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Overview of studies on ecosystem services in riparian zones: a systematic review

Panorama dos estudos sobre serviços ecossistêmicos em zonas ripárias: uma revisão sistemática

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Abstract: Aim: Riparian zones are highly complex ecosystems, located on the banks of water bodies, with a fundamental role in maintaining biodiversity and ecosystem services (ES). This study aimed to systematize the knowledge about studies on ES in riparian zones, emphasizing methodological aspects and pointing out gaps and opportunities to reinforce their importance. **Methods:** The study was carried out based on literature review data over a period of 21 years (2000-2020), using Scopus and Web of Science databases. In the first stage, aspects of bibliometrics were analyzed, as well as the countries that published the most on the subject. In the second stage, the methodological aspects were analyzed (with emphasis on the integrated analysis of multiple ES, which looked at the landscape, adopted multiscale or carried out economic valuation). **Results:** From 2000 to 2020, 6,969 publications were obtained from Scopus and 16,498 from Web of Science, applying the search terms riparian buffer or similar and 371 publications were obtained from Scopus and 1,512 from Web of Science applying ecosystem service and riparian zones or similar terms, with the USA being the country that most published about ES in riparian zones. From a total of 219 publications selected, the ES category most studied in riparian zones was Regulation (65%), followed by Support (16%), Provision (8%) and Cultural (2%). Publications that studied three or more ES corresponded to 9% of the analyzed publications. Approximately 10% of publications used methodological approaches with multiple ESs in an integrated way. Less than 10% of publications focused on economic valuation. Gaps and opportunities were identified concerning the relevance and methods for evaluating and valuing ESs in riparian zones. **Conclusions:** Few studies used methodological approaches integrating different ES. That calls attention to the need to carry out more studies that analyze ES in riparian zones using an integrated and multiscale approach because that is how the components of the ecosystem interact and provide joint responses that may assist in decision making.

Keywords: integration; landscape; economic valuation; gaps; opportunities.

Resumo: Objetivo: As zonas ripárias são ecossistemas de alta complexidade, localizados às margens de corpos hídricos, com papel fundamental na manutenção da biodiversidade e dos serviços ecossistêmicos (SE). Este estudo teve como objetivo sistematizar o conhecimento sobre os SE em zonas ripárias, visando identificar os aspectos metodológicos e apontar lacunas e oportunidades para reforçar a sua importância. **Métodos:** O estudo foi realizado com base em dados da revisão da literatura durante um período de 21 anos (2000-2020), usando as bases Scopus e Web of Science. Na primeira etapa foram analisados aspectos da bibliometria, bem como os países que mais publicaram no tema. Na segunda etapa foram analisados os aspectos metodológicos (com ênfase na análise integrada de multiplos SE, que olharam para a paisagem, adotaram multiescalas ou realizaram valoração econômica). **Resultados:** De 2000 a 2020, 6.969 publicações foram obtidas da base Scopus e 16.498 da Web of Science, aplicando os termos de busca zonas ripárias ou similares e 371 publicações foram obtidas da base Scopus e 1.512 da Web of Science aplicando os termos serviços ecossistêmicos e zonas riparias ou termos similares, sendo os EUA o país que mais publicou sobre ES em zonas ripárias no período analisado. De um total de 219 publicações, a categoria de SE mais estudada em zonas ripárias foi a de Regulação (65%), seguida de Suporte (16%), Provisão (8%) e Cultural (2%). As publicações que estudaram três ou mais SE corresponderam à 9% das publicações analisadas. Aproximadamente 10% das publicações utilizaram abordagens metodológicas com múltiplos SE de forma integrada. Menos de 10% das publicações focaram em valoração econômica. Lacunas e oportunidades foram identificados em relação à relevância e métodos para avaliação e valoração dos SE em zonas ripárias. **Conclusões:** Notou-se que poucos estudos utilizaram abordagens metodológicas integrando diferentes SE, utlizando mutiescalas e fazendo a valoração econômica dos SE, o que chama a atenção para a necessidade de realizar mais estudos que analisem a oferta de ES por zonas ripárias de forma integrada, pois é de forma complexa e em diferentes escalas que os componentes do ecossistema interagem e fornecem respostas conjuntas capazes de auxiliar na tomada de decisões.

Palavras-chave: integração; paisagem; valoração econômica; lacunas; oportunidades.

1. Introduction

The riparian zone is the interface between the aquatic and terrestrial ecosystems, where the natural vegetation is usually present along the rivers, streams, lakes, and dams (Gregory et al., 1991; Kobiyama, 2003; Riis et al., 2020). The ecosystem comprises the interaction system of living things together with their non-living habitat, producing circulation, transformation, and accumulation of energy and matter (Tansley, 1935). As ecotones, riparian zones encompass sharp gradients of environmental factors, ecological processes, and plant communities. Riparian zones are not easily delineated but are comprised of mosaics of landforms, communities, and environments within the larger landscape (Gregory et al., 1991).

