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A conceptual framework for understanding the perspectives on the causes of the science–practice gap in ecology and conservation

Diana Bertuol-Garcia[1,2,*], Carla Morsello[2,3], Charbel N. El-Hani[2,4] and Renata Pardini[2,5]

[1]*Departamento de Ecologia, Instituto de Biociências, Universidade de São Paulo, Rua do Matão, travessa 14, 101 CEP 05508-090, São Paulo, Brazil*
[2]*National Institute of Science and Technology in Interdisciplinary and Transdisciplinary Studies in Ecology and Evolution (IN-TREE), Universidade Federal da Bahia, Rua Barão do Geremoabo, s/n, Campus de Ondina/UFBA, CEP 40170-290 Salvador, Brazil*
[3]*Escola de Artes, Ciências e Humanidades, Universidade de São Paulo, Rua Arlindo Bettio, 1000 CEP 03828-000 São Paulo, Brazil*
[4]*Instituto de Biologia, Universidade Federal da Bahia, Rua Barão do Geremoabo, s/n, Campus de Ondina/UFBA, CEP 40170-290 Salvador, Brazil*
[5]*Departamento de Zoologia, Instituto de Biociências, Universidade de São Paulo, Rua do Matão, travessa 14, 101 CEP 05508-090, São Paulo, Brazil*

ABSTRACT

Applying scientific knowledge to confront societal challenges is a difficult task, an issue known as the science–practice gap. In Ecology and Conservation, scientific evidence has been seldom used directly to support decision-making, despite calls for an increasing role of ecological science in developing solutions for a sustainable future. To date, multiple causes of the science–practice gap and diverse approaches to link science and practice in Ecology and Conservation have been proposed. To foster a transparent debate and broaden our understanding of the difficulties of using scientific knowledge, we reviewed the perceived causes of the science–practice gap, aiming to: (*i*) identify the perspectives of ecologists and conservation scientists on this problem, (*ii*) evaluate the predominance of these perspectives over time and across journals, and (*iii*) assess them in light of disciplines studying the role of science in decision-making. We based our review on 1563 sentences describing causes of the science–practice gap extracted from 122 articles and on discussions with eight scientists on how to classify these sentences. The resulting process-based framework describes three distinct perspectives on the relevant processes, knowledge and actors in the science–practice interface. The most common perspective assumes only scientific knowledge should support practice, perceiving a one-way knowledge flow from science to practice and recognizing flaws in knowledge generation, communication, and/or use. The second assumes that both scientists and decision-makers should contribute to support practice, perceiving a two-way knowledge flow between science and practice through joint knowledge-production/integration processes, which, for several reasons, are perceived to occur infrequently. The last perspective was very rare, and assumes scientists should put their results into practice, but they rarely do. Some causes (e.g. cultural differences between scientists and decision-makers) are shared with other disciplines, while others seem specific to Ecology and Conservation (e.g. inadequate research scales). All identified causes require one of three general types of solutions, depending on whether the causal factor can (e.g. inadequate research questions) or cannot (e.g. scientific uncertainty) be changed, or if misconceptions (e.g. undervaluing abstract knowledge) should be solved. The unchanged predominance of the one-way perspective over time may be associated with the prestige of evidence-based conservation and suggests that debates in Ecology and Conservation lag behind trends in other disciplines towards bidirectional views ascribing larger roles to decision-makers. In turn, the two-way perspective seems primarily restricted to research traditions historically isolated from mainstream conservation biology.

* Address for correspondence (Tel.: +55 11 3091 7510; E-mail: dia.bertuol@gmail.com).

All perspectives represented superficial views of decision-making by not accounting for limits to human rationality, complexity of decision-making contexts, fuzzy science–practice boundaries, ambiguity brought about by science, and different types of knowledge use. However, joint knowledge-production processes from the two-way perspective can potentially allow for democratic decision-making processes, explicit discussions of values and multiple types of science use. To broaden our understanding of the interface and foster productive science–practice linkages, we argue for dialogue among different research traditions within Ecology and Conservation, joint knowledge-production processes between scientists and decision-makers and interdisciplinarity across Ecology, Conservation and Political Science in both research and education.

Key words: environmental policy, environmental management, research–implementation gap, knowing–doing gap, policy-making, science communication, transdisciplinarity, communities of practice, science, technology and society, bounded rationality.

CONTENTS

I. INTRODUCTION

People throughout the world believe that science has often brought positive impacts to society and can help confront many present-day issues (e.g. improving healthcare or adapting to climate change) (Eurobarometer, 2014; Laplane *et al.*, 2015). However, despite public confidence in science, applying scientific knowledge to solve real-world problems and support decision-making is a difficult task. In many fields, such as healthcare (Bero *et al.*, 1998) and education (Anderson, 2007), this disconnection between science and practice has been termed the science–practice, research–implementation, research–practice or knowing–doing gap.

In Ecology and Conservation, the debate regarding the use of scientific knowledge in decision-making has intensified concurrently with the aggravation of environmental problems. The worldwide increase in human wellbeing has taken place at the cost of important regulating and supporting services as well as biodiversity (MEA, 2005; Butchart *et al.*, 2010). In the long run, these changes may impair human livelihoods (Foley *et al.*, 2005), and, as argued by some, lead to a global state shift in the Earth's biosphere (Barnosky *et al.*, 2012). Facing these pressing challenges, several scientists have called for an increasing role of ecological and conservation science in developing solutions for a sustainable future (Carpenter & Folke, 2006; Burger *et al.*, 2012).

Several studies have shown, however, that scientific evidence in Ecology and Conservation is seldom used directly to support decision-making (Pullin *et al.*, 2004; Sutherland & Pullin, 2004; Pullin & Knight, 2005; Cook *et al.*, 2012), while others reported a disconnection between research questions and information required by decision-makers (Linklater, 2003; Esler *et al.*, 2010). Hence, many authors have argued for the existence of a science–practice gap (e.g. Knight *et al.*, 2008; Cabin *et al.*, 2010; Esler *et al.*, 2010; Barmuta, Linke & Turak, 2011), and important ecological journals have dedicated special sections to the barriers, challenges and opportunities for narrowing this gap (e.g. *Biotropica* in 2009 and *Journal of Applied Ecology* in 2014).

To bridge the gap, many ecologists and conservation scientists have called for evidence-based or evidence-informed conservation practices (Pullin & Knight, 2003; Sutherland & Pullin, 2004; Haddaway & Pullin, 2013). Others have emphasized joint knowledge production between scientists and decision-makers (e.g. Shackleton, Cundill & Knight, 2009; Hegger *et al.*, 2012; Aldunce *et al.*, 2016), but these propositions have generally been neglected in mainstream Conservation Biology (Curtin & Parker, 2014). Recently, the term 'science–practice gap' and the prevalence of the evidence-based approach have been criticized for assuming linearity in science communication, overlooking other knowledge types and the intricate processes of decision-making (Adams & Sandbrook, 2013; Toomey, Knight & Barlow, 2016).

Understanding the distinct perspectives on the science–practice interface within this heterogeneity of arguments can increase transparency, revealing diversity, conflicts and synergies of ideas. Such transparency can foster a more effective debate that connects isolated propositions and avoids dominance of single models or solutions (Carpenter *et al.*, 2009). Because perspectives on a given problem are typically associated with causal narratives (e.g. Mattson *et al.*, 2006), synthesizing and organizing the perceived causes of the science–practice gap into common conceptual domains can assist in this endeavour. To date, however, these causes are scattered in the literature, including varied aspects such as practitioners' lack of access to scientific journals (Sunderland *et al.*, 2009), academic reward systems focused on number of publications (Shanley & López, 2009), or a unidirectional flow of knowledge from science to practice (Shackleton *et al.*, 2009; Pardini *et al.*, 2013).

Synthesizing the perceived causes of the science–practice gap into common conceptual domains can also provide a structure for assessing the perspectives of ecologists and conservation scientists in light of disciplines addressing the role of science in decision-making and its relation to society, e.g. Science, Technology and Society (STS) studies and Political Science. The debate on the science–practice gap in Ecology and Conservation has apparently overlooked ideas and conceptualizations from these disciplines (Cairney, 2016), while political scientists have been criticized for giving little attention to decision-making concerning environmental and conservation issues (Agrawal & Ostrom, 2006). STS studies and Political Science focus on decision-making processes, highlighting that decision-making contexts are complex and entail political interests and social values besides scientific evidence (Albaek, 1995). They also argue that science can be used in diverse ways, both directly to solve specific problems and indirectly to influence decision-makers' thinking (Weiss, 1979). Embracing these often-neglected aspects of decision-making can greatly broaden our understanding on the difficulties of using scientific knowledge to support decisions, and thus our ability to envision solutions. It may also encourage scientists to reflect on their ideas and practices, and help highlight paths for advancing the study of the science–practice interface and for a more productive use of science in decision-making.

Herein, we draw on an extensive search of the scientific literature in Ecology and Conservation and qualitative text-analysis techniques to organize the perceived causes of the science–practice gap into a conceptual framework, aiming at identifying the perspectives of ecologists and conservation scientists on the problem. We then evaluate if the predominance of these perspectives changed over time and across journals with distinct research traditions. We discuss these findings in the light of disciplines devoted to understanding the role of science in decision-making and its relation to society, pointing out the strengths and limitations of the perspectives on the science–practice gap encountered in the ecological and conservation literature.

II. MATERIALS AND METHODS

(1) Definitions

We adopted the expression 'science–practice gap' (e.g. Cabin *et al.*, 2010), adapting to the ecological and conservation context the definitions presented in Broekkamp & Hout-Wolters (2007) for Education. We thus consider 'ecological and conservation science' as the structures, processes, products, and people directly involved in the systematic production of knowledge in Ecology and Conservation within academia. 'Ecological and conservation practice', in turn, is defined as the structures, processes, products, and people directly involved in action and decision-making in public, private and non-profit organizations responsible for the development of environmental policies and/or the conservation or management of biodiversity and of ecological and socio-ecological systems. As defined here, the science–practice gap encompasses the distance between research and decision-making/practical actions, between organizations and/or people involved in science and practice (hereafter 'scientists' and 'decision-makers') and between scientific knowledge and the knowledge of decision-makers.

(2) Bibliographic search

We searched the *Web of Science Core Collection* for articles published since 1900 in journals or proceedings categorized in Ecology or Biodiversity Conservation, encompassing the majority of journals in which ecologists and conservation scientists publish (see online Supporting Information: Appendix S1). We searched for articles including different expressions for the 'science–practice gap' (e.g.

