke et al. 2010).

WHY DO WE NEED EVIDENCE-BASED CONSERVATION AND MANAGEMENT?

First and foremost, the EBFCM is the best way to ensure that conservation actions are as effective as possible. This can be achieved by illuminating more effective alternatives in policy, identifying and addressing knowledge gaps, and advocating for current and future monitoring of management plans, making EBMs our best option for protecting the long-term viability of the world's fisheries. Moreover, because of inherent difficulties in observing marine fishes and the large spatial and temporal scales involved, data are often opportunistically gathered and can contain large measurement errors (Thorson and Ward 2013). By using SRs, much of this variability can be accounted for, allowing for comparison of results in a meaningful manner. Systematic reviews can also provide crucial insight into data-poor fisheries, where individual conservation managers with insufficient information may gain sufficient knowledge to make effective decisions by pooling their data (Thorson et al. 2015). Further, because in many cases the problems fisheries managers want to address are comparatively urgent, pertinent review findings can be readily used to direct the policy and management of recreational and commercial fisheries (Thorson et al. 2015).

The economic benefits to the implementation of EBFCM are staggering. On average, $21.5 billion was spent each year on conservation and habitat restoration from 2001 to 2008 (Waldron et al. 2013). That value is expected to rise to $76.1 billion annually, as governments try to meet biodiversity targets (Worm et al. 2009; McCarthy et al. 2012). This immense sum of money and an inability to provide substantive and supportive evidence for an action plan or evaluation only hinders investment. Additionally, ineffective conservation plans waste financial resources and, more important, are often detrimental to the ecosystem as a whole. This not only undermines biodiversity conservation but also weakens socioeconomic viability of fisheries (Salomon et al. 2011). Conversely, conservation action is strengthened when effectiveness can be shown beforehand, making it possible to effectively argue for long-term conservation action over short-term economic development (Pullin and Stewart 2006). Otherwise stated, it is a lot easier to convince relevant bodies to support fisheries conservation efforts financially when it can be shown that an action is the most effective option.

IMPLEMENTING AN EVIDENCE-BASED FRAMEWORK IN FISHERIES AND AQUATIC CONSERVATION AND MANAGEMENT

Although in this article we advocate an evidence-based approach to fisheries and aquatic management and conservation, by doing so we do not intend to imply that such efforts are not already underway in some jurisdictions. Indeed, there are already a number of aquatic-oriented SRs providing managers with credible evidence to inform management and policy (see Box 2). A key challenge in the future will be to produce more SRs that have practical applications to conservation. Basurto and Nenadovic (2012) assessed the effectiveness of conservation interventions of 43 SRs performed between 2001 and 2012. They found that only 53.5% had direct implications for conservation, and only 35% addressed practical management interventions.

Box 2. Examples of Aquatic-Oriented Systematic Reviews

Liming and Fish Recovery
Mant et al. (2013) used an SR to assess the effectiveness of liming (i.e., the addition of calcium carbonate to waterways or catchments in order to raise pH, offsetting freshwater acidification) and revealed that, overall, liming was associated with an increased fish abundance of 1.7 times and thus, in general, was an effective tool for accelerating recovery.
Marine Protected Areas
Sciberras et al. (2015) conducted an SR to assess the effectiveness of increasingly restricted MPAs on the density, biomass, species richness, and body size of fish and invertebrate populations. The SR compared no-take reserves (NTRs), partially protected areas—regarded as a balance between biodiversity conservation and socioeconomic viability—and open access areas (no restrictions). They concluded that NTRs yielded significantly higher biomass of fish species, with a large portion of this response driven by the targeted fish species.
Environmental Effects of Offshore Wind Farms
SRs have also been used to assess the viability of using offshore wind farms as MPAs (Ashley et al. 2014). The review found that effects caused by changes in species assemblage's at these sites needed further research, noting significant knowledge gaps and uncertainties. However, the authors highlight the important recognition that offshore wind farms are already de facto NTRs because of the difficulties involved with commercially fishing within them, making the MPA designation an obvious next step.
Biomanipulation for Managing Eutrophication
Bernes et al. (2015) assessed the impact of a reduction in planktivorous and benthivorous fish on the water quality of temperate eutrophic lakes, as a form of biomanipulation for restoration. After identifying 14,500 articles from their search criteria and screening 233 articles at full-text level, information from 128 biomanipulations in 123 lakes was assessed. The authors found that in the first 3 years following the removal of planktivorous and benthivorous fish, the Secchi depth increased and the concentration of chlorophyll a decreased. However, the results from biomanipulations tended to be more pronounced in lakes that also had intense fish removal projects on them. Further, they found that biomanipulation tends to be more successful in small lakes with short retention times and high phosphorous levels.
Consequences of Stocking
Stewart et al. (2007) used systematic review to assess the global impacts of salmonid stocking on nonstocked native fish species in recreational lake systems. Their review concluded that the effect varied depending on several factors. These factors included the number of fish stocked, time of year when stocked, lake type, carrying capacity, and initial stocking density, with the direct impact from each requiring further research.
Fish Population Response to Stream Restoration
Stewart et al. (2009) assessed the effectiveness of engineered instream structures for the restoration of streams, particularly for achieving the management goal of increasing salmonid abundance. They found that instream devices were less effective in large streams and that their widespread use in all waterbodies is not supported by current available evidence. They also highlighted that the carrying capacity of waterbodies can be limited by factors that are not modified by the addition of instream structures. Addressing those issues first, before considering instream structure installations, will have the most positive effect on the overall success of the engineering project.

