ISPARTA UYGULAMALI BİLİMLER ÜNİVERSİTESİ

Turkish Journal of Forestry | Türkiye Ormancılık Dergisi
2024, 25(2): 233-243 | Review article (Derleme)

Exploring the wide-ranging ecosystem services of riparian vegetation on a global scale

Emine Keleş Özgenç[a,*]

Abstract: Riparian vegetation, as an integral part of river systems, provides various socio-ecological functions by strengthening the link between aquatic and terrestrial ecosystems. They provide comprehensive ecosystem services in physical, chemical, biological and social terms, establishing a critical link between humans and the environment. This study highlights the growing importance of riverine riparian vegetation and ecosystem services through a bibliometric analysis of scientific publications between 2000 and 2023. In the 494 publications analyzed in the study, 72% regulating (water quality, erosion prevention, climate regulation) and 43% supporting (habitat provision) ecosystem services were predominantly evaluated, while provisioning and cultural services were not sufficiently addressed. In addition, although various methods such as statistical analysis, GIS and model-based approaches were used in the reviewed studies, the lack of standardized assessment methods was identified. In conclusion, this study highlights the gaps in informed decision-making and planning in riparian areas. It emphasizes that protecting, managing and restoring riparian vegetation is critical for the sustainability of water resources, biodiversity, human well-being and overall ecosystem health.
Keywords: Riparian vegetation, Riparian zone, Ecosystem services

Kıyı bitki örtüsünün geniş kapsamlı ekosistem hizmetlerinin küresel ölçekte araştırılması

Özet: Kıyı bitki örtüsü, nehir sistemlerinin ayrılmaz bir parçası olarak sucul ve karasal ekosistemler arasında bağlantıyı güçlendirerek çeşitli sosyo-ekolojik işlevler sunar. Fiziksel, kimyasal, biyolojik ve sosyal açıdan kapsamlı ekosistem hizmetleri sunarak insanlar ve çevre arasında kritik bir bağ kurarlar. Bu çalışma, 2000-2023 yılları arasında yapılan bilimsel yayınların bibliyometrik analizi yoluyla nehir kıyı bitki örtüsünün ve ekosistem hizmetlerinin artan önemini vurgulamaktadır. Çalışmada analiz edilen 494 yayında, %72 düzenleyici (su kalitesi, erozyon önleme, iklim düzenleme) ve %43 destekleyici (habitat sağlama) ekosistem hizmetleri ağırlıklı olarak değerlendirilmiş, tedarik ve kültürel hizmetler ise yeterince ele alınmamıştır. Ayrıca, incelenen çalışmalarda istatistiksel analiz, CBS ve model tabanlı yaklaşımlar gibi çeşitli yöntemler kullanılmış olmasına rağmen, standartlaştırılmış değerlendirme yöntemlerinin eksikliği tespit edilmiştir. Sonuç olarak, bu çalışma nehir kıyı alanlarında bilinçli karar alma ve planlama konusundaki eksiklikleri vurgulamaktadır. Nehir kıyı bitki örtüsünün korunması, yönetilmesi ve restore edilmesinin su kaynaklarının sürdürülebilirliği, biyoçeşitlilik, insan refahı ve genel ekosistem sağlığı için kritik olduğunu belirtmektedir.
Anahtar kelimeler: Kıyı bitki örtüsü, Kıyı zonu, Ekosistem hizmetleri

1. Introduction

Riparian zones are transition zones and ecotones, forming the interface between the river channel and the terrestrial ecosystem adjacent to water bodies (Naiman et al., 2010; Hanna et al., 2018; Singh et al., 2021). These regions are acknowledged as among the most productive and biodiverse landscapes globally, facilitating the transfer of vital energy, inorganic and organic materials, and life forms. The regions also significantly impact sustaining livelihoods and preserving traditions, offering many advantages to the local population (Hanna et al., 2018). Although river coastal zones cover a relatively small area, they provide many ecological functions due to their interaction with their environment (Singh et al., 2021). Riparian vegetation, a vital component of fluvial systems, is defined as a complex of vegetation units that have functional connections with other elements of fluvial systems and the adjacent areas bordering streams, river networks, and lakes (Naiman et al., 2010; Dufour and Rodríguez-González, 2020). A riparian zone is a land adjacent to and directly and indirectly affected by a water body (Price and Tubman, 2007). These regions serve as transition zones at the intersection of aquatic and terrestrial ecosystems, characterized by unique biotic and abiotic features that are heavily influenced by the presence of water (Naiman et al., 2010; Riis et al., 2020; Pedraza et al., 2021). Riparian vegetation is of great importance to the ecosystems around them. The riparian vegetation zone displays heterogeneity, marked by significant spatial and temporal variations, primarily attributed to changing bioclimatic, geomorphological, and topographic conditions influenced by human activities and natural factors (Riis et al., 2020). Therefore, they cannot be easily identified. Pedraza et al. (2021) define riparian vegetation as vegetation established in the floodplain. These environments include surface and subsurface hydrology, floodplains, and adjacent slope areas

[a] Department of Landscape Architecture, Faculty of Architecture, Trakya University, 22030, Edirne, Türkiye

[*] **Corresponding author** (İletişim yazarı): eminekeles@trakya.edu.tr

✓ **Received** (Geliş tarihi): 21.11.2023, **Accepted** (Kabul tarihi): 19.03.2024

Citation (Atıf)**:** Keleş Özgenç, E., 2024. Exploring the wide-ranging ecosystem services of riparian vegetation on a global scale. Turkish Journal of Forestry, 25(2): 233-243.
DOI: 10.18182/tjf.1394234

ecologically connected to the water body (Pedraza et al., 2021). Riparian vegetation is also vital to river ecosystems (Muller, 1997). They are highly significant regions within ecosystems, given their susceptibility to numerous direct and indirect stresses resulting from human activities, which affect their functioning (Naiman et al., 2010). Riparian zones are transition areas between aquatic and terrestrial environments (Betz et al., 2018). They span the area from the low-flow water level to the highest water mark, where vegetation is influenced by floods, elevated water tables, and soil characteristics (González et al., 2017). Coastal zones encompass the riverbed, banks, vegetation, surrounding land, and floodplain (Maraseni and Mitchell, 2016).

Coastal zones and their constituents typically exert substantial influence on ecosystems and human welfare, as they offer crucial ecosystem services (ES) such as coastal stabilization, the supply of living and decaying organic materials, habitats for both aquatic and terrestrial life, seasonal water flow, sediment retention, nutrient capture and processing, water storage, potable water, erosion management, flood control, recreational opportunities, and mitigation of heatwave effects (Riis et al., 2020; Singh et al., 2021; Urbanič et al., 2022). Singh and Singh (2020) describe these areas as ecological engineers that provide multiple ES and maintain and improve river health. These functions arise from natural processes that entail intricate interactions between biotic and abiotic environments (De Groot et al., 2002). At the same time, vegetation along these areas affects river processes by altering water flow, trapping sediment, and influencing riverbank erosion sensitivity and morphology through flow-vegetation-sediment feedback mechanisms. The growth rate, diversity, and productivity of river vegetation also influence biogeochemical processes in rivers (Pedraza et al., 2021). Coastal zones and vegetation are recognized as areas of vital importance for nature and people. Still, their degradation tends to increase in the absence of a coherent policy to guide sustainable management efforts. In recent years, an increasing body of literature has emphasized the significance and difficulties associated with conserving biodiversity in riverine coastal vegetation habitats (Dufour et al., 2019; Riis et al., 2020; Fonseca et al., 2021; Pedraza et al., 2021; Singh et al., 2021; Urbanič et al., 2022). In particular, the studies draw attention to improving biodiversity and ES in river coastal vegetation areas and holistic and sustainable landscape management.

