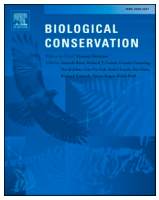
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Review



Uncovering thematic biases in ecosystem services mapping: Knowledge shortfalls and challenges for use in conservation

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ABSTRACT

The process of mapping ecosystem services is experiencing a significant surge in usage, with exponential growth being observed. However, conservation knowledge shortfalls have yet to be characterized, which can lead to essential gaps in decision-making and public policy. We aim to describe thematic changes in mapped ecosystem services and their use in biodiversity conservation. We performed a scientific literature search on this topic and found 1670 documents published from 2005 to 2021. We defined two periods, among which we compared the type of ecosystem services mapped and the thematic conservation categories mentioned in the documents. Despite the continuing dominance of the United States and China in scientific productivity, Europe and the global South are emerging as major contributors to ecosystem services mapping. Very few ecosystem services have been mapped simultaneously in the scientific literature within a single case study. Climate change, ecological restoration, forestry, connectivity, species conservation, risk assessment, and biological invasions are mentioned in less than 8 % of the publications, presenting critical thematic shortfalls in applying ecosystem services mapping in biodiversity conservation. Ecosystem services are not commonly used as surrogates within systematic conservation planning, nor have they been considered in information resources such as Conservation Evidence. The classical approach to knowledge shortfalls in biodiversity does not directly consider the ecosystem services, thus demonstrating the need to define and quantify new categories of shortfalls in the spatial expression of those services. Finally, we discuss the challenges to applying ecosystem services mapping in decision-making, conservation planning, and environmental impact studies.

1. Introduction

The impact of human actions alters the dynamics of ecosystem processes and services and some of those effects can be evidenced spatially (Díaz and Cabido, 2001). Maps are robust tools that represent and project complex scenarios of spatiotemporal changes in single or multiple ecosystem services (Malinga et al., 2015). The ecosystem services mapping is a process that involves phases ranging from spatial data acquisition (field, remotely sensed, simulated, modeled, or projected) to visual and spatial integration of information for the characterization of service supply or demand (Palomo et al., 2018). This complex process should be synthesized when maps of ecosystem services are used to communicate with society or to support government decision-making (Burkhard and Maes, 2017). Ecosystem service maps could support generating policies for sustainability and conservation (Nelson et al., 2009). For example, they could contribute to resolving conflicts between biodiversity conservation and anthropogenic land-use changes (Malinga et al., 2015; Olander et al., 2017). However, entrepreneurs, governments, and local institutions have not been influential when incorporating the spatial dimensions of ecosystem services into decision-making because of the complex relationships between the sectors involved and the diverse perceived values, and interests of different stakeholders (Chaudhary et al., 2015; Palomo et al., 2018; Weyland et al., 2019). Additionally, maps could suffer from poor biophysical and economic characterization for spatiotemporal dynamics of services at local scales (Chan et al., 2006). This results in a spatial mismatch with the practical social systems of the region where decisions are to be made (Chen et al., 2019).

Publications about ecosystem services have dramatically increased in different fields, such as economics, ecology, and management since

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the Millennium Ecosystem Assessment synthesis report was released in 2005 (Chaudhary et al., 2015). From this point, many literature review studies on ecosystem services have been performed (Seppelt et al., 2011; Vigerstol and Aukema, 2011; Martínez-Harms and Balvanera, 2012; Crossman et al., 2013; Logsdon and Chaubey, 2013; Schägner et al., 2013; Villa et al., 2014; Malinga et al., 2015; Wolff et al., 2015; Englund et al., 2017; Ochoa-Cardona and Urbina-Cardona, 2017). However, the exponential growth in the number of published studies on ecosystem services is not matched by a similar growth in studies related to the spatial modeling of these services (Andrew et al., 2015). Thematic biases in the scientific literature on ecosystem services mapping have been recently assessed (Chen et al., 2019), but so far they have not been evaluated from the perspective of knowledge shortfalls. Those shortfalls can lead to poor knowledge and poor use of data for biodiversity conservation in decision-making (Ribeiro et al., 2016; Palomo et al., 2018; Teixido et al., 2020).

Since the mapping of ecosystem services is frequently used as an approach to understanding better the complexity of ecosystem services (Costanza et al., 2017) and can be used as an argument in decision-making scenarios (Hauck et al., 2013), the general aim of this review is to describe the main research biases and knowledge gaps related to the types of ecosystem services maps, as well as its mention in biodiversity conservation studies. Our research seeks to (a) determine spatiotemporal changes in publications on the mapping of ecosystem services; (b) identify ecosystem services that, from their mapping, have enabled integration with other ecosystem services; (c) describe temporal changes in the mapping of different types of ecosystem services; and (d) determine the temporal changes in the use of ecosystem services maps to address specific conservation biology issues and the degree of articulation between these issues. Finally, a reflection on current knowledge shortfalls from ecosystem services and their application to conservation decision-making is made.

2. Method

We conducted a structured literature search (scientific papers, book chapters, and proceedings) on three academic databases (Web of Science, SCOPUS, and Science Direct) using a query string for each database (see online Supporting Information, Table S1). In each database, the search was configured to detect documents published between 2005 and 2021. Using the KNIME Analytics Platform (Berthold et al., 2008), we segmented the data, compiled the metadata for each peer-reviewed article, and deleted duplicates. We then used a filter to review each's documents titles, abstracts, and keywords. We excluded 1337 documents in thematic areas outside the mapping of ecosystem services (e.g., landscape structure and composition, physical processes in hydrographic basins, control of nonpoint source pollution, and ecological niche modeling, among others). The final database of 1670 documents represented studies on mapping ecosystem services published in the peer-reviewed literature that were included in our synthesis (see online Research Data information in Urbina-Cardona et al., 2022).

The number of papers published per year was calculated to define the periods for further analysis. A cumulative curve of publications over time was generated as a performance indicator of productivity for this research area. Under the life cycle theory assumption, exponential productivity growth determines a phase or period change (Ernst, 1997; Chanchetti et al., 2016). Changepoints in scientific production were determined with the changepoint package (Killick and Eckley, 2014) to estimate the point (year) at which the statistical properties of scientific production change, and then segmented the years by periods with different degrees of scientific productivity. The separation of the analyses by time periods allows us to compare changes in the types of ecosystem services mapped during two contrasting moments in the production of scientific literature. This comparison between periods is made under the assumption that points of change in productivity may also indicate changes in the degree of collaboration between researchers from different countries, increasing diversity in conceptual approaches and the type of ecosystem services mapped, and their use in a greater variety of issues in conservation biology.