Riparian zones and their components interact generating important functions that include, in general, bank stabilization, provision of living and dead organic matter, habitat for both aquatic and terrestrial biota, the capture of sediment, retention and processing of nutrients, and moderation of the extreme temperatures by providing shade. These functions are the result of natural processes, which comprise the complex interactions between biotic and abiotic environments (De Groot et al., 2002). The ecosystem functions can be translated into ecosystem service (ES) as they trigger a series of benefits to human wellbeing (Costanza et al., 1997, 2017; Power, 2010). A single ES can be the product of two or more ecosystem functions, or a single ecosystem function can generate more than one ES. The ecosystem services (ES) provided by riparian zones are closely related to water and some authors call them hydrologic ecosystem services (e.g. Brauman et al., 2007). Hydrologic ES are the benefits received by human from water ecosystems (Brauman et al., 2007) and Tabacchi et al. (2000) presented some impacts of riparian vegetation on hydrological processes. Although riparian zones have a multifunctional and fundamental role in the provision of ES they are strongly impacted due to anthropogenic pressures, especially during the urbanization process, in which the riverbanks were prioritized for occupation and had their riparian vegetation eliminated or reduced (Tiegs et al., 2019; Cao & Natuhara, 2020). Sweeney et al. (2004) and Sweeney & Newbold (2014) discussed the relationship between riparian deforestation, loss of stream and ecosystem services provision. Lind et al. (2019) pointed out guidelines to protect ecosystem functions and biodiversity in riparian zones present in agricultural landscapes, and Riis et al. (2020) identified, described, and ranked ES.

Riparian zones and riparian vegetation have been studied from many perspectives that cover multiple scientific and applied disciplines such as hydrology, biology, geography, remote sensing, management, and restoration (Riis et al., 2020). Hence, knowledge on this subject is distributed among a wide range of fields (Dufour et al., 2019).

Quantitative assessment of ecosystem services, functions, and flows is essential to maintain the ecological functions that riparian areas provide (Fu et al., 2016). However, it is observed that ES assessments in RZ are dispersed and there are gaps related to integrated methodological approaches, focusing on landscape, multiscale, and economic valuation aspects, since riparian zones are ecosystems with high interaction and complexity. Perspectives based on isolated components are ecologically incomplete (Gregory et al., 1991) and often have very limited performance in spatial terms, not considering the landscape scale and not using economic valuation methods. Perspectives based on isolated components are unable to assess the trade-offs between the provision of different ES. In this context, we sought to identify in the international literature which the ecosystem services and methodologies have been applied for their evaluation and economic valuation, highlighting gaps and opportunities aiming to analyze multiple ecosystem services in an integrated manner in riparian zones.

2. Material and Methods

Several terms can mean the area or vegetation that occupies the margins of water bodies. The terms most found in the publications on ES in these areas were: riparian zones followed by riparian vegetation/forest, riparian buffer, and riparian areas. Therefore, these were the terms used in the systematic literature search and the term "riparian zones" was adopted and used throughout the text in this study. Some concepts treat the riparian zones from the point of view of the physical space occupied by the vegetation or the area located adjacent to the water body (Torres et al., 1992; Bren, 1993; NRCS, 1997; Souza, 1999; Rodrigues, 2000; Selles, 2001; McKergow et al., 2003; Webb & Erskine, 2003) while others explicitly consider the interaction between terrestrial and aquatic ecosystems (Salvador, 1987; Gregory & Ashkenas, 1990; Gregory et al., 1991; Kobiyama, 2003; Vitalli et al., 2009; Attanasio et al., 2012; Aguiar Junior & Parron, 2015; Riis et al., 2020). Different definitions both based on geomorphology and biological interactions were equally considered, without applying judgment on which term would be more appropriate.

The present study was conducted based on a literature review, to answer two key questions:

- How has the evaluation of ecosystem services in riparian zones occurred in the last two decades (methodological aspects - main ES and indicators)?
- Do the applied methodologies for ES evaluation in riparian zones integrate different ecosystem services, scales and carry out their economic valuation?

Figure 1 presents the main steps of the study.

2.1. Step 1: Bibliographic survey

A literature review was carried out applying a quantitative systematic method (Denyer & Tranfield, 2009). Two databases of international publications (Scopus and Web of Science) were