The complex interaction of riparian zones with rivers and upland habitats makes the vegetation in these areas more sensitive to environmental changes (Hoppenreijs et al., 2022). Generally, the degradation of these areas starts with forest clearing as a result of human activities on riparian vegetation. As river coastal areas are at the interface between water and land, they are affected by different stressors and pressures, including agriculture, population growth, urbanization, river engineering works, pollution, river flow modification, and biological invasions (Urbanič et al., 2022). Although riparian zones play a multifunctional and fundamental role in providing ES, especially in recent decades, they are significantly affected by anthropogenic pressures in the process of urbanization, where riverbanks are prioritized for settlement and coastal vegetation is eliminated or reduced (Prado et al., 2022). In addition to this, deforestation and dam-building activities are gradually increasing in these areas. When these degradations are combined with global problems such as climate change in recent years, the effects on river vegetation are gradually reaching negative dimensions (Nilsson et al., 2013). According to Riis et al. (2020), 80% of natural riparian habitats have been lost in Europe in the last 200 years, mostly in developed countries.

Riparian areas provide important ES in river systems regarding the multiple socio-ecological services they provide to society. Riparian vegetation can provide a large amount of ES thanks to its ecotone characteristics and the ecological functions offered by the vegetation (Sweeney and Newbold, 2014). They are often important for provisioning, regulating, and cultural ecosystems. In terms of service provision, fuel and energy can be extracted from coastal forests and vegetation and can also be providers of genetic resources. Regulating services include water quality regulation through filtration of pollutants and sediments, carbon sequestration and microclimate regulation, pollination, habitat maintenance, water flow regulation, and erosion control. Riparian areas and vegetation also provide cultural services, providing opportunities for environmental education, identity, aesthetics, recreation, etc. (Pedraza et al., 2021).

Riparian vegetation is an important area of research due to its ecological and societal importance. In recent years, many reviews have summarised and discussed the scientific literature on the importance of riparian vegetation and the services it provides, stream restoration efforts, and vegetation. Dufour et al. (2019), investigated the literature from a global perspective, focusing on definitions for riverine riparian vegetation by addressing the scientific trajectory of studies focusing on riparian vegetation over many years. The work also states that studies on river regions change over time and vary according to river systems and geographical regions. Urbanič et al. (2022) discuss the critical priorities and measures that must be considered to successfully develop policies and manage riparian zones. This direction examines the degradation, restoration, and conservation concepts related to wetland management. Singh et al. (2021) discuss riparian zones' concepts, characteristics, functions, and threats and propose an integrated approach for river health improvement in the context of coastal zone management. Verdonschot and Verdonschot (2022), provide an overview of the ES provided by rivers and discuss the challenges and opportunities for improving ecosystems through integrated river basin restoration targeting both biodiversity and ES. Hanna et al. (2018), reviewed publications that quantify river ecosystems and present their global distribution and types of ES. The work highlighted the importance of having clear indicators, data sources, and methods for quantifying river ES that accurately reflect the services intended to measure. Their work underscores the significant potential of the ES concept in informing river ecosystem management and decision-making.

Riparian zones and riverine vegetation have been studied by many disciplines spanning numerous scientific and applied disciplines such as hydrology, geography, biology, management and restoration, and remote sensing. Therefore, knowledge on the topic is scattered across various fields and disciplines (Dufour et al., 2019; Riis et al., 2020; Prado et al., 2022), bringing different methodological approaches to assessing riparian areas. Quantitative evaluation of ES, functions, and fluxes is crucial for preserving the ecological functions offered by riparian areas (Fu et al., 2016). Nonetheless, it seems that assessments of ES in riparian areas are fragmented, and there are deficiencies in terms of comprehensive methodological approaches that emphasize landscape, multi-scale analysis, and economic valuation aspects because riparian zones are ecosystems characterized by a high degree of interaction and complexity (Prado et al., 2022).

In addition to the many ES provided by river coastal areas, they are also threatened by serious anthropogenic impacts such as conversion of land into agricultural areas, alteration of river flows, wrong restoration works, and climate change. Therefore, despite their great importance for human welfare, the degradation and destruction of riparian areas have been increasing in recent years. These areas are important for maintaining riparian vegetation and ecological functions, which are part of the management of riparian areas, and the sustainability of related benefits. It is very important to know and define the ecological functions of these areas in making the right decisions. For this reason, there is still a lack of studies on a global scale within the scope of revealing the importance of riparian areas, understanding the current situation, and determining the trends on the subject. In this context, the main objective of this study is to explore the critical role of riparian vegetation in ES. The importance of riparian vegetation, definitions, ES, and methods commonly used in the assessment of ES are also evaluated. Therefore, it aims to reveal the scientific literature on ES provided by riparian vegetation in 2000-2023 through bibliometric-based analyses. The current study provides an opportunity to systematize the information on ES provided by riparian vegetation and to fill the knowledge gaps in the literature. Ultimately, it may help to identify knowledge gaps to assist decision-making and planning processes for river coastal areas.

2. Material and methods

The literature review on riparian vegetation was done by querying Scopus and Web of Science (WoS) databases. Both databases provide access to various databases to collect bibliometric data of published material in multiple fields of knowledge. Data searches in bibliometric reviews in the literature are generally based on Scopus and WoS (Mongeon and Paul-Hus, 2016). In general, bibliometric analysis is used to assess both research trends and scientific networks in different research disciplines. Bibliometric analyses encourage and guide researchers to conduct further studies (Zhang et al., 2019). It is an important approach to identifying global trends and knowledge gaps.

The search criteria were initially applied to both Scopus and WoS within the scope of the study. First, reviews were conducted within a timeframe covering approximately 23 years, from 2000 to July 2023, encompassing the scientific literature. Document types searched included articles, books, book chapters, and reviews, representing the most important categories of peer-reviewed research materials. The provisioning, regulating, supporting, and cultural ES were used in the categorization of ES, as specified by MEA (2005). The goods and benefits provided by each ecosystem service were identified. The characterization of ES was obtained using relevant scientific literature. Provisioning ES is defined as benefits that can be directly extracted from nature, consumed, and have a specific market value (such as water, food, wood, and biofuels). Regulating ES can be defined as benefits derived from ecosystem processes that alter the current state (carbon storage, soil fertility, etc.). Supporting ES encompasses the fundamental processes of the ecosystem, such as photosynthesis and nutrient cycling, and is a vital service provided by the ecosystem. Cultural ES are abstract benefits that people derive from nature and contribute to the identity of the landscape (recreation, aesthetics, heritage, etc.) (Deeksha and Shukla, 2022).