'research–implementation gap', 'knowing–doing gap') and related sentences (e.g. 'gap between research and implementation', 'linking science and practice'). Three groups of synonymous terms – related to 'science', to 'practice' and to 'gap' or 'bridge'– were searched within the title, abstract or key words of articles. At least one term from each group had to be at most five words from at least one term of each of the other two groups (Fig. S1). Alternatively, articles could include only the word 'transdisciplinarity', frequently adopted to define the integration between academic and non-academic knowledge (Tress, Tress & Fry, 2005; Reyers *et al.*, 2010*a*). The final search was conducted in December 2014 and returned 1524 articles.

We screened the articles by reading the title and abstract and, in case of indecision about appropriateness, the main text (Fig. 1). We selected 122 articles (Table S1) that were accessible and discussed factors causing a divide between science and practice in Ecology and Conservation, even if this was not the paper's main objective (Appendix S1). The first author (D.B.G.) selected 77 priority articles whose explicit objective was to discuss the causes of the science–practice gap or were published in special sections on the topic. The priority articles served to develop a first version of the framework, but all 122 articles were used for the final conceptual framework (Fig. 1).

(3) Framework development

The conceptual framework was developed using an inductive approach, based on similarities between sentences referring to causes of the science–practice gap in Ecology and Conservation within the selected articles. We used the text analysis technique *cutting and sorting*, which involves identifying sentences or expressions related to the research question, printing them into separated pieces of paper (*cutting*) and arranging them by perceived similarity (*sorting*) (Bernard & Ryan, 2010). Each pile is named and the inclusion criteria described, representing recurrent themes or categories. Such text-analysis techniques are adequate for identifying regularities in written data (Bradley, Curry & Devers, 2007; Bernard & Ryan, 2010), helping to identify common domains while valuing the original ideas as expressed by the authors.

During the *cutting*, we identified, within the set of priority articles, 1057 sentences referring to causes of the science–practice gap (Fig. 1), including only those for which the causal connection was comprehensible from the sentence itself or including a context of three to four lines before and/or after the sentence. Selected sentences encompassed causes perceived either by the authors of the paper or by interviewees or respondents, where the paper assessed opinions (e.g. of scientists and/or decision-makers).

To encompass different ways of thinking, the *sorting* was independently conducted by eight scientists whose research involves the science–practice interface (including the authors), organized into three groups (Fig. 1, Appendix S2). For each group, we randomly sampled a different set of 200 sentences taken from the set of 1057, and then reduced it to a subset of 50 sentences by choosing those that represented the diversity of perceived causes present in the initial set of 200 sentences (i.e. avoiding too many sentences referring to a similar cause). This process resulted in three sets of 50 sentences (one for each group). Each scientist sorted the 50 sentences into piles by perceived similarity, named them and described the inclusion criteria, thus producing an independent classification of perceived causes of the science–practice gap in Ecology and Conservation. After this individual *sorting*, each group met personally to discuss the differences, advantages and disadvantages among the classifications.

As a result, eight classifications were obtained, which we later grouped into four distinct types based on the discussed similarities concerning the underlying logic: organized by components, by processes, by personal opinion or with no explicit organization base (Appendix S2). The first two classifications refer to the same logic of understanding the science–practice interface as a system (e.g. CHSRF, 2000), but one focuses on the different components of the system – scientists, decision-makers, different forms of knowledge – while the other focuses on the processes – production, dissemination, exchange, use, application – that interlink system components.

Based on the group discussions, we first listed the advantages and disadvantages of the four classification types (Appendix S2) and then created the following criteria that we considered desirable for the final conceptual framework: (*i*) present a clear underlying logical structure; (*ii*) present mutually exclusive categories; and (*iii*) allow the identification of different perspectives on the science–practice gap. Both the components and process-based classifications fulfilled the first two criteria. However, while components are an important part of any system description, they can be linked in diverse ways by different processes, resulting in distinct conceptions of the system. Thus, a more thorough description of the perspectives for linking science and practice depends upon untangling the processes perceived to be involved, which were made explicit only in the classification based on processes. We thus chose the process-based classification.

The chosen classification was then refined in two steps. First, we reorganized categories and created new ones aiming at eliminating the debated disadvantages. For example, as the chosen classification did not include perceived causes associated with personal and cultural characteristics of scientists and decision-makers (Appendix S2), we created such a category. Then, all 1563 sentences on causes of the science–practice gap from all articles (including the 45 non-priority ones) were allocated into the classification categories by one of the authors (D.B.G.). When one sentence did not fit the categories, we modified the categories and/or criteria, without altering the underlying logic, to ensure the final conceptual framework was representative of the entire set of sentences referring to causes of the science–practice gap from all articles. The final conceptual framework encompassed 48 categories of perceived causes of the science–practice gap organized into four hierarchical levels (Table 1).

(4) Reliability

We estimated the reliability of the conceptual framework through the pairwise agreement between one author (D.G.B.) and two outside evaluators in the allocation of sentences into the framework categories (Appendix S3). Each evaluator was allocated a different set of 150 sentences (∼10% of the total) taken from all 48 categories (Table 1): one set encompassed only sentences expressing explicitly and precisely the perceived causes of the gap, while the other included sentences taken randomly from each category. The inter-rater pairwise agreement was calculated, for each of the four hierarchical levels of the framework, by correcting the observed author–evaluator agreement by the agreement expected by chance, estimated *via* simulations (Appendix S3). The resulting coefficient varies from 0 (observed agreement equal to that expected by chance) to 1 (perfect agreement), with values greater than 0.67 accepted as reliable (Krippendorff, 2004*b*).

The reliability coefficient was greater than 0.67 for the first three higher hierarchical levels of the framework for both sets of sentences (Appendix S3), assuring adequate reliability in terms of repeatability of the categorization procedure (Krippendorff, 2004*b*). Although coefficients were moderately lower for the fourth hierarchical level, observed agreement was still closer to perfect agreement than to agreement expected by chance (> 0.50; Appendix S3). Hence, within this lower hierarchical level, we based our interpretations on which perceived causes of the science–practice gap predominated in the ecological and conservation literature only on expressive differences between categories of perceived causes (i.e. those differences probably sustained irrespective of the identity of the person categorizing the sentences).

(5) Article coding

We recorded whether each of the 122 articles included sentences allocated to each category of the conceptual framework (Table S1). To analyse the predominance of the categories of perceived causes over time and across journals with distinct research traditions, both the publication year and the scientific journal where each article was published were recorded.

III. RESULTS

(1) Conceptual framework

We identified 48 lower-level categories of perceived causes of the science–practice gap arranged into four hierarchical levels, representing different processes linking science and practice that are considered flawed, inefficient or not occurring (Table 1, Table S4). The first hierarchical level divides the causes into three major categories, representing markedly different perspectives of ecologists and conservation scientists regarding which knowledge or actors are important in linking science and practice (Fig. 2). Thus, for each perspective, the processes linking science and practice are different, constituting the second hierarchical level of the framework (Fig. 2).

The first major category (‘One-way’) represents a perspective in which both scientists and decision-makers are recognized as actors, but only scientific knowledge is considered important to support decision-making, therefore establishing a unidirectional, one-way flow of knowledge from science to practice (Fig. 2A). In this case, the linkage between science and practice is often described with terms such as ‘adoption’, ‘transmitting’, ‘transferring’, and ‘translating’, implying a view of scientific knowledge being produced in science and assimilated into practice:

> We [scientists] must recognize our role in **translating** science into management and policy. We have been successful at times with this **translation**, especially when research has been motivated by a specific management question, but in general our record in this regard is poor. (. . .) we can do far more to **transfer** scientific understanding to practice.
>
> (Hall & Fleishman, 2010, p. 121)

By contrast, the perspective of the second major category (‘Two-way’) assumes that both science and practice should contribute with knowledge to support decision-making, therefore establishing a bidirectional, two-way flow of knowledge between science and practice *via* collaborative interactions between scientists and decision-makers (Fig. 2B). In this case, common terms are ‘exchanges’, ‘partnerships’, ‘dialogues’, ‘collaborations’, ‘learning’, ‘integration’ and ‘co-production’, suggesting that interactions between scientists and decision-makers are understood as a process with intellectual contributions from both parties rather than a process facilitating scientific knowledge transfer:

> . . . the lack of **interaction** between scientists and practitioners poses further challenges to produce socially robust knowledge and solve sustainability problems (. . .) Attempts to link scientists and practitioners in sustainability science aim to strengthen the **exchange** and **integration** of different disciplinary and non-academic knowledge, enabling **mutual learning** between scientists and practitioners . . .
>
> (Brandt *et al.*, 2013, pp. 1–2)

Lastly, the third major category (‘One actor’) is associated with a perspective on the science–practice linkage that also assumes a unidirectional, one-way flow of knowledge from science to practice, but disregards decision-makers, considering only scientists to be important actors that should

Table 1. Simplified version of the conceptual framework of perceived causes of the science–practice gap in Ecology and Conservation found in the scientific literature. The complete version of the framework includes, besides the categories presented here, a category of 'other causes' in every hierarchical level (see Table S4). Detailed criteria for all categories and examples of original sentences are also in given Table S4. *N* = number of articles containing sentences related to each category.

Category					
First hierarchical level	Second hierarchical level	Third hierarchical level	Fourth hierarchical level	*N*	Brief explanation of perceived cause
ONE-WAY	Problems in knowledge generation	*Flawed or inefficient research*	Fragmentation	29	The generation of scientific knowledge is fragmented, disciplinary and conducted without communication between different areas.
			Inadequate questions	38	Research questions and objectives are inadequate (i.e. do not answer) to the knowledge needs of decision-makers.
			Inadequate scale	27	Research is conducted at spatial and temporal scales inadequate to practical questions faced by decision-makers.
			Reductionist approach	11	Scientific approach is reductionist, focusing on isolated factors and not considering environmental complexity or the joint action of several factors in practice.
			Technical focus	5	Scientific approaches focus mostly on technical development of methodological procedures, e.g. spatial prioritization techniques.
			Isolation from practice	20	Research as a whole is conducted isolated or disconnected from practice, without involvement of decision-makers and ignoring their perspectives and values.
			Long time period for scientific-knowledge generation	14	Generation of scientific knowledge is slow, with long time periods elapsing between beginning of research and publication of results.
			Limits for research	13	Not all research useful for practice can be conducted, because of issues of scale, time and limited resources.
		Characteristics of knowledge or of implications	Irrelevant	24	Scientific knowledge is irrelevant, inappropriate and/or useless for practice, without further explanation given.
			Disciplinary	8	Scientific knowledge is disciplinary.
			Abstract/theoretical	8	Scientific knowledge consists mainly of abstract, theoretical and/or conceptual constructions and, therefore, is barely applicable.
			Limited generalizability	11	Scientific knowledge generated by single studies is not generalizable or has limited generalizability, hindering extrapolation of results from one place to another.
			Uncertain	21	There are uncertainties associated with scientific knowledge.
			Complicated	17	The existent body of scientific knowledge is complicated.
			Controversial	23	Scientific knowledge is controversial, with often contradictory results that can change over time and lack of consensus regarding practical recommendations.
			Unreliable	4	Scientific knowledge generated by particular studies is unreliable or of poor quality, being generated without scientific rigour.
			Inadequate implications	19	Recommendations, tools and practical protocols proposed by scientists are inadequate given practical restrictions of time, space and resources.
		Knowledge gaps	Lack of knowledge	28	Scientific knowledge regarding questions that are relevant in practice is lacking.
			Lack of implications	22	Recommendations, tools and/or practical protocols regarding questions that are relevant are lacking.
	Problems in knowledge communication	*Problems in knowledge transfer by scientists*	Limited availability	25	Scientists do not make scientific knowledge available for decision-makers, either because scientific journals are restricted to academia, because scientists do not look for other means of communication or because there is no dissemination of results.