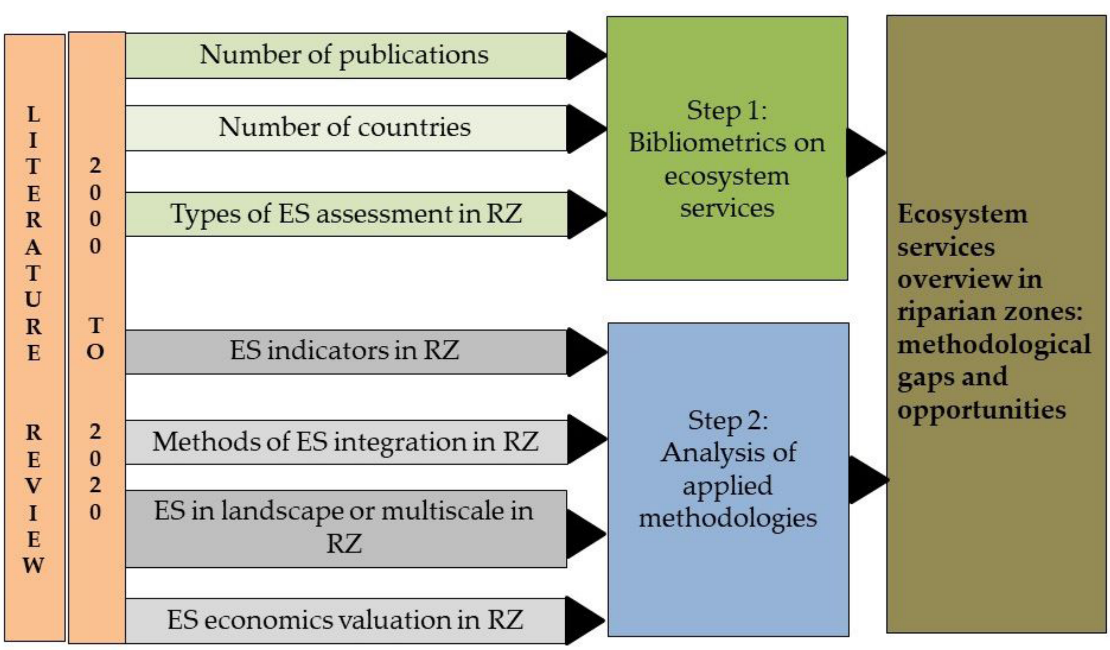

Figure 1. Main steps of this study.

used, from 2000 to 2020, considering papers published in journals and conference proceedings. The search terms were applied in three steps as shown in Table 1 and the searches were performed using the fields: title, abstract and keywords of the manuscripts. The purpose of the first search was to get an idea of the trend of publications on the theme of "riparian zones" and similar terms (called of all terms), to compare with the results of the second search that included the term ecosystem service. In relation to the countries, the affiliation of the authors was considered, in order to know which countries are studying and investing more in the central theme of the article. It was not the scope of this article to analyze the study area of each article. The third search aimed to identify the publications that studied the selected ecosystem services, adopting the criteria presented below and in Table 1, in riparian zones or similar terms (called of all terms). In this step, publications found both in the Scopus and Web of Science databases were counted only once. In addition, in this step publications that studied three or more ecosystem services were grouped into another category (called several ES).

As the types of ES are many, as well as their classification, we chose to organize the ES according to the classification of Costanza et al. (1997) and Soman et al. (2007). While Costanza et al. (1997) considered "water supply" as a regulating ES, in the present study we chose to consider it in the provision ES category, as used by Grizzetti et al. (2016), which is a synonym for "water provisioning for drinking". We also added carbon stock/sequestration/ carbon storage and nutrient retention ES, due to its importance in riparian zones, although it was not contemplated by Costanza et al. (1997), Soman et al. (2007), and Grizzetti et al. (2016). Searches were performed on titles, abstracts, and keywords of publications in both databases Scopus and Web of Science. Due to the proximity and function shading in the studies surveyed, some ecosystem services were grouped, such as: carbon storage, carbon sequestration, gas regulation (greenhouse gases), and climate regulation; erosion control and sediment retention; nutrient cycling and soil formation; nutrient retention and sewage treatment; nursery and refugia; food production and row material and recreation and aesthetic. Table 2 shows the ES organized by category used in the present study. The main ecosystem functions and flows addressed in these publications were also identified at this step.

2.2. Step 2: Analysis of the methodological aspects applied to analyze ES in riparian zones

In this step, only the methodological aspects of publications that focused on ES in riparian zones (and similar terms) were analyzed (resulting from the third search). The analysis carried out from the publications that studied ecosystem services, according to the cut made in the present study, were analyzed regarding the most used indicators, integration methods of different ecosystem services, if they approached landscape and multiscale and if economic valuation methodologies were applied.

Table 1. Terms and methodology of the search in the literature used.

Search 1		Search 2				Search 3			
	Terms		1st terms		2nd term		1st terms		2nd term
OR	"riparian buffer"	OR	"riparian buffer"	AND	"ecosystem service"	Search performed separately for each ES	"biological control"	AND	"ecosystem service"
	"riparian vegetation"		"riparian vegetation"				"pollination"		
	"riparian zone"		"riparian zone"				"erosion control" OR "sediment retention"		
	"riparian area"		"riparian area"				"nutrient retention" OR "sewage treatment"		
	"riparian forest"		"riparian forest"				"carbon stock" OR "sequestration" OR "gas regulation" OR "climate regulation"		
							"water supply"		
							"water regulation"		
							"nutrient cycling" OR "soil formation"		
							"food production" OR "raw material"		
							"nursery" OR "refugia"		
							"recreation" OR "aesthetic"		

This analysis was not quantitative but sought to bring out an overview of what has been applied. The publications obtained were read in full to obtain the information necessary to carry out the analysis that was intended. The discussion of results was based on gaps and opportunities for research and decision-making support linked to the topic addressed.