The number of citations was obtained for each document, and the country was extracted from the institutional affiliation of each author. The metric of forward citations per country was calculated for each period from these variables. The data were visualized in the Mapbox tool (Bogle, 2012). Finally, each document was classified, by the first author, according to the type of ecosystem service it mapped, looking for the types of services in the title, abstract, and keyword sections. To determine the ecosystem service types in the present study, the hierarchical structure of the Common International Classification of Ecosystem Goods and Services-CICES V5.1 (Haines-Young and Potschin-Young, 2018) typology was adapted to three levels: section, division, and group/class (see online Supporting Information, Table S2). Group/class levels were not considered separately because the reviewed articles on mapping of ecosystem services mixed both levels.

We conducted a co-word analysis, identifying the relationships between the most frequent ecosystem services used in the title, abstract, and keywords sections. This analysis was done with the software VosViewer (van Eck and Waltman, 2010) to create and display bibliometric maps of key terms using the modularity-based cluster and mapping techniques, optimizing the process through a reduction in the weighted sum of squares of Euclidean distances between all pairs of terms. Based on the co-occurrence matrices, we built networks between ecosystem services. The importance of an ecosystem service visualized as a node within a network was evaluated from the number of links each service has (node-based centrality; Liu et al., 2005). We described the position of essential nodes in the network through two descriptor variables: (a) The degree of centrality that determine those ecosystem services, as nodes, that have the greatest number of connections in the network; and (b) the betweenness centrality to distinguish those bridging nodes that stand between groups of nodes, integrating different groups of ecosystem services. In that sense, ecosystem services with high values in centrality (degree and betweenness) are crucial in integrating different nodes (Liu et al., 2005), increasing the flow of information on knowledge of the mapping ecosystem services.

For each period and ecosystem service section (Provisioning, Regulating, and Cultural), we visualized a hierarchical Voronoi Treemap for the classification of divisions and groups/classes in which the size of each polygon is proportional to the number of papers in each category (https://carrotsear ch.com/foamtree/).

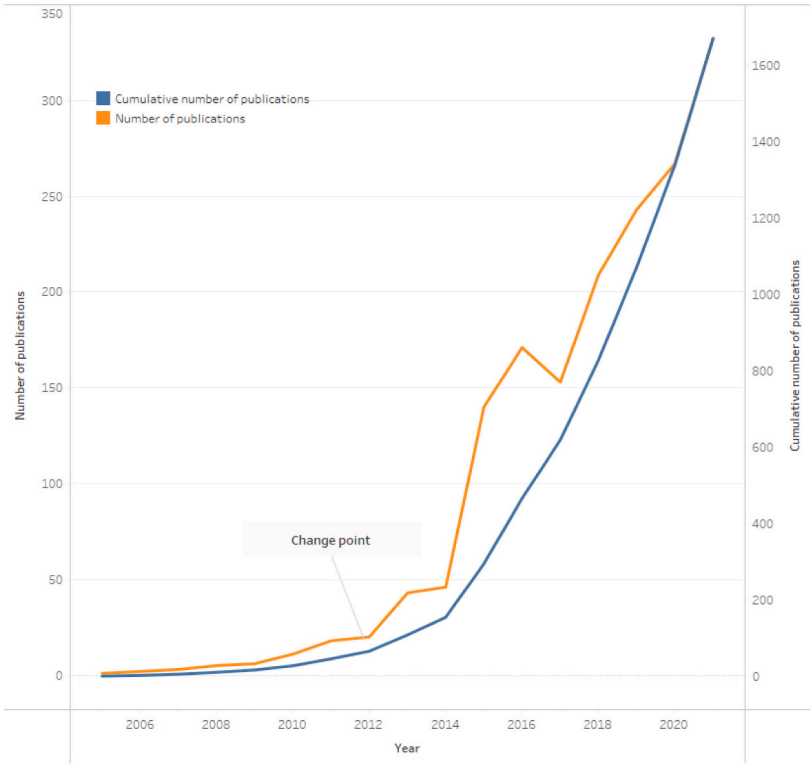
We searched in each document (from the title, abstract, and keyword sections) 108 key terms related to biodiversity conservation following the typology of Urbina-Cardona et al. (2019) that includes 15 categories: Conservation planning and management, Ecological/environmental impact, Land use change, Protected areas, Sustainable development, Government/public policy, Human activities, Climate change, Ecological restoration, Forestry, Connectivity, Species conservation, Risk assessment, Biological invasions, and Biogeography (see online Supporting Information, Table S3).