Producing a systematic review is costly and time consuming and requires a high level of methodological expertise within the review team (gained through specific training such as that offered by CEE). A "typical" SR can easily take longer than 1 year and many take 2 years from start to finish, if the SR is done on a part-time basis. Efforts are currently underway to develop rapid evidence synthesis approaches given that some pressing policy and management decisions may not be able to wait for a full SR to be completed (Gannan et al. 2010). There is also a large body of existing literature reviews and meta-analyses related to fisheries and aquatic science and management. By no means are we suggesting that they are worthless. Most of these fail to follow the strict criteria of SRs, which ensure that procedural bias is minimized, the process is repeatable, and all evidence is explicitly examined. However, it is also possible to evaluate literature reviews and meta-analyses to determine the extent to which their methods were consistent with good evidence synthesis practice (see Woodcock et al. 2014).

Getting fisheries managers to use the findings from SRs for policy implementation in the best manner is another step that may pose a challenge. Despite SRs synthesizing information into comprehensive reports, managers are not required to actively search for them. Although CEE is actively communicating new SRs and evidence through their user-friendly and accessible website and the journal *Environmental Evidence*, there are currently no requirements to seek out these findings before enacting a conservation plan. We think that a requirement for policies to be informed by sound scientific evidence is needed to ensure that SRs become a commonly used tool for fisheries management.

CONCLUSION

The immense biological and financial importance of the world's fisheries requires policies that are based in evidence and science. Fortunately, in more recent years, the importance of conservation and the loss of biodiversity has entered mainstream political agendas. However, this attention alone is not enough, and more effective use of resources is crucial for future advances. Managers and policy makers require an evidence base to underpin future decision making and effectively bolster conservation efforts (Pullin and Knight 2009, 2013). We need SRs that address urgent and practical conservation questions and disseminate them in accessible, meaningful, and comprehensive formats.

Systematic reviews are not intended to replace existing science advice frameworks, such as the Canadian Science Advisory Secretariat process or the widespread use of management strategy evaluation in the United States, Europe, and Australia (Bunnefeld et al. 2011; Trenkel et al. 2015). However, SRs can easily be incorporated into these and other processes and frameworks (see Cooke et al. 2016 for an example from Canada). Evidence synthesis in the form of SRs often tackles broad questions (e.g., does a given management intervention work) whose answers and associated information can be interfaced with other more local and nuanced information such as stock assessment, stakeholder knowledge, and various socioeconomic factors that are relevant to the local context and ultimately influence complex decision-making processes.

Using EBFCM gives managers access to the best available evidence on the effectiveness of alternative management plans and provides concrete evidence to guide aquatic and fisheries policies (Pullin and Knight 2004, 2013). EBFCM also bolsters biodiversity conservation and socioeconomic viability of fisheries. Our vision is that in the coming years, EBFCM will become the gold standard for accessing, appraising, and synthesizing scientific evidence within fisheries and aquatic conservation and management. Professional societies such as the American Fisheries Society have the potential to play important roles in promoting such approaches through training, professional development opportunities, and promoting evidence-based management and conservation in science support programs.

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