3. Results

3.1. Bibliometrics

3.1.1. Riparian zones and ecosystem services in riparian zones terms (2000-2020)

From 2000 to 2020, 6,969 publications were obtained from Scopus and 16,498 from Web of Science, applying the search terms: riparian buffer or riparian vegetation or riparian zone or riparian areas or riparian forest (all terms) (Figure 2a). 371 publications were obtained from Scopus and 1,512 from Web of Science applying ecosystem service and riparian zones and similar terms (Figure 2b). It is observed that the growth in the number of publications in the different databases follows the same trend of publications that address riparian zones and similar terms, without using the ES approach. The United States was the country that has published most about all terms related to riparian zones (45%), followed by Brazil (10%), Canada (8%), China (7%), Australia (7%) and others (23%). The USA also has published more when the focus was on ES in riparian zones (55%), followed by Canada (8%), Brazil (6%), German (5%), United Kingdom (5%), Australia (5%) and others (16%). The United States has invested heavily in studies on riparian zones in recent years to mitigate and remedy their degradation, because between 1780 and 1980, 53% of these areas were destroyed in the 48 states of the United States (Dahl, 1990; Mitsch & Gosselink, 2000). The high investments in science and research turned the United States into one of the countries that most publishes scientific articles in the world according to SCImago (2020).

3.1.2. Ecosystem services most studied in riparian zones

A total of 219 publications were obtained by applying the terms of the third search. The ES category most studied in the riparian zones was

Table 2. Ecosystem services provided by riparian zones by categories.

Ecosystem services categories	Ecosystem services
Provisioning	Water supply, food production, raw materials, and genetic resources
Regulating	Biological control, erosion control, sediment retention, nutrient retention, disturbance regulation, climate regulation, gas regulation, water regulation, pollination, waste treatment, carbon stock or sequestration
Support	Nutrient cycling, soil formation, nursery and refugia
Cultural	Aesthetic and recreation

Source: Modified from Costanza et al. (1997), Soman et al. (2007) and Grizzetti et al. (2016).

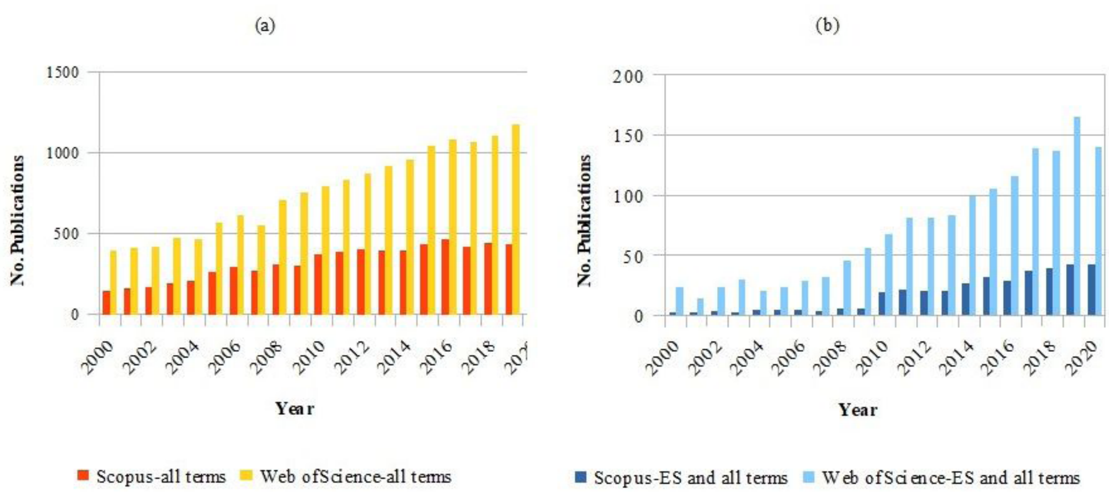

Figure 2. (a) Number of publications annually from 2000 to 2020 applying all terms. (b) Number of publications annually from 2000 to 2020 applying all terms and ecosystem services (Scopus and Web of Science databases).

Regulating (65%), followed by Support (16%), Provisioning (8%) and Cultural (2%). Publications that studied three or more ecosystem services were grouped into another category (called several ES), equivalent to 9% of the analyzed publications (Figure 3).

In the Regulating category, the ES studied were carbon stock or sequestration, gas regulation (greenhouse gases) and climate regulation (26%), biological control (17%), pollination (14%), erosion control and sediment retention (14%), water regulation (13%), nutrient retention and sewage treatment (11%), and disturbance regulation (5%). In the Provisioning category, the ES studied were water supply (76%) and food production and raw material (24%). Genetic resources ES was not found in the analyzed publications and if we included the term "agriculture" in the search, the number of publications related to food production and raw material would greatly increase, but this was not the focus of the study. The Support category included the ES of nutrient cycling and soil formation (56%) and nursery, refugia (44%). In the Cultural category, the ES studied were Recreation and aesthetic (Figure 3).