The study used a systematic method to conduct a literature review in three stages. International databases, Scopus and WoS, covering the period from 2000 to July 2023, were utilized for searching, encompassing journals, books, and reviews. In the first stage, the search index was conducted as follows: searches were performed in the titles, abstracts, and keywords of studies using the terms ("riparian area" OR "riparian zone" OR "riparian vegetation" OR "riparian forest"). The initial stage aimed to determine the trends in coastal areas and coastal vegetation studies. In the second search, studies containing the term "ecosystem services" were associated with the first search results, allowing for identifying publications that examined ES in studies related to riparian areas and vegetation. The classification of ES was based on the grouping established by MEA (2005). In the third stage, ES-related benefits were searched and examined to identify specific studies on ES. This stage was carried out using the Scopus database. Scopus was chosen over WoS for its recognition as the largest database of peer-reviewed literature containing more indexed journals (Mongeon and Paul-Hus, 2016; Kandel et al., 2021) and for identifying a greater number of publications in the second search. It is noted that Scopus represents the topic of ES more comprehensively in research (McDonough et al., 2017). Therefore, in the search conducted in the Scopus database, the 664 records obtained in the first and second stages were re-evaluated, focusing on publications containing one or more ES values. In this context, 494 publications addressing the ES value provided by riparian areas or vegetation were considered. The scientific literature related to the ES offered by riparian areas or vegetation was examined through bibliometric analyses. Non-statistical meta-analysis was performed to analyze the data. An assessment was made regarding the temporal status, geographical distribution, research area, research type, publication sources, and keywords of the publications. VOSviewer was used to analyze the bibliometrics of keywords (https://www.vosviewer.com). VOSviewer is a widely used social network tool for creating academic network maps in similar studies (Kandel et al., 2021).

3. Results and discussion

3.1. Definitions related to riparian area and vegetation

Definitions of riparian vegetation often include keywords used to describe a subject expressed with various terms. Various names are given to riparian vegetation in river systems. The diversity in these definitions varies depending on geographical regions, subjects under investigation, and purposes, sometimes leading to misunderstandings (Dufour et al., 2019). Therefore, it is essential to establish the definitions of these concepts. Most definitions of the riparian zone use a functional approach and highlight the two-way influences of hydrological, morphological, chemical, and biological processes between aquatic and terrestrial systems. Riparian zone definitions generally describe them as "transitional between terrestrial and aquatic ecosystems and distinguished by gradients in biophysical conditions, ecological processes, and biota. They are areas through which surface and subsurface hydrology connect water bodies with their adjacent uplands. They include those portions of terrestrial ecosystems that significantly influence exchanges of energy and matter with aquatic ecosystems" (National Research Council, 2002). When examining the literature, various definitions made for these areas are compiled by Dufour et al. (2019) in Table 1. Riparian vegetation emphasizes the effects of hydrological, morphological, chemical, and biological processes between aquatic and terrestrial systems. Riparian vegetation is defined as "a complex of communities found in the river region and distinguished by gradients in biophysical conditions and ecological processes and biota between terrestrial and aquatic ecosystems".

3.2. Quantitative analysis of studies on riparian vegetation and ES

From 2000 to July 2023, 15,304 publications were found in Scopus and 7,067 in WoS using the search terms "riparian zone, riparian area, riparian vegetation, and riparian forest". When these publications were searched with the term "ecosystem services", 664 publications in Scopus and 395 publications in WoS were obtained using similar terms. In 2018 and afterwards, a gradual increase was observed in the number of studies on these terms. In 2022, it was determined that there was a significant increase in the number of studies (Figure 1).

The temporal trend in the number of publications has shown a remarkable increase, particularly since 2005, following the publication of the Millennium Ecosystem Assessment (MEA) and a sharp increase after the establishment of IPBES in 2012 (Martin-Lopez et al., 2019).

The scientific fields on which these studies are based are shown in Figure 2. Environmental Science (503), Agricultural and Biological Sciences (339), and Social Sciences (87) are the most popular subject categories (Figure 2). Studies related to riparian areas and ES have steadily developed within their subject categories. In studies concerning ES (McDonough et al., 2017; Zhang et al., 2019) the Environmental Science category consistently ranks at the top. The diversity of scientific fields reflects the inherently multidisciplinary nature of the concept of ES.

Between 2000 and 2023, the types of studies related to the search terms included articles (574), book chapters (33), reviews (33), and conference papers (21). An assessment of the sources/publications where these studies were published reveals that most were published in journals. The journals include Science of The Total Environment (32), Ecological Indicators (19), Ecological Engineering (19), and Forest Ecology and Management (18) (Figure 3). It is evident from Figure 3 that studies published in the most prolific journals are closely related to the field of environmental science. Additionally, as noted in the studies by Martin-Lopez et al. (2019) and Aznar-Sánchez et al. (2018) there is less focus on ES in the social sciences. Therefore, globally, there is a need to create more interdisciplinary studies on riparian areas and ES.

Table 1. Definitions associated with riparian vegetation (Dufour et al., 2019)

Expression	Definitions
Riparian	"Refers to land adjacent to a body of water."
Riparian zone	“Zone of direct interaction between terrestrial and aquatic environments.” “Encompasses the stream channel between the low and high water marks and that portion of the terrestrial landscape from the high water mark toward the uplands where vegetation may be influenced by elevated water tables or flooding and by the ability of the soils to hold water.” “Transitions between terrestrial and aquatic ecosystems are distinguished by gradients in biophysical conditions, ecological processes, and biota. These are areas through which surface and subsurface hydrology connect water bodies with their adjacent uplands.”
Riparian area	“Three-dimensional ecotones of interaction that include terrestrial and aquatic ecosystems, that extend down into the groundwater, up above the canopy, outward across the floodplain, up the near-slopes that drain to the water, laterally into the terrestrial ecosystem, and along the watercourse at a variable width.”
Riparian forest	“Floodplain vegetation or vegetation directly adjacent to rivers and streams. The riparian forest extends laterally from the active channel to include the active floodplain and terraces.”
Riparian vegetation	“Hydrophytic vegetation growing near a […] river close enough so that its annual evapotranspiration represents a factor in the […] river regime.”