Table 1. Continued

Category					
First hierarchical level	Second hierarchical level	Third hierarchical level	Fourth hierarchical level	*N*	Brief explanation of perceived cause
			Inadequate translation	50	Scientific knowledge is translated into inadequate formats, tools or languages or in a distorted way to decision-makers.
		Problems in knowledge reception by decision-makers	Lack of access	37	Scientific knowledge is not accessed by decision-makers, either because access is difficult for them or because decision-makers do not concern themselves with accessing scientific knowledge.
			Difficulty in understanding	37	Scientific knowledge is not understood or critically analysed by decision-makers, is incorrectly understood or is difficult to understand.
		Problems in communication as a whole		6	Flaws, errors or inefficiencies affect communication of scientific knowledge as a whole, including high costs in terms of time and resources involved in communicating this knowledge.
	Problems in knowledge use	*Knowledge disregarded*	Rejection by decision-makers	26	Decision-makers reject the use of scientific knowledge in practice, either because they have negative beliefs and attitudes towards science, preferring to use their personal experiences, or because they do not trust the knowledge source.
			Impediment by the organizational and/or institutional structure	23	Structures of practice force decision-makers to disregard scientific knowledge, because of legislative factors, bureaucratic mechanisms or lack of time in day-to-day activities to use scientific knowledge.
		Knowledge selected		11	Scientific knowledge reaching practice is selected and misused or partially used to support interests of decision-makers.
		Knowledge outweighed		28	Political and economic interests or values and beliefs of social groups involved outweigh scientific knowledge in practice.
	Problems in the feedback from practice	*Lack of communication of practical results*		10	Practical results are not communicated and/or published.
		Lack of communication of practical needs		6	Decision-makers do not communicate their needs or do not ask scientists for help.
	General problems	*Cultural difficulties*		43	Behaviours, negative attitudes or misguided perceptions towards each other and differences between science and practice in terms of language, values and working routines hinder the unidirectional flow of scientific knowledge.
		Difficulties associated with the organizational context	Evaluation systems	38	Evaluation and reward systems of scientists or decision-makers do not consider acting in linking science and practice as an integral part of professional activities.
			Formal education	18	Formal education does not prepare professionals to take part in the activities involved in linking science and practice.
			Resources	22	Resources are lacking or funding schemes are incompatible with involvement of scientists and decision-makers in linking science and practice.
		Difficulties associated with models of science and of science–practice linkages	Post-normal science	2	A model assuming all forms of knowledge are equally valid devalues the use of scientific knowledge and scientists' opinions in practice.
			Neutral science	6	A model of science assuming science must be neutral and objective, without any influence of issues from outside academia, hinders the linking of science and practice.
		Complexity of problems		12	Problems faced in practice are complex, involving diverse systems interacting with each other and changing over time, hindering the linking of science and practice.
TWO-WAY	Problems in interactions	*Lack of interactions*		19	Interactions, exchanges, partnerships, dialogues or collaborations between science and practice are lacking.

Table 1. Continued

Category					
First hierarchical level	Second hierarchical level	Third hierarchical level	Fourth hierarchical level	*N*	Brief explanation of perceived cause
		Epistemological difficulties		20	The nature of knowledge, the processes of generating knowledge deemed valid or epistemological differences between science and practice hinder interactions between them.
		Cultural difficulties		24	Behaviours, negative attitudes or misguided perceptions towards each other and cultural differences between science and practice in terms of language, values and working routines hinder interactions between them.
		Difficulties associated with the organizational context	Evaluation systems	19	Evaluation and reward systems of scientists and decision-makers do not consider interactions between science and practice as an integral part of professional activities and do not value knowledge produced in these interactions.
			Formal education	7	Formal education does not prepare scientists and decision-makers to act in an integrated manner.
			Resources	6	Resources are lacking or funding schemes are incompatible with supporting interactions between science and practice.
			High turnover in practice	2	Employment positions for decision-makers in organizations involved in practice have high turnover, impeding fruitful interactions with the scientific community.
		Difficulties associated with models of science and science–practice linkages	Unidirectional model	15	A model assuming a unidirectional flow of knowledge from science to practice hinders interactions between science and practice.
			Model emphasizing scientific rigour/quality	2	A model assuming the science–practice gap is due only to lack of scientific rigour and the solution to environmental problems lies in a science of better quality hinders interactions between science and practice.
			Model emphasizing objective and impartial knowledge	8	A model that values only explicit, objective and impartial (i.e. value-free) knowledge and disregards other knowledge types hinders interactions between science and practice.
ONE ACTOR	Problems in action			5	Scientists themselves do not act in, i.e. do not perform, practical activities, or face difficulties in performing them.

act in 'doing' conservation or 'putting results into practice', besides producing scientific knowledge (Fig. 2C):

> Researchers dealing with conservation subjects usually do not **put the results of their work into practice**, even when the primary purpose of their research is the preservation of biodiversity.
>
> (Gallo *et al*., 2009, p. 895).

However, this third major category was rare, being present in only five articles, and, therefore, was not divided into further categories.

(*a*) *'One-way' perspective*

The important processes linking science and practice from the perspective 'One-way' – which assumes a unidirectional flow of knowledge from science to practice – are the generation, communication and use of scientific knowledge, as well as the feedback from practice to science regarding research needs and practical results (Fig. 2A). Thus, within this perspective, the second-level categories of causes of the science–practice gap are associated with problems deemed to affect one or all of these processes (Fig. 3A).

The category 'Problems in knowledge generation' is further divided into three third-level categories associated with (*i*) the research process, (*ii*) the characteristics of the produced knowledge, and (*iii*) knowledge gaps (Fig. 3A). In the first case, the perceived causes of the gap lie on flaws, errors or inefficiencies in scientific research. For example, some authors argue that the fragmentation of research efforts (Githiru *et al*., 2011) or the reductionist approach in scientific research (Cabin, 2007) renders research incompatible with the generation of useful knowledge for practice. In the second case, causes are related to characteristics of scientific research products (either scientific knowledge or proposed practical recommendations derived from it) that are perceived to render them irrelevant to practice, such as the difficulty of

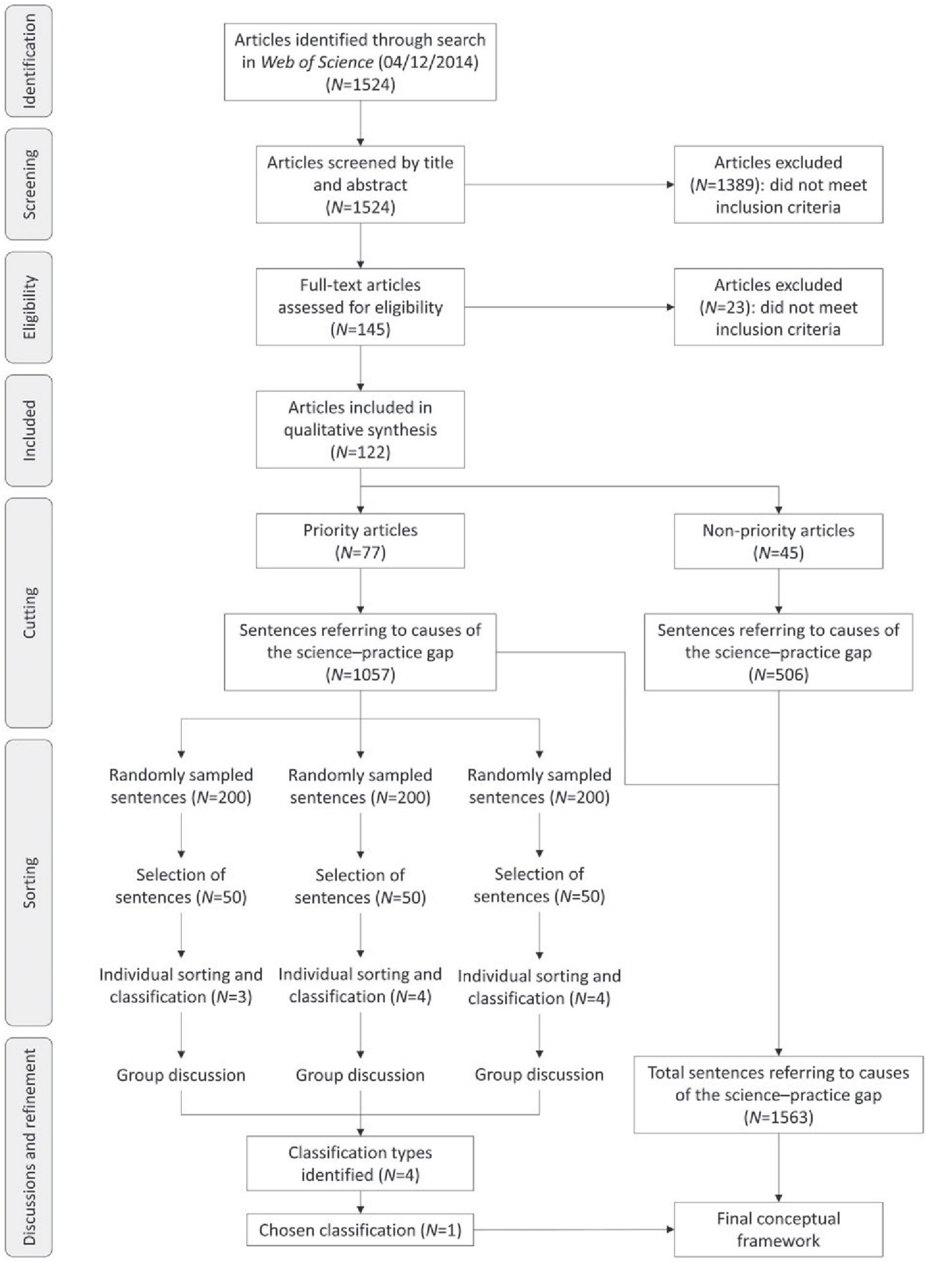

Fig. 1. Flow diagram of the procedures used for searching and selecting articles and for developing the conceptual framework of perceived causes of the science–practice gap in Ecology and Conservation.

using scientific knowledge that is abstract (Sunderland *et al.*, 2009) or uncertain (Bradshaw & Borchers, 2000). Finally, in the third case, perceived causes refer to a lack of knowledge or recommendations regarding relevant questions to practice.