3.2. Ecosystem services in riparian zones: analysis of the methodological aspects

3.2.1. Ecosystem services indicators in riparian zones

Approximately 25% of the publications resulting from the third search that studied ES in RZ (219 publications) and stood out for using the Millenium Ecosystem Assessment (MEA, 2005) as a reference. Table 3 shows the ES and example of indicators used in the analyzed publications.

3.2.2. Methodologies of integrated analysis of ecosystem services in riparian zones

Approximately 9% of the publications, resulting from the third search that studied ES in RZ (219 publications), studied three or more ES, and it was in these cases that methodologies of integrated analysis of ecosystem services were applied. The list with the main methods of integrated analysis of ES used (models and indexes), the objective of the analysis, and some references related can be found in Table 4.

3.2.3. Ecosystem services zone at landscape or spatial multiscale in riparian

Approximately 15% of the publications resulting from the third search that studied ES in RZ (219 publications), used landscape scales or spatial multiscale. The most of them aimed to evaluate the impact of human activities on the natural landscape in riparian areas and understand how these activities can jeopardize the provision of ES.

3.2.4. Economic valuation of ecosystem services in riparian zones

Less than 10% of the publications resulting from the third search that studied ES in RZ (219 publications), focused on the economic

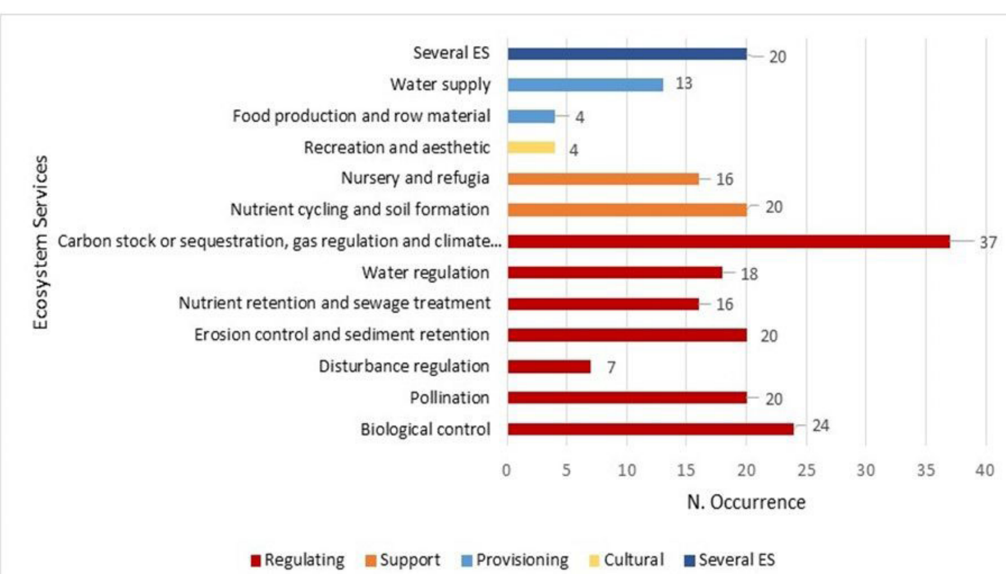

Figure 3. Number of occurrences found for ecosystem service (ES) in riparian zones, according to the classification by Costanza et al. (1997), Soman et al. (2007) and Grizzetti et al. (2016).

Table 3. Main indicators used to assess ecosystem services in riparian zones.

ES category	Ecosystem services	Example of indicators
Provisioning	Water supply	Infiltration of water in the soil, slope, and water entering the system
	Raw material	Raw material collected, wood biomass
	Food production	Arable areas on fertile soils, the production method, the method of purchase or acquisition by the consumer, the environmental impact of the production method, the price
	Genetic resources	No studies were found for this ES based on the search terms.
Regulating	Nutrient retention	Denitrification rate, P retention level, soil type
	Biological control	Diversity of predator, non-native invasive species presence, potential for allelopathic effects, germination and seedling growth
	Carbon stock or sequestration, gas regulation and climate regulation	C content, stock and sequestration in soil and trees (above ground living biomass, diameter at breast height, height of trees, soil organic matter), N_2O production, hillslope broadleaf afforestation
	Disturbance regulation	Total storage capacity in the system and % of water body occupation in the floodplain, abundance and richness of animals and plants species, water quality indicators, and percentage of land use and cover
	Pollination	The area with potential pollinator nests, the distance between nests and fertile areas and number of visits of native pollinators to fertile areas
	Erosion control and sediment retention	Sediment and nutrient removal, sediment deposition, erosion rates, land use and land cover, soil parameters (temperature, moisture, increased bulk density, sand content, and pH), nutrient turnover from decomposition, net N mineralization rates, microbial C and N
	Water regulation	Physical indicators of water bodies (extent, width, water level), nutrient mass flow in water, flow watersheds, runoff volume, % land use and land cover, water quality indicators
Support	Nutrient cycling	Total organic carbon, total phosphorus, total nitrogen, denitrification potential, nitrogen in the microbial mass and nitrogen mineralization potential
	Soil formation	Soil parameters (% of sand/silt/clay, moisture, temperature, microbial activity, density and porosity)
	Nursery and refugia	Trees planted/area, tree cover, remnants of natural vegetation, diversity of bryophyte and, bird, mammals and fish population feature
Cultural	Recreation and aesthetic	Accessible areas with potential for visitation and noise pollution level

valuation of ES. The main methods applied were Benefit Transfer Method (BTM) and the contingent assessment method (CAM), also known as contingent valuation (MVC).