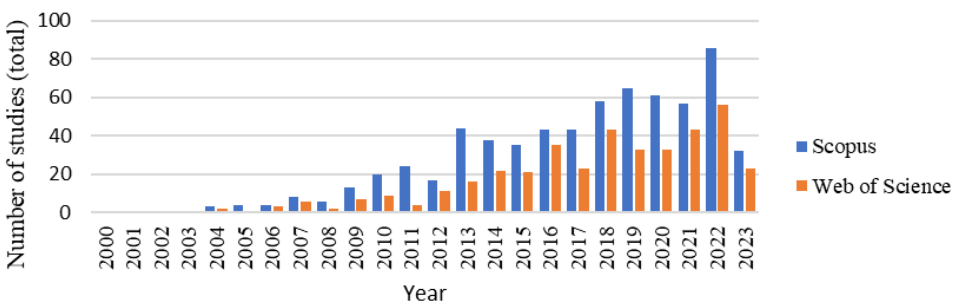

Figure 1. Number of studies annually from 2000 to 2023 applying all terms and ES

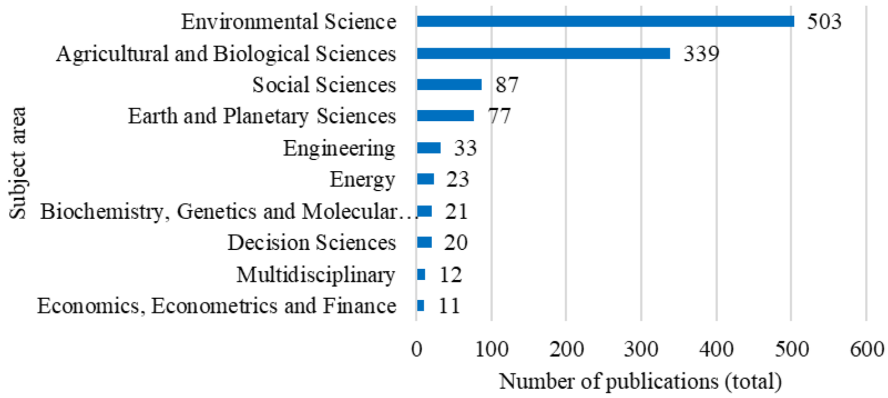

Figure 2. Distributions of the subject categories

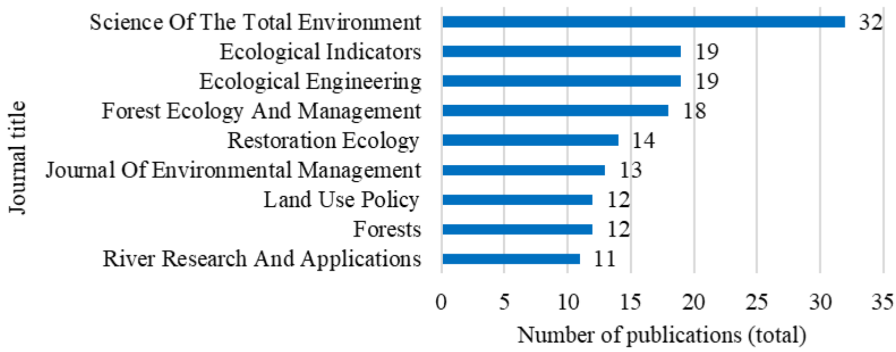

Figure 3. Journals in which the studies were published

Among the most active countries in research on coastal areas and the ES provided by vegetation, the United States (33%), China (11%), Brazil (10%), Germany (9%), the United Kingdom (8%), Australia (7%), and other countries (21%) stand out (Figure 4). The study by Prado et al. (2022), states that 53% of river coastal areas in the United States were destroyed in the 1980s. Therefore research was encouraged to reduce and regulate degradation in coastal areas. Other studies also indicate that the United States is at the forefront of ES research (Zhang et al., 2019).

When examining the keywords used in riparian areas and ES studies, "ecosystem services" is the most commonly used keyword. Other frequently used keywords include "riparian vegetation, riparian zone, riparian forest, biodiversity, restoration, water quality, climate change, floodplain, and conservation" (Figure 5). A word cloud generated from the prominent keywords in the study is presented in Figure 6.

In ES research, the prominent keywords often align with terms like biological diversity, conservation, and ES (Pauna et al., 2018; Kandel et al., 2021). As noted in the study by Xu et al. (2019), keywords such as climate change and land use change are also prominently feature in the research.

According to the evaluation conducted using VOSviewer, recent studies in ES and riparian vegetation/forest research have seen the emergence of keywords such as "remote sensing, land use change, nature-based solutions, and river management." This trend suggests that riparian areas are significantly affected by rapid changes in the ecosystem, and researchers are focusing on examining the impacts on these valuable areas. Bibliometric analyses can contribute to a comprehensive assessment of ES studies conducted globally, regionally, and in different ecosystems, helping to identify knowledge gaps in this field.

3.3. ES provided by riparian zones and assessment methods

Studies available in the Scopus database were reviewed to assess the ES provided by riparian vegetation, and 664 publications up to July 2023 were scanned. This scanning process included all publications, such as articles, books, and conference papers. The studies were considered regardless of the language in which they were published. Studies that did not explicitly focus on evaluating ES during the research process were excluded. All studies directly examining ES (articles, books, and conference papers) were included in the evaluation process. As a result of the scanning, it was determined that ES provided by riparian vegetation was identified in the reviewed 494 studies. Quantitative data were obtained for each study, including keywords, the location of the study, the journal it was published in, assessed ES, and the methods used to measure these services.

According to the obtained results, among the scanned 494 publications, the most evaluated ecosystem service categories were as follows: regulating (72%), supporting (43%), cultural (6%), and provisioning (5%). During the scanning process, it was determined that regulating ES was assessed in 356 publications, supporting services in 210 publications, cultural services in 30 publications, and provisioning services in 26 publications (Figure 7). Overall, it was observed that regulating and supporting ES were more frequently measured compared to other categories, while cultural and provisioning services were less frequently measured. The primary reason is that cultural ES are abstract, making the measurement processes more challenging.