3. Results

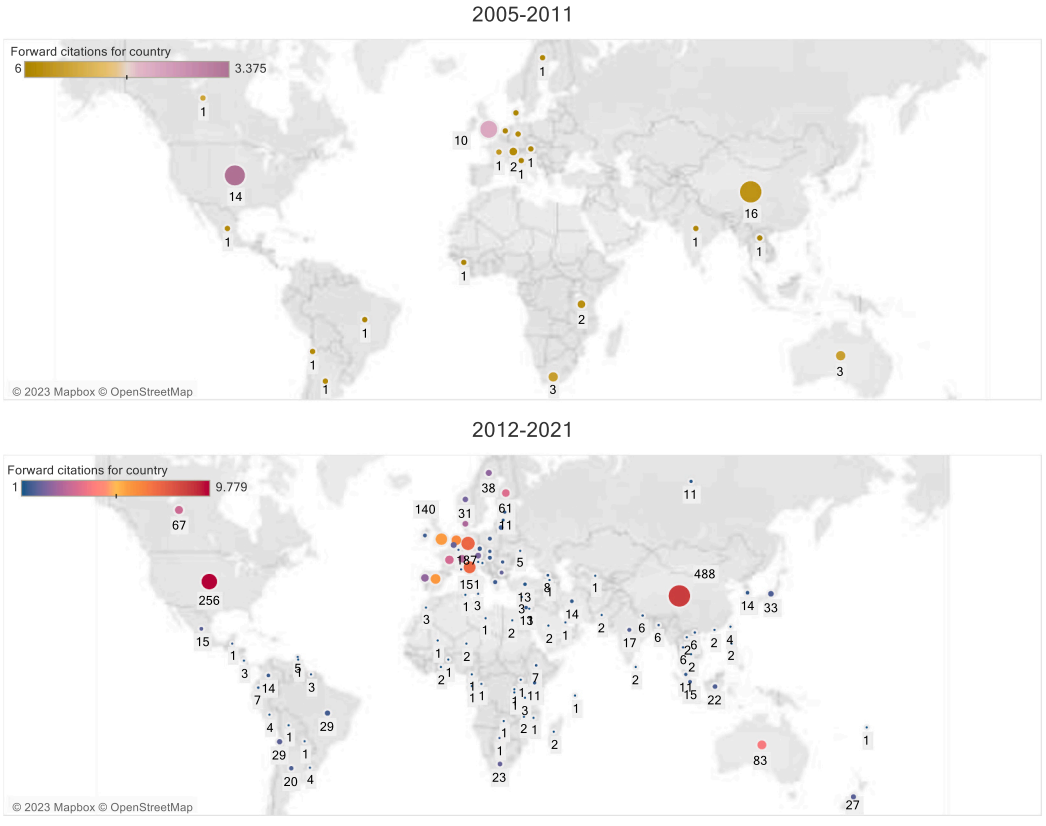
3.1. Spatial and temporal changes

From the 1670 published documents (the database is available at Mendeley Data; Urbina-Cardona et al., 2022), we identified two main periods based on the number of publications. The first or emergent stage was between 2005 and 2011, with low academic production (46 documents published in peer-reviewed literature) (Fig. 1A). During this period, there was a clear dominance of forward citations from three countries on three continents: The United States in America, England in the United Kingdom, and China in Asia (Fig. 1B).

The second or growth stage began in 2012 with an impressive increase in productivity until 2021 (1624 documents) (Fig. 1A). During



(A)



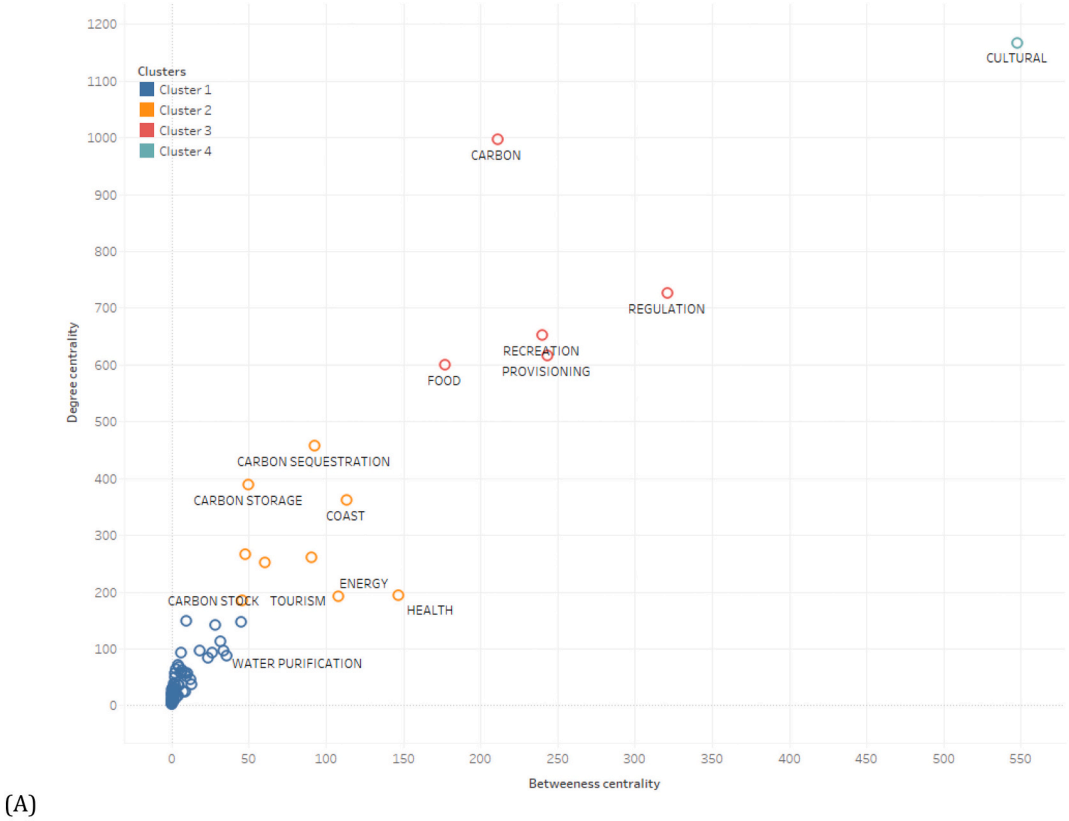
(B)

Fig. 1. Spatiotemporal changes in publications on the mapping of ecosystem services. (A) Exponential productivity growth determines a change point defining two periods: 2005–2011 and 2012–2021. (B) Productivity by country is characterized based on the number of papers (circle size) and forward citations (color gradient of each circle) per period.

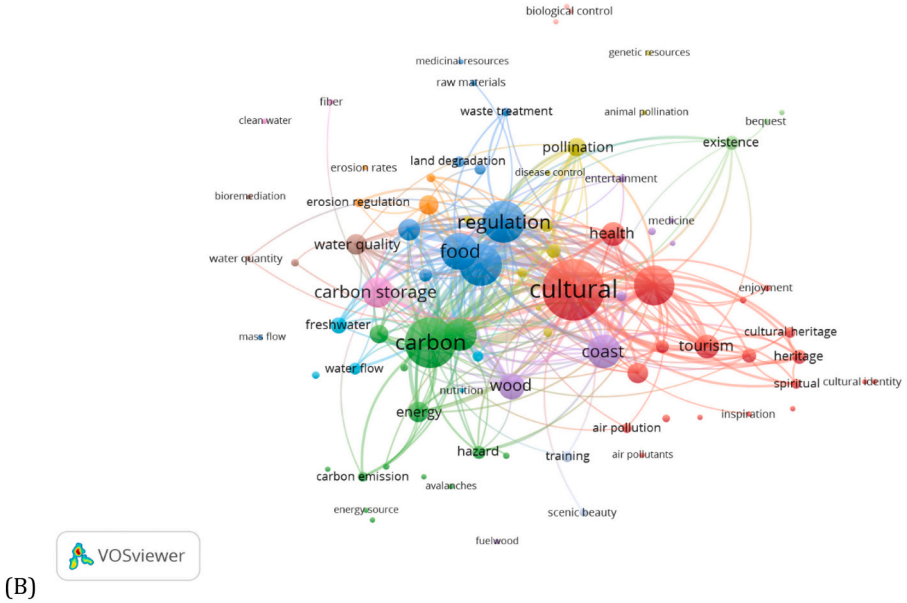
this period, China doubled the forward citations of the United States, and the contribution of other European countries, Australia, and Canada, increased (Fig. 1B), strengthening the global South's contribution to the mapping of ecosystem services.