4. Discussion

4.1. Bibliometrics

The number of publications using at least one of the terms of riparian zones (riparian buffer or riparian vegetation or riparian zone or riparian areas or riparian forest) increased exponentially during the 21 years period and approximately 10% of them applied the ES evaluation (Figure 2a and b). We partially attribute this increase in studies regarding ES in riparian zones due to the influence of the Millenium Ecosystem Assessment (MEA, 2005). The ecosystem services evaluation makes it possible to assess the capacity of different ecosystems, that are part of the landscape, to provide ecosystem services and, above all, the trade-offs influenced by land use and management. That is, this approach can assimilate the high complexity of natural and anthropogenic landscapes, offering the opportunity to understand how changes in environments affect the supply of ES. Thus, it can help us understand the ecological and social functions performed by natural ecosystems, strengthening the importance of conservation and rational use of the RZ.

In this study, we found that the countries that most published on RZ were: the United States, Brazil, Canada, China, Australia, and Germany. Rood et al. (2020) found a similar result: United States, Canada, China, Australia, Brazil, and England. Even though some countries, like Japan, have substantially published about riparian zones during our study period, they do not remain in the ranking in terms of the application of the ES approach. On the other hand, countries that traditionally have not published much on the theme of riparian zones, like South Africa, are standing out (in the number of publications) in applying the ES evaluation. We also highlight that the top 10 countries that have published the most about

Table 4. Main methods used for ecosystem service (ES) integration in riparian zones, the objective of analysis, and the associated references.

Methods	Objectives	Examples of references
Bayesian belief network (BBN)	Assessing SE provided by riparian zones	McVittie et al. (2015)
FyrisSKZ, working for water (WFW)	Assessing water quality	Turpie et al. (2008), Collentine et al. (2015)
Integrated valuation of ES and tradeoffs (InVEST)	Assessing the consequences of reducing riparian zones and ES pollination	Meehan et al. (2013), Garrastazú et al. (2015)
Soil and water assessment tool (SWAT)	Assessing sediment and water dynamics	Amatya et al. (2011), Palazón et al. (2014), Vigiak et al. (2016)
STELLA	Assessing interactions between water bodies and land use	Randhir & Ekness (2013)
CAESAR LISFLOOD (C-L)	Simulating the effect of in-channel obstructions on the distribution of erosion and deposition sediments	Walsh et al. (2020)
Riparian ecosystem management model (REMM)	Simulating ecological processes in riparian zones	Altier et al. (2002), Kim et al. (2007)
Copernicus land monitoring service (CLMS)	Assessing and monitoring green infrastructure in riparian zones	Piedelobo et al. (2019)
Land utilization capability indicator (LUCI)	Integrating land management decision support model applied to map areas providing ecosystem goods and services	Sharps et al. (2017)
Biotic integrity, Jaccard and Shanon-Weaver diversity indexes	Assessing the diversity and distribution of species and individuals in the riparian zones related to ES	Huh & Choi (2019), Burdon et al. (2020)
Riparian quality index (RQI), Stream visual assessment protocol (SVAP)	Assessing the quality of riparian zones	Bjorkland et al. (2001), Del Tánago & Jalón (2006), Warren II et al. (2015)
Normalized difference vegetation index (NDVI)	Assessing and mapping green infrastructure in riparian zones by remote sensing	Yang (2007), Fu et al. (2016)
Normalized difference water index (NDWI)	Assessing and mapping changes in water content in riparian zones by remote sensing	Pereira et al. (2018), Vanderhoof & Burt (2018)
Relative aggregated value of ecosystem services indexes (RAVES)	Prioritizing sites for ecological restoration based on ecosystem services	Comín et al. (2018)
Generalized additive models (GAM)	Describing the spatial pattern of pollination benefits using predictors	Lautenbach et al. (2011)
Relative pollination potential index (RPP)	Evaluating the benefits of pollination for crop yield	Zulian et al. (2013)
A new comprehensive ecosystem service index (CES)	Analyzing spatiotemporal changes and trade-offs to support the supply of multiple ecosystem services	Sun et al. (2018)
Water retention index	Planning land use to manage water resources	Vandecasteele et al. (2018)
Ecological limits of hydrologic alteration (ELOHA)	Developing environmental flow prescriptions for many streams and rivers in a user-defined geographic region or jurisdiction	Mackay et al. (2014)

riparian zones using the ES approach are spread through all the continents of the globe, which demonstrates the importance of the topic addressed at the global level.