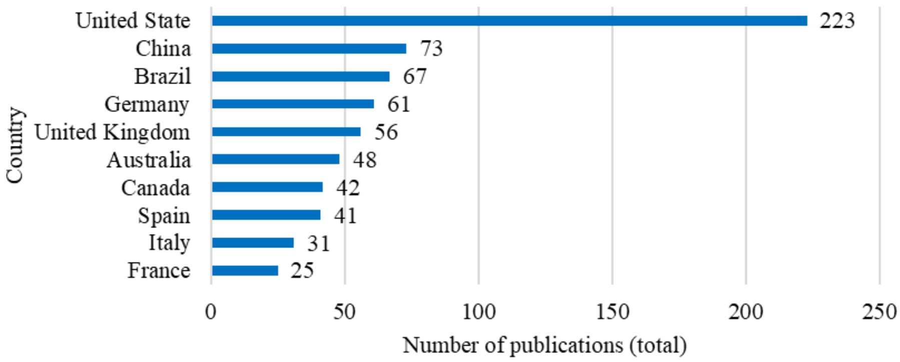

Figure 4. Distribution of countries where studies were published

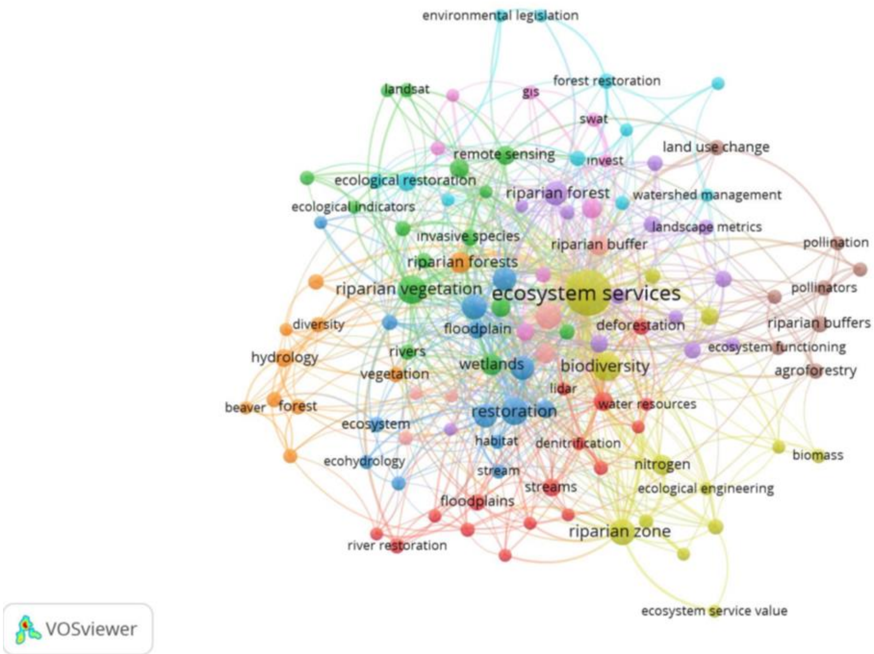

Figure 5. Riparian areas terms and keywords occurrence network for ES research

Figure 6. Featured keyword cloud

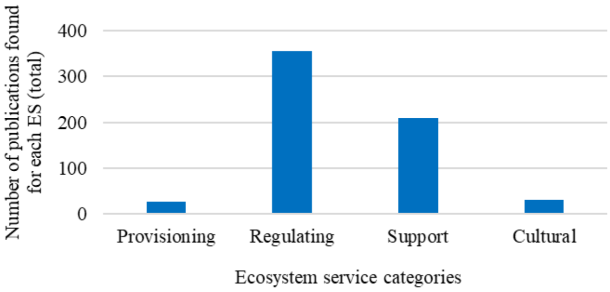

Figure 7. ES assessment in the studies reviewed

Hanna et al. (2018) evaluated riparian vegetation ES and examined studies conducted until 2017. According to the results of their study, it was determined that the most frequently measured ES were provisioning and regulating services. However, this study observed that the number of studies conducted on riparian areas and ES increased after 2018. This increase has led to more studies focusing on categories other than regulating services, resulting in increased assessments of supporting services. Therefore, the findings obtained are consistent with the existing literature. In the study by Mengist et al. (2020), a general assessment of ES was presented, with regulating (36) and provisioning services (27) being highlighted as the most discussed services. However, when evaluating the ecological functions provided by riparian areas, the prevalence of supporting ES in these areas sets this study apart from others. The current study is in line with the findings of Prado et al. (2022). In the study, ES provided by the keywords identified in the relevant literature, based on the categories and indicators of the MEA, are provided in Table 2.

In the examined 494 studies, a total of 622 measurements of ES were conducted, evaluating 23 ES in total (Table 2). The most commonly assessed ES in the research were identified as water quality, habitat provision, erosion retention, climate regulation, biological control, carbon sequestration, and flood mitigation (Figure 8). It has been observed that these evaluations are generally measured more frequently because they can be measured more easily with the GIS and model approaches on which the evaluation methods are based.

Based on the classification according to MEA (2005) categories, the most studied services were provisioning (raw material production, food provision), regulating (water quality, erosion prevention, climate regulation, biological control, and carbon sequestration), supporting (habitat provision, primary production, and soil formation), and cultural (recreation & tourism and aesthetics). However, the least studied services were energy, genetic material, education, heritage, nursery & refugia, and pollination. The findings are consistent with other studies on ES in the literature (Hanna et al., 2018; Mengist et al., 2020; Prado et al., 2022).

River ecosystems are interconnected with their surroundings, which is why the ES they provide are interrelated. Liu et al. (2019) stated that net primary production, soil conservation, and habitat quality are associated with elevation and vegetation cover. River ecosystems also have important habitat functions both locally and in landscapes. De Groot et al. (2002) mentioned that river ecosystems tend to increase the diversity of species pools at regional scales (Clarke et al., 2008). Moreover, the heterogeneous structure of river ecosystems is essential for providing habitat functions and associated goods and services. Therefore, habitat provision, evaluated within the supporting service category in the examined studies, is extensively studied in the literature.

There is no standard framework for assessing river ecosystems, making it challenging to evaluate the ES provided by riparian vegetation (Hanna et al., 2018; Mengist et al., 2020). Methodological uncertainties can negatively affect the reliability of the findings. Typically, depending on the research objectives and scope, one or several ES are evaluated using tools such as Geographic Information Systems (GIS), statistical analysis, and models (e.g., SWAT, INVEST model, etc.) (Table 3) as observed in the literature. Hanna et al. (2018) stated that statistical analysis is the most frequently used method for measuring ES. According to the assessment conducted in the study, statistical analysis, GIS, and various modeling tools are utilized. In the work by Mengist et al. (2020), the analysis of ES literature generally identifies bio-physical, empirical, GIS-based, INVEST, and mixed (economic, etc.) models as the most commonly used methods.

Table 2. ES provided by riparian vegetation

ES category	ES indicator
Provisioning	Water supply (freshwater), raw material production, food provision, energy, genetic material
Regulating	Climate regulation (air quality, gas regulation), carbon sequestration & storage, biological control, nutrient regulation, pollination, water quality, waste treatment, erosion control/prevention, flood mitigation
Supporting	Primary production, nutrient cycling, habitat provision, soil formation, nursery & refugia
Cultural	Recreation & tourism, aesthetics, heritage, education

