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Biodiversity research still falls short of creating links with ecosystem services and human well-being in a global hotspot

Aliny P.F. Pires[a,b,c,*], Aryanne G. Amaral[b,d], Maíra C.G. Padgurschi[e], Carlos A. Joly[e], Fabio R. Scarano[a,b]

[a] Universidade Federal do Rio de Janeiro, UFRJ, Rio de Janeiro, RJ, Brazil
[b] Fundação Brasileira para o Desenvolvimento Sustentável, FBDS, Rio de Janeiro, RJ, Brazil
[c] Brazilian Research Network on Climate Change – Rede Clima, INPE, São José dos Campos, SP, Brazil
[d] Instituto Internacional de Educação do Brasil, IEB, Brasília, DF, Brazil
[e] Universidade Estadual de Campinas, Unicamp, Campinas, SP, Brazil

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ABSTRACT

Understanding the links between biodiversity, ecosystem services (ES) and human well-being (HWB) is a prerequisite for furthering the agenda of several multilateral environmental agreements and global goals. We performed a systematic review to discuss the extent to which biodiversity research has addressed the interface between ES and HWB and we focused on Brazil as a case study of global relevance. We found that biodiversity research in Brazil remains focused predominantly on biological processes and that research on the links with ES and HWB is in its early phases, exhibiting scarce connections with provisioning and cultural services. This pattern reveals the nature of existing funding policies and scientific gaps in the country. Given the global relevance of Brazil's stock of biodiversity and ES, we argue that research on their links with HWB will be a crucial element of the national and global process of achieving Sustainable Development Goals by 2030.

1. Introduction

At the heart of many socioecological initiatives worldwide is the recognition that solutions to complex challenges require transdisciplinary approaches that integrate research and its application to policy (Brink et al., 2017; Jahn et al., 2012). These initiatives start from the premise that issues such as poverty alleviation, climate change and the biodiversity crisis are intertwined and interrelated (Bourne et al., 2016; Fisher et al., 2014; Scarano, 2017). Indeed, many such issues are currently targeted collectively by agreements such as the Sustainable Development Goals (SDGs; Folke et al., 2016) or addressed by science-policy interface bodies such as the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES; Larigauderie and Watson, 2017) and the Intergovernmental Panel on Climate Change (Pearce et al., 2018).

Science plays a determining role in promoting such transdisciplinarity because it provides a foothold for developing new approaches, arguments and methods (Schröter et al., 2017; Sutherland et al., 2013). There is a call for new frameworks that integrate ecosystems and societies in order to simultaneously promote biodiversity conservation and social change (Colloff et al., 2017; Sandifer et al., 2015). To address the complex challenges related to global socio-ecological crises, 'normal' disciplinary science is no longer sufficient, and conservation science should embrace the transdisciplinarity required by the 'post-normal' problems societies currently face (Colloff et al., 2017), which are characterised by complexity, chaos and contradictions (Funtowicz and Ravetz, 1993; Sardar, 2015). Colloff et al. (2017) argued that conservation science should be co-produced with policy-makers and practitioners in order to promote science-based decision-making. This type of concern is very similar to those that characterise the sustainability science agenda, which simultaneously requires transdisciplinarity (Brink et al., 2017; Lang et al., 2012) and a focus on measurable positive societal impacts (Bettencourt and Kaur, 2011); such a scientific approach is to be developed in "constructive tension between a descriptive-analytical and a transformational mode" (Wiek et al., 2012). Thus, this scientific endeavor should not only produce credible knowledge but also be relevant to decision-making and built according to a legitimate process that includes diverse stakeholders, including non-academics (Sarkki et al., 2014; Scarano and Martinelli, 2010).

One of the most critical transformations needed is related to building links between biodiversity research, ecosystem services and human well-being that both address hot scientific questions and provide

* Corresponding author at: Universidade Federal do Rio de Janeiro, UFRJ, Rio de Janeiro, RJ, Brazil.
E-mail address: alinypfpires@gmail.com (A.P.F. Pires).

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strong support for decision-making related to sustainability (Díaz et al., 2015; Rieb et al., 2017). It is well-known that biodiversity underpins most ecosystem functions and services that are key to people in multiple ways, including food and water security, health, climate change adaptation and cultural benefits (Cardinale et al., 2012; Isbell et al., 2017; Pires et al., 2018). However, this is not always considered into the decision-making process; instead, biodiversity conservation is usually addressed as 'another issue to solve' rather than as part of the solution for existing problems (Brancalion et al., 2016; Isbell et al., 2017; Naeem et al., 2016). Whenever this is the case, there is a major risk that socioeconomic development is promoted by compromising biodiversity, with negative consequences to ecosystem services (ES) and human well-being (HWB) (Naeem et al., 2016). This is of special concern in Latin America and the Caribbean (Balvanera et al., 2012), which contain seven of the 17 most biodiverse countries (Rands et al., 2010) and 10 of the 15 countries in the world with greatest socioeconomic inequality (UNDP, 2017). To accomplish the Sustainable Development Agenda by 2030, it is crucial to ensure that these countries will be able to combine biodiversity conservation with socioeconomic development in the coming years.

