Restoration Ecology
THE JOURNAL OF THE SOCIETY FOR ECOLOGICAL RESTORATION

INVITED STRATEGIC ARTICLE

Evidence-based restoration in the Anthropocene—from acting with purpose to acting for impact

Steven J. Cooke[1,2,3], Andrew M. Rous[1,2], Lisa A. Donaldson[1,2], Jessica J. Taylor[1,2], Trina Rytwinski[1,2], Kent A. Prior[4], Karen E. Smokorowski[5], Joseph R. Bennett[1,6]

The recognition that we are in the distinct new epoch of the Anthropocene suggests the necessity for ecological restoration to play a substantial role in repairing the Earth's damaged ecosystems. Moreover, the precious yet limited resources devoted to restoration need to be used wisely. To do so, we call for the ecological restoration community to embrace the concept of evidence-based restoration. Evidence-based restoration involves the use of rigorous, repeatable, and transparent methods (i.e. systematic reviews) to identify and amass relevant knowledge sources, critically evaluate the science, and synthesize the credible science to yield robust policy and/or management advice needed to restore the Earth's ecosystems. There are now several examples of restoration-relevant systematic reviews that have identified instances where restoration is entirely ineffective. Systematic reviews also serve as a tool to identify the knowledge gaps and the type of science needed (e.g. repeatable, appropriate replication, use of controls) to improve the evidence base. The restoration community, including both scientists and practitioners, needs to make evidence-based restoration a reality so that we can move from best intentions and acting with so-called "purpose" to acting for meaningful impact. Doing so has the potential to serve as a rallying point for reframing the Anthropocene as a so-called "good" epoch.

Key words: restoration ecology, systematic review, evidence synthesis, CEE

Implications for Practice

- The Anthropocene demands evidence-based restoration supported by evidence synthesis methods such as systematic reviews.
- Systematic reviews provide means of ensuring restoration efforts are truly meaningful and also help to guide future empirical science and monitoring.
- Failure to embrace evidence-based approaches to conservation will impede our ability to achieve a good Anthropocene.

The Anthropocene—an epoch defined by the overwhelming effects of humans on the biotic and abiotic components of the planet Earth (Crutzen 2006)—is upon us. Key features of the Anthropocene include widespread, and in some cases irreversible, environmental change at regional and even global scales (Vitousek et al. 1997; Steffen et al. 2007), unprecedented population declines among many taxa (Mace et al. 2008), and loss of biodiversity (i.e. extinction; Cardinale et al. 2012; Pimm et al. 2014). The fact that we are in "the Anthropocene" is not something worthy of celebration and is generally regarded as carrying negative connotations regarding the state of the environment and the future of life on Earth as we know it. However, a counter narrative has emerged where the concept of being in the Anthropocene is harnessed and leveraged to make it a "good" Anthropocene (see Dalby 2016). There is much debate regarding the extent to which a good Anthropocene is possible, what it might look like, and what is needed to get us there. For example, Bennett et al. (2016) have argued that there is a need to identify "bright spots" where we share successes and work as a community to scale them to the level needed. This inherently optimistic perspective is one that is gaining traction in that it seems much more palatable than simply throwing in the towel and musing about the dystopian future that awaits.

Restoration ecology is regarded as being a forward-looking and solution-oriented discipline tasked with repairing physical habitats and ecosystem processes, recovering populations, and reversing declines in biodiversity (Hobbs & Harris 2001; Allen 2003; Choi 2007)—or, as defined by Davis and Slobodkin

Author Contributions: all authors generated ideas, wrote text, and participated in editing the manuscript.

[1]Canadian Centre for Evidence-Based Conservation and Environmental Management, Carleton University, Ottawa, K1S 5B6, ON Canada
[2]Fish Ecology and Conservation Physiology Laboratory, Department of Biology and Institute of Environmental Science, Carleton University, Ottawa, K1S 5B6, ON Canada
[3]Address correspondence to S. J. Cooke, email steven_cooke@carleton.ca
[4]Ecosystem Restoration, Parks Canada Agency, Gatineau, QC, J8X 0B3, Canada
[5]Great Lakes Laboratory for Fisheries and Aquatic Sciences, Fisheries and Oceans Canada, Sault Ste. Marie, P6A 2E5, ON Canada
[6]Department of Biology and Institute of Environmental Science, Carleton University, Ottawa, K1S 5B6, ON Canada

