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Thematic Section: Biodiversity Revisited

Re-conceptualizing the role(s) of science in biodiversity conservation

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Summary

Science, as both a body of knowledge and a process of acquiring new knowledge, is widely regarded as playing a central role in biodiversity conservation. Science undoubtedly enhances our understanding of the drivers of biodiversity loss and assists in the formulation of practical and policy responses, but it has not yet proved sufficiently influential to reverse global trends of biodiversity decline. This review seeks to critically examine the science of biodiversity conservation and to identify any hidden assumptions that, once interrogated and explored, may assist in improving conservation science, policy and practice. By drawing on existing reviews of the literature, this review describes the major themes of the literature and examines the historical shifts in the framing of conservation. It highlights the dominance of research philosophies that view conservation through a primarily ecological lens, changes in the goal(s) of conservation and a lack of clarity over the role(s) of science in biodiversity conservation. Finally, this review offers a simple framework to more clearly and consistently conceptualize the role(s) of science in biodiversity conservation in the future. Greater critical reflection on how conservation science might better accommodate multiple knowledges, goals and values could assist in 'opening up' new, legitimate pathways for biodiversity conservation.

Introduction

Biodiversity conservation, as a social, political and normative endeavour, has a strong foundation in the sciences. The 'synthetic' discipline of conservation biology was originally conceived to provide 'principles and tools for preserving biological diversity' (Soulé 1985). Since then, what is now more commonly known as 'conservation science' (Kareiva & Marvier 2012) has broadened and diversified to draw on many more fields of research, most notably from the social sciences and humanities (Sandbrook et al. 2013, Moon & Blackman 2014, Bennett et al. 2017). Despite considerable changes in the framing and narratives of conservation (Louder & Wyborn 2020), its key ideas and the relative dominance of particular scientific approaches over time (Mace 2014), the importance of science has remained deeply entrenched within the mainstream conservation community. Indeed, the vast majority of conservationists agree that conservation goals should be based on science (Sandbrook et al. 2019).

Science has provided unequivocal evidence of the impacts of human activities on biodiversity (Godet & Devictor 2018, Mace et al. 2018). An estimated 1 million species of terrestrial, freshwater and marine plants and animals (vertebrate and invertebrate) are threatened with extinction, with an average of *c.* 25% of species at risk of extinction within each of these taxonomic groups. Nature's contributions to people (Díaz et al. 2018) have similarly declined globally over the past 50 years (Díaz et al. 2019, IPBES 2019). Science has also showed that conservation investments and measures implemented to date have not yet translated into a reversal of global biodiversity decline (Hoffmann et al. 2010, Waldron et al. 2017, Bolam et al. 2021), threatening the likelihood of achieving the Aichi Targets under the Convention on Biological Diversity and the United Nations Sustainable Development Goals (Díaz et al. 2019, Secretariat of the Convention on Biological Diversity 2020).

Despite an abundance of scientific evidence that biodiversity loss is a clear, worsening and pervasive global problem, humanity's collective response to this crisis has been insufficient. It is this apparent paradox that the Biodiversity Revisited initiative has sought to interrogate through deep, creative reflection on the constructs of 'biodiversity' itself (Wyborn et al. 2020a, 2020b). The science underpinning biodiversity is one of several themes that Biodiversity Revisited aimed to critically examine, alongside narratives (Louder & Wyborn 2020), systems (Davila et al. 2021), governance and futures (Wyborn et al. 2021a). Scientific knowledge, actors and institutions are but small components of global systems that must be transformed to reverse biodiversity loss (IPBES 2019), yet they are far more within the control of the conservation science community than powerful global economic, social and political factors. It is this spirit of self-reflection, humility and curiosity that has motivated the Biodiversity Revisited process and its collective outputs (Wyborn et al. 2020a, 2020b, 2021b).

Table 1. Existing reviews of the conservation science literature, including their stated aims and how their findings are organized. Reviews were identified through a literature search and by cross-examining reference lists (most reviews cited previous review articles). Reviews were selected for consideration in this scoping review if they: (1) aimed to review the conservation science literature; and (2) conducted a systematic review or examined a representative sample of the literature. Bennett et al. (2017) does not neatly fit these criteria, but it is included here for the sake of completeness since no other review article has specifically focused on the conservation social sciences. Narrative reviews (e.g., Meine et al. 2006) and opinion pieces (e.g., Doak et al. 2014) were not selected for detailed analysis, but are drawn on elsewhere in this review.