In this paper, we investigated the extent to which biodiversity research has addressed the interface between biodiversity, ES and HWB through a systematic review of the available scientific literature in order to answer two questions. First, to what extent has biodiversity research addressed issues related to ES and HWB? Second, does biodiversity research prioritise transdisciplinary approaches or business-as-usual disciplinary approaches? We then examined whether or not the research patterns indicate adherence between biodiversity research and the SDGs (Wood and DeClerck, 2015; Wood et al., 2018). We did so by using biodiversity research in Brazil as a case study. Brazil seemed a relevant choice for this study for several reasons: (i) it is a biodiversity powerhouse that provides ES that are relevant not only nationally but also globally (Scarano et al., 2012); (ii) the country aspires to deliver on ambitious global commitments to various UN conventions and agreements that have biodiversity conservation as a key component; and (iii) Brazil's biodiversity science output is comparable to that of developed nations (Scarano, 2007), although, paradoxically, Brazil remains underrepresented in biodiversity and ES studies (McDonough et al., 2017).

2. Materials and methods

We employed the Web of Science database to search for papers published until May 2018 (with an open initial date) using the terms "*biodiversity*" AND "*ecosystem service**". We did not restrict our search by any other classification, including year or title of publications. It is likely that the links between biodiversity, ES and HWB were explored in other papers and documents, such as company and government assessments and reports, which are not represented in the Web of Science database. However, we decided not to include such sources, because (i) they did not represent conventional scientific knowledge in peer-reviewed documents, and/or (ii) they did not explicitly explore the ES concept.

To contextualize the global relevance of our case study, we compared the Brazilian biodiversity research pattern with other nine countries. We filtered the results by five developed countries ("*term*"): United States of America ("*United States*" OR "*USA*"), The Netherlands ("*Netherland**"), England ("*England**"), Sweden ("*Swed**") and Australia ("*Australia**") and five developing countries ("*term*"): China ("*Chin**"), South Africa ("*South Africa**"), India ("*India**"), Mexico ("*Mexic**") and Brazil ("*Brazil**"). For all countries, we filtered the results by the term "*human well-being*" OR "*human welfare*" to provide an overview of the number of papers that potentially explored the links between biodiversity, ES and HWB.

We focused on Brazil by analyzing in detail all the papers that were retained by the term "*Brazil**", considering their full content. Then, we selected those papers that explicitly verified the effects of some dimension of biodiversity on some ES (e.g. food production, water and air purification, carbon sequestration and recreation). We determined how *biodiversity* was used in the paper by classifying it into one of three categories: native vegetation, functional role and water bodies and coastal areas. Studies that reported the services provided by an inland habitat or area were classified as 'native vegetation' (e.g. studies focused on the effects of changes in the land cover of forested and non-forested biomes). Studies that explored the services related to the functional and biological activity of plants, animals and microorganisms were classified as 'functional role' (e.g. studies focused on the services provided by dispersers and pollinators). Studies that reported services performed by freshwater ecosystems and coastal areas were classified as 'water bodies and coastal areas' (e.g. studies focused on provisioning of water by rivers and reservoirs). We also identified two studies that reported services or cultural roles of indigenous people; we did not include them in the graphs or analysis, as they were not quantitatively representative but we discussed them in the paper.

We classified the *ecosystem services* in the selected papers into the four categories identified by Millennium Ecosystem Assessment: provisioning (water, wood, food, nature products, etc.), supporting (biodiversity, habitat-related services, etc.), regulating (carbon storage and sequestration, resistance, pollination) and cultural (cultural, spiritual and aesthetic aspects of nature). It has been observed that supporting services are related to the maintenance of minimal ecological conditions and that they can be used only indirectly by humans (Costanza et al., 2017; La Notte et al., 2017). Thus, we considered that studies focused on supporting services are restricted to the biodiversity perspective, as predicted by the ecosystem service cascade model (Potschin-Young et al., 2016).

For each paper, we identified the institutions that provided the financial support for these papers and classified them into five categories: Brazilian government, non-Brazilian research institutes, Brazilian NGOs, private sector and not declared. We classified studies according to the spatial scales at which they discussed biodiversity (local, subnational and national) and ES (local, subnational, national and global). For example, if an ecosystem service has the potential to provide global benefits but the paper discussed that service on a local scale, we classified the study as local. We also identified the biome where the biodiversity research took place (Amazon, Atlantic forest, Cerrado, Caatinga, Pampa, Pantanal, Coastal/Marine and All, if the paper had a national perspective). Studies that reported more than one level of the same category were accounted for in all of them. We carried out our analysis with base functions in R v. 3.2.2 and using the *dplyr* package (R Development Core Team, 2015). We performed all graphs using GraphPad Prism software v. 7.0.

3. Results and discussion

3.1. Global research gap in the links between biodiversity, ES and HWB

We demonstrated that biodiversity research that addresses ES and HWB is increasing but it is still small in several countries worldwide (Fig. 1). Particularly in the last decade, there has been an increase in the number of publications linking biodiversity and ES in all countries, especially for the USA, China and Brazil. In 2017, the number of papers that discussed biodiversity in the context of ecosystem services in those countries was two-fold higher than in England, India, Mexico, Netherlands, and Sweden. This result can be related to the importance of these three countries in providing and demanding ecosystem services worldwide (Sun et al., 2017), including important commodities, while they are considered megadiverse countries (Rands et al., 2010; Torres et al., 2017).

However, biodiversity and ecosystem services research still falls short of addressing human well-being. In all countries, less than 7.5% of the studies linking biodiversity and ES cited the term "*human well-being*" (Fig. 1), which suggests that there is a significant research gap to be