3.2. Key ecosystem services

Based on the typology adapted from the CICES (Haines-Young and Potschin-Young, 2018), we consolidated a list of ecosystem services comprised of three sections (provisioning, regulating, and cultural), 32 divisions, and 98 groups/classes. It should be noted that no studies on 16



(A)



(B)

Fig. 2. Relationship between mapped ecosystem services within the same publication. (A) The position of each ecosystem service, as a node, is determined by its number of connections in the network (degree centrality) and their degree of importance as bridging nodes that stand between groups of nodes, integrating different groups of ecosystem services (betweenness centrality). (B) Network of ecosystem services that have been mapped in the scientific literature. The size of the circle represents the number of scientific publications in which the ecosystem service has been mapped, and the thickness of the line represents the number of times both services have been mapped in the same publication.

ecosystem services were found for either of the two periods evaluated (In the provisioning section: fisheries resources, water source, water energy, wind energy, and solar energy; In the regulating section: wind protection, fire protection, water pollutant, toxic substances, disease regulation, vector-borne disease, atmospheric pollutants, and removal of particulate matter; In the cultural section: Sense of belonging, traditional medicine, and physical health) and 39 other ecosystem services have been mapped in less than 10 studies (see online Supporting Information, Table S2). Between the whole study period (from 2005 to 2021), most ecosystem services had low betweenness and degree centrality, showing a low degree of integration in a single study case (i.e., very few publications have mapped several ecosystem services simultaneously in the same case study). The six ecosystem services with the highest degree and betweenness centrality were the cultural section (mentioned in 522 publications), carbon division (mentioned in 361 publications), regulation section (mentioned in 242 publications), recreation division (mentioned in 222 publications), provisioning section (mentioned in 243 publications), and food division (mentioned in 184 publications); in that sense, they stand out as crucial services in the integration with other ecosystem service groups within the area of mapping of services (Fig. 2 A-B).

3.3. Types of ecosystem services mapped

During the first period (2005–2011) none of the provisioning section services were mapped frequently (Fig. 3A). For the regulating section services, the carbon division dominated the scientific literature (Fig. 3B). Recreation and tourism divisions were the most frequently modeled cultural section services (Fig. 3C).

For the second period (2012−2021), 54 ecosystem services were mapped for the first time for a total of 82 ecosystem services that were mapped from the scientific literature. During this period, the most frequently mapped services of the provisioning section were those of the food division, followed by wood, energy, and freshwater. There was a low frequency of studies on fiber, genetic resources, medicine, biofuel, fuel wood, nutrition, water for drinking, and biochemical divisions (Fig. 4A). The most frequently mapped services in the regulation section were carbon, climate and weather, water quality, and erosion regulation divisions. There was a low frequency in the study of water regulation, pollination, pest regulation, seed dispersal, and air quality divisions (Fig. 4B). In the cultural section, the most frequently mapped divisions were recreation and tourism, health, and cultural identity. Still, there was a low frequency of the services of spiritual and symbolic values, sense of belonging, mental and physical health, inspiration, bequest value, education, training, and scenic beauty (Fig. 4C).

3.4. Use of ecosystem services mapping in conservation

Due to the increase from 46 to 1624 publications between the two periods evaluated, each thematic area related to biodiversity conservation increased in their mention between 86 and 100 % for the second period. In the most recent period, species conservation has begun to be mentioned in mapping ecosystem services. Over time, the conservation planning and management category has continued to be mentioned in many papers (74.5 % of the documents published from 2005 to 2021). There was a slight percentage increase (but a large increase in the total number of publications) during the second period for the thematic categories of sustainable development and ecological restoration. Finally, it is evident that despite the increase in the number of publications in the second period, there are six thematic categories (Forestry, Connectivity, Species conservation, Risk assessment, Biological invasions, and Biogeography) that still maintain a low mention (less than 5 %) in the publications (Table 1).

We found that most of the thematic areas in biodiversity conservation present values above the median in both centrality metrics (degree and betweenness), indicating a high number of connections and high importance as nodes that integrate other thematic areas within the same case study. Of these thematic areas, those that played a crucial role in their integration with other thematic areas within biodiversity conservation were forestry, connectivity, ecological restoration, and government/public policy (Fig. 5).

4. Discussion

4.1. Science production and drivers

Our results suggest that as productivity increases from a greater number of countries (Fig. 1), the diversity of types (groups/classes and divisions) of ecosystem services mapped in the cultural section, and mainly in the regulating section, also increases (Figs. 3 and 4). The first period in publications on the mapping of ecosystem services (2005 to 2011) coincides with critical milestones (Chaudhary et al., 2015), such as the release of the Millennium Ecosystem Assessment (MEA, 2005). The MEA (2005) managed to position the concept of "ecosystem services" and published the synthesis report at a global level, concluding that 62 % (which corresponds to 15 of the ecosystem services evaluated) are degraded. At the end of this emerging period, there was also the establishment of the conceptual basis for the Intergovernmental Panel on Biodiversity and Ecosystem Services - IPBES (Borie and Hulme, 2015; Díaz et al., 2015) and the report of The Economics of Ecosystems and Biodiversity – TEEB (Sukhdev, 2009). IPBES and TEEB articulate researchers from different countries who lead the mainstreaming of the concept of ecosystem services between governments, academia, NGOs, and society.

During the second period (2012 to 2021), more frequent use of the software of the Integrated valuation of ecosystem services and trade-offs software (InVEST; Tallis and Polasky, 2009) is evident over the Soil Water Assessment Tool (SWAT; Gassman et al., 2007), which dominates the mapping of ecosystem services worldwide (Ochoa-Cardona and Urbina-Cardona, 2017). However, each software has a different approach since the Integrated valuation of ecosystem services and trade-offs - InVEST allows spatial modeling and valuation of services such as carbon storage and sequestration, crop pollination, fisheries, and habitat quality, among others (Vihervaara et al., 2019); while Soil and water assessment tool - SWAT is a modeling tool specialized in the management of water resources in watersheds (Gassman et al., 2007). The increase in software for spatial modeling of ecosystem services (Ochoa-Cardona and Urbina-Cardona, 2017), and initiatives for the valuation of natural capital may promote the development of research on the valuation of ecosystem services with a spatially explicit component (Braat and de Groot, 2012).

