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Ten simple rules to facilitate evidence implementation in the environmental sciences.

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Abstract

We understand natural systems through many pathways. Research and the scientific literature can be viewed as descriptions of nature that we use 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. There is an implementation gap between environmental researchers and managers. However, there are many strategies to close this gap. We need to move beyond context dependency and singular, unidirectional linear thinking. Solutions can be made to scale, and we need to better leverage the primary scientific literature. This capacity for environmental and social good can be enhanced by bridging the implementation gap, i.e. strengthening the linkages between basic published science in journals and its ability to inform applied interpretations and decisions. Herein, we provide a succinct list of ten simple rules to support environmental management through better scientific writing and suggest scaffolding for primary publications. These rules can also be used as a checklist for reading and processing the primary literature when searching for relevant evidence in the environmental sciences. With this framework, we extend science-policy-practice developments and provide structure knowledge connections within sustainable societies.

Keywords

Conservation, decision making, environmental challenges, evidence, grand challenges, implementation, scientific knowledge, simple rules

Introduction

People understand nature primarily through interactions with nature. Experience and values are always shaped by context (Fernández 2016); however, the scientific literature is another important tool that we use to describe and measure natural systems. It can capture our observations and conclusions for others. Managers typically have scientific backgrounds and routinely navigate the technical literature. However, engagement with scientific literature is non-trivial for all scientists, including practitioners, because of time, restricted access, relevance of the science, and reporting standards (Noorden 2014). Environmental managers and conservationists need to be able to easily access primary evidence to inform decisions. Ideally, critical research is co-produced with stakeholders in key sustainability contexts (Regeer et al. 2009, Maillet et al. 2019) but also among many scientific sub-disciplines (Haines 2004). Scientific co-production is a collaboration between those that will use the research directly such as land managers and agency scientists and those that work in other contexts such as academic scientists. Stronger relationships between knowledge production and use ensure that the needs of all those impacted by the research are represented (Nörstrom 2020).

However, the ideal situation of basic-knowledge-researchers and practitioners working congruently is not always possible or practical. Environmental and ecological research is produced globally at fantastic rates, and it does not inherently have to be co-produced with end-users to be useful. Literature that is defined as applied or clearly relevant to the environmental sciences because it is published in a specific journal is routinely used as such. Nonetheless, basic or fundamental science published in other journals can also inform the environmental sciences provided the papers are written to facilitate discovery and potential implementation. We can do better in our writing in the sciences to enable this capacity. Evidence-based solution science and policy decision making are the gold standard in all disciplines—including the environmental sciences. We define ‘evidence’ here simply as the scientific findings of papers published in peer-reviewed journals. Admittedly, this is a relatively narrow focus, but it is a good starting point because it is a well-established (albeit imperfect) system to describe findings and share conclusions based on observation. ‘Solutions’ in this framework are similarly presented in publications of peer-reviewed journals; however, they instead specifically describe how a scientific finding can address an environmental concern through action examined by scientific inquiry.

There is an implementation gap between basic science and management for at least three reasons. Firstly, the publication reports research on a specific species or system. It is not always clear how to connect specific findings to a demonstrable outcome needed to solve an urgent management issue—even for the same species but in a different context (Naidoo et al. 2006, Iacona et al. 2018). This is a very real limitation in restoration ecology (Lortie et al. 2018). Secondly, the link between the biology or ecology studied and its potential application is not clear. There are notable examples with journals such as the *Journal of Applied Ecology, Basic and Applied Ecology, Facets, The Journal of Environmental Engineering, People and Nature*, and others. It is also true that general audience/plain language publications, university-issued press releases, social media science communication, and many other forms of information disbursement can support implementation—though none of these necessarily provide the scientific specificity needed by practitioners, and it has been proposed that the communication is in a state of crisis (Smol 2018; Sopinka et al. 2019). Nonetheless, solution development from publications in other journals is an underexploited set of opportunities. Studies from one system can be re-purposed for insights into another (Fischer and Riechers 2019) when properly communicated (Freeling et al. 2019). Finally, the capacity to "see the forest for the trees" can be a gap. 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 (Lewinsohn et al. 2015, Hao 2018). Often, "seeing the forest" also requires sampling many "trees". This leads to the proposal that experts writing or evidence-mining papers can bridge the implementation gap by considering the ten simple rules developed herein. Deeper consideration of the application of scientific publications to management challenges benefits the scientists writing papers and other citizens seeking to use them in practical contexts.