Review citation	Stated review aim	Findings organized by
Clark & May (2002)	'To evaluate taxonomic bias in conservation research'	Taxonomic group
Fazey et al. (2005)	'... we provide a snapshot overview of conservation research'	Type of research, topic, threatening process, climatic zone, degree of habitat modification, landscape structure, species status, organizational level, spatial scale, relevance to policy and management
Lawler et al. (2006)	'... to find out whether [conservation science] has tracked conservation priorities over the past 20 years'	Taxonomic group, geographical location, threatening process
Velasco et al. (2015)	'... a systematic review of publications in biodiversity conservation'	Type of research, main topic, geographical location, the biodiversity component that was the object of study and its characteristics, pressures and drivers
Donaldson et al. (2016)	'... we investigated taxonomic and geographic biodiversity conservation research trends worldwide' Number of published papers for 10 615 animal species listed on International Union for Conservation of Nature (IUCN) Red List	Taxonomic group, ecological system, geographical location
Bennett et al. (2017)	'... to clarify the role and solidify the rationale for engaging with the social sciences in conservation'	Summarizes classic, applied and interdisciplinary social science disciplines; identifies scales, units and topics of analysis; categorizes methods; articulates values and contributions of conservation social sciences
Di Marco et al. (2017)	'We evaluated past and present trends in the focus of the conservation literature, and how they relate to conservation needs'	Taxonomic group, level of organization, geographical location, ecological system
Godet & Devictor (2018)	'We review the 12,971 papers published in the leading conservation journals during the last 15 years to assess what conservation actually does'	Biodiversity status, threats, solutions, taxonomic group, geographical location
Mazor et al. (2018)	'... we synthesize >44,000 articles published in the past decade to assess the research focus on global drivers of loss'	Threats/drivers of loss, ecological systems (freshwater, marine, terrestrial)
Williams et al. (2020)	Quoting Soulé (1986, pp. 1–12), this paper asks 'how well conservation science research is contributing to the development of "prescriptions" that can address the "real world problems" facing biodiversity'	Threats (state, mechanism, source, driver) and responses ('prescriptions', propose, design, implement, evaluate)

This review aims to critically examine the science of biodiversity conservation. Specifically, this review seeks to identify any hidden assumptions that, once interrogated and explored, may assist in improving conservation science, policy and practice. It does so by examining historical trends in the conservation science literature with respect to its major themes, frames and dominant philosophies. It also considers how the goal(s) and role(s) of conservation science have been conceptualized over time and how these terms may be more consistently defined in future. As the conservation science community frequently engages in debate over its approaches and efficacy, numerous detailed literature reviews (Table 1) and critical commentaries already exist. Rather than conduct another comprehensive or systematic analysis of the conservation science literature, this review is purposely selective and considers existing reviews and seminal works to explore major themes and identify potential gaps. Such an iterative and reflexive scoping review approach is appropriate in this context given this review's aims to identify knowledge gaps, examine how existing research has been conducted and clarify terminology (Arksey & O'Malley 2005, Munn et al. 2018).

In the first section, the present review describes major themes of the conservation science literature, including its conceptualization as a crisis discipline and historical trends in conservation priorities. Next, existing reviews of the conservation science literature (Table 1) are examined in greater detail by considering their stated aims and findings in the context of the four main historical phases in the framing of conservation (Mace 2014). A quantitative content analysis of key terms identified by Mace (2014) is used to showcase the emergence and relative dominance of these four framings and to explore how conservation science as a whole has been conceptualized over time. This review then interrogates how the goal(s) and role(s) of conservation science have previously been described in the literature and proposes a simple framework that may assist in re-conceptualizing the role(s) of science in biodiversity conservation for the benefit of conservation science, policy and practice. This review concludes with a discussion of emerging trends and suggestions for the future.

Science for a global crisis

Conservation science has been characterized by crisis and urgency since its inception (Soulé 1985, 1991, Meine et al. 2006), given the sheer scale and complexity of the world's conservation challenges and the rate at which biodiversity is being eroded. Biodiversity itself, encompassing the genes, species and ecosystems that make up life on Earth, is an incredibly fertile area for scientific research, irrespective of the conservation crisis. The collective knowledge of biodiversity has exponentially expanded over the past 50 years (Liu et al. 2011), yet it remains woefully incomplete. For example, most of the estimated 8.7 million species in existence worldwide have yet to be described (Mora et al. 2011, Pimm et al. 2014). Which components – and what amount – of biodiversity need to be maintained in order to avoid dangerous feedbacks at the ecosystem and planetary scales, and whether it is possible to detect such thresholds in time is also not fully understood (Mace et al. 2014, Knapp 2019).

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Science has also provided evidence that conservation efforts, such as protected area expansion (Butchart et al. 2015, Visconti et al. 2019), have contributed to slowing some species extinction trends (Hoffmann et al. 2010, Bolam et al. 2021). It is clear that investment in conservation reduces biodiversity loss and existing global conservation funding is wholly inadequate (McCarthy et al. 2012, Waldron et al. 2017). Yet the conservation community is still learning what interventions and governance systems are most effective for maintaining different aspects of biodiversity over a range of socio-political and landscape contexts (Miteva et al. 2012, Sutherland et al. 2015, Godet & Devictor 2018). The questions and answers that science might uncover about biodiversity and its conservation are arguably limitless, but the resources and time available to do so are not. This juxtaposition has underpinned repeated calls within the literature to prioritize conservation research and action on particular geographical locations, threatening processes or components of biodiversity.