4.2. Biases and gaps in knowledge

The present review shows a recent exponential increase in scientific publications that map different types of ecosystem services (see online Supporting Information, Table S2) but with a low diversity of services mapped from a single study (Fig. 2). Many of the studies that develop maps of ecosystem services didn't go far enough to implement them in the field practically (Chen et al., 2019) due to the complexity of analyzing the flow between supply areas and demand areas by different types of social actors who will be beneficiaries of the social-ecological interventions in the planning region (Villarreal-Rosas et al., 2020). Furthermore, with the increase in scientific productivity that produces maps and the diversity users of these models for decision-making, the perceived values, interests, and discourses around ecosystem services have become more complex by including diverse organizations that range from entrepreneurs, governments, academia, and society at both the local and global level (Chaudhary et al., 2015; Weyland et al., 2019).

There is still a significant knowledge gap in the relationship (and spatial congruence) between biodiversity features and ecosystem services for systematic conservation planning (Egoh et al., 2008). Still,

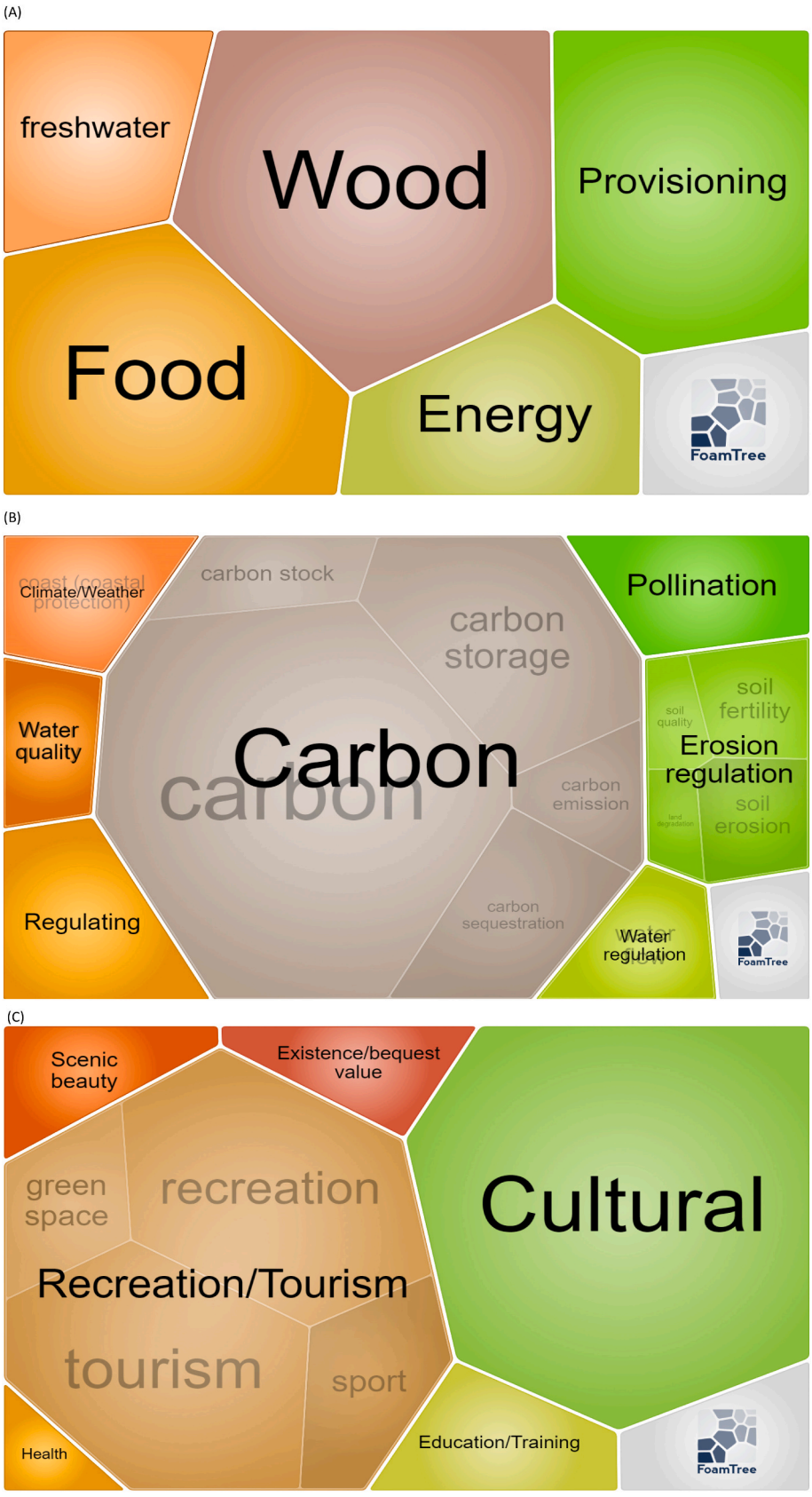


Fig. 3. Voronoi Treemap shows the number of scientific publications on mapping ecosystem services during the first period (years 2005 to 2011) (see online Supporting Information, Table S2). (A) Provisioning section services are composed of 5 divisions. (B) Regulating section services composed of 12 groups/classes within 7 divisions. (C) Cultural section services are composed of 4 groups/classes within 6 divisions. In each panel, the size of the polygon represents the number of papers published in that category. When a panel does not present internal divisions, it is because the document only reports the level of the ecosystem service section (e.g., Provisioning, Regulating, or Cultural).