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). Simple rules in science are a blend of opinion and evidence. They are meant to engender discussion, inspire introspection, and challenge how we typically practice our work in the sciences. Published simple rules contributions are mostly written first from principles of logic and reasoning, then summarize the positive practices accepted within the community—including perspectives from experts on how to do better (Bourne and Chalupa 2006). Expert insight is often a primary pillar. We applied that process here to capture some, but not all, of the best practices particularly evident to us as ecologists in scientific writing that we identified as successful mechanisms to bridge the gap between evidence and implementation. To do so, we used two concepts to structure the rules: challenges and solutions. An environmental management challenge is a ‘problem’ redefined though the lens of structured scientific thinking such as factor-response or treatment-control principles (Doubleday and Connell 2020). An environmental challenge can be ethical, legal, or social (Acocella 2015, Bonebrake et al. 2018) varying in impact and often a product of ecological stress rooted in anthropogenic actions (Johnson 2017). Grand challenges for the environment are ones that necessitate connections between disciplines and require evidence from potential studies that examine varied components of the environment (Macpherson and Segarra 2017, Bonebrake et al. 2018). A solution is a desired outcome that can be supported by evidence (Maillet et al. 2019). Typically, solutions represent sustainable paths forward. A solution should also use a tool or methodology that can either identify ways to (a) measure/identify key issues deconstructed in the formulation of problem-as-challenge or (b) provide solutions to directly address a challenge. Any tool can thus become a solution provided we can use it more than once (Baker 2016). Here, we propose that published science for the environment should include both direct replication (replicating the same approach in another context) or conceptual replication (repeated tests of the same concept but with different methods) (Kelly 2006). The primary goal of these simple rules is to facilitate evidence implementation in environmental management by making papers more practical. We provide evidence and opinions and highlight common practices to counter the argument that ‘everything is context-specific’ as a criticism of the field. It is our responsibility to envision how basic science can be useful.

We propose that by distilling the concepts promoting engagement with scientific literature in addition to and outside of the academic community, managers can rely on broader sources of scientific knowledge to make decisions. This is novel and important because it increases the scope of published science to support decisions. Furthermore, researchers can reframe their scientific writing (when appropriate) to make it more relevant to managers without compromising their respective fundamental research programs. Here, we briefly discuss simple rules that scientists can use to make their research more practical and accessible to managers and that managers can in turn use to identify basic science that fits their needs.

Rules

1. Reframe the problem as a challenge. “Doom-and-gloom” is a pervasive theme in media discussions of ecology and environmental sciences. It reduces our productivity and capacity to solve problems. It can shut down even the most motivated through compassion fatigue, burnouts, and psychic numbing (Pihkala 2019). Reframing a problem as a *challenge* can illuminate solutions despite disheartening information so that researchers create their own “bright spot” within a research topic that may frequently frustrate (Reid 2019). 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 creates a clear objective for scientists and is more goal-oriented. This perspective will refine communication, enhance creativity, promote innovation, and produce actionable items amongst actors (Johnson and Adams 2011; Mahoney 2011). Additionally, this small change in semantics has profound implications in social contexts for stakeholders, managers, and researchers because it promotes action-based thinking and collaborative work. This rule is not without boundaries of course, but a subtle shift in writing (even within the implications at the end a paper) to re-frame findings and link to a positive management goal will significantly bridge the gap between a problem and a solution.

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. In most ecological studies, the spatial extent is often described, but moving across scales in application is a common challenge in many disciplines of basic and environmental science (Sandel 2015). 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. When we link scales, we unite different instances of an environmental issue and suggest that they can be similarly addressed. However, understanding the geographical extent also allows us to pinpoint differences. This is an important boundary to this rule. The example of human-wildlife conflict is a global issue, but the *extent* is conflict-specific because it is directly observable in Southern California coastlines, Tanzanian park boarders, or Ontarian roadways (Dickman 2010, Dupuis-Désormeaux et al. 2019, Schakner et al. 2019). Most introductions and methods sections in peer-reviewed publications include scope and extent as a description of what was done in their study, but many do not include the potential impacts of stakeholders beyond the authors. 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. It is our opinion that a simple description and definition of the scientific evidence and how it can be linked to evidence-based decision making for environmental challenges is a useful tactic to consider when writing about most basic environmentally relevant science. 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). Do not overstate the link or stretch the implications too far. When this happens, it can undermine legitimate links between evidence and implementation.