What is a conservation priority?

What is, and is not, regarded as a conservation priority is highly contested and has changed considerably over time as conservation itself has evolved (Marris 2007, Game et al. 2013, Mace 2014). Conservation prioritization is arguably one of the most prominent and influential themes in the literature, with the global 'hotspots' analysis by Myers et al. (2000) being the best-known example (Brooks et al. 2006). The growth of conservation decision science (Moilanen et al. 2009, Wilson et al. 2009, Game et al. 2013) occurred partly in response to this proliferation of global priority maps in an effort to support the identification of conservation priorities more objectively, transparently and cost-effectively (Wilson et al. 2006, Marris 2007).

Calls to focus on 'conservation priorities' in the literature can broadly be divided into priorities for research (i.e., provision of information about taxa, geographical areas, threats or management responses that are currently understudied) and priorities for action (i.e., funding, locations, conservation or management of particular biodiversity components or combinations thereof). In many cases, the underlying logic is that research into these understudied components is necessary to inform conservation action. For example, Clark and May (2002) identified taxonomic biases in conservation research and argued that 'Saving all these parts [of biodiversity] necessarily requires research on each of them'. Other reviews highlight mismatches between the availability of research on major drivers of biodiversity loss, taxonomic groups according to conservation status or threatened geographical areas (Lawler et al. 2006, Di Marco et al. 2017, Mazor et al. 2018). Williams et al. (2020) point to a scarcity of research on policy and management responses relative to the drivers of biodiversity decline.

Conservation research priorities are typically identified in the literature for the sake of other researchers (Williams et al. 2020), funders, journals (Di Marco et al. 2017) or conservation science as a whole (Lawler et al. 2006, Godet & Devictor 2018). In contrast, there is often less clarity over for whom conservation action priorities are intended, other than a broad reference to policymakers, managers or non-governmental organizations (NGOs). More recently, some scientists have contested the notion that any particular taxa, location or threatening process can be considered a 'conservation priority', unless they are tied explicitly to an action (Game et al. 2013). Some scholarship, and particularly during the growth phase of global conservation prioritization (Brooks et al. 2006), fails to explicitly consider how a conservation priority should be actioned, such as by assuming protected areas are the primary (Margules & Pressey 2000) or most important conservation tool (Godet & Devictor 2018). As a conservation strategy, protected areas have been a prominent feature of conservation discourse since the 1960s (Mace 2014), and they are still considered to be a 'cornerstone' of global conservation efforts (Gaston et al. 2008, Watson et al. 2014).

Shifts in the framing of conservation

Mace (2014) previously documented four major shifts in the framing and goal(s) of conservation over time, from an early focus on species, habitats and protected areas in the 1960s–1970s, to the most recent emphasis on interdisciplinarity and socioecological systems. These four frames primarily relate to how the relationship between biodiversity and people is viewed – from wholly separate to intimately connected (Mace 2014). Frames are powerful, as they provide a lens through which to define a problem, articulate goals and identify relevant actions (Pregernig 2014). As described by Rein and Schön (1996), framing also 'provides conceptual coherence, a direction for action, a basis for persuasion, and a framework for the collection and analysis of data – order, action, rhetoric, and analysis'. As such, the four frames documented by Mace (2014) are used here as a conceptual framework to examine how conservation science has been conceptualized over time (Fig. 1), using the content of existing reviews of the conservation science (Table 1) literature as a heuristic.

Mace (2014) argued that shifts in the framing of conservation over time have not displaced the focus on 'traditional' topics, and so multiple frames exist in current conservation science and practice. This phenomenon is illustrated (Fig. 1) using a quantitative, directed content analysis of the selected review articles (Supplementary Table S1, available online) (Dixon-Woods et al. 2005, Hsieh & Shannon 2005). The progression of key ideas and underpinnings over time has not been strictly linear, since some earlier reviews considering topics related to the more recent 'People and nature' frame (Fazey et al. 2005), while newer reviews focus primarily on topics that are more indicative of 'Nature for itself' and 'Nature despite people' (Di Marco et al. 2017, Godet & Devictor 2018).

A simple frequency analysis of key terms within these selected literature reviews risks missing crucial context (Morgan 1993, Vaismoradi et al. 2013), and so a more detailed examination is warranted. Yet these results (Fig. 1) are corroborated by considering the scope and aims of the selected literature reviews (Table 1), which have broadened from an initial focus on taxonomic and geographical bias (Clark & May 2002) towards emphasizing the need for more research on specific threatening processes (Lawler et al. 2006, Di Marco et al. 2017) and policy and management responses (Godet & Devictor 2018, Williams et al. 2020). The next section describes three additional emergent themes: the dominance of research philosophies that view conservation through a primarily ecological lens; shifts and a lack of agreement over the goal(s) of conservation; and a lack of clarity over the role(s) of science in biodiversity.

