a multidisciplinary open access journal
published by Canadian Science Publishing

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Journal:	*FACETS*
Manuscript ID	Draft
Manuscript Type:	Science Applications Forum
Date Submitted by the Author:	n/a
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Primary manuscript subject:	Conservation and Sustainability < Integrative Sciences
Secondary manuscript subject:	Science Communication < Integrative Sciences
Is the paper being submitted for consideration in a FACETS Collection? :	Not Applicable (regular submission)

Ten simple principles for engineering reproducible solutions to environmental management challenges from primary research.

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Abstract

We understand natural systems through many pathways. Research and the scientific literature can be viewed as descriptions that we use and reuse to make decisions for policy and management. An environmental management challenge can thus be an opportunity to use fundamental science to inform evidence-based decisions for environmental stakeholders and conservationists. Contemporary science is embracing open science and increasingly conscious of reproducibility. Synergistically, applying these two paradigms in concert advances our capacity to move beyond context dependency and singular, unidirectional linear thinking to reverse engineer solutions from published scientific evidence associated with one challenge to many. Solutions can scale, and we need to better reuse the scientific literature. Herein, we provide a succinct list of principles to address environmental management through primary scientific literature reuse. This extends and supports science-policy-practice developments and the increasing attention to scientific co-production as a mechanism to better connect knowledge and sustainable societies.

Keywords

Conservation, decision making, environmental challenges, evidence, grand challenges, reproducible science, scientific co-production, scientific knowledge

Introduction

People can understand nature through interactions with nature. Experience and values are shaped by context (Fernández 2016). However, the primary scientific literature is another important mechanism or resource that we use to understand nature because we describe and measure natural systems. Conservation decisions typically reside with legislators or with environmental managers. Managers typically have scientific backgrounds and routinely navigate the technical literature. However, engagement with scientific literature is non-trivial for all practitioners because of time, restricted access, relevance of the science, and reporting standards. Environmental managers and conservationists need to be able to use primary evidence to inform decisions (Cash, et al. 2003, Koontz and Thomas 2018) and provide clear roadmaps of change in coupled natural-human systems (Fischer and Riechers 2019). Ideally, critical research is co-produced with stakeholders in key sustainability contexts (Maillet, et al. 2019, Regeer, et al. 2009). However, there are very high volumes of useful research produced globally nor does it have to be co-produced to be useful. There can also be a gap in communication between basic science in these other contexts and management for at least three reasons. Firstly, the research is not a direct study of an ecosystem, and an immediate, real-world solution is needed by managers - preferably with a demonstrable outcome and reasonable cost estimate (Iacona, et al. 2018, Naidoo, et al. 2006). This is a very real limitation in the primary science literature restoration ecology for instance (Lortie, et al. 2018). Secondly, the link between the biology and ecology present in the literature is not articulately connected to the similar process for the system at hand. There are notable examples with journals just as the Journal of Applied Ecology, Basic and Applied Ecology, Facets, The Journal of Environmental Engineering, People and Nature, and others. Nonetheless, there remains an opportunity for solution development from publications in other journals that are not necessarily directly linked to stakeholders or co-produced. Context-specific findings in science are a legitimate and useful means to advance discovery, but at times, studies from one system can be re-purposed for insights into another (Fischer and Riechers 2019). Finally, the capacity to see the forest for the trees for even large-scale or broad basic research study can be a challenge. Science can be very specialized (Baron 2010), and mobilizing knowledge for solutions requires both detailed expertise, scientific synthesis tools (Lortie 2014), or a focus on identifying the salient elements associated with a study (Hao 2018, Lewinsohn, et al. 2015). Often, seeing the forest also requires sampling many trees. This leads to the general proposal here that experts that not currently engaged in collaboration and co-production with stakeholders can promote reproducible and mobile knowledge for many fundamental scientific endeavors by considering these principles. This is both a set of principles to enable reusable research by environmental managers and conservationists (Gerstner, et al. 2017) and inform solutions for the environmental crisis. We do not meant to imply that knowledge transfer is linear or exclusively the domain of experts (Calo 2018, Fernández 2016), but that the wealth of published environmental science can be made more accessible through these simple ideas.

