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Ten simple rules for reuse of environmental science research.

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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 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. We also need to move beyond context dependency and singular, unidirectional linear thinking. Solutions can be made to scale, and we need to better reuse the scientific literature. Herein, we provide a succinct list of ten principles to support environmental management through primary scientific literature production and reuse. This extends science-policy-practice developments and the increasing attention on better connecting knowledge with sustainable societies.

Keywords

Conservation, decision making, environmental challenges, evidence, grand challenges, reuse, 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 understanding for others. 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. Ideally, critical research is co-produced with stakeholders in key sustainability contexts (Regeer et al. 2009, Maillet et al. 2019). 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. However, environmental and ecological research is produced globally at fantastic rates, and it does not have to be co-produced with end-users to be useful. There is also a gap in communication 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 just as the Journal of Applied Ecology, Basic and Applied Ecology, Facets, The Journal of Environmental Engineering, People and Nature, and others. 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). 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 can enhance reuse by considering the ten simple rules developed herein. We do not mean to imply that knowledge transfer is linear or exclusively the domain of experts (Fernández 2016, Calo 2018), but that the wealth of published environmental science can be made much more accessible.

We used two concepts to structure the rules. Challenges and solutions. An environmental management challenge is a 'problem' redefined through the lens of structured scientific thinking such as factor-response or treatment-control principles (Doubleday and Connell 2020). A challenge can be ethical, legal, social, or environmental - typically all a product of anthropogenic stress (Acocella 2015, Bonebrake et al. 2018). 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-informed decision making in conservation (Maillet et al. 2019). Typically, solutions are a better path forward sustainably. A solution is 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 become a solution provided we can reuse it more than once (Baker 2016). Here, we propose that reuse of science for the environment can include both direct (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 simple rules for reuse in the environmental sciences is to thus escape the argument that ‘everything is context-specific’ as a criticism of the field.

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 academic community, managers can rely on broader sources of scientific knowledge to make decisions. 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 briefly discuss simple “principles” that scientists can use to make their research more accessible 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. It 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 thereby refining communication and action between actors. 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.

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 differences. 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 borders, 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. A simple description and definition of the scientific evidence 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. Further anthropogenic pressures on these 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). 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 (Kates et al. 2001, Fernández 2016). 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 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. It can also prevent the emergence of new related challenges or pressures on the system in question. This statement can further include 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). 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 rules 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. We are proposing that a statement of the relative strength of evidence and gaps in the research provides a future direction for additional research and for appropriate reuse and decision making. Make it easy for end-users to know when not to apply the findings of a specific study.

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. Typically, there is at least one primary tool that the researchers used to explore a challenge in a given study. 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) to name a few. The tools in basic biology and ecology relevant to environmental management can be reused if they can be replicated in another system or similar challenge. Citizen science is one of the best examples 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.

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 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, and this capacity is clearly described right in the title. The identification and provision of

descriptive evidence 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 golden rule proposes that the proof is in the pudding. Apply the primary tool to another challenge to show that it can be reused. If not, at least speculate how it can be reused. This will promote increases in efficiency for tackling novel environmental challenges as they emerge, and it also supports the overarching assumption herein that we cannot afford to ignore basic science for better decision making.

Implications

These rules distribute the burden of scientific communication between scientists and stakeholders more evenly 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 pressing issues. 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 rules 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). 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 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 in all dimensions of 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 perception will increase the stickiness of our ideas and enable novel connections between evidence and outcome, challenge and solution, and people and nature.

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