Research philosophies in conservation science

It is clear when considering the selected reviews of conservation science (Fig. 1 & Table 1) that biodiversity is the primary object of study, rather than the social and policy systems with which it

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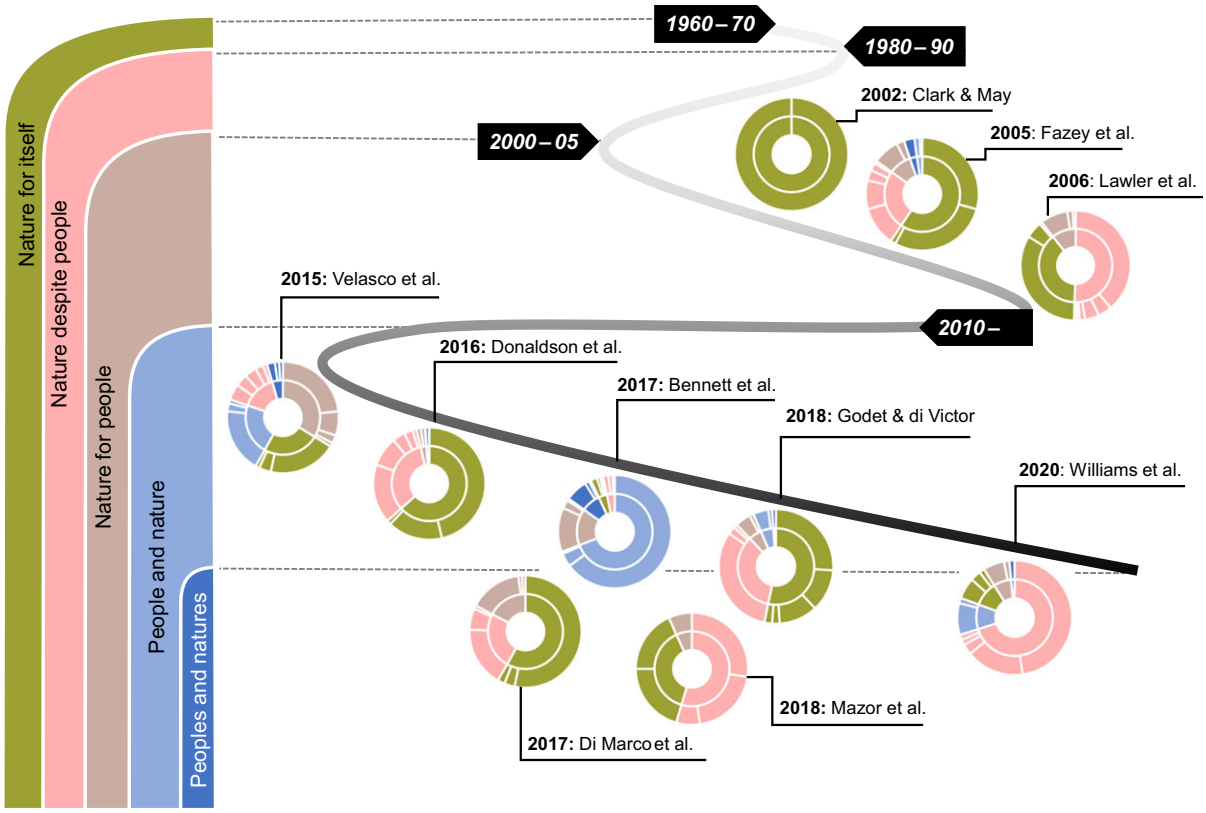

Fig. 1. A timeline illustrating how 10 existing reviews of the conservation science literature (Table 1) align with the key ideas and four major frames of conservation identified by Mace (2014). Starburst diagrams show the frequency of key terms in each review (see Supplementary Materials) according to how Mace (2014) categorized these terms with respect to the four frames. A fifth frame, 'Peoples and natures', aims to capture terms not identified by Mace (2014), but that correspond to more recent emergent themes within the conservation literature, such as co-production and transdisciplinarity.

interacts. It should be noted that the authors of more recent reviews (Velasco et al. 2015, Di Marco et al. 2017) have sought to ensure continuity and comparability of findings, and so they have maintained many of the original categories devised by early reviews (Clark & May 2002, Fazey et al. 2005). Bennett et al. (2017) note that conservation – as a set of social phenomena, processes or human attributes – can be researched according to relevant units of analysis at multiple spatial scales (e.g., global and regional, national and subnational, to local and individual), just as biodiversity can be understood at multiple levels of organization. And yet, to date, it appears that no other existing reviews of conservation science have organized their findings according to this perspective.