4.2. Ecosystem services studies in riparian zones

Most of these studies were related to the Regulating category and aimed to analyze the ES regarding the structure and functions of natural vegetation in riparian zones, ecological restoration processes, habitat maintenance, and aimed at improving water quality and climate regulation (Figure 2). There were some publications that performed a specific meta-analysis on this topic (e.g. Dybala et al, 2019). Currently, among the ES surveyed, the services that are being studied the most are nutrient cycling, carbon sequestration, water supply, water regulation, and sediment retention (Angradi et al., 2016; De Sosa et al., 2018; Cole et al., 2020; Riis et al., 2020). Water purification and water stock were the most studied ecosystem functions (e.g. Yang et al., 2009; Lautenbach et al., 2011; Gutiérrez & Alonso, 2013), followed by the contribution to biodiversity (e.g. Gollan et al., 2013; Gray et al., 2014) and soil retention (e.g. Vigiak et al., 2016). The studies about nutrient flow have emphasized the erosion control and sediment retention ES, provided by riparian zones through sediment trapping and enhancement of the cohesion in root systems, providing channel stability and resistance to erosion (e.g. Vigiak et al., 2016).

4.3. Indicators of ecosystem services in riparian zones

The indicators used in the surveyed publications relate to different categories of ES, with emphasis on regulating (Table 3). The indicators that evaluated the cycling of nutrients were the most used based on the measurement of different values and attributes of the soil as well as the indicators used to assess the quantity and quality of water in riparian zones. These indicators are conventionally being used, regardless of the ES approach, over time.

Some indicators can measure more than one ES, mainly those related to water such as: disturbance regulation, water regulation, erosion control and sediment retention. But we chose to keep them separately in Table 3, as they are associated to the studies found from the search terms, which were related to each ES. While the studies that used the ES water regulation measured physical indicators related to the water flow, the disturbance regulation ES correlated these indicators with indicators of another nature such as those related to biodiversity or land use, aiming to identify disturbances in the riparian zone. Additionally, indicators related to pollination and cultural services appear in more recent publications, consistent with the ES approach, from MEA (2005).

It was observed either none or few studies (e.g. Sha et al., 2011; Kachenchart et al., 2012; Kaushal et al., 2014) focused on the dynamics and flows of SE. Ecosystem flows can be understood as the movement of substances, compounds, or nutrients in an ecosystem passing from one compartment to another (Jenkins, 2005). Identifying indicators to measure the dynamics of ecosystem services is a great challenge, but also an opportunity for futures researches on the theme.

4.4. Methodologies of integrated analysis of ecosystem service in riparian zones

The methodologies of integrated analysis of ES have not been widely used to evaluate riparian zones. Water supply and erosion control ES, often associated with nutrient cycling, stood out among the publications that applied an integrated approach of ES (methods presented in Table 4). The Soil and Water Assessment Tool (SWAT) was the model most frequently used to model the dynamics of rivers and the flow of sediments in them (e.g. Amatya et al., 2011; Arnold et al., 2012; Palazón et al., 2014; Arnold et al., 2014; Vigiak et al., 2016; Francesconi et al., 2016).

Other methods have also been used to assess the relationship between land use and water ES (Water retention index, STELLA, and CAESAR LISFLOOD), but also models and indexes to assess ES provision capacity or ecology integrity of riparian zones as a whole (e.g. Bayesian belief network, Riparian ecosystem management model, Riparian quality index, Stream visual assessment protocol, and A new comprehensive ecosystem service index) (Table 4).

Studies on the habitat and diversity function assessed the biodiversity of the riparian landscape, its ability to provide habitat and resources for different species (Cole et al., 2015; Cole et al., 2020), and its influence on the distribution of native and invasive species (Shaker et al., 2017). Models and indexes were also found to assess biotic integrity (Biotic integrity, Jaccard and Shanon-Weaver diversity indexes) and green infrastructure in riparian zones, priority areas for restoration like Copernicus land monitoring service, Relative aggregated value of ecosystem services index, and Normalized difference vegetation index. Most of the publications that studied the pollination ES (regulation) were associated with the services refuge (support) and food production (provision) (e. g. Lautenbach et al., 2011; Meehan et al., 2013). The main methods applied were: Relative pollination potential index, Generalized additive models, and Integrated valuation of ES and tradeoffs (InVEST). InVEST is a suite of models used to map and value the goods and services from nature that sustain and fulfill human life. It helps explore how changes in ecosystems can lead to changes in the flows of many different benefits to people (e.g. Nelson et al., 2009; Garrastazú, et al., 2015; Posner et al., 2016).

Methodologies of integrated analysis of ES are extremely important, as this is how they work in the ecosystem itself, interacting and providing joint responses in a complex system. This approach seems to be more adequate to evaluate sustainability in riparian zones as a support for their management. Riparian zones play essential roles in water and landscape planning, in restoration of aquatic systems, and in catalyzing institutional and societal cooperation for these efforts (Naiman & Décamps, 1997). Only an integrated analysis of ES can effectively help decision-makers to make choices that mutually benefit ecosystems and populations (Muller et al., 2010).