The category 'Problems in knowledge communication' is also divided into three third-level categories (Fig. 3A). The first refers to the perception of flaws, errors or inefficiencies in communication processes for which scientists are deemed responsible; that is, scientists either do not make scientific knowledge available for decision-makers (e.g. only publishing in scientific journals read by their own peers; Dramstad & Fjellstad, 2012) or translate available knowledge in formats, language or tools that are inadequate for decision-makers (e.g. Finch & Patton-Mallory, 1993). The second one refers to perceived problems in the reception of knowledge by decision-makers: they either do not access scientific literature, for example, because of lack of time in daily activities (e.g. Shaw, Wilson & Richardson, 2010), or have trouble understanding scientific knowledge (e.g. Bradshaw & Borchers, 2000). The third one refers to problems perceived to affect the communication process as a whole, such as the high costs in terms of resources and time involved in communicating scientific knowledge to practice (Seavy & Howell, 2010).

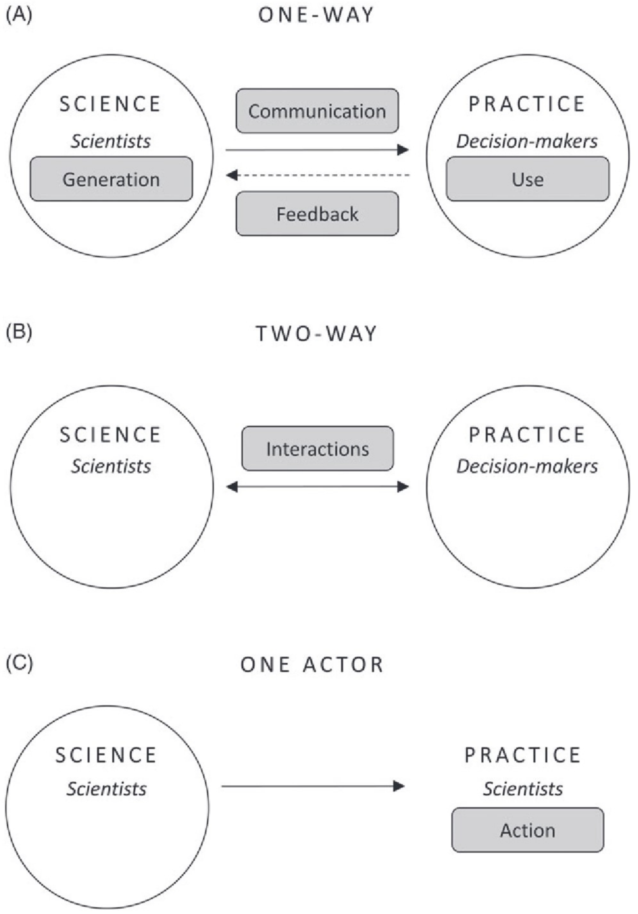

Fig. 2. Schematic representation of the three perspectives regarding which knowledge or actor is considered important in linking science and practice in Ecology and Conservation. Text in italic represents recognized actors within each perspective and boxes represent the processes that are considered flawed (i.e. second hierarchical-level categories of perceived causes). (A) The perspective 'One-way' assumes that only scientific knowledge is important to support decision-making, therefore establishing a unidirectional flow of knowledge from science to practice (one-way continuous arrow), with possible feedback of practical needs (one-way dashed arrow). (B) The perspective 'Two-way' assumes that both science and practice should contribute with knowledge to support practice, therefore establishing a bidirectional flow of knowledge between science and practice *via* joint knowledge production and interactions between scientists and decision-makers (two-way continuous arrow). (C) The perspective 'One actor' assumes that only scientists are important actors and should act in conservation, besides producing scientific knowledge.

The category 'Problems in knowledge use' also includes three third-level categories (Fig. 3A). The first implies that scientific knowledge is disregarded in practice, either because decision-makers reject it, for example, when new scientific ideas contradict personal beliefs (McCleery, Lopez & Silvy, 2007), or it is not used because of the structure of organizations involved in practice (e.g. Murphy & Kaeding, 1998). The second and third categories refer to the perception of scientific knowledge being (*i*) partially selected to support decision-makers' interests (e.g. Peuhkuri, 2002), or (*ii*) outweighed by other factors (e.g. by political interests; Barbour *et al.*, 2008).

Although the 'One-way' perspective assumes a unidirectional flow of knowledge from science to practice, some articles also indicate perceived problems in the feedback from practice to science ('Problems in the feedback from practice', Fig. 3A). In this category, causes are related to a perceived lack of communication either (*i*) of practical results or (*ii*) of research needs back to scientists. For example, Finch & Patton-Mallory (1993) argue that land managers have not always done a good job explaining their needs or soliciting research help.

Finally, some articles reported causes perceived to affect more than one process linking science and practice, hindering as a whole the flow of knowledge originating in scientific research. We grouped those perceived causes into the category 'General problems', divided into four third-level categories (Fig. 3A). The first one refers to cultural aspects (i.e. values, expectations, perceptions, attitudes, and/or behaviours) of scientists and/or decision-makers deemed to hinder the knowledge flow from science to practice, e.g. misguided perceptions and criticisms from one side towards the other preventing an effective conversion of scientific findings into management actions (e.g. Cabin, 2007). The second category includes aspects of the organizational context, associated with the perception that either (*i*) professional evaluation systems do not reward scientists for engaging in processes related to the flow of scientific knowledge to practice; (*ii*) formal education does not train professionals to engage in these processes; or (*iii*) resources are lacking to support such activities. Bainbridge (2014), for example, criticizes formal scientific education for not exposing students to the functioning and methods of policy-making. The third and fourth categories are related to currently predominant models governing scientific production and science–practice linkages and to the complexity of problems faced by decision-makers (Fig. 3A), which were also perceived to affect all the processes of knowledge generation, communication and use as well as feedback.

(*b*) *'Two-way' perspective*

Within the perspective 'Two-way' – which assumes a bidirectional knowledge flow between science and practice – we identified only one important process deemed to link science and practice: joint knowledge production and integration *via* interactions between scientists and decision-makers (Fig. 2B). Thus, this perspective includes a single second-level category 'Problems in interactions' (Fig. 3B).

The category 'Problems in interactions' is in turn subdivided into five third-level categories of perceived causes (Fig. 3B): one related to lack of interactions between science and practice, without delving into the underlying reasons, and four categories dealing with different factors perceived

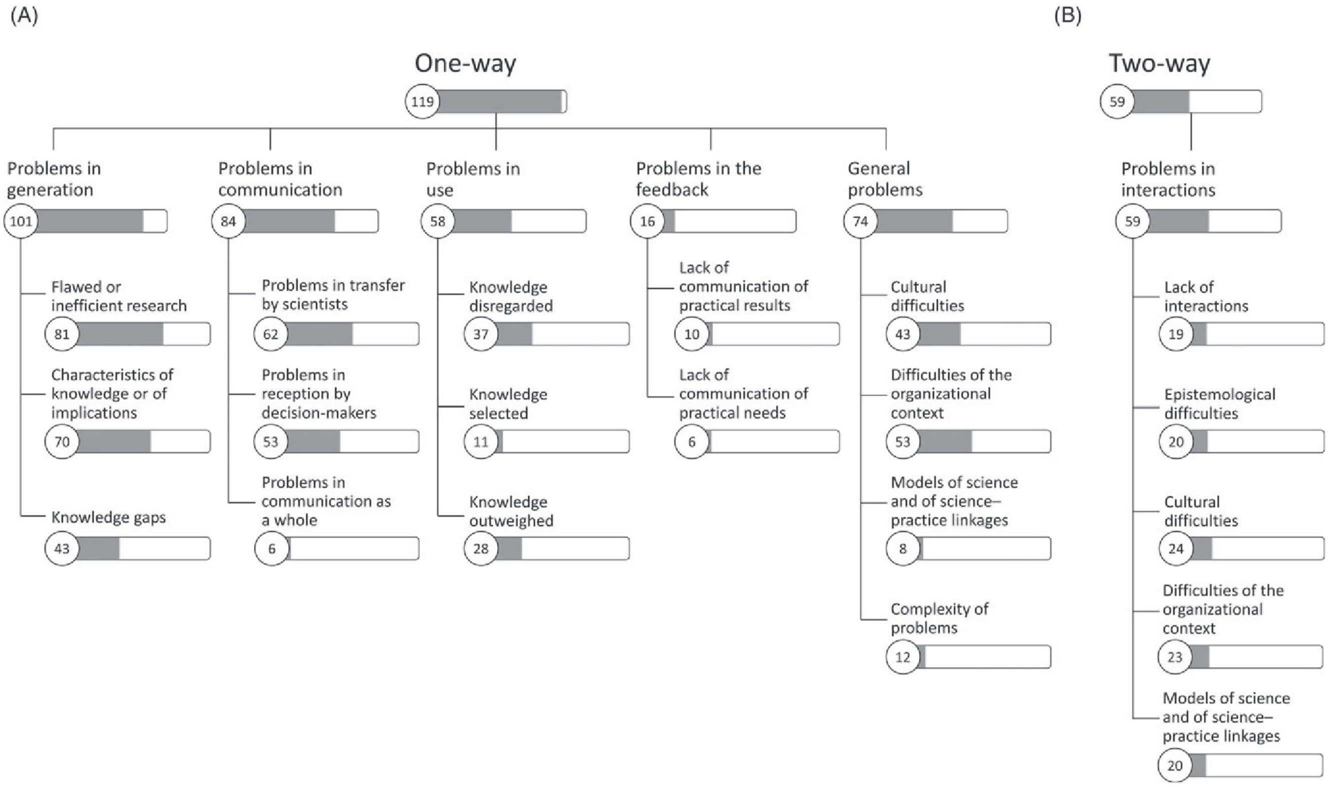

Fig. 3. Hierarchical organization of the second- and third-level categories of perceived causes of the science–practice gap in Ecology and Conservation within the perspectives 'One-way' (A) and 'Two-way' (B), showing the number (inside circles) and the proportion (bars) of articles ($N = 122$) that contained sentences allocated to each category.

to hinder or prevent interactions. The first category of factors perceived to hinder interactions – 'Epistemological difficulties' – encompasses differences between science and practice regarding either the nature of knowledge or which knowledge-generation processes are deemed valid. For example, Hulme (2014) stresses that while science seeks generalizations, knowledge is context dependent and variable across decision-makers, complicating knowledge integration. The other categories of factors deemed to hinder interactions are related to perceived difficulties associated with cultural aspects, the organizational context, and predominant models of science and science–practice linkages (Fig. 3B). The category 'Difficulties associated with the organizational context' is further subdivided into (*i*) professional evaluation systems, (*ii*) formal education, (*iii*) lack of resources, and (*iv*) high turnover of decision-makers' employment positions. In the latter category, Shackleton *et al.* (2009) perceived the constant change of people involved in practice as a major difficulty in developing social-learning partnerships. Lastly, the category 'Difficulties associated with models of science and science–practice linkages' is subdivided into three different models perceived to hinder interactions between science and practice (e.g. the unidirectional model of knowledge dissemination from scientists to decision-makers focusing on knowledge transfer and translation; Shackleton *et al.*, 2009).