Viewing conservation science primarily through an ecological lens is not unexpected given the history of the discipline (Meine et al. 2006) and the well-documented underrepresentation of the social sciences that is still in the process of being corrected (Mascia et al. 2003, Bennett et al. 2017). A primary focus on biodiversity itself within conservation science is also not necessarily problematic, as long as there is explicit consideration of theories of change (Pilbeam 2019) and likely pathways between knowledge and action (Evans et al. 2017, Toomey et al. 2017). But the dominance of an ecological perspective does point to the centrality within conservation science of a particular way of thinking and knowing that is ubiquitous within the natural, physical and some social sciences, but does not necessarily align with how other conservation actors see and understand the world (Roebuck & Phifer 1999, Moon & Blackman 2014, Moon et al. 2019, Latulippe & Klenk 2020). Far from being an esoteric, academic issue, research philosophy has a very real impact on how conservation is framed (Mace 2014, Díaz et al. 2015), the extent to which values and preferences are considered to be within the domain of science (Barry & Oelschlaeger 1996, Noss 2007) and what are considered to be legitimate goal(s) of conservation science (Sandbrook 2015).

Diverse goal(s) of conservation science

The explicitly normative nature of conservation science and the presence of diverse values and ways of seeing and understanding the world (Moon & Blackman 2014, Green et al. 2015, Kohler et al. 2019) mean that there is ample scope within the discipline for a wide range of goals (also referred to as aims, objectives or purpose). Sandbrook (2015) described this vision of conservation as 'a forest rather than a single tree – a parliament not a corporation'. But the conceptualization of diverse goals in conservation science is not universally accepted, as authors often point to how conservation biology was originally defined not by a discipline, but by its goal (Soulé 1985, Ehrenfeld 1992). As such, articles within the mainstream literature will usually refer to the seminal works of Soulé, Ehrenfeld, Noss or Wilcox to describe the goal(s) of conservation (science), but they will often make subtle yet crucial adjustments to reflect their own views and study aims (Table 1) (Doak et al. 2014, Sandbrook 2015).

For example, Lawler et al. (2006) identified research gaps according to threatened taxa and key threats, and they emphasized that '. . . understanding the primary threats to biodiversity is a central goal in conservation biology'. Fazey et al. (2005) considered

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Table 2. Explicit references to the role(s) of science in biodiversity conservation within selected reviews (Table 1) according to a directed content analysis (see Supplementary Materials). Statements are categorized according to whether review authors broadly referred to 'science', or more specifically to knowledges, actors or institutions associated with science. Note that Williams et al. (2020) explicitly referred to the role of science in the title, but not in the paper's main text.

Domain	Quote(s)	Review
Science	'. . . a broader understanding of conservation science has emerged that more directly recognizes the **role** of a diverse set of natural, social, interdisciplinary and applied science traditions'	Bennett et al. (2017)
	'Although conservation research is affected by specific bias, conservation is playing a major **role** in providing empirical evidence of human impacts on biodiversity'	Godet & Devictor (2018)
	'The past and future **role** of conservation science in saving biodiversity'	Williams et al. (2020)
Knowledge	'A hallmark of law is defining the scale at which conservation can occur, and the actors who have a formal **role** in decision-making for environmental management'	Bennett et al. (2017)
	'STS [Science and Technology Studies] can play a vital **role** in connecting conservation science with conservation outcomes'	
	'Our results therefore suggest that [cross-disciplinary] studies clearly have a **role** to play in providing policy advice about conservation issues'	Fazey et al. (2005)
Actors	'[Social marketing] emphasizes the center stage **role** of the target audience, making sure that the values, perceptions and social norms of this group underpin any marketing campaign'	Bennett et al. (2017)
	'. . . conservation marketers can also play an important **role** across the behavioral and conservation sciences'	
	'Beyond the **role** of the researcher, organisations that fund conservation research clearly need to play more of a proactive **role** in closing these gaps by encouraging research on understudied taxa and regions, especially where high levels of human pressure are known to occur'	Di Marco et al. (2017)
	'Leading conservation journals, such as those we analyse here, play a central role in shaping the trends and focus of conservation science'	
Institutions	'. . . the **role** of markets and regulations in managing pollution and public goods'	Bennett et al. (2017)

the policy and management relevance of the literature they examined and described conservation biology as '. . . an applied discipline that aims to inform practitioners about how best to understand and manage species and habitats'. Di Marco et al. (2017) focused on underrepresented taxa, threats and geographical locations, and they acknowledged that while conservation science has undergone shifts in its goals and approaches over time, '. . . the overall purpose of increasing our understanding of what threatens biodiversity, and what actions and policies are needed to preserve it, has remained unchanged'.