4.5. Ecosystem services at landscape or spatial multiscale in riparian zones

Publication on landscape management focused on assessing the willingness to adopt riparian buffers, especially in the agricultural landscape, in addition to proposing ways of managing riparian zones to contribute to their greater ecosystem potential (e.g. Kenwick et al., 2009; Hefting et al., 2013; Angelstam & Lazdinis, 2017). Studies that focused on riparian corridors addressed the importance of ecological corridors in riparian zones to ensure the connectivity of habitats in fragmented landscapes (e.g. Clerici et al., 2014; Lee et al., 2014; Resasco et al., 2014). Regarding water quality, the studies focused on the evaluation of the riparian landscape's capacity to retain nutrients and sediments, in addition to its function of water filtration and purification that guarantee the quality of water for human supply (e.g. Nava-López et al., 2016).

Few studies have chosen the multiscale approach (e.g. Jones et al., 2010; Uriarte et al., 2011; Salo & Theobald, 2016; Biggs et al. 2019). This is probably due to riparian zones being considered only stretches of landscape. This fact can also be explained by the great complexity and the difficulty of carrying out studies in these areas, not only due to high costs, but also due to the difficulty of access to riparian zones (Busato et al., 2019). Landscape and spatial multiscale approaches are important in decision-making, especially in very heterogeneous and more complex landscapes (Power, 2010). Then, it is an opportunity to consider these aspects in the studies regarding ES. The ES of water supply and water regulation, for example, depend on runoff patterns in the landscape and are influenced by several biophysical factors.

4.6. Economic valuation of ecosystem services in riparian zones

Regarding economic valuation of ES, these methods estimate the monetary value of ES in relation to other goods and services available in the economy, indicating a sustainable use of environmental market resources that makes viable use of environmental resources (e.g. Da Motta, 1997; Liu et al., 2010; Costanza et al., 2011). The main methods are BTM and MVC. BTM estimates the value of an ecosystem based on the results of pre-existing primary studies on different sites or policies (e.g. Liu et al., 2010; Rolfe et al., 2015). In the MVC, questionnaires are applied to individuals through direct consultation and simulation of contingent markets to reveal the willingness to pay (WTP) for the preservation or improvement of the ecosystem conditions, or the willingness to receive (WTR) some compensation for the loss of ecosystems conditions (e.g. Mueller, 2014; Garcia et al., 2015). Models for the economic valuation of ES, such as the Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST), were also identified in the analyzed publications (e.g. Garrastazú et al., 2015). Studies aimed at supporting policies and markets, with a very applied focus related to carbon and other gases, assess to subsidize carbon credit markets and climate change adaptation (e.g. Matzek et al., 2014; Dittrich et al., 2018), as well as carrying out an economic valuation to support Payments for Ecosystem Services schemes (e.g. Lewis et al., 2017), have been increasingly frequent in the literature.

Valuing ES is important, as it shows understandably that investing in the maintenance of ecosystems can be more economical than later investing in actions for remediation, restoration and mitigation of the impacts arising from degradation. This approach is also key to subsidizing rising Payments for Ecosystem Services schemes around the world, encouraging conservation and greater provision of ES in RZ.

5. Conclusions

Despite the different definitions, functions, and high complexity, riparian zones have attracted the attention of scientists around the world who seek to understand their functioning and the provision of ecosystem services.

From 2000 to 2020, the most studied category of ecosystem services was Regulating, mostly carbon stock/sequestration, gas (GHG's) and climate regulation; biological control; pollination; erosion control and sediment retention; water regulation; nutrient retention, and sewage treatment. In the Provisioning category the ES most studied were water supply, food production, and raw material. The Support category included the ES of nutrient cycling, soil formation, nursery, and refugia. In the Cultural category the ES studied the most were recreation and aesthetics.

The most applied indicators were those ones that evaluated the cycling of nutrients based on the measurement of soil and water attributes in riparian zones. Among the publications surveyed, it was noted that even with the use of riparian zone assessment and modeling indexes, few studies used methodologies of integrated analysis of ES. This fact calls attention to the need to carry out further studies that analyze ES in riparian zones using an integrated and multiscale approach because that is how the components of the ecosystem interact and provide joint responses capable of assisting in decision making.

Studies about ES in riparian zones using the landscape or spatial multiscale approach rarely appeared in the literature during the period studied. To assess the impacts of anthropogenic actions on ecosystem services, a spatial multiscale approach must be considered.

ES economic valuation was an approach rarely found in the publications surveyed in RZ, but it is very important to convince investors, decision-makers, and the society that it is better to invest in maintaining ES in riparian zones now than investing in remediation, restoration and mitigation of anthropogenic impacts later.

Finally, planning of water and landscape use, focusing on ES provision in RZ demand inter-institutional and social cooperation to strengthen management efforts, management, restoration and conservation of fauna, flora, water resources and ecosystem services in hydrographic basins, transforming conservation and sustainable use into a great opportunity for innovative development. Hence, connecting science and policy is essential to generate effective strategies for planning land use and monitoring ES's in natural and anthropized environments.

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