Many perceived causes within 'Problems in interactions' (Fig. 3B) are similar to those perceived to affect as a whole the unidirectional flow of knowledge from science to practice in the 'General problems' category, within the 'One-way' perspective (Fig. 3A). However, perceived causes within 'Problems in interactions' are deemed to hinder joint knowledge production and/or integration between scientists and practitioners, while causes within 'General problems' are perceived to impair the unidirectional flow of knowledge from science to practice.

(2) Predominance of perceived causes of the science–practice gap in the literature, over the years and across journals

From the 122 reviewed articles, 92 were published in the last decade. In fact, the proportion of articles mentioning causes of the science–practice gap in Ecology and Conservation has increased over the years, particularly since 2007 (Fig. 4A).

Half of the reviewed articles included causes of the science–practice gap from just one major perspective (mainly 'One-way'), while the other half included causes from two, mainly 'One-way' and 'Two-way', or all three major perspectives (Fig. 4A). The 'One-way' perspective – which assumes a unidirectional flow of knowledge from science to practice – was the most common perspective overall (Fig. 4A), with only three articles not including perceived

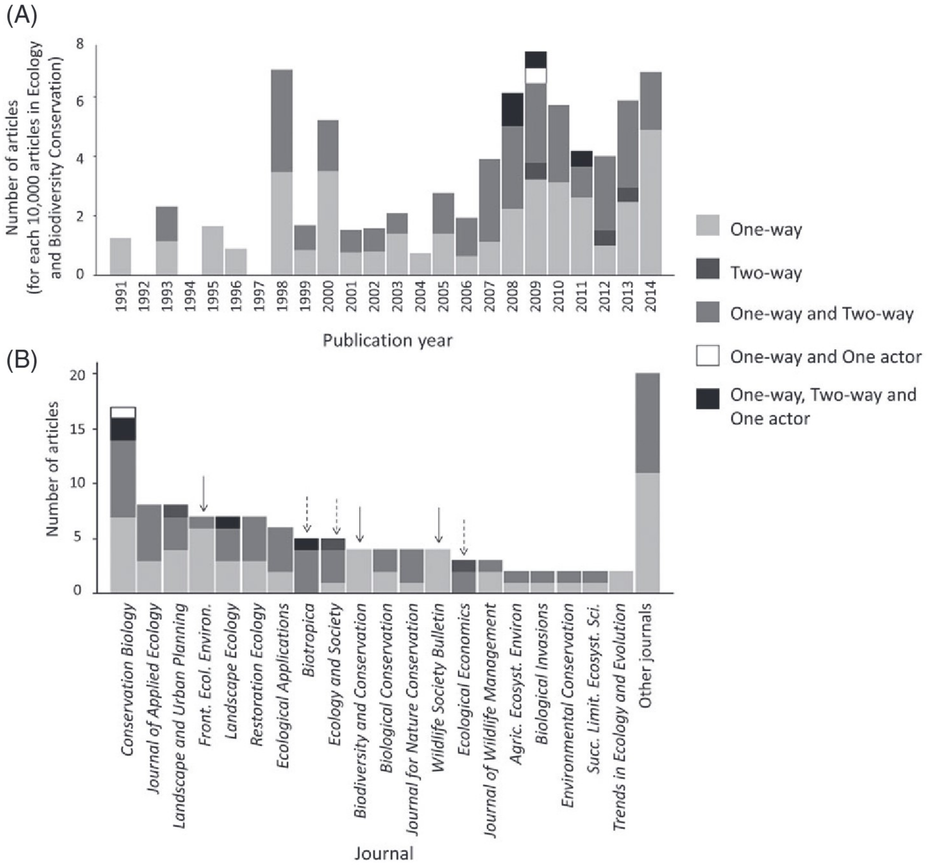

Fig. 4. Distribution of reviewed articles associated with each major category of perceived causes of the science–practice gap in Ecology and Conservation between 1991 and 2014 (A) and across scientific journals (B). In A, bars represent the number of reviewed articles divided by the total number of articles indexed in the categories 'Ecology' and 'Biodiversity Conservation' in the *Web of Science Core Collection* for each publication year. In B, continuous arrows point to journals dominated by articles associated only with the major category 'One-way' and dashed arrows to journals dominated by articles also associated with the major category 'Two-way'. *Front. Ecol. Environ.* = *Frontiers in Ecology and the Environment*; *Agric. Ecosyst. Environ.* = *Agriculture Ecosystems & Environment*; *Succ. Limit. Ecosyst. Sci.* = *Successes, Limitations, and Frontiers in Ecosystem Science*.

causes of the science–practice gap from this perspective (Fig. 4A). The 'Two-way' perspective – which assumes a bidirectional flow of knowledge between science and practice – was the second most common, while the 'One actor' perspective – which assumes only scientists to be important actors – was the least common (Fig. 4A). The proportion of articles associated with the perspectives 'One-way' and 'Two-way' did not change substantially over the years, while the few articles including perceived causes from the 'One actor' perspective were published more recently, between 2008 and 2011 (Fig. 4A).

The reviewed articles were published mostly in *Conservation Biology*, followed by *Journal of Applied Ecology* and *Landscape and Urban Planning* (Fig. 4B). The proportion of reviewed articles associated with each perspective was similar across most scientific journals (Fig. 4B). However, articles published in *Frontiers in Ecology and the Environment*, *Biodiversity and Conservation* and *Wildlife Society Bulletin* were predominantly associated only with the perspective 'One-way', while most articles published in *Biotropica*, *Ecology and Society* and *Ecological Economics* also included perceived causes from the perspective 'Two-way' (Fig. 4B).

Considering the 'One-way' perspective, causes referring to 'Problems in knowledge generation' were present in approximately 80% of the articles, being the most common in the second hierarchical level, followed closely by 'Problems in knowledge communication' and 'General problems' (Fig. 3A). Within the category 'Problems in knowledge generation', causes related to research process or characteristics of knowledge were the most frequent (Fig. 3A). Within the category 'Problems in knowledge communication', the number of articles citing causes in knowledge transfer was slightly greater than in knowledge reception (Fig. 3A). The inadequate translation of scientific knowledge by scientists (within knowledge transfer) was the most cited lower-level category of the entire framework, being mentioned by 40% of reviewed articles (Table 1). Within 'Problems in knowledge use', knowledge being disregarded in practice appeared more frequently in the literature than knowledge being selected by decision-makers to fit their own interests or being outweighed by other factors (Fig. 3A). Finally, within the category 'General problems', the most common perceived causes were those related to cultural aspects or difficulties associated with the organizational context (Fig. 3A), the latter reflecting the high proportion of articles mentioning that professional evaluation systems hinder the flow of knowledge from science to practice (Table 1).

Regarding the 'Two-way' perspective, all categories of perceived causes related to 'Problems in interactions' were equally frequent in the literature, being found in approximately one fifth of the articles (Fig. 3B). Most articles mentioning causes in the categories 'Difficulties associated with the organizational context' and 'Difficulties associated with models of science and science–practice linkages' refer to problems perceived to be associated with professional evaluation systems and a unidirectional model of knowledge transfer from science to practice, respectively (Table 1).

When divided by publication year, the proportion of reviewed articles including causes from second- and third-level categories did not change substantially over time (Appendix S4). Fourth-level categories presented too few articles to allow division by publication year. All trends described above remain similar when considering only the articles expressing exclusively the authors' ideas, i.e. after excluding the 21 articles that empirically investigated the opinions of scientists or decision-makers (Appendix S5).

IV. DISCUSSION

We reviewed the scientific literature in Ecology and Conservation and, by using an inductive text-analysis approach, organized the perceived causes of the science–practice gap into a process-based conceptual framework. We identified three perspectives of ecologists and conservation scientists on the important processes linking science and practice that coexist in the literature, frequently within the same articles and journals. Below, we first discuss the predominant causes of the science–practice gap perceived by ecologists and conservation scientists, and then contextualize the identified perspectives in terms of predominance over time and across journals with distinct research traditions. Next, we consider insights from scientific disciplines studying the role of science in decision-making and its relation to society to highlight the strengths and limitations of ecologists and conservation scientists' perspectives on the science–practice gap. Finally, we describe the implications for fostering productive linkages between science and practice in Ecology and Conservation.

(1) The perceived causes of the science–practice gap in Ecology and Conservation

Within the perspective 'One-way', the great majority of articles mentioned 'Problems in knowledge generation', suggesting that the generation of scientific knowledge is a widely acknowledged problem causing the science–practice gap among ecologists and conservation scientists. The idea that current scientific processes may be inadequate to address societal challenges is also present in the critique of the implicit social contract of science (i.e. science supplies knowledge to society in exchange for support through taxes and liberty to self-regulate; NASEM, 2015). According to Lubchenco (1998), this contract is no longer sufficient to confront pressing environmental challenges, and a new contract is needed in which science is directed to the most pressing problems. However, this is a controversial view that disregards that science searching for explanations that provide intellectual satisfaction (Braithwaite, 1955) is also important both for understanding the systems we may wish to conserve (Dayton, 2003) and for general advances in technology (Oates, 2013). Hence, a focus on diverse ways of conducting science may be more useful.