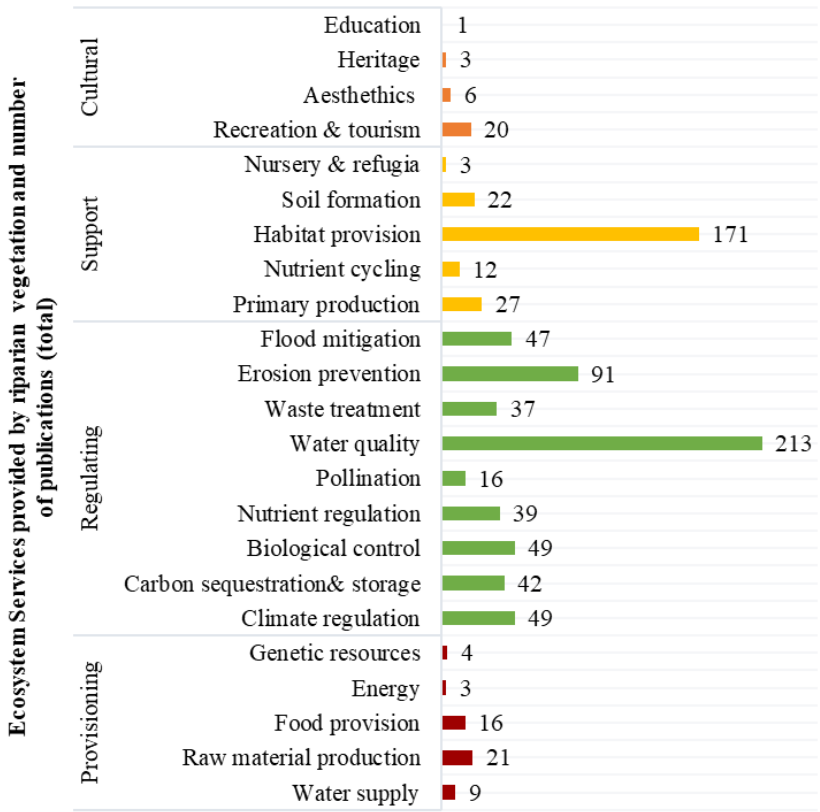

Figure 8. ES assessed in riparian vegetation studies

Table 3. Methods for assessing ES provided by riparian areas

Methods	Objectives
Integrated valuation of ES and tradeoffs (InVEST)	It is a tool for assessing ES and sustainable management of natural capital. It quantitatively assesses ES in areas such as water quality improvement, water regime regulation, erosion control, and biodiversity support.
Soil and Water Assessment Tool (SWAT)	Riparian area/vegetation assessments are used to understand and manage environmental and ecological processes. In particular, it assesses ES in areas such as water quality and erosion control.
Qualitative Habitat Evaluation Index (QBR), Riparian quality index (RQI), Stream visual assessment protocol (SVAP), River Habitat Survey (RHS)	Models assess the habitat quality of wetlands.
Normalized difference vegetation index (NDVI)	Models enable monitoring and assessment of the state of vegetation in wetlands.
Normalized difference water index (NDWI)	The model enables the assessment of aquatic ecology and water resources in wetlands.
Green Normalized Difference Vegetation Index (GNDVI)	The model allows assessing the health status of vegetation in wetlands.
USLE (Universal Soil Loss Equation), RUSLE (Revised Universal Soil Loss Equation)	The models allow for predicting and managing soil erosion in riparian areas.
WaterGAP3 (Global Assessment and Prognosis for Water Resources)	Understanding the water regimes and the health of water ecosystems in riparian areas is critical for the sustainable management of water resources. To achieve this goal, it also analyzes the state of water resources, assesses the relationships between water supply and demand, and creates projections for how future water resources may be affected.
i-Tree Eco Model	The model is used to understand the ES and value of trees in riparian areas.
Structural Equation Modeling (SEM)	The model is used as a statistical analysis method to analyze and understand the complex relationships of various social and ecological factors in wetlands.
Stream Evolution Model (SEM)	It is a hydromorphological model used to understand the evolution and shaping of river systems in riparian areas. The model also analyzes how rivers change over time and how fluvial processes affect riparian areas.
DSPIR (Disturbance, Sensitivity, Productivity, Intactness, Resilience)	It is an analytical tool for ecosystem assessment and management in riparian areas. The framework offers an assessment approach where different components are taken into account to assess the condition and health of riparian ecosystems.
Econometric model (Random Utility Model (RUM))	An econometric model is a statistical model used for analyzing and quantifying economic relationships and behaviors.
Analytic Hierarchy Process (AHP)	It is a multi-criteria decision analysis method used in complex decision-making processes in riparian areas. It provides a structured framework for decision-making processes, enabling the evaluating and weighing of different factors and criteria.

When examining keywords, it becomes evident that the use of models such as SWAT and INVEST, as well as remote sensing and practical images like Landsat, contributes to the assessment and mapping of ES (Martin-Lopez et al., 2019). GIS has been predominantly used in studies to identify hydrological networks, evaluate relationships between land use and water quality in the surrounding environment, and conduct temporal-spatial analyses. Depending on the research objectives, meteorological, hydrological, soil, and other data sets are also employed (Haase et al., 2014). In assessing river ecosystems' vegetation, specialized evaluations can be conducted using habitat assessment methods for rivers, such as QBR, SVAP, and RHP models, customized based on the area's uniqueness through factors like quantitative and qualitative characteristics, morphological structure, and water properties. These methods play a significant role in evaluating the ecological health of rivers and habitat quality, and they are taken into account in the planning and implementation of water management and conservation projects.

Model-based studies are commonly used to assess riparian areas' water, erosion, and climate regulation. In recent years, scenario-based studies looking into the future, combining GIS and modeling, have gained importance (Vihervaara et al., 2019). Using models like SWAT and INVEST is a growing trend in various studies (Sil et al., 2016). These models also understand and manage environmental and ecological processes in riparian areas/vegetation. Therefore, these models play a crucial role, particularly in areas such as water quality, erosion control, habitat health, and the assessment of ES (Wang et al., 2017), and can also provide valuable information for understanding the ecological functions of riparian areas, planning their management, and conserving them. In this regard, the related models can contribute to decision-making processes related to the sustainability of water resources and ecosystems.

Furthermore, specific models are used to assess certain services. Models like the Revised Universal Soil Loss Equation (RUSLE) and the Universal Soil Loss Equation (USLE) can be employed to estimate stream and sheet erosion (Bogdan et al., 2016). Erosion prevention has frequently been measured in the literature on river vegetation, and ES can be a constructive tool in making decisions related to erosion prevention (Hanna et al., 2018).

The number of studies using search terms related to river areas, such as "riparian vegetation, riparian forest, riparian area, riparian zone," has steadily increased from 2000 to 2023. The majority of studies also include assessments related to ES. Prado et al. (2022), attribute the increase in studies related to ES in riverine areas to the significant influence of the MEA, supported by the graph provided in Figure 2.

In general, ES assessments enable the evaluation of the capacity of different ecosystems, which are part of the landscape, to provide services and assess land use and management. These approaches provide an opportunity to understand how complex ecosystems like riparian areas and changes in these areas affect the supply of ES, which enhances the understanding of the importance of conserving and using riparian vegetation for ecosystems' ecological and social functions. Each indicator of ES provides different information. The results demonstrate the variability in indicators, data sources, and methods used to measure ES in river habitats. The wide variety of methods reflects the flexible nature of the concept of ES, which is one of its strengths. Nevertheless, using valid methods for measuring ES to yield useful results for river ecosystem management is important. The most critical characteristics of an ES indicator are that it should be clearly defined and accurately represent the service and direction it intends to quantify. These findings suggest that more attention should be given to evaluating various ES in river ecosystem service research, covering all categories, alongside individual studies.

4. Conclusion

In the 21st century, coastal ecosystems play a critical role in determining the vulnerability of natural and human systems to climate change and the impact on their adaptive capacity. Riparian vegetation, found in semi-terrestrial regions bordering water bodies and influenced by freshwater, stands as one of the world's most dynamic and vulnerable ecosystems. River ecosystems are crucial for their services to humans and the environment. Due to anthropogenic activities (land use changes, pollution, etc.), alterations in hydrological regimes, or the invasion of non-native species, these areas are rapidly deteriorating and becoming less resilient and more susceptible to degradation. Since interactions between terrestrial and aquatic ecosystems characterize river ecosystems, most of their ecological processes affect the wetland and the surrounding landscape, making these areas increasingly sensitive. Consequently, in recent years, riparian vegetation and its functions, depending on various definitions, have attracted the attention of many researchers.