An environmental management challenge is a problem presented in scientific literature or society that, when redefined and reviewed using these principles, can result in a solution to the original problem. Typically, a challenge is ethical, legal, social, or derived from implications associated with research and evidence of change or anthropogenic stress (Acocella 2015, Bonebrake, et al. 2018). Grand challenges for the environment in particular are ones that necessitate connections between disciplines and require evidence from potential studies that examine different components of the environment such as climate, ecology, species biology, or research from any number of levels (Bonebrake, et al. 2018, Macpherson and Segarra 2017). A (reverse-engineered) reproducible solution is a suggested solution to a challenge derived from identifying all the components of the challenge. In software engineering, this process includes analysis of the architecture of a system, examining the relationships between subsystems, and creating a mental model of how the system functions (Fiutem and Antoniol 1996). The same process can be applied to basic science as a system for supporting environmental management decisions. It should be applicable to multiple local-extent challenges when adjusted to fit the circumstances (like a software application that can run under different operating systems). Finally, a tool or solution is the desired outcome from the primary research to support evidence-based/informed decision making in conservation (Maillet, et al. 2019). In this case, a tool is a methodology researchers can promote to either identify ways to measure/identify issues or to provide solutions for their specific challenge - not necessarily directly examined in a publication or produced through stakeholder collaboration a priori. Any tool is linked to its respective reproducible solution by the fundamental concepts of reproducibility (Baker 2016). These can include conceptual replication, i.e. repeating the ideas, but there are many other solutions. Here, we propose that both direct replication (replicating the same approach in another context) and conceptual replication (repeated tests of the same concept but with different methods) (Kelly 2006) will advance our capacity to explore reproducibility of basic science to different challenges associated with environmental management. The primary goal is to escape the ‘everything is context-specific’ assumption sometimes applied to many natural science sub-disciplines.

The heuristic developed here was inspired by the ‘ten simple rules’ paper format pioneered by Phillip Bourne in the field of computational biology (Bourne and Chalupa 2006). We propose that by distilling the concepts that promote engagement with scientific literature outside of the research community, managers can rely on broader sources of scientific knowledge to make decisions in addition to those co-produced and collaboratively developed. Furthermore, researchers can reframe their scientific communication (when appropriate) to make it more relevant to managers without compromising their respective fundamental research programs. Here, we will outline and discuss simple “principles” scientists can use to make their research more applicable to managers and that managers can in turn use to identify basic science that fits their needs.

Principles

1. Reframe the problem as challenge. Doom-and-gloom is a pervasive theme in the media discussions of ecology and environmental sciences that reduces our productivity and capacity to solve problems. It can shut down even the most motivated of minds through compassion fatigue, burnouts, and psychic numbing (Pihkala 2019). Reframing a problem as a *challenge* can illuminate solutions despite disheartening information. For example, human-wildlife conflict is a pervasive issue for managers and researchers that requires tact and a deep understanding of the relationships between people and wildlife (Conover 1998). Instead of defining a problem as, "people and wildlife are in danger when they interact" re-frame the issue as a *challenge* such as "our goal is to improve safety of wildlife and humans in areas with high human-wildlife interactions." A challenge statement is more goal oriented, therefore refining communication and action between actors. This small change in semantics has profound implications in social context for stakeholders, managers, and researchers because it promotes action-based thinking and collaborative work.

2. Describe the scope and extent of the challenge. Defining the scope of a challenge conceptually and the extent geographically will ensure that potential solutions fit the challenge. Moving across scales is a common issue in ecology (Sandel 2015), and proposing a spatial scale, using common terms, and describing the breadth of the challenge will accelerate interdisciplinary solutions (i.e. the wildlife-human challenge above is ecological *and* societal). The challenge can be relevant for local, regional, or global scales. We unite different instances of an issue and how they can be similarly addressed when we link scales. However, understanding the geographical extent also allows us to pinpoint issue differences. The example of human-wildlife conflict is a global issue, but the *extent* is conflict-specific because it is directly observables in Southern California coastlines, Tanzanian park boarders, Ontarian roadways (Dickman 2010, Dupuis-Désormeaux, et al. 2019, Schakner, et al. 2019). Articulating scope and extent informs our assessment of severity and urgency, but it also identifies interdisciplinary and cross-cultural solutions.

3. Explicitly link the basic science to management implications and policy. Perhaps the most facile principle, a simple description and definition of the basic scientific evidence in a study and how it can be reused is a fundamental step in linking science to evidence-based decision making for environmental challenges. In the wildlife-human challenge, perception of loss and actual losses are not necessarily equivalent, and culture (not direct experience) is shaping subsequent conflicts (Dickman, et al. 2014). Consequently, a clear and balanced statement of evidence can highlight limitations in the science relative to the social acceptability of a solution (Bonebrake, et al. 2018).