Within the category 'Problems in knowledge generation', often-mentioned causes related both to scientific research and to characteristics of scientific knowledge reinforce this perception of inadequacy of scientific processes and products. The fragmentation of research efforts and inadequate research questions and scales (the most frequently cited causes related to the research process) were perceived to render scientific knowledge irrelevant (the most cited cause related to characteristics of knowledge). Thus, the prevalence of these causes in the literature points to a general perception that conducting more-relevant research is the main step towards bridging the science–practice gap, a perception also common within the medical field (Cairney, 2016). Indeed, several articles in Ecology and Conservation discuss what renders scientific knowledge relevant to practice (e.g. Cash *et al.*, 2003; Cook *et al.*, 2013). Ecologists and conservation scientists may thus place great importance on transforming institutional and organizational arrangements of science to allow for the generation of knowledge that is relevant to practice, indicating that they support diverse ways of conducting science.

Besides being irrelevant to practice, characteristics inherent to scientific knowledge, such as uncertainty and controversy, were also frequently cited as causes of the science–practice gap. For example, the uncertainty associated with scientific knowledge is perceived as hindering its acceptance and use in practice because most decision-makers seek certainty (Bainbridge, 2014) and/or are not used to probabilistic modes of discourse (Bradshaw & Borchers, 2000). However, any knowledge about the empirical world is inherently uncertain and conjectural, and even the most consensual topics are surrounded by irreducible uncertainty (Dovers, Norton & Handmer, 1996; Bradshaw & Borchers, 2000). In Ecology and Conservation, uncertainty may be an even more pressing problem in the application of scientific knowledge than in other disciplines, partly because they are relatively young sciences and there is still much to understand, but also because of the inherent complexity of ecological and socio-ecological systems (Dovers *et al.*, 1996; Polasky *et al.*, 2011). Although uncertainty can be reduced over time, it is not a problem in itself, but an inherent characteristic of scientific knowledge, which may be miscomprehended (Bradshaw & Borchers, 2000), potentially leading to rejection of ecological knowledge among decision-makers (van Latesteijn, 1998), and to ambiguity and complication in public debate when science is brought to assist decision-making (Sarewitz, 2004; Cairney, 2016).

The ecological and conservation literature also encompassed perceived causes of the science–practice gap related to another intrinsic characteristic of scientific knowledge, namely its abstract nature. This is surprising as it suggests a misconception from scientists themselves about science and its potential for solving problems. Being abstract means that scientific knowledge aims at generalizations, building general propositions applicable to different situations and contexts (Tress *et al.*, 2005). Precisely because it is general, scientific knowledge has explanatory and predictive power. Nonetheless, knowledge generalizability can be limited in some instances, which has also been perceived as hampering productive science–practice linkages ('Limited generalizability', Table 1). Ecological generalizations, in contrast to generalizations in other disciplines, have a more restricted application domain (Weber, 1999; El-Hani, 2006), and some have proposed that developing solutions to specific problems may often require that new local, context-specific knowledge – and therefore not applicable elsewhere – is produced (Tress *et al.*, 2005). However, generalized ecological knowledge (i.e. ecological theories and models), by identifying key processes or mechanisms, can help to identify which specific information is needed in particular situations or contexts.

Although problems in knowledge generation were more salient, inadequate translation, included in the category 'Problems in knowledge communication', was the most cited lower-level category of the entire framework. Indeed, translation difficulties are perceived to result from failures in several other processes, such as formal education, as well as from characteristics of scientific knowledge such as uncertainty. Formal scientific education does not usually focus on the processes and methods used in decision-making or on human interaction skills (Cannon, Dietz & Dietz, 1996; Jacobson & Duff, 1998; Baxter *et al.*, 1999), possibly leading to lack of competence on how to present scientific knowledge for audiences outside academia, or how to frame scientific knowledge into relevant and meaningful practical recommendations. In addition, scientific uncertainty was perceived as increasing the challenge of translating science in a meaningful way to decision-makers (Dovers *et al.*, 1996; Bradshaw & Borchers, 2000). However, as Bainbridge (2014) suggests, although most authors place an onus on scientists for improving communication, decision-makers' responsibility to understand and engage with science should not be overlooked.

In the category 'Problems in knowledge use', the most commonly cited cause was a disregard for scientific knowledge in practice. This was perceived to be a result of either an organizational impediment, such as a lack of operational capacity to implement science-based recommendations (Young & Van Aarde, 2011) or of science rejection by decision-makers. Rejection, in turn, was perceived to be associated with, among other factors, a lack of trust in knowledge sources (Lauber *et al.*, 2011), resistance to change in managing paradigms (McCleery *et al.*, 2007) or unjustified expectations towards scientific knowledge, e.g. certainty (Bradshaw & Borchers, 2000). Irrespective of the reason, the prevalence in the literature suggests a widespread perception among scientists that ecological and conservation science is rarely used and is rejected by practitioners in decision-making.

Although less frequent than problems in knowledge generation and communication, causes associated with 'General problems' within the perspective 'One-way', which were perceived as overall hindering the knowledge flow from science to practice, were commonly mentioned. Many of these causes were similar to those perceived as hindering joint knowledge production and/or integration between scientists and decision-makers within the perspective 'Two-way'. Within both perspectives, problems related to professional evaluation systems were the most commonly cited within the category 'Difficulties associated with the organizational context'. This indicates that such systems are perceived as a hurdle to a broad range of processes expected to link science and practice, for example, because the focus on the quantity of high-impact publications discourages scientists to dedicate time to knowledge communication or integration (Born, Boreux & Lawes, 2009; Shanley & López, 2009; Sunderland *et al.*, 2009; Whitmer *et al.*, 2010). Similarly, cultural aspects of scientists and decision-makers arising from different values, attitudes and languages (e.g. Cabin, 2007), or ingrained misconceptions and negative attitudes towards one another (e.g. Roux *et al.*, 2006), are also commonly perceived as hampering both the one-way flow of knowledge from science to practice and the process of joint knowledge production and/or integration between scientists and decision-makers.

Within the perspective 'Two-way', the categories 'Epistemological difficulties' and 'Difficulties associated with models of science and science–practice linkages' (especially a unidirectional model of knowledge transfer) were as common as the cultural and organizational aspects mentioned above. Epistemological difficulties – such as different conceptions of scientists and decision-makers on the nature of knowledge and how it should be produced – have already been reported as significant challenges hindering integration of different knowledge sources, given that different conceptions prevent consensus on how to integrate knowledge or which integration outputs are valuable (Raymond *et al.*, 2010). In fact, the hindrance to integrative joint knowledge-production processes between scientists and decision-makers perceived to be caused by the unidirectional model can be explained by such epistemological challenges, as this model places greater importance on scientific knowledge, simultaneously devaluing other knowledge types, such as the context-situated knowledge of decision-makers.

Apparently, scientists in distinct fields perceive similar causes affecting the science–practice gap. This is the case for cultural difficulties and professional evaluation systems, also perceived as a hindrance to linking science and practice in Education (Anderson, 2007; Broekkamp & Hout-Wolters, 2007), Nursing (Closs & Cheater, 1994), and Medicine (Waddell, 2002; Nutley, Walter & Davies, 2007). However, certain aspects of scientific knowledge generation, such as research being conducted at inadequate scales (i.e. either temporal or spatial scales different from those relevant to decision-makers) and research being limited because of scale, time and funding issues, seem to be perceived as a cause of the science–practice gap only in Ecology and Conservation. Comparing the conservation and medical fields, Walsh (2015) identified several perceived barriers specific to conservation, including the problem of research scale. Indeed, relevant temporal and spatial scales in Ecology and Conservation are more varied than in other disciplines, ranging from genes to ecosystems (Pullin & Knight, 2005). Research funding and larger samples are also harder to obtain in Ecology and Conservation (e.g. compared to medicine; Fazey *et al.*, 2004). Despite differences in perceived causes, our conceptual framework suggests that the science–practice gap in Ecology and Conservation is perceived to be as complex and multifaceted as within other scientific disciplines (Broekkamp & Hout-Wolters, 2007; Nutley *et al.*, 2007).

The variety of perceived causes of the science–practice gap in Ecology and Conservation requires three distinct, general types of solution (Fig. 5). First, several perceived causes require solutions directly eliminating the causal factor (Fig. 5A). For example, inadequate research questions were often perceived as a causal factor. To eliminate this factor and change research agendas, lists of priority topics have been developed by consulting scientists and practitioners (e.g. Sutherland *et al.*, 2009; Jones *et al.*, 2015). Second, some perceived causes are related to factors that cannot be eliminated or changed, such as those regarding intrinsic characteristics of ecological knowledge (e.g. uncertainty). Here, solutions require the recognition of, and then ways to deal with, the problem or factor (Fig. 5B), such as assisting decision-makers to tackle uncertainty *via* adaptive management or scenario planning (Dovers *et al.*, 1996; Polasky *et al.*, 2011). Finally, some perceived causes cannot be tackled by either eliminating or dealing with the causal factor, given they are mostly based on misconceptions (Fig. 5C). For example, the perceived cause of scientific knowledge being abstract is either a misconception about the potential of generalized knowledge to guide action or an incorrect use of concepts such as 'abstract' or 'conceptual'. Either way, a more adequate solution would be to encourage discussions on the nature of knowledge, including historical, philosophical and sociological approaches to science.

(2) The perspectives of ecologists and conservation scientists on the science–practice gap

By classifying the perceived causes of the science–practice gap in Ecology and Conservation into a process-based framework, we identified three distinct perspectives or ways to understand the interface. The perspective 'One-way'

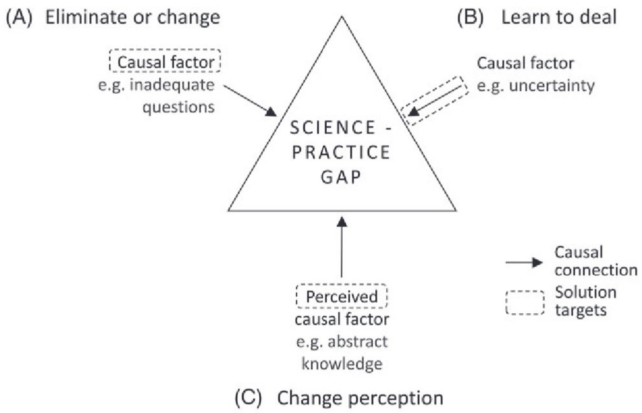

Fig. 5. Distinct types of solutions to the perceived causes of the science–practice gap in Ecology and Conservation. (A) Solutions that aim at eliminating or changing the causal factor. (B) Solutions that aim at recognizing and dealing with problems (causal factors) that cannot be eliminated. (C) Solutions that aim at changing the perception of causal factors that are based on misconceptions about the potential of science for supporting practice.

assumes that only scientific knowledge should support practice, establishing a unidirectional flow of knowledge from science to practice, while the perspective 'Two-way' assumes that both scientists and decision-makers should support practice *via* a bidirectional process of joint knowledge production and integration. The perspective 'One actor' in turn disregards decision-makers by assuming that scientists should put their results into practice. Although this is, to our knowledge, the first formal review on the science–practice gap in Ecology and Conservation, the few studies exploring conceptualizations of the interface in this field mention perspectives similar to those we identified. For example, Roux *et al.* (2006) portray ongoing initiatives to link science and practice in sustainable ecosystem management as adhering to a model of unidirectional knowledge transfer and argue instead for bidirectional knowledge-sharing processes. Likewise, among the framings of interactions between science and environmental or conservation policy presented by Pregernig (2014), several focus mainly on scientific knowledge, while only one recognizes a plurality of knowledge systems.