doi: 10.1111/rec.12675

(2004), “the process of restoring one or more valued processes or attributes of a landscape.” Restoration is only needed when a system is impaired, and it attempts to return the system structure and function relative to an appropriate historical state (although we acknowledge the debate regarding alternative definitions and goals/targets of contemporary ecological restoration; see Higgs et al. 2014; Kueffer & Kaiser-Bunbury 2014; Bowman et al. 2017). As such, restoration ecology is inherently aligned with the concept of achieving a good Anthropocene and indeed serves as one of the few practical means of doing so (van Andel & Aronson 2012). Admittedly, restoration ecology is still a young discipline but it does have a rich and ever-expanding theoretical foundation (e.g. papers which lay out conceptual frameworks for restoration ecology; see Diamond 1987; Hobbs & Norton 1996) as well as practical “how to” resources (e.g. Clewell et al. 2000; Keenelyside et al. 2012; Perrow & Davy 2002; Clewell et al. 2007) to guide practitioners who engage in restoration. There is also a growing list of examples of how restoration interfaces with other solution-oriented paradigms (e.g. conservation science; Wiens & Hobbs 2015). Restoration certainly depends on practitioners plying their trade (and has been referred to by some as an “art”; e.g. Cabin 2007; Halle 2007) with creativity, trial-and-error, and even luck (Higgs 1994), but at its core it is science (Bradshaw 1993) and there have been calls to better integrate the science and practice (Higgs 1994; Pickett & Parker 1994). Indeed, if we are to achieve a good Anthropocene it is imperative and timely that restoration practice is informed by, and reflective of, the best available evidence.

Although much restoration is conducted by “science-based” organizations (e.g. government, non-governmental organizations [NGOs]) that does not necessarily mean that contemporary restoration activities are based on the totality of best available evidence. There is growing recognition that environmental practitioners’ decisions are most heavily influenced by past experience, tradition, or input from coworkers (Pullin et al. 2004; Cook et al. 2013; Young et al. 2016*a*, 2016*b*). Quite simply, practitioners are failing to make full use of the available body of evidence. The literature is rapidly expanding such that even if a practitioner searches the evidence base there will almost certainly be studies that have contradictory findings, which creates the potential to cherry pick the study of one’s choice to reinforce a given presumption. It is widely regarded that almost anything can be published (not if, but where) and we know that peer review is imperfect (Alpert 2007; or even flawed in the eyes of some, Smith 2006) so even in the most prestigious journals the quality of science is highly variable.

For a mission-oriented discipline like restoration ecology where the mantra is to “do good,” the idea that a given restoration action could in fact do harm (see Pullin & Knight 2009) is something that is rarely considered. When practitioners decide to act it is done with purpose—it is done with the assumption that the actions are going to directly or indirectly contribute to achieving a desired restoration objective. Yet, how often does the action yield the impact that the practitioner identified as their purpose? Given the need to ensure that the scarce human and financial resources devoted to restoration are used wisely, coupled with the time-sensitive nature of many threats to ecosystems, there is little room for restoration actions that are ill-informed and/or that fail to base their action on the best available evidence. It is important to realize that failure to use the best available evidence is unlikely to be done out of malice or reflect incompetence—it is simply a reality of how humans make decisions, especially when under time pressure. In restoration ecology, it is well known that monitoring is uncommon (Block et al. 2001) and it is likely that there is a file-drawer effect (Csada et al. 1996) where failures are less likely to be shared/published than successes. So—how can restoration ecology move forward in a truly meaningful way—well beyond the previous calls for “change” in restoration science and practice (see Higgs 1994; Pickett & Parker 1994; Choi 2007)? Here, we introduce the concept of evidence-based restoration and discuss a tool that can help both scientists and practitioners make better-informed decisions.