4. Propose implications of ignoring this challenge. A description of the impact a challenge on a system if left unchecked will help clarify the severity of the challenge. The trickle-down effects and indirect implications of the challenge should also be examined. For instance, anti-carnivore sentiment will likely only grow as climate change and pressures to confine pastoral herders makes livestock more difficult to manage (Jones and Thornton 2009, Lindsey, et al. 2009). Many large carnivores are already threatened and endangered, and further anthropogenic pressures on the populations will lead to severe declines in populations including potential extinction of keystone species (Bagchi and Mishra 2006, Johnson, et al. 2006, Towns, et al. 2009); but it is often associated with underlying human-human conflict (Dickman 2010). Hence, citizens are not only the recipients of scientific knowledge but relevant stakeholders in both the potential knowledge production processes and the consequences socially and ecologically (Fernández 2016, Kates, et al. 2001). Implications should encompass both the ecology of a system and the people.

5. State the direct human needs associated with this challenge. State the direct needs of humans as part of the process of generating reproducible solutions for environmental challenges. The intrinsic value of the ecosystem is impossible to quantify (Davidson 2013), but linking the challenge and its solutions to direct human needs makes it less likely to be dismissed. Identifying anthropogenic needs will help a problem solver create a solution that is appropriate for the challenge, and it can also prevent the emergence of new related challenges or pressures on the system in question. This statement can also include engagement with stakeholders as a mechanism to inform benefits and solutions (Colvin, et al. 2016, Reed 2008). Benefits to stakeholders can include cultural ecosystem services and these will in turn further sustainable local planning and more directed science (Tew, et al. 2019). The science-practice connection is not that simple (Regeer, et al. 2009) but articulating human needs in any ecological system will go a long way to more acceptable science and collaboration.

6. List at least one limitation of the study and explain. There is no perfect experiment (Ruxton 2018) or synthesis (Kotiaho and Tomkins 2002). Critically reading the study associated with the challenge can mean the difference between success and failure of a derived management solution that otherwise follows all other principles presented here. A clear analysis of causation and correlation can help avoid a fatal misstep and ensures effective framing of expected outcomes that include an environmental intervention for conservationists. This is not to say that interventions must always be cause-effect studies or that decisions cannot be made with compelling preliminary evidence or mensurative data. We are simply proposing that a statement of the relative strength of evidence and gaps in the research provides a future direction for additional research and for implementation.

7. Explore the benefits of minimal intervention for stakeholders. Resources are limiting, and at times, the business-as-usual model can provide a guide to intervention for some environmental management challenges (Ferguson 2015, Mosnier, et al. 2017). At the minimum, exploration of a hope-for-the-best strategy or minimal intervention is critical because of costs. Business-as-usual models can also provide an economic mechanism to value ecosystems services (Fu, et al. 2018, Karttunen, et al. 2018), and whilst this is not without debate, this can expand the breadth of stakeholders and potential investors in a solution for a particular challenge. A best and worst case scenario analysis is also a frequent need for many environmental challenges because of inertia in the socio-political structures that we use to manage people and resources.

8. List the tools applied to this challenge. In an environmental management challenge case study, there is typically at least one primary tool that the researchers used to explore a challenge, but there are many tools such as meta-analyses (Busch and Ferretti-Gallon 2017), big data (Hampton, et al. 2013), mapping (Halpern, et al. 2008), modeling (Vogt, et al. 2017), citizen science (Burkle, et al. 2013), and team science (Nielsen, et al. 2017). The tools in basic biology and ecology relevant to environmental management can be reproducible if, at least conceptually, they can be replicated in another system or applied to similar challenge – i.e. citizen science as a means to collect environmental data (McKinley, et al. 2017) is relevant to many of the challenges we face including global warming, water quality, and declining biodiversity.

9. Link the primary reproducible tool to the outcome. A reproducible science tool can provide a means to collect data, detect patterns, directly solve an environmental challenge, or inform policy. If the paper was a direct test of basic ecology for an environmental challenge, this can be very straightforward. For instance, the paper entitled "Odonata (Insecta) as a tool for the bio-monitoring of environmental quality" (Miguel, et al. 2017) explicitly provides a means to measure and detect in the title. However, the other proposed roles can address challenges in a diversity of ways. The identification of or provision of research evidence is the most 'basic' role, and it is also likely the most typical role for much of ecology for example. Tools that can function in this capacity include surveys, citizen science data collection, mapping, open-access data, and modeling to predict changes. Tests in the second category that directly examine the efficacy of a management strategy or intervention can further include bio-monitoring (Miguel, et al. 2017), mitigation and remediation experiments (Zhu, et al. 2010), and population demography studies (Botero, et al. 2015). Studies that inform policy are typically more indirect and synthetic and can take the form of anthropocentric studies that consider ecological or environmental policy. Any of the above tools can serve this role, but some tools that fit most squarely include economic incentivization models (Tilman, et al. 2018), human health impact studies (Chiabai, et al. 2018), and human well-being monitoring associated with environmental interventions (McKinnon, et al. 2015).