In fact, the two main perspectives on the science–practice gap we identified also parallel those recognized among scientists from other disciplines, such as Medicine and Education. In these disciplines, earlier ideas of research utilization in practice suggested a unidirectional transfer of information (Huberman, 1994; Nutley *et al.*, 2007), equivalent to our major category 'One-way'. However, recently, the unidirectional view has been replaced by bidirectional conceptions highlighting dialogue and joint knowledge production and/or integration between researchers and practitioners (Waddell, 2002; Nutley *et al.*, 2007; Vanderlinde & van Braak, 2010), similar to our major category 'Two-way'. Despite this historical tendency in other disciplines, the proportion of articles associated with our two major categories did not substantially change over time and there was a clear prevalence of the 'One-way' perspective. Our findings thus suggest the debate of the science–practice gap in Ecology and Conservation may lag behind discussions in other disciplines, being still dominated by a perspective assuming a one-way flow of knowledge from science to practice and a primacy of scientific knowledge.

The prevalence of the unidirectional view of knowledge transfer may be associated with the leverage or prestige of the evidence-based approach in Ecology and Conservation (Toomey *et al.*, 2016). This approach, transposed from Medicine to Conservation, focuses on methods that systematically collate and synthesize scientific evidence to enhance the flow of knowledge from science to practice (Pullin & Knight, 2001; Fazey *et al.*, 2004; Sutherland & Pullin, 2004; Dicks, Walsh & Sutherland, 2014*b*). More than ten years after its proposal (Pullin & Knight, 2003; Sutherland & Pullin, 2004), the evidence-based approach has become widely established, resulting in journals (e.g. *Conservation Evidence*), online databases (e.g. www.conservationevidence.com, www.environmentalevidence.org), and international collaborations (e.g. Collaboration for Environmental Evidence), and has been found to effectively facilitate the use of science in practice (Walsh, Dicks & Sutherland, 2015). However, although the evidence-based approach acknowledges the need to integrate scientific and non-scientific knowledge in decision-making (Fazey *et al.*, 2004; Haddaway & Pullin, 2013; Walsh, 2015), there has been a focus on the systematic collation of scientific evidence and less so on the integration of different knowledge sources (Adams & Sandbrook, 2013; Walsh, 2015). This dominance may have precluded advances towards perspectives emphasizing interactions between scientists and decision-makers and the use of local and practitioners' knowledge to deal with environmental problems.

In contrast to the evidence-based approach originating in Medicine, integrative approaches for linking science and practice are more common in Education (e.g. McIntyre, 2005; El-Hani & Greca, 2013). These initiatives are inspired by contributions emphasizing learning and knowledge production as an integral part of social practice, such as social-learning theories (e.g. Lave & Wenger, 1991) and communities of practice (Wenger, 1998). In Ecology and Conservation, some similar successful experiences of joint knowledge production have been reported, such as those integrating scientific knowledge with decision-makers' strategic knowledge (*sensu* Hulme, 2014) about what is legislatively, politically and administratively feasible (Pardini *et al.*, 2013; Rigueira *et al.*, 2013), or initiatives also incorporating local resource users and their (traditional) knowledge (Knight & Cowling, 2006; Shackleton *et al.*, 2009). Hence, although the medical field has provided many important lessons for linking science and practice in Ecology and Conservation, as attested by the achievements of evidence-based approaches, avoiding dominance in the debate regarding the science–practice gap will require inspiration from other disciplines such as Education.

Despite the unchanged predominance of the 'One-way' perspective over time, the distribution of perspectives on the science–practice gap across ecological and conservation journals was not homogeneous. Even though the proportion of articles associated with each perspective was similar across most journals, some are dominated by articles mentioning causes of the gap related only to the unidirectional perspective 'One-way', while in others most articles include also the bidirectional 'Two-way' perspective. The former are associated with conservation and wildlife management traditions, such as *Biodiversity and Conservation* and *Wildlife Society Bulletin*, whereas the latter are mostly linked to traditions such as sustainability science and socio-ecological resilience, e.g. *Ecology and Society* and *Ecological Economics*. The focus on joint knowledge production and integration between scientists and decision-makers, besides being less frequent, may thus have also been primarily restricted to research traditions historically isolated from mainstream Conservation Biology (Curtin & Parker, 2014). Together with the overall dominance of the 'One-way' perspective over time, this reinforces the idea of a debate dominated by a single unidirectional view of knowledge transference from science to practice, which may prevent the incorporation of diverse perspectives when planning solutions for improving the use of science in decision-making (Carpenter *et al.*, 2009).

(3) Putting into context the perspectives of ecologists and conservation scientists on the science–practice gap

As understanding the process of decision-making can bring a broader perception of the role of science (Oliver, Lorenc & Innvaer, 2014), the debate on the science–practice gap in Ecology and Conservation can be enlightened by considering the input of disciplines such as STS studies and Political Science. Whereas these disciplines focus mainly on decision-making processes and on the role of science in society (Cairney, 2016), the literature on the science–practice gap in Ecology and Conservation addresses primarily the process of knowledge generation and the connection between science and practice, either through knowledge communication or joint knowledge production/ integration (depending on the perspective). Below, we present four main topics we believe disciplines such as Political Science and STS studies could contribute to the debate on the science–practice gap in Ecology and Conservation.

The first topic refers to several criticisms to the traditional model of decision- and policy-making, in which science is the sole provider of relevant information to a rational decision-maker, who accesses and evaluates such information, ranks the benefits and costs of all possible actions, and arrives at a solution that maximizes the benefits (Collingridge & Reeve, 1986; Albaek, 1995). Instead, more recent conceptualizations contemplate a complex decision-making context (reviewed in Albaek, 1995; Neilson, 2001; Nutley *et al.*, 2007; Cairney, 2016), with different relevant factors besides science, such as political interests, social values, and feasibility of actions. In this complex context, decision-makers do not act fully rationally and are instead 'boundedly rational', i.e. they cannot access all relevant information nor act upon it. They just make 'good enough' decisions or make only incremental changes without considering the science. Some conceptualizations even describe decision-making as chaotic and unpredictable, with solutions arising independently of problems and becoming attached to them when opportunity arises. In this scenario, one can barely say that decisions are being made. Also, because of diverse social interests that must be considered, political scientists and STS scholars have questioned the technocratic solution of science being the sole provider of information as this goes against democratic principles of diversity of opinions and debate (Collingridge & Reeve, 1986; Albaek, 1995). In fact, solutions based on science may undermine the social identity and local knowledge of involved social groups (Wynne, 1996).

The several criticisms to the rational model of decision-making emphasize the importance of understanding how decisions are made within an influential socio-political context and of considering diverse viewpoints. None of the identified perspectives in the ecological and conservation literature specifies how decision-makers rely on science or are influenced by their context, and thus are committed to naïve views of decision-making (Oliver *et al.*, 2014). However, the perspectives 'One-way' and 'One actor' seem to present a more rational view of the decision-making process by emphasizing that only scientific knowledge should support decision-making, and neglecting the complexity of this process. Within the perspective 'One-way', for instance, one of the most cited lower-level categories concerns scientific knowledge being outweighed by other factors ('Knowledge outweighed' within 'Problems in knowledge use'), while the lower-level category that indicates a recognition of the complexity of decision-making ('Complexity of problems' within 'General problems') was uncommon. By contrast, the perspective 'Two-way' seems to take a more realistic view of decision-making by emphasizing that decision-makers have important knowledge – especially strategic knowledge (*sensu* Hulme, 2014) about what is legislatively, politically and administratively feasible – and by recognizing that decision-making cannot be based solely on science. In this sense, the perspective 'Two-way' may create paths for more democratic decision-making processes valuing other knowledges and social identities.

Secondly, the disciplines studying the role of science in decision-making propose that the science–practice boundary is more diffuse than normally assumed. Current approaches from Political Science explain decision-making complexity by describing different networks influencing policy decisions (reviewed in Neilson, 2001; Nutley *et al.*, 2007; Cairney, 2016). These networks are composed by diverse actors, such as policy-makers from different government levels, academics from diverse backgrounds, businesses representatives, consultants, activists, interest-group leaders and the media. Thus, the relationship between science and practice does not necessarily occur directly between scientists and decision-makers (Nutley *et al.*, 2007). Furthermore, STS studies emphasize that the boundaries between science and policy are constantly negotiated in a political process (Jasanoff, 1987) and that science is embedded within society, as the construction of science involves not only scientists but rather all society (Jasanoff, 2004). By emphasizing few (one or two) distinct types of actors, all perspectives on the science–practice gap encountered in the ecological and conservation literature are similar in disregarding these fuzzy boundaries between science and policy/practice. Only recently has the consideration of science not as a separate entity but as immersed in society entered the science–practice gap debate in Ecology and Conservation (Toomey *et al.*, 2016).

The third contribution from disciplines such as STS studies and Political Science deals with the relevance of science for supporting decision-making. Some studies emphasize that science, when brought to assist decision-making, actually complicates controversies by adding, to innate value conflicts, technical disagreements regarding scientific evidence (Collingridge & Reeve, 1986; Sarewitz, 2004). As scientific knowledge is not an absolute truth, but empirically based assertions subject to criticism, it is indeed liable to different interpretations filtered through each person's worldview (Collingridge & Reeve, 1986). In the public process of decision-making, each side of the debate naturally finds in the accumulated body of scientific knowledge the evidence to support their position and technical arguments to criticize the interpretation of the opposing side (Collingridge & Reeve, 1986; Sarewitz, 2004). In this sense, the uncertainty associated with scientific knowledge takes a new dimension when brought to public debate (Sarewitz, 2004), which has also been called ambiguity (Cairney, 2016). In contrast to uncertainty, ambiguity cannot be reduced by simply conducting more research (Cairney, 2016).