The concept of ES is a crucial tool for river ecosystem management. However, when examining the literature over many years, it becomes evident that the number of studies on this subject is still insufficient. Conducting comprehensive reviews in the Scopus database covering all languages and categories helps address the gaps in the existing literature. The current study, an analysis of studies conducted from 2000 to July 2023 in the Scopus database revealed that the most studied ES category associated with riparian vegetation is regulating ES. Within this category, issues such as water quality regulation, climate regulation, and erosion control have been studied extensively. Water supply is studied in provisioning services, habitat provision in supporting services, and recreation and tourism in cultural services. Other ES are underrepresented due to unclear assessment methods and data availability issues. The fact that these services are often provisioning and cultural ES may be related to a lack of interest in studying ES services and methodological challenges. Among these studies, very few studies have considered methodological approaches to ES assessment. Therefore, more comprehensive studies are needed to analyze the ES provided by riparian zones and vegetation. Although there are some remarkable studies in the world trying to explain the interactions and functions of river coastal areas and vegetation with their environment, there are limited studies. In Turkey, the number of studies in this field is almost non-existent. Analyses of riparian studies often focus on single features or functions of riparian areas. Specifically, studies focus on habitat function and water dynamics. Since ecosystems work as a whole, that is, they are interrelated. However, studies focusing on one or a few services do not help fully understand river ecosystems. Very few studies in the literature evaluate all components of ES. Future research should adopt an integrated multidisciplinary approach and focus on the combined assessment of the many ES provided by river ecosystems. Considering the climate and land cover change processes, it will be important to examine the effects of these changes on river coastal vegetation today and in future projections and to consider landscape and spatial scale approaches. Developing more integrated approaches to river coastal areas and vegetation will help to understand the comprehensive assessment of the services provided by the ecosystem (de Sosa et al., 2018). At the same time, river bank vegetation is an important indicator for assessing the condition of the river bank. It should be taken into account for successful river restoration efforts.

Riparian vegetation plays a critical role in the conservation and sustainability of water resources and aquatic ecosystems, along with the important ES provided by natural ecosystems. These areas are important for the functionality and richness of aquatic ecosystems and the natural life around them. The ES provided by riparian vegetation have great importance in a wide range of areas such as ensuring the functioning of aquatic ecosystems, supporting biodiversity, protecting water quality, combating climate change, and protecting water resources. Protection and restoration of riparian areas should be considered an important step in ensuring the sustainability of water resources and the natural environment. Conservation of riparian vegetation is an urgent need for the sustainable development of ecosystems and societies, and therefore protecting and improving these areas can play a key role in the conservation and management of wetlands and vegetation.

Even with "high-level" policy and legal measures [European Green Deal (UN, 2019), UN Decade of Ecosystem Restoration (UN, 2019)] to address issues related to the ecological functions of riparian vegetation, there is little or no basic knowledge of riparian vegetation. Therefore, clear recognition and sustainable management are urgently needed to protect and restore important wetland functions and services for current and future generations. Especially in recent years, there has been a contrast between the establishing of important frameworks such as the European Green Deal, the UN Decade of Ecosystem Restoration, and the targets for 2050 to restore ecosystems and the lack of emphasis on these areas. The targets of the UN Decade of Ecosystem Restoration for the restoration of all European rivers by 2050 require an increase in the importance of these areas and a clearer definition of the assessment procedures. In this respect, understanding the importance of riparian vegetation, which provides many services with its ecological functions, will be important in ensuring the sustainability of the ecosystem.

Despite high-level policies and legal measures to address issues related to the quality and current condition of aquatic habitats, there is little or no designation of riparian zones. The European Union Water Framework Directive (WFD) also aims to improve river coastal health in the European Union by promoting the sustainable use of ES provided by watercourses (Singh et al., 2021). The UN Decade (2021-2030) (UN, 2019) establishes a common vision of ecosystem restoration as "a process of halting or reversing degradation with improved ES and restored biodiversity to halt the degradation of ecosystems and restore terrestrial, freshwater and marine ecosystems". The European Green Deal (EC, 2019) is a holistic document that aims to improve the well-being and health of citizens and future generations. The 2030 EU Biodiversity Strategy includes legally binding EU nature conservation targets for restoring degraded ecosystems. The main objective of these processes is to restore degraded river areas through restoration activities, and the most important indicator of this is riparian vegetation. In restoring ecosystem health, the improvement of vegetation cover and the sustainability of ES should be ensured. Therefore, clear recognition and sustainable management are urgently needed to protect and restore important wetland functions and services for present and future generations. Despite the critical role of riparian zones for freshwater ecosystems, there is still a need to clarify the key priorities and actions for developing and managing effective policies. Demonstrating the importance of riparian areas and mitigating their vulnerability to land use and climate change, preventing biodiversity loss, and ensuring the sustainability of ES will be important for building resilient and sustainable ecosystems in the future.

References

Aznar-Sánchez, J.A., Belmonte-Ureña, L.J., López-Serrano, M.J., Velasco-Muñoz, J.F., 2018. Forest ecosystem services: An analysis of worldwide research. Forests, 9(8): 453.

Betz, F., Lauermann M., Cyffka, B., 2018. Delineation of the riparian zone in data-scarce regions using fuzzy membership functions: An evaluation based on the case of the Naryn River in Kyrgyzstan. Geomorphology, 306:170-181.

Bogdan, S.M., Pătru-Stupariu, I., Zaharia L., 2016. The assessment of regulatory ecosystem services: the case of the sediment retention service in a mountain landscape in the Southern Romanian Carpathians. Procedia Environmental Sciences, 32:12-27.

Clarke, A., Mac Nally, R., Bond, N., Lake, P.S., 2008. Macroinvertebrate diversity in headwater streams: a review. Freshwater biology, 53(9): 1707-1721.

National Research Council, 2002. Riparian areas: functions and strategies for management. National Academies Press, Washington, DC.

De Groot, R.S., Wilson, M.A., Boumans, R.M., 2002. A typology for the classification, description and valuation of ecosystem functions, goods and services. Ecological Economics, 41(3): 393-408.

de Sosa, L.L., Glanville, H.C., Marshall, M.R., Williams, A.P., Jones, D.L., 2018. Quantifying the contribution of riparian soils to the provision of ecosystem services. Science of the Total Environment, 624: 807-819.

Deeksha, Shukla, A.K., 2022. Ecosystem services: A systematic literature review and future dimension in freshwater ecosystems. Applied Sciences, 12(17): 8518.

Dufour, S., Rodríguez-González, P., 2020. Riparian zone/riparian vegetation definition: principles and recommendations. report, COST Action CA16208, Converges European Riparian Ecosystems, 20, https://converges.eu/resources/riparian-zone-riparian-vegetation-definition-principles-and-recommendations/. Access date: 01.11.2023

Dufour, S., Rodríguez-González, P.M., Laslier, M., 2019. Tracing the scientific trajectory of riparian vegetation studies: Main topics, approaches and needs in a globally changing world. Science of the Total Environment, 653: 1168-1185.

EC, 2019. European Commission, The European Green Deal, https://eur-lex.europa.eu/resource.html?uri=cellar:b828d165-1c22-11ea-8c1f-01aa75ed71a1.0002.02/DOC_1&format=PDF

Fonseca, A., Zina, V., Duarte, G., Aguiar, F.C., Rodríguez-González, P.M., Ferreira, M.T., Fernandes, M.R., 2021. Riparian Ecological Infrastructures: Potential for biodiversity-related ecosystem services in Mediterranean human-dominated landscapes. Sustainability, 13(19): 10508.