10. Apply the tool to another challenge or explain how it is generalizable. This principle proposes that the primary tool is reproducible if it can be applied to another challenge or context. It ties together the concept that reverse-engineered reproducible solutions are relevant to more than the unpacked, single environmental management challenge case. This can promote increased in efficiency for tackling novel environmental challenges as they emerge, and it also supports the overarching philosophy here for basic science that we cannot continue to ignore reuse given the global environmental needs for better decision making.

Implications

These principles can distribute the burden of scientific communication between scientists and stakeholders and enable better two-way interactions with scientific knowledge. This is not a surrogate for scientific co-production with stakeholders, but it is a heuristic that can enable adaptive management for the environmental sciences from studies that are not necessarily coupled to issues or partnerships. A core tenet of adaptive management is that managing and learning should be connected and iterative in the natural resource sciences (Williams and Brown 2016). Decision making adjusts as understanding improves both through doing and through learning. This is not a new approach to managing the environment but requires a well articulated framework to be an active process for stakeholders and to improve long-term conservation outcomes (McDonald-Madden, et al. 2010). Making the research literature more functional through these principles will accelerate the learning phase of adaptive management. We can make deliberation (i.e. planning) and iteration (i.e. testing) integrate with evidence by adopting these principles (Williams and Brown 2016). Reuse is also not the sole criterion for useful science nor should it be, but professional advocacy and knowledge mobilization are increasingly important priorities for universities and science in general (Pace, et al. 2010). Evidence-informed decision making is a critical area for growth and knowledge in many disciplines (Aarons, et al. 2011, Roy-Byrne, et al. 2010, Tranfield, et al. 2003) – not just environmental management. Increased consumption and production of scientific evidence by managers and practitioners that is more accessible to a broader audience will result in increased functional use of scientific literature. Collaboration with stakeholders will facilitate this process at every step of the scientific endeavour, and open science will be pivotal to adaptive management opportunities. A recent discussion of rewilding ecosystems formally modeled societal context as a boundary that must always be considered in all dimensions of restoration efforts by managers and stakeholders (Perino, et al. 2019). Using at least some of these principles similarly advances connecting people to nature to primary research. This integrated thinking is critical. Better reporting of research and discussion of relevance and thus perception will increase the stickiness of our ideas and enable novel connections between evidence and outcome, challenge and solution, and people and nature.

Simple principles for the framing of environmental science that enable more connected science to people augment extensive discussion and developments in the field of science, technology, and society and the social studies of science. Knowledge transfer and scientific co-production are profoundly useful to the environmental sciences but at times can be decoupled from basic science (Lang, et al. 2012). Transdisciplinary science strongly contrasts with a linear knowledge-deficit model that assumes knowledge moves from experts to citizens and instead emphasizes that integrated thinking focusing on overlap between disciplines and between scientists and citizens eclipses simplistic models of scientific knowledge (Lang, et al. 2012). Joint production of knowledge is an ideal, but it is not without debate and challenges (Maillet, et al. 2019, Regeer, et al. 2009, Williams and Brown 2016). It has been proposed that production of knowledge always includes social and cultural factors and that decision making is always political (Fernández 2016). Knowledge-policy interactions in particular are likely non-linear and complex, require multiple knowledge domains with multiple perspectives, and are shaped by personal and professional filters. Moving from data to decisions must include consideration of biases, beliefs, values, and heuristics (such as the ones proposed herein) (Glynn, et al. 2017). Even with standardized and accessible data, it is a substantial challenge to develop mechanisms that incorporate these forms of evidence into policy development (Magnusson 2019). Consequently, framing scientific publications in these fields to ensure that they provide the means for two-way interactions with evidence provides a means to translate principles into action. We implicitly adopted a 'science-policy-practice' perspective linking science to management (Dale, et al. 2019) in developing these principles to ensure that a wider subset of basic science can be used to inform decisions - primarily through a simple checklist that authors and readers can use to promote and structure reuse. Science is a movement, and the language we use is important (Wezel, et al. 2009). Knowledge is not a static concept held by experts but a series of actions that we engage with through principles, concepts, data, beliefs, and relationships (Maillet, et al. 2019). Here, we provide principles that we hope build a bridge and stepping-stones between publications that are not necessarily co-produced and immediately relevant to people that need to use, reuse, and interact with these ideas to inform sustainable societies.