All identified perspectives of ecologists and conservation scientists on the science–practice gap similarly imply that scientific knowledge can be used to assist decision-making, suggesting that the discussion regarding the ambiguity of science when transposed to the public debate has not found its way into the ecological and conservation literature. However, the perspectives 'One-way' and 'Two-way' included a category of perceived causes related to 'Cultural difficulties', which comprises different values and beliefs among scientists and decision-makers. The perspective 'Two-way' also included the category 'Epistemological difficulties', encompassing different conceptions of scientists and decision-makers regarding valid processes of knowledge generation. These cultural and epistemological differences may account for some of the different interpretations assigned to scientific knowledge when used to assist decision-making. More importantly, though, the perspective 'Two-way' assumes a process of joint knowledge production through collaborative and sustained interactions among scientists, decision-makers and other stakeholders, which may be a path to deal with value differences in a more reflexive manner, by allowing the involved actors to be explicit about and negotiate their value positions.

Finally, the last topic refers to three main ways for scientific knowledge to be used in decision-making. Instrumental use occurs when a specific piece of scientific evidence is used directly to assist a specific decision or solve a clearly defined problem (Amara, 2004; Nutley *et al.*, 2007), while symbolic use occurs when scientific knowledge is used to support and confirm an already established position (Amara, 2004). Conceptual use occurs when scientific findings, concepts or theoretical perspectives influence decision-makers' thinking or attitudes towards an issue, bringing new issues to the fore or turning 'what were nonproblems into policy problems' (Weiss, 1979, p. 430). Although instrumental use is the most common view of science utilization (Nutley *et al.*, 2007), symbolic and conceptual uses of science are more relevant than previously thought, being equally or more important than instrumental use (Amara, 2004). In a complex decision-making context, the main role of science may be to assist in developing arguments for already made positions (Collingridge & Reeve, 1986; Albaek, 1995) or to 'enlighten' the process with concepts and perspectives (Weiss, 1979). However, because such indirect uses of science are harder to detect, and because we tend to focus on instrumental use, a perception of non-use of science can prevail (Caplan, 1979; Weiss, 1979; Nutley *et al.*, 2007).

None of the identified perspectives on the science–practice gap explicitly discuss these types of knowledge use, reinforcing the idea of a simplified view of science utilization. However, while some perspectives tend to focus more exclusively on instrumental use, others may potentially allow for alternative uses. The perspective 'One actor' focuses on scientists solving specific problems in practice, thus emphasizing instrumental use. The 'One-way' perspective similarly suggests a focus on instrumental use, as scientific knowledge is considered to be the sole provider of information to solve a specific problem. Within the category 'Problems in knowledge use', for instance, scientific knowledge being selected by decision-makers to support their interests is perceived as a cause of the gap ('Knowledge selected'), indicating that symbolic uses are viewed as a misuse of science, instead of a valid way for science to influence decision-making. By contrast, the perspective 'Two-way' highlights a collaborative process of joint knowledge production/integration and social learning among scientists and decision-makers, allowing for greater exchange of ideas and perceptions, and thus potentially fostering conceptual uses of science, although the concept is not made explicit.

Overall, considering these four insights from the disciplines studying the role of science in decision-making, the three identified perspectives on the science–practice gap in Ecology and Conservation represent similarly superficial views of decision-making, not accounting for the complexity of factors influencing decisions, the fuzzy boundaries between science and practice, the multitude of actors involved, the potential ambiguity of science in decision-making, or different types of knowledge use. However, in some aspects, the perspective 'Two-way' seems to imply a more realistic view of decision-making by focusing on joint knowledge-production processes, which may allow for a more inclusive and democratic decision-making process, an explicit discussion of the ambiguity brought about by science and its underlying value positions, and diverse ways for science to be used.

(4) Implications for advancing the debate and fostering productive science–practice linkages in Ecology and Conservation

The science–practice gap in Ecology and Conservation is perceived as a multifaceted problem with different causes arising from two main perspectives. The emphasis on a one-way flow of knowledge from science to practice dominates the debate, which may result from the prestige of the evidence-based approach, especially within research traditions associated with mainstream conservation biology. There is therefore room for the expansion of a complementary approach for linking science and practice focusing on collaborative interactions and joint knowledge production between scientists and decision-makers. However, this will require increased dialogue among research traditions within the ecological and conservation field that have historically been isolated from each other.

In addition, our work suggests the importance of increased dialogue between Ecology and Conservation Science and disciplines such as Political Science and STS studies. On the one hand, insights from these disciplines suggest that the perspectives of ecologists and conservation scientists on the science–practice interface take naïve views of decision-making processes. Thus, more-effective linkages between science and practice in Ecology and Conservation depend on ecologists and conservation scientists embracing the disciplines that focus on the role of science in decision-making and in society in general. From this standpoint, the process of joint knowledge production *via* collaborative interactions between scientists and decision-makers from the 'Two-way' perspective may help ecologists and conservation scientists effectively to account for more-inclusive and democratic decision-making processes, allowing for explicit discussions of values and scientific interpretations, and for multiple types of science use. Indeed, STS studies have emphasized the idea of co-production of science and society, where scientific knowledge, cultures and political structures mutually influence and construct each other (Jasanoff, 2004). Joint knowledge production between scientists and decision-makers to solve specific problems can then be understood as a more circumscribed and recognizable form of this broader societal process of co-production (Hegger *et al.*, 2012). It may thus represent a path for more-effective science–practice linkages, supporting the incorporation of scientific knowledge in decision-making.

On the other hand, political scientists have been criticized for giving little attention to decision-making concerning environmental and conservation issues (Agrawal & Ostrom, 2006). Moreover, while Political Science tends to focus on national and federal levels of policy-making, environmental and conservation problems considered in the literature frequently relate to more local problems (Agrawal & Ostrom, 2006) such as protected areas' management or restoration of degraded land. At the macro-levels of policy-making, complexity may be greater and the ambiguity brought about by science may further complicate the debate, while at the local and micro-level of frontline practice and management, there may be fewer factors to consider and a hindrance to effective decision-making may lie upon how knowledge is produced and communicated/integrated. By understanding how the different decision levels influence both the factors relevant for decision-making and the role science can play, we can arrive at a more comprehensive view of the science–practice interface. This suggests the importance of synthesis and interdisciplinary work across disciplines such as Ecology, Conservation, Political Science and STS studies.

However, for collaborative, integrative joint knowledge-production processes to be effective in incorporating scientific knowledge into decision-making, as well as for fostering interdisciplinary studies on the science–practice interface, scientists and decision-makers should be trained and prepared to engage in dialogue with people from diverse backgrounds (Pardini *et al.*, 2013). Hence, transforming undergraduate and graduate programs in Ecology and Conservation so that students gain contact with different disciplines, including courses on the socio-political dimension of decision-making (Cannon *et al.*, 1996; Jacobson & Duff, 1998; Toomey *et al.*, 2016), and nurturing a stronger scientific education for those students who intend to work as decision-makers (Lewinsohn *et al.*, 2015) should be a priority.

V. CONCLUSIONS

(1) In the ecological and conservation literature, the science–practice gap is perceived as a multifaceted problem with a multitude of causes. Some of these causes are also recognized among scientists from other disciplines, such as Medicine, while others are specific to the ecological and conservation arena (e.g. mismatched spatial and temporal scales between scientific research and environmental problems).

(2) The variety of perceived causes of the science–practice gap in Ecology and Conservation requires three general types of solutions: solutions eliminating or changing the causal factor (e.g. inadequate research questions), solutions requiring the recognition of, and then ways to deal with, the problem (e.g. scientific uncertainty), and solutions solving misconceptions (e.g. scientific knowledge being abstract).

(3) The variety of perceived causes arises from three perspectives on the relationship between science and practice in Ecology and Conservation. The first assumes that only scientific knowledge should support practice, establishing a unidirectional flow of knowledge from science to practice, while the second assumes a bidirectional flow of knowledge, with both scientists and decision-makers collaboratively contributing with knowledge to support practice. The last perspective disregards decision-makers by assuming that scientists should put their results into practice.

(4) Although the identified perspectives parallel those in other disciplines, such as Medicine and Education, our findings suggest a mismatch between the prevalence of the unidirectional view in the ecological and conservation literature and the historical tendency towards bidirectional views ascribing larger roles to decision-makers in other disciplines.

(5) The prevalence of the unidirectional perspective on the science–practice interface may be associated with the prestige of the evidence-based approach, while the bidirectional perspective seems primarily restricted to particular traditions, such as socio-ecological resilience and sustainability science.

(6) The debate on the science–practice gap in Ecology and Conservation reflects an outdated view of decision-making, by not accounting for limits to human rationality, the complexity of actors, factors and interests influencing decisions, the fuzzy boundaries between science and practice, the potential ambiguity brought about by science and the different types of knowledge use.

(7) However, while the unidirectional perspective implies a more simplistic and rational view of decision-making, the bidirectional perspective, through the process of joint knowledge production, can potentially account for more inclusive and democratic decision-making processes, allowing for explicit discussions of values and scientific interpretations, and for multiple types of science use.

(8) A more-productive relationship between science and practice in Ecology and Conservation may be achieved by increasing dialogue both among different research traditions within the field and with other disciplines, fostering joint knowledge-production processes between scientists and decision-makers as well as interdisciplinary research across Ecology, Conservation, STS studies and Political Science, and transforming undergraduate and graduate courses to train both scientists and decision-makers to engage with people from diverse backgrounds.

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VIII. SUPPORTING INFORMATION

Additional supporting information may be found in the online version of this article.

Appendix S1. Additional information on the bibliographic search. (1) Database scope. (2) Criteria for selecting the articles.

Fig. S1. Organization of terms and connectors of the search string used in the *Web of Science Core Collection*.

Table S1. List of the 122 articles selected for the review of perceived causes of the science–practice gap in Ecology and Conservation.

Appendix S2. Additional information on the *sorting* activities. (1) Groups of scientists for the *sorting* activity. (2) Classifications of perceived causes obtained in the *sorting* activities with advantages and disadvantages discussed in the group meetings (Table S2).

Appendix S3. Additional information on the conceptual framework reliability. (1) Detailed methods. (2) Results (Table S3).

Table S4. Complete version of the conceptual framework of perceived causes of the science–practice gap in Ecology and Conservation, with detailed descriptions of criteria defining each category and the number of sentences found in the literature for each category.

Appendix S4. Relative proportion of articles including each lower-level category of perceived causes of the conceptual framework, in total and divided by publication year (Figs S2–S5).

Appendix S5. Research results after excluding the 21 articles that investigated empirically the opinions of scientists and/or decision-makers (Figs S6–S11, Table S5).

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