Fu, B., Li, Y., Wang, Y., Zhang, B., Yin, S., Zhu, H., Xing, Z., 2016. Evaluation of ecosystem service value of riparian zone using land use data from 1986 to 2012. Ecological Indicators, 69: 873-881.

González, E., Felipe-Lucia, M.R., Bourgeois, B., Boz, B., Nilsson, C., Palmer, G., Sher A.A., 2017. Integrative conservation of riparian zones. Biological Conservation, 211: 20-29.

Haase, D., Larondelle, N., Andersson, E., Artmann, M., Borgström, S., Breuste, J., Gomez-Baggethun, E., Gren, Å., Hamstead, Z., Hansen, R., 2014. A quantitative review of urban ecosystem service assessments: concepts, models, and implementation. Ambio, 43: 413-433.

Hanna, D.E., Tomscha, S.A., Ouellet Dallaire, C., Bennett, E.M., 2018. A review of riverine ecosystem service quantification: Research gaps and recommendations. Journal of Applied Ecology, 55(3): 1299-1311.

Hoppenreijs, J.H., Eckstein, R.L., Lind, L., 2022. Pressures on boreal riparian vegetation: A literature review. Frontiers in Ecology and Evolution, 9: 806130.

Kandel, P., Chettri, N., Chaudhary, S., Sharma, P., Uddin, K., 2021. Ecosystem services research trends in the water tower of Asia: A bibliometric analysis from the Hindu Kush Himalaya. Ecological Indicators, 121: 107152.

Liu, L., Wang, Z., Wang, Y., Zhang, Y., Shen, J., Qin, D., Li, S., 2019. Trade-off analyses of multiple mountain ecosystem services along elevation, vegetation cover and precipitation gradients: A case study in the Taihang Mountains. Ecological Indicators, 103: 94-104.

Maraseni, T., Mitchell, C., 2016. An assessment of carbon sequestration potential of riparian zone of Condamine Catchment, Queensland, Australia. Land Use Policy, 54: 139-146.

Martin-Lopez, B., Leister, I., Lorenzo Cruz, P., Palomo, I., Grêt-Regamey, A., Harrison, P.A., Lavorel, S., Locatelli, B., Luque, S., Walz, A., 2019. Nature’s contributions to people in mountains: A review. PloS one, 14(6): e0217847.

McDonough, K., Hutchinson, S., Moore, T., Hutchinson, J.S., 2017. Analysis of publication trends in ecosystem services research. Ecosystem Services, 25: 82-88.

Millennium Ecosystem Assessment, 2005. Ecosystems and human well-being. Island Press, Washington, DC.

Mengist, W., Soromessa, T., Legese, G., 2020. Ecosystem services research in mountainous regions: A systematic literature review on current knowledge and research gaps. Science of The Total Environment, 702: 134581.

Mongeon, P., Paul-Hus, A., 2016. The journal coverage of Web of Science and Scopus: a comparative analysis. Scientometrics, 106: 213-228.

Muller, E., 1997. Mapping riparian vegetation along rivers: old concepts and new methods. Aquatic Botany, 58(3-4): 411-437.

Naiman, R.J., Decamps, H., McClain, M.E., 2010. Riparia: ecology, conservation, and management of streamside communities. Elsevier Academic Press, London, UK.

Nilsson, C., Jansson, R., Kuglerová, L., Lind, L., Ström, L., 2013. Boreal riparian vegetation under climate change. Ecosystems, 16: 401-410.

Pauna, V.H., Picone, F., Le Guyader, G., Buonocore, E., Franzese, P.P., 2018. The scientific research on ecosystem services: A bibliometric analysis. Ecological Questions, 29(3): 53-62.

Pedraza, S., Clerici, N., Zuluaga Gaviria, J.D., Sanchez, A., 2021. Global research on riparian zones in the XXI century: A bibliometric analysis. Water, 13(13): 1836.

Prado, R.B., Damasceno, G.M.S., Aquino, F.d.G., 2022. Overview of studies on ecosystem services in riparian zones: a systematic review. Acta Limnologica Brasiliensia, 34 (e19):1-16.

Price, P., Tubman, W., 2007. Structure and characteristics of riparian lands. Principles for Riparian Lands Management, Land & Water: Australia, Braddon ACT.

Riis, T., Kelly-Quinn, M., Aguiar, F.C., Manolaki, P., Bruno, D., Bejarano, M.D., Clerici, N., Fernandes, M.R., Franco, J.C., Pettit, N., 2020. Global overview of ecosystem services provided by riparian vegetation. BioScience, 70(6): 501-514.

Sil, Â., Rodrigues, A.P., Carvalho-Santos, C., Nunes, J.P., Honrado, J., Alonso, J., Marta-Pedroso, C., Azevedo, J.C., 2016. Trade-offs and synergies between provisioning and regulating ecosystem services in a mountain area in Portugal affected by landscape change. Mountain Research and Development, 36(4): 452-464.

Singh, R., Singh, G., 2020. Integrated management of the Ganga River: An ecohydrological approach. Ecohydrology & Hydrobiology, 20(2): 153-174.

Singh, R., Tiwari, A., Singh, G., 2021. Managing riparian zones for river health improvement: an integrated approach. Landscape and ecological engineering, 17: 195-223.

Sweeney, B.W., Newbold, J.D., 2014. Streamside forest buffer width needed to protect stream water quality, habitat, and organisms: a literature review. JAWRA Journal of the American Water Resources Association, 50(3): 560-584.

UN, 2019. United Nations,Resolution adopted by the general assembly, The UN Decade on Ecosystem Restoration(2021-2030). https://documents.un.org/doc/undoc/gen/n19/060/16/pdf/n1906016.pdf?token=xrNHWZHcy5YJNJDUDM&fe=true

Urbanič, G., Politti, E., Rodríguez-González, P.M., Payne, R., Schook, D., Alves, M.H., Anđelković, A., Bruno, D., Chilikova-Lubomirova, M., Di Lonardo, S., 2022. Riparian zones-from policy neglected to policy integrated. Frontiers in Environmental Science, 10: 868527.

Verdonschot, P., Verdonschot, R., 2022. The role of stream restoration in enhancing ecosystem services. Hydrobiologia, 850: 2537-2562.

Vihervaara, P., Viinikka, A., Brander, L., Santos-Martín, F., Poikolainen, L., Nedkov, S., 2019. Methodological interlinkages for mapping ecosystem services-from data to analysis and decision-support. One Ecosystem 4: e26368

Wang, B., Tang, H., Xu, Y., 2017. Integrating ecosystem services and human well-being into management practices: Insights from a mountain-basin area, China. Ecosystem Services, 27: 58-69.

Xu, J., Badola, R., Chettri, N., Chaudhary, R.P., Zomer, R., Pokhrel, B., Hussain, S.A., Pradhan, S., Pradhan, R., 2019. Sustaining biodiversity and ecosystem services in the Hindu Kush Himalaya. The Hindu Kush Himalaya Assessment: Mountains, Climate Change, Sustainability and People. Springer, Cham.

Zhang, X., Estoque, R.C., Xie, H., Murayama, Y., Ranagalage, M., 2019. Bibliometric analysis of highly cited articles on ecosystem services. PloS one, 14(2): e0210707.