Literature cited

Aarons, G. A., Hurlburt, M. and Horwitz, S. M. 2011. Advancing a conceptual model of evidence-based practice implementation in public service sectors. - Administration and policy in mental health 38: 4-23.

Acocella, V. 2015. Grand challenges in Earth science: research toward a sustainable environment. - Frontiers in Earth Science 3: 68.

Bagchi, S. and Mishra, C. 2006. Living with large carnivores: predation on livestock by the snow leopard (Uncia uncia). - Journal of Zoology 268: 217-224.

Baker, M. 2016. Is there a reproducibility crisis? - Nature 533: 452-454.

Baron, N. 2010. Escape from the Ivory Tower: A Guide to Making Your Science Matter. - Island Press.

Bonebrake, T. C., Brown, C. J., Bell, J. D., Blanchard, J. L., Chauvenet, A., Champion, C., Chen, I. C., Clark, T. D., Colwell, R. K., Danielsen, F., Dell, A. I., Donelson, J. M., Evengård, B., Ferrier, S., Frusher, S., Garcia, R. A., Griffis, R. B., Hobday, A. J., Jarzyna, M. A., Lee, E., Lenoir, J., Linnetved, H., Martin, V. Y., McCormack, P. C., McDonald, J., McDonald-Madden, E., Mitchell, N., Mustonen, T., Pandolfi, J. M., Pettorelli, N., Possingham, H., Pulsifer, P., Reynolds, M., Scheffers, B. R., Sorte, C. J. B., Strugnell, J. M., Tuanmu, M.-N., Twiname, S., Vergés, A., Villanueva, C., Wapstra, E., Wernberg, T. and Pecl, G. T. 2018. Managing consequences of climate-driven species redistribution requires integration of ecology, conservation and social science. - Biological Reviews 93: 284-305.

Botero, C. A., Weissing, F. J., Wright, J. and Rubenstein, D. R. 2015. Evolutionary tipping points in the capacity to adapt to environmental change. - Proceedings of the National Academy of Sciences of the United States of America 112: 184-189.

Bourne, P. E. and Chalupa, L. M. 2006. Ten simple rules for getting grants. - Plos Computational Biology 2: 59-60.

Burkle, L. A., Marlin, J. C. and Knight, T. M. 2013. Plant-Pollinator Interactions over 120 Years: Loss of Species, Co-Occurrence, and Function. - Science 339: 1611.

Busch, J. and Ferretti-Gallon, K. 2017. What Drives Deforestation and What Stops It? A Meta-Analysis. - Review of Environmental Economics and Policy 11: 3-23.

Calo, A. 2018. How knowledge deficit interventions fail to resolve beginning farmer challenges. - Agriculture and Human Values 35: 367-381.

Cash, D. W., Clark, W. C., Alcock, F., Dickson, N. M., Eckley, N., Guston, D. H., Jäger, J. and Mitchell, R. B. 2003. Knowledge systems for sustainable development. - Proceedings of the National Academy of Sciences 100: 8086.

Chiabai, A., Quiroga, S., Martinez-Juarez, P., Higgins, S. and Taylor, T. 2018. The nexus between climate change, ecosystem services and human health: Towards a conceptual framework. - Science of The Total Environment 635: 1191-1204.

Colvin, R. M., Witt, G. B. and Lacey, J. 2016. Approaches to identifying stakeholders in environmental management: Insights from practitioners to go beyond the 'usual suspects'. - Land Use Policy 52: 266-276.

Conover, M. R. 1998. Perceptions of American Agricultural Producers about Wildlife on Their Farms and Ranches. - Wildlife Society Bulletin (1973-2006) 26: 597-604.

Dale, P., Sporne, I., Knight, J., Sheaves, M., Eslami-Andergoli, L. and Dwyer, P. 2019. A conceptual model to improve links between science, policy and practice in coastal management. - Marine Policy 103: 42-49.

Davidson, M. D. 2013. On the relation between ecosystem services, intrinsic value, existence value and economic valuation. - Ecological Economics 95: 171-177.