In their review of the conservation social sciences, Bennett et al. (2017) explicitly acknowledged the possibility of multiple conservation (science) goals (Sandbrook 2015) by explaining that 'Social science researchers can have a number of objectives, including to understand, describe, theorize, deconstruct, predict, imagine or plan'. They aimed to foster a better understanding of 'the role that the social sciences can play in guiding and improving conservation', which is 'often misunderstood' (Bennett et al. 2017). Yet within the literature there appears to be a lack of clarity and explicit discussion regarding the role(s) of science in conservation and the extent to which these may align with or differ from the goal(s) of science in conservation.

Clarifying the role(s) of science in meeting conservation goal(s)

The *Oxford English Dictionary* defines 'role' as 'the function performed by someone or something in a particular situation or process'. 'Role' is distinct from 'goal', which is 'an aim or outcome which a person, group, or organization works towards or strives to achieve'. With the existence of multiple conservation goals, it logically follows that there may be multiple roles or 'function(s) performed by someone or something' for science in biodiversity conservation. None of the selected reviews (Table 1) explicitly referred to the possibility of multiple roles for science, but collectively they point to a range of roles for science (as a whole), as well as knowledges, actors and institutions (Table 2).

The role of science has certainly been discussed within the conservation literature, but this has largely occurred as part of rather dichotomous debates (Garrard et al. 2016) over whether scientists can legitimately engage with values (Barry & Oelschlaeger 1996, Noss 2007), public policy discussions (Robertson & Hull 2001) or protest and civil disobedience (Castree 2019, Gardner & Wordley 2019, Hagedorn et al. 2019). There has also been considerable discussion regarding the skills that conservation scientists should develop over their careers, such as policy implementation, outreach and communications (Jacobson 1990, Noss 1997, Jacobson & McDuff 1998, Muir & Schwartz 2009), which do not neatly fit within a traditional 'knowledge provision' role of science. But explicit analysis of the role(s) of science in society has typically been the domain for scholars of science and technology studies (Jasanoff 2004, Miller & Wyborn 2018) and knowledge governance (Turnhout et al. 2013, van Kerkhoff & Lebel 2015), and it has only entered the mainstream conservation literature in the past decade (Colloff et al. 2017, Evans et al. 2017).

For the sake of clarity, the framework in Fig. 2 is offered to illustrate the possible role(s) of science in meeting biodiversity conservation goal(s). In a simple conceptualization of the role of science in biodiversity conservation (Fig. 2(a)), 'science' encompasses actors (scientists, researchers, practitioners), institutions (journals, NGOs, research organizations) and knowledge (scientific evidence), which each play a role in meeting a conservation goal. When only a single conservation goal is considered, only one or a small number of roles may be considered legitimate. Once a plurality of conservation goals are recognized (Fig. 2(b)), it becomes more apparent that there may be multiple legitimate roles and pathways for science in biodiversity conservation, depending on the values embedded within conservation goals and the actors, institutions and knowledges (including traditional, Indigenous, local) associated with different fields of research, policy and practice.

Conservation science itself has always been explicitly multidisciplinary (Meine et al. 2006, Kareiva & Marvier 2012), but some

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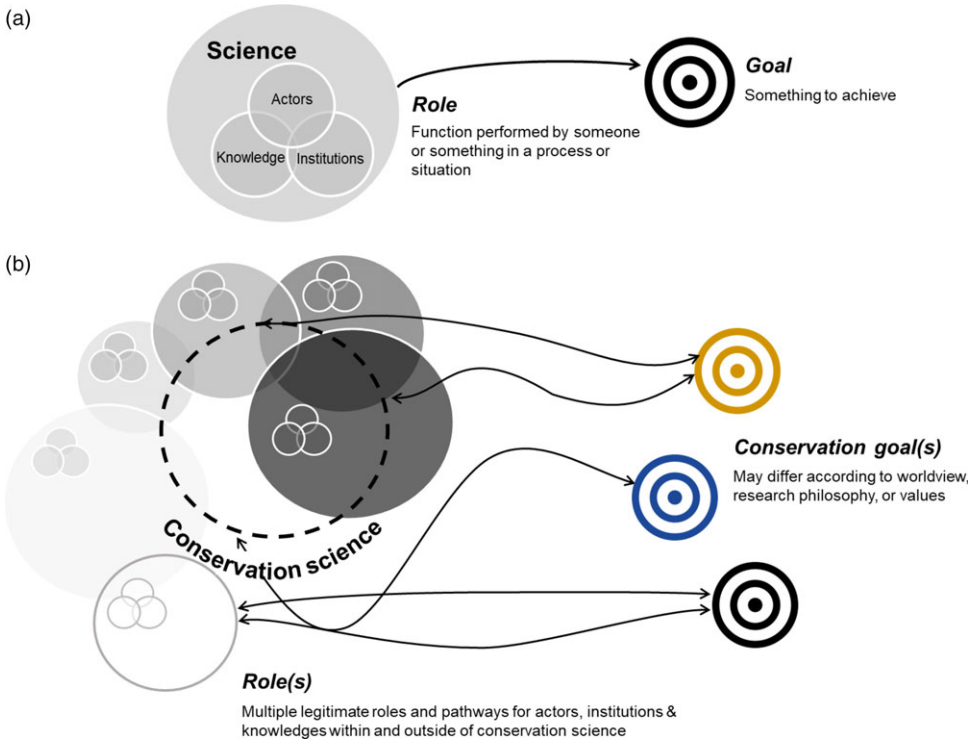