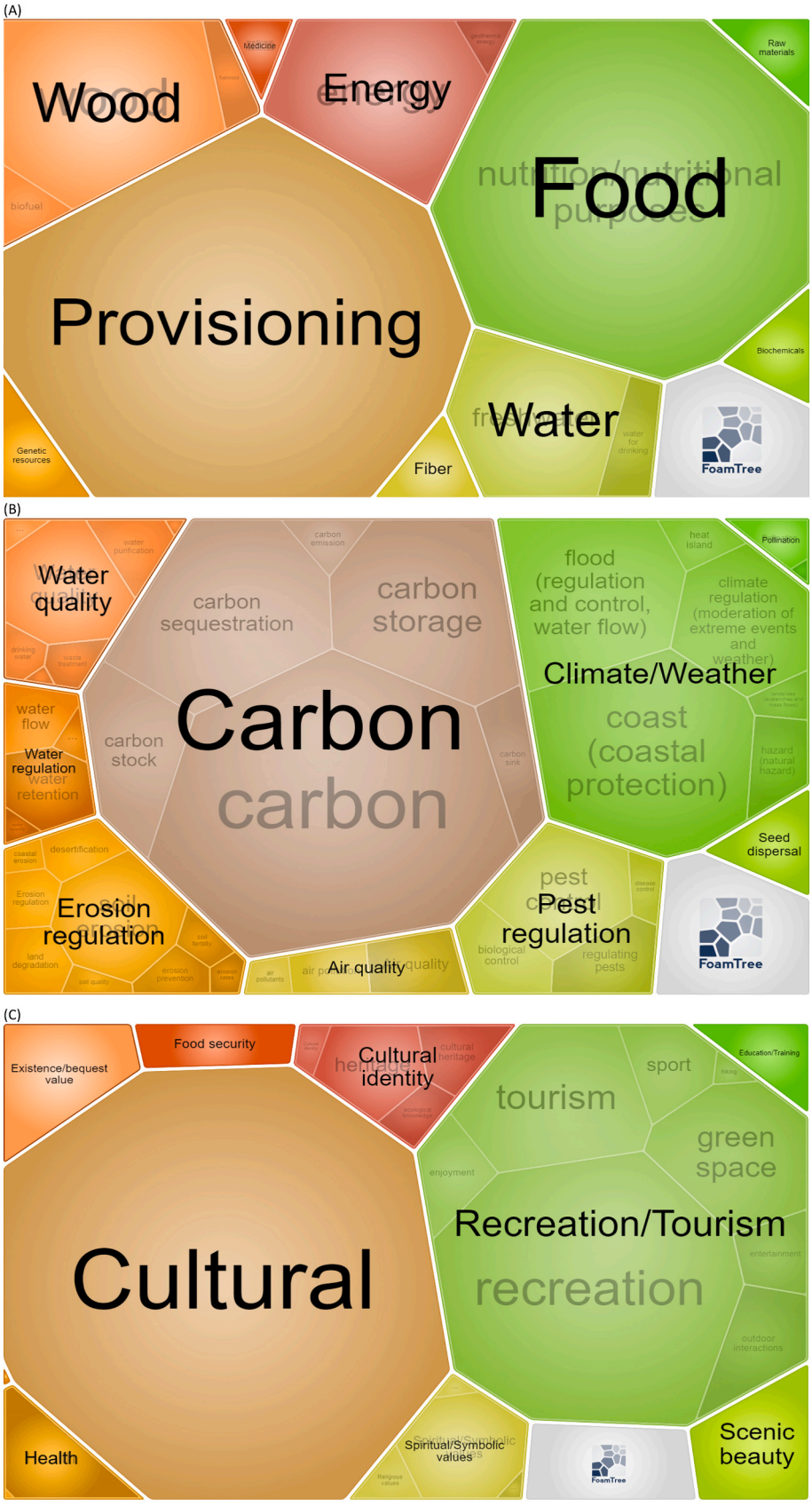


Fig. 4. Voronoi Treemap shows the number of scientific publications on mapping ecosystem services during the second period (years 2012 to 2021) (see online Supporting Information, Table S2). (A) Provisioning section services composed of 9 groups/classes within 10 divisions. (B) Regulating section services composed of 18 groups/classes within 9 divisions. (C) Cultural section services are composed of 19 groups/classes within 10 divisions. In each panel, the size of the polygon represents the number of papers published in that category. When a panel does not present internal divisions, it is because the document only reports the level of the ecosystem service section (e.g., Provisioning, Regulating, or Cultural).

Table 1
Characterization of periods based on the thematic areas of biodiversity conservation. The percentage of each category represents its proportion of the total number of articles published for each period.

Thematic areas	Period 2005–2011 (n = 46)		Period 2012–2021 (n = 1624)		All year range (n = 1670)	
	No. of papers	% of papers in the period	No. of papers	% of the papers in the period	No. of papers	% of all papers
Conservation planning and management	41	65.08	1247	75.35	1288	74.58
Ecological/environmental impact	16	25.4	455	27.49	471	27.27
Land use change	40	63.49	439	26.53	479	27.74
Protected area	13	20.63	427	25.8	440	25.48
Sustainable development	8	12.7	386	23.32	394	22.81
Government/public policy	19	30.16	200	12.08	219	12.68
Human activities	5	7.94	180	10.88	185	10.71
Climate change	6	9.52	147	8.88	153	8.86
Ecological restoration	3	4.76	141	8.52	144	8.34
Forestry	2	3.17	72	4.35	74	4.28
Connectivity	1	1.59	71	4.29	72	4.17
Species conservation	0	0	61	3.69	61	3.53
Risk assessment	1	1.59	37	2.24	38	2.20
Biological invasions	3	4.76	19	1.15	22	1.27
Biogeography	1	1.59	7	0.42	8	0.46