Evidence-based restoration involves the use of rigorous, repeatable, and transparent methods to identify and amass relevant knowledge sources, critically evaluate the science, and synthesize the credible science to yield robust policy and/or management advice needed to restore the Earth’s ecosystems. Linked to this, any management intervention efforts (e.g. creation of a given habitat feature) must have an integrated monitoring program to further build the evidence base. The concept of evidence-based restoration is not a new idea and indeed grows out of the broader evidence-based conservation and environmental management movement (see Sutherland et al. 2004) spearheaded by the Collaboration for Environmental Evidence (CEE) and involving systematic reviews. Drawing upon evidence synthesis practices used for health care and medicine by the Cochrane Collaboration (Bero & Rennie 1995; see Pullin & Knight 2001), the CEE has developed a series of guidelines used for conducting systematic reviews relevant to various topics in conservation and environmental management. Traditional literature reviews and meta-analyses are common ways of assembling and synthesizing different studies on a similar topic (Roberts et al. 2006). However, traditional literature reviews and meta-analysis tend to be subjective (and thus not repeatable) and rarely is the evidence critically evaluated, with less rigorous studies (e.g. pseudoreplication or lack of replicates, lack of appropriate controls and comparators, etc.) excluded or down-weighted (O’Leary et al. 2016). The hallmark of systematic reviews (when done properly; Haddaway et al. 2017) is the comprehensiveness of the literature search and the transparent critical evaluation and justification of the conclusions made by the authors (Haddaway & Bilotta 2016).

In the realm of ecological restoration, there have been a number of literature reviews and meta-analyses written (some published in the peer-reviewed literature and others as government or NGO technical reports) that have become “authoritative” sources to inform restoration practice. Yet, if those syntheses include studies of low quality or fail to survey the entire literature base (both of which are common pitfalls with traditional reviews; see Roberts et al. 2006) there is much room for bias and thus implementation of actions that are unsound and potentially counterproductive (or even harmful). To address this deficiency, we call upon the scientific community in the realm of restoration ecology to embrace the concept of evidence-based restoration. Doing so means learning about and engaging in proper evidence synthesis activities (see CEE 2013; Pullin & Stewart 2006) as well as generating science that is considered "high quality" and repeatable (Haddaway & Verhoeven 2015) so that it can be used in such evidence synthesis activities (see Cooke et al. 2017*a*, e.g. pitfalls to avoid if one wants to generate science that is relevant to practitioners). Inadequate evaluations, incomplete sharing, and biased reporting of restoration outcomes fail to contribute to expanding the evidence base for the entire community. There are growing opportunities for learning about SRs and evidence synthesis and freely available guidelines to follow such that expertise should not be inherently limiting. That is not to say that conducting systematic reviews is easy or necessarily rapid (which can be problematic given time-sensitive nature of many problems). Rather there is a growing community of individuals and organizations who are committed to supporting the broader development and adoption of systematic reviews, expanding the opportunities for training and mentoring, and thus increasing capacity (see Cooke et al. 2017*b*). There is also much effort underway to determine the extent to which we can potentially rely on "rapid systematic reviews" as a means of arriving at similar findings and do so in a more rapid manner. That said, with sufficient resourcing, the correct team, and a well-defined and well-bounded research question, systematic reviews can be conducted within several months.

The science (and monitoring) associated with restoration is often lacking the rigor that one would like. The gold standard "BACI" design (see Green 1979) implies a long-term financial commitment that begins prior to any "shovels in the ground"; and the political appetite for funding such studies seems limited. This varies somewhat among systems, taxa, imperilment status of the ecosystem or species, and restoration strategy, but it is fair to say that compromises are often required in experimental design such that "modified" BACI designs are common (Underwood 1992; Smokorowski & Randall 2017). There is also an onus on the practitioner to seek out rigorous evidence rather than blindly accepting the status quo, but few restoration practitioners seek out such evidence. Our knowledge base is ever-growing, which provides countless opportunities to refine management interventions to ensure they have as much impact as possible. Systematic reviews serve as the most credible form of evidence synthesis available (Pullin & Knight 2009; Haddaway & Bilotta 2016) and can be interfaced with other contemporary environmental decision support tools, including adaptive management (Bower et al. 2017; Schwartz et al. 2017).