Fig. 2. A simple framework illustrating the relationship between conservation goal(s) and role(s) for science (encompassing actors, knowledges and institutions). (a) When conservation is conceptualized as having only a single goal and science is considered as monolithic, only one or a small number of roles may be considered legitimate for science. (b) With more explicit recognition of the actors, knowledges and institutions associated with diverse fields of research, policy and practice that contribute to multiple conservation goals (which may not necessarily be considered as be part of conservation science), a more nuanced conceptualization of the roles for 'science' in conservation is possible.

fields (Fig. 2(b), shaded grey circles) are more dominant than others (Velasco et al. 2015, Bennett et al. 2017). Indeed, it is telling that Soulé (1985) emphasized the 'dependence of the biological sciences on social science disciplines', yet social science terminology only really began to appear in reviews of the conservation science literature 30 years later (Fig. 1) (Velasco et al. 2015, Bennett et al. 2017). Other fields (Fig. 2(b), white circle with grey outline) may not be widely recognized as being part of conservation science itself, but nonetheless may play a role in meeting conservation goals. For example, it may be that social science and humanities disciplines are more greatly represented in conservation than existing reviews of conservation science would indicate (Fig. 1 & Table 1), simply because the selection of journals considered by previous review authors as being broadly representative of conservation science are often heavily skewed towards ecological journals (Table 3 & Supplementary Materials).

Discussion

Clearly, the 10 reviews of the conservation science literature examined here are not fully representative of the discipline at large, even though most have broadly aimed to evaluate trends and biases in conservation research, policy and practice (Table 1). Analysis of the aims, findings and frames embedded in each review nevertheless provides a useful insight into how conservation science has been conceptualized by at least a portion of the community. The present review points to the dominance of a positivist research philosophy in conservation science (Roebuck & Phifer 1999, Sandbrook et al. 2013, Moon et al. 2019), as well as the existence of multiple, legitimate conservation goals (Sandbrook 2015, Sandbrook et al. 2019). While there is already an expansive body of work that corroborates these first two claims, this review has also highlighted a lack of clarity and explicit discussion over the role(s) of science in biodiversity conservation within the mainstream literature.

What does it mean to re-conceptualize the role(s) of science in biodiversity conservation and how could this assist in improving conservation science, policy and practice? In the first instance, deeper and more explicit recognition of the complex spaces in which science operates (Evans et al. 2017, Toomey et al. 2017) could help to clarify roles and pathways for science in meeting conservation goals. The framework offered in Fig. 2 might assist conservation scientists (including those who conduct future reviews of the literature) in conceptualizing which conservation goal(s) they are envisioning as they go about their work, as well as the goal(s) of their colleagues working within and outside their own particular field of research, policy or practice. For example, considering a range of conservation goals and broadening study aims (Table 1) to encompass social, economic and policy systems in addition to biodiversity itself may assist in creating more space for contributions from diverse social science and humanities traditions (Sandbrook et al. 2013, Bennett et al. 2017).

Acknowledging the diversity of views within conservation science (Sandbrook et al. 2019) does not devalue or discredit the conservation goals articulated by Soulé (1985) and other authors (Sandbrook et al. 2013). Rather, a too-narrow focus on particular goal(s), role(s) and research philosophies may inadvertently 'close down' conversations that could generate novel insights for biodiversity conservation (Stirling 2008, Lövbrand et al. 2015). It is common for scientists to adopt a particular way of thinking and knowing (Moon & Blackman 2014), as well as a view on the role(s) of science and scientists in society. But individual worldviews do not negate the existence of the multiple ways in which scientists can legitimately engage in society (Pielke Jr 2007, Turnhout et al. 2013). As a normative dilemma, a conclusive answer to 'what is the role of science?' is impossible to obtain, and so a broad range of views will continue to exist.

Discussion of the ways in which knowledge shapes action (and vice versa) has been part of scientific discourse to varying degrees

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Table 3. Journals that were selected for analysis by more than one of the existing reviews of the conservation science literature (Table 1). Note that the maximum frequency is 8, as neither Donaldson et al. (2016) nor Bennett et al. (2017) selected literature to review according to journal title. Further information is provided in the Supplementary Materials.