Dickman, A. J. 2010. Complexities of conflict: the importance of considering social factors for effectively resolving human–wildlife conflict. - Animal Conservation 13: 458-466.

Dickman, A. J., Hazzah, L., Carbone, C. and Durant, S. M. 2014. Carnivores, culture and 'contagious conflict': Multiple factors influence perceived problems with carnivores in Tanzania's Ruaha landscape. - Biological Conservation 178: 19-27.

Dupuis-Désormeaux, M., D'Elia, V., Burns, R., White, B. and MacDonald, S. E. 2019. A turtle population study in an isolated urban wetland complex in Ontario reveals a few surprises. - FACETS 4: 584-597.

Ferguson, P. 2015. The green economy agenda: business as usual or transformational discourse? - Environmental Politics 24: 17-37.

Fernández, R. J. 2016. How to be a more effective environmental scientist in management and policy contexts. - Environmental Science & Policy 64: 171-176.

Fischer, J. and Riechers, M. 2019. A leverage points perspective on sustainability. - People and Nature 1: 115-120.

Fiutem, T. and Antoniol, M. 1996. A cliche-based environment to support architectural reverse engineering. 1996 Proceedings of International Conference on Software Maintenance, pp. 319-328.

Fu, Q., Hou, Y., Wang, B., Bi, X., Li, B. and Zhang, X. 2018. Scenario analysis of ecosystem service changes and interactions in a mountain-oasis-desert system: a case study in Altay Prefecture, China. - Scientific Reports 8: 12939.

Gerstner, K., Moreno-Mateos, D., Gurevitch, J., Beckmann, M., Kambach, S., Jones, H. P. and Seppelt, R. 2017. Will your paper be used in a meta-analysis? Make the reach of your research broader and longer lasting. - Methods in Ecology and Evolution 8: 777-784.

Glynn, P. D., Voinov, A. A., Shapiro, C. D. and White, P. A. 2017. From data to decisions: Processing information, biases, and beliefs for improved management of natural resources and environments. - Earth's Future 5: 356-378.

Halpern, B. S., Walbridge, S., Selkoe, K. A., Kappel, C. V., Micheli, F., Agrosa, C., Bruno, J. F., Casey, K. S., Ebert, C., Fox, H. E., Fujita, R., Heinemann, D., Lenihan, H. S., Madin, E. M. P., Perry, M. T., Selig, E. R., Spalding, M., Steneck, R. and Watson, R. 2008. A Global Map of Human Impact on Marine Ecosystems. - Science 319: 948.

Hampton, S. E., Strasser, C. A., Tewksbury, J. J., Gram, W. K., Budden, A. E., Batcheller, A. L., Duke, C. S. and Porter, J. H. 2013. Big data and the future of ecology. - Frontiers in Ecology & the Environment 11: 156-162.

Hao, J. 2018. Reconsidering 'cause inside the clause 'in scientific discourse – from a discourse semantic perspective in systemic functional linguistics. - Text & Talk - An Interdisciplinary Journal of Language Discourse Communication Studies 38.

Iacona, G. D., Sutherland, W. J., Mappin, B., Adams, V. M., Armsworth, P. R., Coleshaw, T., Cook, C., Craigie, I., Dicks, L. V., Fitzsimons, J. A., McGowan, J., Plumptre, A. J., Polak, T., Pullin, A. S., Ringma, J., Rushworth, I., Santangeli, A., Stewart, A., Tulloch, A., Walsh, J. C. and Possingham, H. P. 2018. Standardized reporting of the costs of management interventions for biodiversity conservation. - Conservation Biology 32: 979-988.

Johnson, A., Vongkhamheng, C., Hedemark, M. and Saithongdam, T. 2006. Effects of human–carnivore conflict on tiger (Panthera tigris) and prey populations in Lao PDR. - Animal Conservation 9: 421-430.

Jones, P. G. and Thornton, P. K. 2009. Croppers to livestock keepers: livelihood transitions to 2050 in Africa due to climate change. - Environmental Science & Policy 12: 427-437.

Karttunen, K., Ahtikoski, A., Kujala, S., Törmä, H., Kinnunen, J., Salminen, H., Huuskonen, S., Kojola, S., Lehtonen, M., Hynynen, J. and Ranta, T. 2018. Regional socio-economic impacts of intensive forest management, a CGE approach. - Biomass and Bioenergy 118: 8-15.