Fortunately, there are already several examples of systematic reviews conducted to CEE standards that focus on topics relevant to ecological restoration and serve as models of what is possible. For example, Stewart et al. (2009) determined that in-stream structure placement failed to increase salmonid fish abundance and biomass, whereas efforts to restore the riparian zone were generally beneficial. Considering the many programs around the globe that engage citizens in stream restoration, this article was foundational in refocusing those volunteers on activities (e.g. riparian planting, keeping cattle out of streams with fencing) that achieved restoration targets. Given that implementing invasive plant control measures is a common approach to restoration of invader-dominated ecosystems, Kettenring and Adams (2011) conducted a systematic review to determine effectiveness. The authors revealed that invasive plant management efforts have had only moderate success on the restoration of invader-dominated ecosystems, and identified a number of specific interventions that require additional empirical research. Another systematic review attempted to determine whether spring ecosystem restoration projects in arid regions had been effective in restoring hydrology, geomorphology, and ecology, but found that there were insufficient studies with appropriate controls to enable quantitative analysis (Stacey et al. 2011), thus identifying a clear research need. In a systematic review of the effectiveness of wet meadow restoration, Ramstead et al. (2012) noted that the pond-and-plug approach—whereby eroded gullies are filled at various intervals to reduce or divert water flow—was an effective technique for restoring many aspects of wet meadows, confirming that current practice was appropriate. In a final example, Land et al. (2016) evaluated the effectiveness of created and restored wetlands for nitrogen and phosphorus removal. In general, this eutrophication abatement method led to significant decreases in the transport of nutrients. Importantly, the authors also determined that the effectiveness was context specific (e.g. restored wetlands on former farmland were less effective at total phosphorus [TP] removal and more broadly, hydrologic regime influenced effectiveness of TP removal).

Collectively, these examples highlight how systematic reviews can be used for various purposes including dispelling myths that have become dogma, identifying the context specificity of a given restoration method, boosting evidence (i.e. providing support for ongoing restoration activities), identifying knowledge gaps, and improving future empirical science related to ecological restoration.

In addition to the completed restoration-relevant systematic reviews described above, there are others underway covering topics such as the effectiveness of spawning habitat creation or enhancement for substrate spawning temperate fish (Taylor et al. 2017), the effects of prescribed burning in temperate and boreal forest on biodiversity (Eales et al. 2016), and the effectiveness of non-native fish eradication techniques in freshwater ecosystems (Donaldson & Cooke 2016). Such systematic reviews have typically been commissioned by government agencies tasked with allocating funding and other resources, which is a promising development that suggests many management agencies buy into the concept of evidence-based restoration and are willing to incorporate systematic reviews into their science support programs (e.g. Cooke et al. 2016).

The Anthropocene is here and the restoration practitioner of today and tomorrow has a mighty task before them. Those agencies and organizations funding restoration need to determine where resources should best be allocated, and systematic reviews can inform such allocations, especially when combined with other methods such as rigorously documented adaptive management and long-term science-based rigorous monitoring using well-designed experimental frameworks. Much of the restoration work done today is led by community groups and other concerned individuals who honestly believe they are "doing good." Systematic reviews provide a rational means of ensuring those valuable efforts are truly meaningful especially if we can learn from ongoing restoration activities in a manner where the evidence base is strengthened. It is important that practitioners share their findings and *Restoration Ecology* provides mechanisms for doing so (e.g. case-based articles covering technical or practical aspects). As the journal *Restoration Ecology* celebrates its 25th year, it would seem prudent to call for greater reliance on established evidence synthesis methods to help guide restoration practices. This is particularly salient as more "radical" approaches to restoration are considered and tested (e.g. assisted migration, taxon substitution, de-extinction, and genetic modification; see Corlett 2016).

The journal *Restoration Ecology* is well suited towards publishing authoritative systematic reviews but also in working closely with its constituent communities to advance evidence-based restoration. Systematic reviews identify key knowledge gaps and also help to refine future science, such that it is robust and defensible, contributing to the knowledge base necessary to conduct or update a systematic review. There is opportunity to consider various knowledge forms (including indigenous knowledge systems) in systematic reviews (Tranfield et al. 2003) such that the "artistic" elements of restoration practice can also be captured. Yet, at the end of the day, one would not want health care decisions being based on art—rather you want the best available evidence to guide those decisions. It is time to stop arguing about whether restoration is an art or a science, and instead focus on growing the evidence base and learning from the studies that have been done. Shooting from the hip wastes time and resources, putting the credibility of the entire ecological restoration field at risk and delaying the immense task before us. The Anthropocene demands evidence-based restoration. Now it is our collective job as a community to help make evidence-based restoration a reality so that we can move from best intentions and acting with so-called "purpose" to acting for meaningful impact such that bright spots (Bennett et al. 2016) become common and serve as a rallying point for reframing the Anthropocene as a good epoch.