Journal	Frequency of selection
Biological Conservation	8
Conservation Biology	8
Biodiversity & Conservation	6
Animal Conservation	3
Conservation Letters	3
Ecological Applications	3
Global Change Biology	3
Oryx	3
Environmental Conservation	2
Journal of Animal Ecology	2
Diversity & Distributions	2
Ecology Letters	2
Ecosystems	2
Journal of Applied Ecology	2

over the past four decades (Funtowicz & Ravetz 1993, Knapp et al. 2019, Wyborn et al. 2019), although it has only become prominent within conservation science relatively recently (Robertson & Hull 2001, Tengö et al. 2014, Colloff et al. 2017). Co-productive research processes often require significant investment by non-research stakeholders, skilful facilitation and coordination, long-term commitment and recognition that the role(s) and primacy of science itself may necessarily change (Lövbrand et al. 2015, Norström et al. 2020, Rose et al. 2020).

Given the urgency, scale and resource-limited nature of the biodiversity crisis, investment in such adaptive, inclusive and often messy processes may seem infeasible (Sutherland et al. 2017). This is not to suggest that all scientific research can – or should – be actively and deliberately co-produced (Lemos et al. 2018, Knapp et al. 2019, Oliver et al. 2019). However, it must be recognized that science is inevitably co-produced within spaces where multiple knowledges and values exist, with or without the direct involvement of scientists (Evans et al. 2017, Miller & Wyborn 2018). This means that it is beneficial to – at the very least – consider exactly how science may ultimately influence conservation outcomes (Pilbeam 2019), including what other actors, knowledges and institutions may play a role (Reed et al. 2009, Colvin et al. 2016, Evans & Cvitanovic 2018).

Effective co-production explicitly acknowledges the role of power and its effects on engagement processes and outcomes and seeks a more equitable role for science and scientists alongside other actors and knowledge systems (Benham & Daniell 2016, Norström et al. 2020, Rose et al. 2020). Conservation science has been complicit in historical and ongoing discrimination against marginalized peoples, and calls for recognition and correction of inequities and injustice are growing in prominence (Mammides et al. 2016, Salomon et al. 2018, Chaudhury & Colla 2020). Actively creating space for the consideration of diverse voices, values and approaches, even when critical or in conflict, can only serve to strengthen conservation (Green et al. 2015, Gould et al. 2018, Latulippe & Klenk 2020). Crucially, conflicting views must be made explicit and openly deliberated (Sandbrook et al. 2019), since even good-willed attempts to focus only on the common ground amongst diverse voices may suppress innovation and serve to further entrench dominant views 'by denying the very existence of margins' (Matulis & Moyer 2017).

Finally, conservation science can provide crucial insights into how and why social changes occur (Isgren et al. 2019) and where leverage points may exist to facilitate transformations to sustainability (Díaz et al. 2019, Fischer & Riechers 2019, Chan et al. 2020). Numerous opportunities exist for conservation scientists to engage in transformational change (Pereira et al. 2020, Scoones et al. 2020, Wyborn et al. 2020a), including with narratives (Louder & Wyborn 2020), systems (Davila et al. 2021) and futures thinking (Wyborn et al. 2021a). This necessarily requires scientists and science as a whole to '. . . become more reflective about [their] own assumptions and paradigms, including those relating to how change comes about' (O'Brien 2012). It is therefore crucial that conservation scientists continually reflect on how their own values and ethics shape their science, have an appreciation of and respect for other ways of thinking and knowing and understand that there are multiple, legitimate pathways to achieving conservation goals.

Conclusions

Conservation science emerged due to the need for a 'more comprehensive, better-integrated response' (Meine 2004, p. 75, Meine et al. 2006) to understanding and solving complex conservation problems that traditional scientific disciplines had 'failed' to adequately address (Noss 1999). This review has shown that although conservation science has clearly diversified in its ideas, frames, philosophies and goals over the past four decades (Mace 2014), this diversity is not often represented within existing reviews of the literature. An overwhelming focus on biodiversity as the primary object of study (Table 1) and the identification of primarily ecological journals by review authors (Table 3) are indicative of the historical and contemporary biases that still occur within conservation science as a discipline.

In future, broader and deeper recognition that conservation science can accommodate a diversity of goal(s), values and ways of knowing could assist in 'opening up' novel insights and pathways. Within these complex spaces are opportunities to co-produce solutions that are appropriate to specific contexts, as well as ample scope to study whether and how change occurred, to learn and to adapt. In the face of multiple urgent global crises, it may seem indulgent to critically reflect on what logics and assumptions have been embedded within mainstream conservation science to date. But just as conservation occurs within highly contested and complex socio-political environments, so too does conservation science. What better way to learn how science can better facilitate transformational change than to turn the lens onto ourselves?

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