Kates, R. W., Clark, W. C., Corell, R., Hall, J. M., Jaeger, C. C., Lowe, I., McCarthy, J. J., Schellnhuber, H. J., Bolin, B., Dickson, N. M., Faucheux, S., Gallopin, G. C., Grübler, A., Huntley, B., Jäger, J., Jodha, N. S., Kasperson, R. E., Mabogunje, A., Matson, P., Mooney, H., Moore, B., Riordan, T. and Svedin, U. 2001. Sustainability Science. - Science 292: 641.

Kelly, C. D. 2006. Replicating Empirical Research in Behavioral Ecology: How and Why It Should Be Done But Rarely Ever Is. - The Quarterly Review of Biology 81: 221-236.

Koontz, T. M. and Thomas, C. W. 2018. Use of science in collaborative environmental management: Evidence from local watershed partnerships in the Puget Sound. - Environmental Science & Policy 88: 17-23.

Kotiaho, J. S. and Tomkins, J. L. 2002. Meta-analysis, can it ever fail? - Oikos 96: 551-553.

Lang, D. J., Wiek, A., Bergmann, M., Stauffacher, M., Martens, P., Moll, P., Swilling, M. and Thomas, C. J. 2012. Transdisciplinary research in sustainability science: practice, principles, and challenges. - Sustainability Science 7: 25-43.

Lewinsohn, T. M., Attayde, J. L., Fonseca, C. R., Ganade, G., Jorge, L. R., Kollmann, J., Overbeck, G. E., Prado, P. I., Pillar, V. D., Popp, D., da Rocha, P. L. B., Silva, W. R., Spiekermann, A. and Weisser, W. W. 2015. Ecological literacy and beyond: Problem-based learning for future professionals. - AMBIO 44: 154-162.

Lindsey, P. A., Romañach, S. S. and Davies-Mostert, H. T. 2009. The importance of conservancies for enhancing the value of game ranch land for large mammal conservation in southern Africa. - Journal of Zoology 277: 99-105.

Lortie, C. J. 2014. Formalized synthesis opportunities for ecology: systematic reviews and meta-analyses. - Oikos 123: 897-902.

Lortie, C. J., Filazzola, A., Kelsey, R., Hart, A. K. and Butterfield, H. S. 2018. Better late than never: a synthesis of strategic land retirement and restoration in California. - Ecosphere 9: e02367.

Macpherson, I. and Segarra, I. 2017. Commentary: Grand challenge: ELSI in a changing global environment. - Frontiers in Genetics 8: 135.

Magnusson, W. E. 2019. Biodiversity: the chasm between what we know and we need to know. - Anais da Academia Brasileira de Ciências 91.

Maillet, D. G. C., Wiber, M. G. and Barnett, A. 2019. Actions towards the joint production of knowledge: the risk of salmon aquaculture on American Lobster. - Journal of Risk Research 22: 67-80.

McDonald-Madden, E., Probert, W. J. M., Hauser, C. E., Runge, M. C., Possingham, H. P., Jones, M. E., Moore, J. L., Rout, T. M., Vesk, P. A. and Wintle, B. A. 2010. Active adaptive conservation of threatened species in the face of uncertainty. - Ecological Applications 20: 1476-1489.

McKinley, D. C., Miller-Rushing, A. J., Ballard, H. L., Bonney, R., Brown, H., Cook-Patton, S. C., Evans, D. M., French, R. A., Parrish, J. K., Phillips, T. B., Ryan, S. F., Shanley, L. A., Shirk, J. L., Stepenuck, K. F., Weltzin, J. F., Wiggins, A., Boyle, O. D., Briggs, R. D., Chapin, S. F., Hewitt, D. A., Preuss, P. W. and Soukup, M. A. 2017. Citizen science can improve conservation science, natural resource management, and environmental protection. - Biological Conservation 208: 15-28.

McKinnon, M. C., Cheng, S. H., Garside, R., Masuda, Y. J. and Miller, D. C. 2015. Sustainability: Map the evidence. - Nature 528: 185-187.

Miguel, T. B., Oliveira-Junior, J. M. B., Ligeiro, R. and Juen, L. 2017. Odonata (Insecta) as a tool for the biomonitoring of environmental quality. - Ecological Indicators 81: 555-566.

Mosnier, C., Duclos, A., Agabriel, J. and Gac, A. 2017. What prospective scenarios for 2035 will be compatible with reduced impact of French beef and dairy farm on climate change? - Agricultural Systems 157: 193-201.