Acknowledgments

S. J. C. is supported by NSERC and the Canada Research Chairs Program. J. R. B. is also supported by NSERC. Further support for the development of the ideas presented here was provided by Carleton University through their Research Excellence Fund. We also acknowledge the support of Parks Canada and Fisheries and Oceans Canada in development of systematic review capacity in Canada. We declare no conflict of interest.

LITERATURE CITED

Allen EB (2003) New directions and growth of restoration ecology. Restoration Ecology 11:1–2

Alpert JS (2007) Peer review: the best of the blemished. The American Journal of Medicine 120:287–288

van Andel J, Aronson J (eds) (2012) Restoration ecology: the new frontier. John Wiley & Sons, Chichester, United Kingdom

Bennett EM, Solan M, Biggs R, McPhearson T, Norström AV, Olsson P, et al. (2016) Bright spots: seeds of a good Anthropocene. Frontiers in Ecology and the Environment 14:441–448

Bero L, Rennie D (1995) The Cochrane Collaboration: preparing, maintaining, and disseminating systematic reviews of the effects of health care. JAMA 274:1935–1938

Block WM, Franklin AB, Ward JP, Ganey JL, White GC (2001) Design and implementation of monitoring studies to evaluate the success of ecological restoration on wildlife. Restoration Ecology 9:293–303

Bower SD, Brownscombe JW, Birnie-Gauvin K, Ford M, Moraga AD, Pusiak RJP, Turenne E, Zolderdo AJ, Cooke SJ, Bennett JR (2017) Making tough choices: picking the appropriate conservation decision-making tool. Conservation Letters, 00:1–7 https://doi.org/10.1111/conl.12418

Bowman DM, Garnett ST, Barlow S, Bekessy SA, Bellairs SM, Bishop MJ, et al. (2017) Renewal ecology: conservation for the Anthropocene. Restoration Ecology 25:674–680

Bradshaw AD (1993) Restoration ecology as a science. Restoration Ecology 1:7173

Cabin RJ (2007) Science-driven restoration: a square grid on a round Earth? Restoration Ecology 15:1–7

Cardinale BJ, Duffy JE, Gonzalez A, Hooper DU, Perrings C, Venail P, et al. (2012) Biodiversity loss and its impact on humanity. Nature 486:59–67

CEE (2013) Guidelines for systematic review and evidence synthesis in environmental management. Version 4.2. Environmental Evidence. www.environmentalevidence.org/Documents/Guidelines/Guidelines4.2.pdf

Choi YD (2007) Restoration ecology to the future: a call for new paradigm. Restoration Ecology 15:351–353

Clewell A, Rieger J, Munro J (2000) Guidelines for developing and managing ecological restoration projects. Society for Ecological Restoration International, Tucson, Arizona

Cook CN, Mascia MB, Schwartz MW, Possingham HP, Fuller RA (2013) Achieving conservation science that bridges the knowledge–action boundary. Conservation Biology 27:669–678

Cooke SJ, Rice JC, Prior KA, Bloom R, Jensen O, Browne DR, Donaldson LA, Bennett JR, Vermaire JC, Auld G (2016) The Canadian context for evidence-based conservation and environmental management. Environmental Evidence 5:14

Cooke SJ, Birnie-Gauvin K, Lennox RJ, Taylor JJ, Rytwinski T, Rummer JL, Franklin CE, Bennett JR, Haddaway NR (2017a) How experimental biology and ecology can support evidence-based decision-making in conservation: avoiding pitfalls and enabling application. Conservation Physiology 5:COX043

Cooke SJ, Johansson S, Andersson K, Livoreil B, Post G, Richards R, Stewart R, Pullin AS (2017b) Better evidence, better decisions, better environment: emergent themes from the first environmental evidence conference. Environmental Evidence 6:15

Corlett RT (2016) Restoration, reintroduction, and rewilding in a changing world. Trends in Ecology & Evolution 31:453–462