4. Propose implications of ignoring this challenge. A description of the impact a challenge, if left unchecked, can have on a system will help clarify the severity of the challenge. This practice is common in most basic scientific literature when the topic is of societal or economic impact including invasion biology, global change, biodiversity studies, and anthropogenic driver studies. However, we propose that the trickle-down effects and indirect implications that are not immediately evident must also be examined and discussed. For instance, there is compelling evidence that further anthropogenic pressures on carnivore 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; Ripple et al. 2014). Despite this, 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). Therefore, failure to bridge the implementation gap can impact food security regionally in this situation (Kates et al. 2001, Fernández 2016). Hence, the implications and trickle-down effects are pertinent not only to the direct stakeholders, but also citizens at large—socially and ecologically. This is to say that any scientific conversation on solutions should best explicitly consider any and all impacts of a challenge—especially business-as-usual eventualities—even beyond their own work. It is our opinion that implications described in basic scientific publications can encompass both the ecology of a system and the people.

5. State the direct human needs associated with this challenge. It is not common to state the direct needs of humans as part of the process of generating solutions for environmental challenges in many basic science publications. 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 and ignored. This rule would be a novel addition to many basic scientific papers that are not directly coupled to an environmental issue. Identifying anthropogenic needs will also prevent the emergence of new, related challenges or pressures on the system in question. Bridging the gap between evidence and implementation can also be accomplished by including a proposed strategy for engagement with stakeholders as a mechanism to inform benefits and solutions (Reed 2008, Colvin et al. 2016). Benefits to stakeholders include cultural ecosystem services, and these will in turn further sustainable local planning and more directed science (Tew et al. 2019). Not every study has to have global scope or large societal implications, and the scope of the science-practice connection is rarely simple (Regeer et al. 2009). This is an important boundary to this rule and suggests that it need not apply to every study; but articulating human needs in more ecological system papers will go a long way to filling the gap between acceptable science and collaboration. It will also improve the perception of science by the public. Mentions of human needs or at least recognition that there are human stakeholders associated with almost every natural ecosystem globally can reduce an ivory-tower effect by showing that scientists do consider people when writing some of our basic science.

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 rules presented. A clearly written analysis of causation and correlation in our papers will help avoid fatal missteps in readership and will ensure effective framing of expected outcomes, including environmental interventions for conservationists. We are proposing a change here from the typical and formulaic norm in scientific writing wherein many papers end with a call for additional research on that specific topic. Instead, consider providing a specific statement of the relative strength of evidence and gaps in the research. Be truthful and transparent. Describe the extent that these findings can be generalized. These statements will provide a future direction for additional research and for appropriate decision making. Make it easy for end-users to know when not to implement the findings of a specific study. This rule is not based on evidence but on preference. For instance, a statement that additional research is needed in some general form neither inspires nor directs the reader where to consider novel applications. An admission that certain findings are directly relevant to this particular species (and not others) generates both a clear sense how to implement this specific discovery (i.e. this biocontrol works for this species) and spotlights a path forward (i.e. we need to test the method on related species or other functionally similar invasive species). There are many great examples of this rule in action once you are cognizant of the nuances in how limitations can be stated.

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 due to cost limitations. Business-as-usual models can also provide an economic mechanism to value ecosystems services (Fu et al. 2018, Karttunen et al. 2018), and while this is not without debate, this can expand the range of invested 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 as the inertia of the socio-political structures that we use limits our ability to quickly manage people and resources. The best and worst-case scenarios are not always clear or equal between strategies or in severity, but navigating the likelihood of these implications can provide perspective to researchers and stakeholders. There is a boundary to using this rule to bridge an evidence-implementation gap—some studies are not amenable to costing because we have not developed the valuation framework or do not yet have the means to implement a solution even if we understand the biology or ecology of a system.