Naidoo, R., Balmford, A., Ferraro, P. J., Polasky, S., Ricketts, T. H. and Rouget, M. 2006. Integrating economic costs into conservation planning. - Trends in Ecology & Evolution 21: 681-687.

Nielsen, J. A., Grøndahl, E., Callaway, R. M., Dickinson, K. J. M. and Ehlers, B. K. 2017. Home and away: biogeographical comparison of species diversity in Thymus vulgaris communities. - Biological Invasions 19: 2533-2542.

Pace, M. L., Hampton, S. E., Limburg, K. E., Bennett, E. M., Cook, E. M., Davis, A. E., Grove, J. M., Kaneshiro, K. Y., LaDeau, S. L., Likens, G. E., McKnight, D. M., Richardson, D. C. and Strayer, D. L. 2010. Communicating with the public: opportunities and rewards for individual ecologists. - Frontiers in Ecology and the Environment 8: 292-298.

Perino, A., Pereira, H. M., Navarro, L. M., Fernández, N., Bullock, J. M., Ceaușu, S., Cortés-Avizanda, A., van Klink, R., Kuemmerle, T., Lomba, A., Pe'er, G., Plieninger, T., Rey Benayas, J. M., Sandom, C. J., Svenning, J.-C. and Wheeler, H. C. 2019. Rewilding complex ecosystems. - Science 364: eaav5570.

Pihkala, P. 2019. The Cost of Bearing Witness to the Environmental Crisis: Vicarious Traumatization and Dealing with Secondary Traumatic Stress among Environmental Researchers. - Social Epistemology: 1-15.

Reed, M. S. 2008. Stakeholder participation for environmental management: A literature review. - Biological Conservation 141: 2417-2431.

Regeer, B. J., Hoes, A.-C., van Amstel-van Saane, M., Caron-Flinterman, F. F. and Bunders, J. F. G. 2009. Six Guiding Principles for Evaluating Mode-2 Strategies for Sustainable Development. - American Journal of Evaluation 30: 515-537.

Roy-Byrne, P., Craske, M. G., Sullivan, G., Rose, R. D., Edlund, M. J., Lang, A. J., Bystritsky, A., Welch, S. S., Chavira, D. A., Golinelli, D., Campbell-Sills, L., Sherbourne, C. D. and Stein, M. B. 2010. Delivery of Evidence-Based Treatment for Multiple

Anxiety Disorders in Primary Care: A Randomized Controlled Trial. - JAMA 303: 1921-1928.

Ruxton, G. D., and N. Colgrave. 2018. Experimental Design for the Life Sciences. - Oxford University Press.

Sandel, B. 2015. Towards a taxonomy of spatial scale-dependence. - Ecography 38: 358-369.

Schakner, Z., Purdy, C. and Blumstein, D. T. 2019. Contrasting attitudes and perceptions of California sea lions by recreational anglers and the media. - Marine Policy 109: 103710.

Tew, E. R., Simmons, B. I. and Sutherland, W. J. 2019. Quantifying cultural ecosystem services: Disentangling the effects of management from landscape features. - People and Nature 1: 70-86.

Tilman, A. R., Levin, S. and Watson, J. R. 2018. Revenue-sharing clubs provide economic insurance and incentives for sustainability in common-pool resource systems. - Journal of Theoretical Biology 454: 205-214.

Towns, L., Derocher, A. E., Stirling, I., Lunn, N. J. and Hedman, D. 2009. Spatial and temporal patterns of problem polar bears in Churchill, Manitoba. - Polar Biology 32: 1529-1537.

Tranfield, D., Denyer, D. and Smart, P. 2003. Towards a Methodology for Developing Evidence-Informed Management Knowledge by Means of Systematic Review. - British Journal of Management 14: 207-222.

Vogt, R., Sharma, S. and Leavitt, P. 2017. Direct and interactive effects of climate, meteorology, river hydrology, and lake characteristics on water quality in productive lakes of the Canadian Prairies. - Canadian Journal of Fisheries and Aquatic Sciences 75.

Wezel, A., Bellon, S., Doré, T., Francis, C., Vallod, D. and David, C. 2009. Agroecology as a science, a movement and a practice. A review. - Agronomy for Sustainable Development 29: 503-515.

Williams, B. K. and Brown, E. D. 2016. Technical challenges in the application of adaptive management. - Biological Conservation 195: 255-263.

Zhu, L., Lu, L. and Zhang, D. 2010. Mitigation and remediation technologies for organic contaminated soils. - Frontiers of Environmental Science & Engineering in China 4: 373-386.