Crutzen PJ (2006) The "Anthropocene". Pages 13–18. In: Ehlers E, Kraff T (eds) Earth system science in the Anthropocene. Springer Berlin, Heidelberg, Germany

Csada RD, James PC, Espie RH (1996) The "file file drawer problem" of non-significant results: does it apply to biological research? Oikos 76:591–593

Dalby S (2016) Framing the Anthropocene: the good, the bad and the ugly. The Anthropocene Review 3:33–51

Davis MA, Slobodkin LB (2004) The science and values of restoration ecology. Restoration Ecology 12:1–3

Diamond J (1987) Reflections on goals and on the relationship between theory and practice. Pages 329–336. In: Jordan WR III, Gilpin ME (eds). Restoration ecology: a synthetic approach to ecological restoration. Cambridge University Press, Cambridge, United Kingdom

Donaldson LA, Cooke SJ (2016) The effectiveness of non-native fish eradication techniques in freshwater ecosystems: a systematic review protocol. Environmental Evidence 5:1–10

Eales J, Haddaway NR, Bernes C, Cooke SJ, Jonsson BG, Kouki J, Petrokofsky G (2016) What is the effect of prescribed burning in temperate and boreal forest on biodiversity, beyond tree regeneration, pyrophilous and saproxylic species? A systematic review protocol. Environmental Evidence 5:24

Green RH (1979) Sampling design and statistical methods for environmental biologists. Wiley, Chichester, United Kingdom

Haddaway NR, Bilotta GS (2016) Systematic reviews: separating fact from fiction. Environment International 92:578–584

Haddaway NR, Verhoeven JT (2015) Poor methodological detail precludes experimental repeatability and hampers synthesis in ecology. Ecology and Evolution 5:4451–4454

Haddaway NR, Land M, Macura B (2017) "A little learning is a dangerous thing": a call for better understanding of the term 'systematic review'. Environment International 99:356–360

Halle S (2007) Science, art, or application—the "karma" of restoration ecology. Restoration Ecology 15:358–361

Higgs E (1994) Expanding the scope of restoration ecology. Restoration Ecology 2:137–146

Higgs E, Falk DA, Guerrini A, Hall M, Harris J, Hobbs RJ, Jackson ST, Rhemtulla JM, Throop W (2014) The changing role of history in restoration ecology. Frontiers in Ecology and the Environment 12:499–506

Hobbs RJ, Harris JA (2001) Restoration ecology: repairing the earth's ecosystems in the new millennium. Restoration Ecology 9:239–246

Hobbs RJ, Norton DA (1996) Towards a conceptual framework for restoration ecology. Restoration Ecology 4:93–110

Keenelyside K, Dudley N, Cairns S, Hall C, Stolton S (2012) Ecological restoration for protected areas: principles, guidelines and best practices. Vol 18. IUCN, Gland, Switzerland

Kettenring KM, Adams CR (2011) Lessons learned from invasive plant control experiments: a systematic review and meta-analysis. Journal of Applied Ecology 48:970–979

Kueffer C, Kaiser-Bunbury CN (2014) Reconciling conflicting perspectives for biodiversity conservation in the Anthropocene. Frontiers in Ecology and the Environment 12:131–137

Land M, Granéli W, Grimvall A, Hoffmann CC, Mitsch WJ, Tonderski KS, Verhoeven JT (2016) How effective are created or restored freshwater wetlands for nitrogen and phosphorus removal? A systematic review. Environmental Evidence 5:9

Mace GM, Collar NJ, Gaston KJ, Hilton-Taylor C, Akçakaya HR, Leader-Williams N, Milner-Gulland EJ, Stuart SN (2008) Quantification of extinction risk: IUCN's system for classifying threatened species. Conservation Biology 22:1424–1442

O'Leary BC, Kvist K, Bayliss HR, Derroire G, Healey JR, Hughes K, Kleinschroth F, Sciberras M, Woodcock P, Pullin AS (2016) The reliability of evidence review methodology in environmental science and conservation. Environmental Science & Policy 64:75–82

Perrow MR, Davy AJ (eds) (2002) Handbook of ecological restoration. Vol 2. Cambridge University Press, Cambridge, United Kingdom