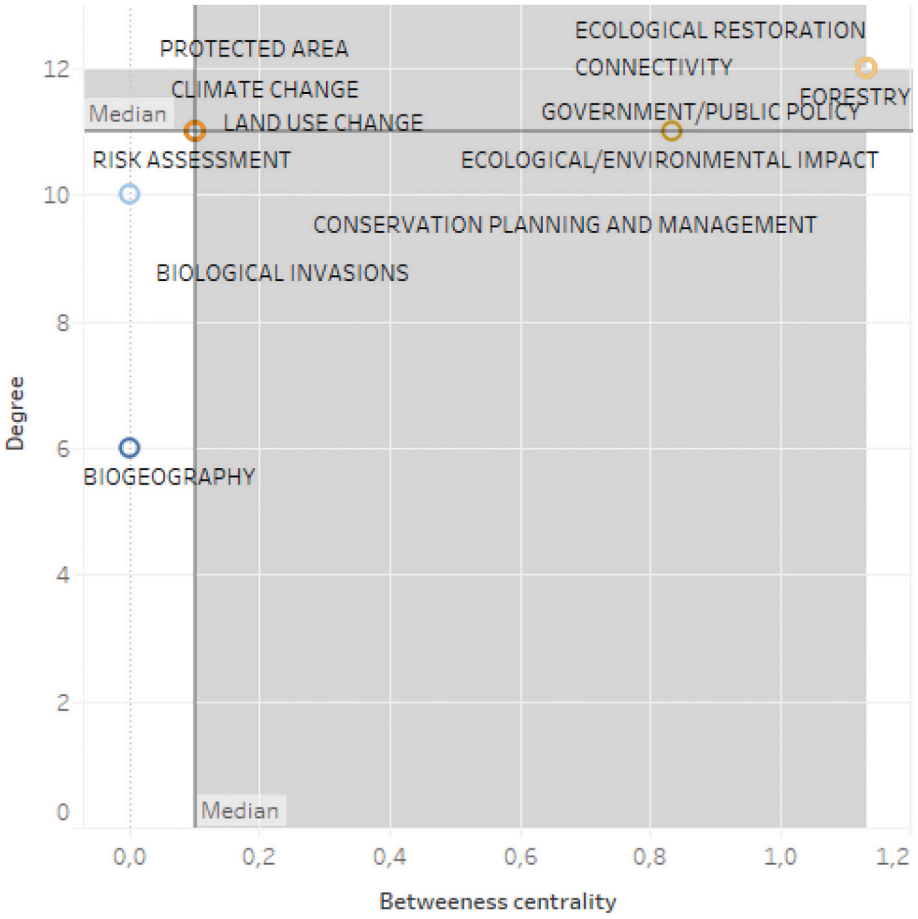


Fig. 5. Relationship between thematic areas of biodiversity conservation considered in mapped ecosystem services within the same publication. The position of each thematic area, as a node, is determined by its number of connections in the network (degree centrality) and their degree of importance as bridging nodes that stand between groups of nodes, integrating different thematic areas (betweenness centrality).

functional diversity is a promising link as a biodiversity surrogate that merits further study (Cimon-Morin et al., 2013). However, in our database, only 3.5 % of the studies relate threatened species to the mapping of ecosystem services (Table 1), and only 7 studies relate those maps to facets of functional diversity (Mitchell et al., 2015; Jarzyna and Jetz, 2016; Maes et al., 2016; Dumont et al., 2019; Smith et al., 2019; Benedetti et al., 2020; Esquivel et al., 2020), which constitutes a significant gap in knowledge for using ecosystem services as surrogates of biodiversity in conservation planning, and explicit support of the Raunkiæran shortfall (Hortal et al., 2015).

In a recent review study, Chen et al. (2019) found that 59 % of the studies that have mapped ecosystem services focused on natural resource management, followed by 30 % of the studies on landscape planning. In our review, 75 % of studies that mapped ecosystem services were found to mention conservation planning and management (Table 1). Still, it is not typical for this thematic area to be mentioned

together with other conservation areas in the same study (Fig. 5). Furthermore, we found that ecosystem services are not considered surrogates of biodiversity for the prioritization of conservation area networks (see online Supporting Information, Table S4). Few studies have also been published that explore the degree to which an ecosystem service is represented as a surrogate for other ecosystem services, biodiversity features, or cultural values (see online Supporting Information, Table S4). In contrast to the use of species and ecosystems as surrogates of biodiversity (Burbano-Girón et al., 2022), one of the great challenges for incorporating ecosystem services in planning is the need to consider the social actors (in a disaggregated manner by socioeconomic factors) that demand or need these services, and that should be beneficiaries when implementing conservation actions (Villarreal-Rosas et al., 2020).

In contrast, public policy presented high values in its centrality in the network of thematic areas, which positions it as a crucial issue integrating other areas within biodiversity conservation (Fig. 2). We also found studies that consider the incorporation of maps of ecosystem services into public policy at different spatial scales (see online Supporting Information, Table S5). Of these, 45 % were conducted at a local level, 15 % at a national level, and 13 % at a continental level (European Union). Finally, we highlight 11 studies that provide broad conceptual frameworks on the incorporation of ecosystem services mapping into public policy (see online Supporting Information, Table S5) that can be a strategic input for a single operational model for implementing policy into decision-making (e.g., Knight et al., 2006; Villarreal-Rosas et al., 2020). These maps of ecosystem services must be integrated with the benefits perceived by different types of stakeholders to characterize the narratives of policy scenarios (Costanza and Kubiszewski, 2012) and to engage them through simulation games that allow them to understand the consequences of decision-making better (Costanza et al., 2014).

Our results show that cultural services are mentioned in the largest number of scientific publications that mapped ecosystem services (Figs. 2A-B) and that these, in turn, are mapped simultaneously with other types of services within the same case study (as previously repported by, Plieninger et al., 2013 and Martínez-Pastur et al., 2016). However, more than 50 % of these publications present a bias towards mapped recreation, tourism, health, and green areas (Paracchini et al., 2014; Figueroa-Alfaro & Tang, 2017), leaving a gap in the knowledge of other cultural services, such as cultural identity, inspiration, enjoyment, and entertainment or the spiritual and symbolic values of the regions (see online Supporting Information, Table S2). Furthermore, the lack of recognition of these cultural ecosystem services within conservation planning and policies reduces their viability for implementation in the regions by ignoring the preferences of the actors who will ultimately be the beneficiaries (Martínez-Pastur et al., 2016; Villarreal-Rosas et al., 2020).

4.3. Challenges for decision-making and conservation

Since the emergence of ecosystem services mapping in scientific literature, there has been a growing expectation that it should integrate complex environmental information into decision-making (Palomo et al., 2013, 2018) and go further by supporting policies that affect natural resource management (Burkhard and Maes, 2017). However, the use of ecosystem service maps for decision-making is limited, as only some countries or regions have spatial information with adequate resolution to characterize the social scale (Chen et al., 2019) and the biophysical and ecological dimensions of services (Chan et al., 2006; Ochoa-Cardona and Urbina-Cardona, 2017). Some challenges must be addressed for ecosystem service mapping to be fully considered for decision-making (Chen et al., 2019). Currently, methodological approaches simplify landscape reality by relying only on available spatial models, showing a strong bias towards modeling a few ecosystem services and ignoring the social-administrative organization of the planning region (Grêt-Regamey et al., 2017; Geneletti et al., 2020).

Before integrating ecosystem service maps into conservation evidence, it should be considered that increases in the long-term provision, flow, and stock of services do not always generate net gains in biodiversity. For example, carbon sequestration, wood sequestration, and stocking in commercial forest plantations or food production in agricultural systems may not always benefit biodiversity. Therefore, evidence on ecosystem service conservation should incorporate how increasing or maintaining an ecosystem service over the long term, makes contributions towards: (a) generating spatial tradeoffs where other abiotic and habitat services are also increased to enhance structural and functional connectivity for native species; (b) increasing the diversity of functional traits affecting ecosystem processes by assemblages of native species; (c) increasing the dispersal of native species which, from their functional role, increases the ecological connectivity of biotic ecosystem processes in multifunctional landscapes (e.g. Palomo et al., 2014; Garibaldi et al., 2021); and (d) improving well-being, quality of life, and good living in human communities under a sustainable livelihoods approach.