8. List the tools applied to this challenge. Typically, there is at least one primary tool that the researchers used to explore a challenge in a given study. There are many possible 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) to name a few. We propose that scientific tools in basic biology and ecology relevant to environmental management, such as species identification, habitat use, diet analyses etc., can bridge a gap between evidence and implementation when they can be replicated in another system or similar challenge. This rule is vital for successful co-production in that it intrinsically improves communication between current and future actors. Be specific in your methods and general in your proposed application. Citizen science is one of the best examples of implementation that supports the relative importance of this rule because it provides a means to collect environmental data (McKinley et al. 2017) relevant to many of the challenges we face including global warming, water quality, and declining biodiversity. Populating a brief discussion of the tool(s) used when writing your research provides a useful linkage to other studies that will not always be apparent to readers.

9. Link the primary tool to the outcome. A scientific tool from a study can collect data, detect patterns, directly solve an environmental challenge, demonstrate an intervention, or inform policy. If the paper is a direct test of basic ecology for an environmental challenge, this can be very straightforward. For instance, the paper titled "Odonata (Insecta) as a tool for the bio-monitoring of environmental quality" (Miguel et al. 2017) explicitly provides a means to measure and detect, and this capacity is clearly described right in the title. The evidence in the scientific literature strongly suggests that this is a common practice in many contexts and thus a sound rule. The identification and provision of descriptive evidence to explain casual relationships is the most 'basic' role of science, and it is also likely the most typical role for much of ecology (i.e. we describe and measure how species interact with one another and the environment). Tools can also directly examine the efficacy of a management strategy or intervention such as 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 also 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 at least explain how. This rule primarily applies to follow-up studies or stakeholders implementing basic science. Apply the primary tool to another challenge to show that it can be a link between primary evidence and use. If not possible, at least speculate how it can be applied in the follow-up studies. This promotes efficiency when tackling novel environmental challenges as they emerge, and it also supports the overarching assumption that we cannot afford to ignore basic science for better decision making.

Implications

These rules can distribute the burden of scientific communication and implementation between scientists and stakeholders more evenly and enable better two-way interactions with the scientific knowledge described in publications. These rules are a blend of opinion, exemplary evidence, and common practices in the field. There are likely many other rules, but this is a representative set of some of the more robust bridges between evidence and implementation in writing and using papers to inform solutions to many environmental challenges. Consider these rules when writing, not *all* all of the time, but *some* some of the time. We can make basic natural science more practical and expand the scope of environmental knowledge. These rules are not a surrogate for scientific co-production with stakeholders, but a heuristic that can enable adaptive management for the environmental sciences from studies that are not necessarily directly coupled to pressing issues. We propose that more basic science can be used in applied contexts and to a much greater extent. Both case studies and individual papers contribute to our collective scientific understanding. Considering these ten simple rules will enable better identification of overarching patterns from disparate papers, provided we embrace some of the scaffolding developed here such as common language for challenges and solutions, identification of tools, mention of direct human needs, and consequences within each system of minimal interventions. A few new norms in scientific writing that align with practical application will facilitate linking evidence together for scientific syntheses and more applicable theories.

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 within publications to become an active process for stakeholders to improve long-term conservation outcomes through evidence (McDonald-Madden et al. 2010). Making the primary research literature more functional through these rules for writing and structure will accelerate the learning phase of adaptive management. We can make deliberation (i.e. planning) and iteration (i.e. testing) integrate with evidence by practicing at least some of these rules (Williams and Brown 2016). Spanning this gap is not the sole criterion for useful science nor should it be, but professional advocacy and knowledge mobilization are increasingly important for universities and scientists (Pace et al. 2010). Evidence-informed decision making is a critical area for growth and knowledge in many disciplines (Tranfield et al. 2003, Roy-Byrne et al. 2010, Aarons et al. 2011)—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 during restoration efforts by managers and stakeholders (Perino et al. 2019). Using these rules similarly advances connecting people to nature to research. This integrated thinking is critical. Better reporting of research and discussion of relevance, and thus better perception of the challenge, will increase the relevance of our ideas and enable novel connections between evidence and outcome and between challenge and solution.

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