Pickett STA, Parker VT (1994) Avoiding theold pitfalls: opportunities in a new discipline. Restoration Ecology 2:75–79

Pimm SL, Jenkins CN, Abell R, Brooks TM, Gittleman JL, Joppa LN, Raven PH, Roberts CM, Sexton JO (2014) The biodiversity of species and their rates of extinction, distribution, and protection. Science 344:1246752

Pullin AS, Knight T (2001) Effectiveness in conservation practice: pointers from medicine and public health. Conservation Biology 15:50–54

Pullin AS, Knight TM (2009) Doing more good than harm–building an evidence-base for conservation and environmental management. Biological Conservation 142:931–934

Pullin AS, Stewart GB (2006) Guidelines for systematic review in conservation and environmental management. Biological Conservation 20:1647–1656

Pullin AS, Knight TM, Stone DA, Charman K (2004) Do conservation managers use scientific evidence to support their decision-making? Biological Conservation 119:245–252

Ramstead KM, Allen JA, Springer AE (2012) Have wet meadow restoration projects in the Southwestern US been effective in restoring geomorphology, hydrology, soils, and plant species composition? Environmental Evidence 1:11

Roberts PD, Stewart GB, Pullin AS (2006) Are review articles a reliable source of evidence to support conservation and environmental management? A comparison with medicine. Biological Conservation 132:409–423

Schwartz MW, Cook CN, Pressey RL, Pullin AS, Runge MC, Salafsky N, Sutherland WJ, Williamson MA (2017) Decision support frameworks and tools for conservation. Conservation Letters, 00:1–12 https://doi.org/10.1111/conl.12385

Smith R (2006) Peer review: a flawed process at the heart of science and journals. Journal of the Royal Society of Medicine 99:178–182

Smokorowski KE, Randall RG (2017) Cautions on using the before-after-control-impact design in environmental effects monitoring programs. FACETS 2:212–232

Stacey CJ, Springer AE, Stevens LE (2011) Have arid land springs restoration projects been effective in storing hydrology, geomorphology, and invertebrate and plant species composition comparable to natural springs with minimal anthropogenic disturbance? Systematic review 87. Collaboration for Environmental Evidence, Flagstaff, Arizona

Steffen W, Crutzen PJ, McNeill JR (2007) The Anthropocene: are humans now overwhelming the great forces of nature. Ambio 36:614–621

Stewart GB, Bayliss HR, Showler DA, Sutherland WJ, Pullin AS (2009) Effectiveness of engineered in-stream structure mitigation measures to increase salmonid abundance: a systematic review. Ecological Applications 19:931–941

Sutherland WJ, Pullin AS, Dolman PM, Knight TM (2004) The need for evidence-based conservation. Trends in Ecology & Evolution 19:305–308

Taylor JJ, Rytwinski T, Bennett JR, Smokorowski KE, Cooke SJ (2017) The effectiveness of spawning habitat creation or enhancement for substrate spawning temperate fish: a systematic review protocol. Environmental Evidence 06:05

Tranfield D, Denyer D, Smart P (2003) Towards a methodology for developing evidence-informed management knowledge by means of systematic review. British Journal of Management 14:207–222

Underwood AJ (1992) Beyond BACI: the detection of environmental impacts on populations in the real, but variable, world. Journal of Experimental Marine Biology and Ecology 161:145–178

Vitousek PM, Mooney HA, Lubchenco J, Melillo JM (1997) Human domination of Earth's ecosystems. Science 277:494–499

Wiens JA, Hobbs RJ (2015) Integrating conservation and restoration in a changing world. Bioscience 65:302–312

Young N, Nguyen VM, Corriveau M, Cooke SJ, Hinch SG (2016a) Knowledge users' perspectives and advice on how to improve knowledge exchange and mobilization in the case of a co-managed fishery. Environmental Science & Policy 66:170–178

Young N, Corriveau M, Nguyen VM, Cooke SJ, Hinch SG (2016b) How do potential knowledge users evaluate new claims about a contested resource? Problems of power and politics in knowledge exchange and mobilization. Journal of Environmental Management 184:380–388

Coordinating Editor: Stephen Murphy

Received: 22 December, 2017; First decision: 22 December, 2017; Accepted: 22 December, 2017; First published online: 6 February, 2018