4.4. Biodiversity knowledge shortfalls and ecosystem services

Among the limited ways biodiversity is currently measured, and the narrow range of information available to generate knowledge about nature, seven categories of knowledge gaps have been proposed (Hortal et al., 2015), within which ecosystem services have yet to be mentioned. Of the current gaps in biodiversity knowledge, the mapping of ecosystem services can only be evaluated under four of the following shortfalls (Hortal et al., 2015): biases in geographic distribution (from a Wallacean shortfalls perspective) and lack of knowledge about the relationship between species traits and their functional role in ecosystem processes (Raunkiæran shortfall), as well as the biotic interaction networks (Eltonian shortfall) or the abiotic niche where they occur (Hutchinsonian shortfall).

Although there are many more species than ecosystem services on the planet, mapping ecosystem services requires large amounts of biotic and abiotic information to be measured at appropriate spatial and ecological scales (Crossman et al., 2013; Ochoa-Cardona and Urbina-Cardona, 2017). These maps allow an initial overview of the ecosystem service supply's state and identify the flows of these services with human requirements (demand) and the benefits obtained (Verhagen et al., 2015). However, the gap in the knowledge of the distribution of ecosystem services can only be reduced to the extent that adequate standards in spatial modeling are applied (Palomo et al., 2018). Still, it is also critical to know the geographic biases in the mapping of ecosystem services. It is then necessary to consolidate a platform in which the ecosystem services maps published in the scientific literature can be visualized and downloaded to perform meta-analysie and to describe the biases in spatial distribution (e.g., for the Wallacean shortfall perspective on species distributions; Hortal et al., 2008). The Ecosystem Services Partnership (ESP) Visualization Tool (Drakou et al., 2015) is the ideal community of practice for the compilation of ecosystem services maps (and their metadata), given that the ESP is a recognized global network whose objective is to articulate science with practice and public policy for conservation. Specifically, the expertise of the ESP thematic working groups on mapping and modeling (https://www.es-partnership.org/community/workings-groups/thematic-working-groups/) addresses guiding questions about standards and guidelines for the appropriate modeling of ecosystem services, the use of maps by different stakeholders and their application in decision making (Drakou et al., 2015).

Regarding the Raunkiæran shortfall, it has been proposed that those functional traits that appear most quantified in the scientific literature are more straightforward and easier to measure, reducing our understanding of ecosystem processes (Hortal et al., 2015). Additionally, the Eltonian shortfall on biotic interactions is the appropriate conceptual framework, linking regulating ecosystem services such as pollination

and seed dispersal, many of which are the basis of provisioning ecosystem services (e.g., food and raw materials) and habitat for other species. Both Raunkiæran and Eltonian shortfalls currently ignore the need for evidence of spatial biases of functional traits and biotic interactions, and their relationship with ecosystem services.

Finally, it is necessary to identify gaps in knowledge about the identity, distribution, and use or application of maps in ecosystem services to approach the effect that global change may have on biodiversity more holistically. Palomo et al. (2018) have proposed a series of bottlenecks for mapping ecosystem services. The following can be considered knowledge shortfalls for ecosystem service mapping: nomenclatures and ontologies, availability of maps and data, and oversimplification of complexity. From the clarification of ontologies (Drakou et al., 2019), it is possible to inquire about the knowledge gaps in the ecosystem service classification systems under a spatial perspective to delimit the type of service characterized in a given map. The ESP thematic groups, and the GEOBON ecosystem services group (https://geobon.org/ebvs/ecosystem-services/), can take the lead in advancing the conceptualization and spatiotemporal quantification of gaps and biases in ecosystem service mapping under the perspective of knowledge shortfalls.

The knowledge shortfalls identified in this study represent a major challenge in consolidating the evidence for biodiversity conservation from ecosystem services. One expression of this problem is that ecosystem services are not even mentioned in the most recent version of the book "What Works in Conservation" (Sutherland et al., 2021), and the information resource of Conservation Evidence only considers species and ecosystems (https://www.conservationevidence.com/). The tool proposed by Mupepele et al. (2016) for assessing evidence in ecosystem services and conservation studies is a great starting point, but it must also incorporate the spatial dimension of ecosystem services, as mapping is not currently considered. IPBES (2022) acknowledges that ecosystem services mapping has a greater relevance (the capacity to draw out diverse values in multiple social-ecological contexts) than biodiversity mapping for nature-based valuation and is recommended as a tool for prioritizing public policy interventions in scenarios of environmental degradation. As knowledge gaps in ecosystem services mapping are identified and quantified, it will be possible to progress towards their recognition as reliable evidence for biodiversity conservation.

5. Conclusions

Our review has revealed that several thematic conservation areas and types of ecosystem services have received insufficient attention in the context of the mapping process. The thematic biases on ecosystem services maps highlighted in this study reveal significant gaps with several challenges, including (a) understanding the spatial expression of ecosystem services in the landscape, and their relationship to functional traits, biotic interactions, and ecosystem processes; (b) consideration of ecosystem services in decision-making at local and regional scales (e.g., human impacts on natural capital), (c) recognition of ecosystem services in government policies guiding land use planning; and (d) recognition of the effects of global change on human well-being.

We have identified the need to define and quantify new categories of knowledge shortfalls in the spatial expression of ecosystem services. Furthermore, these new categories from ecosystem services mapping must be integrated with at least four of the seven knowledge shortfalls in biodiversity (Wallacean, Raunkiæran, Eltonian, and Hutchinsonian). Inadequate knowledge of ecosystem services mapping can result in critical shortfalls leading to gaps in decision-making, land use planning and public policy. To the extent that knowledge shortfalls associated with ecosystem services mapping can be characterized and future studies quantify biases and gaps in a spatiotemporal manner, it will be more feasible to include ecosystem services as surrogates for conservation planning, environmental impact studies and as long-term monitoring targets in protected areas.

CRediT authorship contribution statement

Nicolas Urbina-Cardona: Conceptualization, Methodology, Software, Formal analysis, Writing – original draft. **Vivian Ochoa Cardona:** Data curation, Methodology, Writing – review & editing. **Sergio Cuellar:** Conceptualization, Methodology, Software, Formal analysis, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

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