A Systematic Review of Non-Monetary Valuation of Ecosystem Services for Stream Restoration Practitioners

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1 Introduction

Small streams make up around 80% of the total stream length in the world (Richardson, 2020) and provide benefits through services such as water quality, recreation, and biodiversity. For example, the Lotic Intersite Nitrogen eXperiment (LINX) study showed that there were shorter inorganic nitrogen uptake distances within lower order streams (Peterson et al., 2001). Given the diverse habitats of headwater streams, there is a range of biota that exist only within these systems and which play a critical role in shaping downstream food webs (Meyer et al., 2007). Small streams are targeted for restoration due to their impact on downstream waterbodies and their cultural significance (Durance et al., 2016; Elosegi et al., 2017). Additionally, because they are widespread and easily manipulated, small streams are frequently impacted by human activities.

Unfortunately, there is no universally agreed-upon definition of “small” or “headwater” streams. Meyer et al. (2007) defined headwaters as “springs and intermittent, first and second-order streams.” Richardson (2020) defined headwaters as the origin of a stream or waterway that does not have consistent tributaries feeding the stream. Similarly, in Ferreira et al. (2023) headwaters were defined as 1st order streams, and small streams were considered 2nd order streams. In contrast, differentiation of streams versus rivers was made using the bankfull width, where flowing bodies of water with a bankfull width less than 15 ft. were considered streams (Czuba, 2023). Due to the lack of a widely accepted definitions of small streams and headwaters, this literature review focused on 1st to 3rd order perennial streams, with drainage areas of less than 50 mi.^{2}.

Common goals of stream restoration include improving fisheries, mitigating impacts, increasing overall ecological integrity, and restoring the geomorphic stability of streams. However, the drivers of stream restoration have changed over time. Initial projects focused on improving fisheries; habitat improvement projects started in the northeastern U.S. in the early 1900s (Thompson and Stull, 2002). With the adoption of the U.S. Clean Water Act in 1972, mitigation of unavoidable impacts to aquatic resources was required to restore lost ecosystem functions; however, early stream restoration efforts often focused primarily on geomorphic channel stability, rather than ecological functions. This focus on channel stabilization increased in the Chesapeake Bay watershed in 2010 when the U.S. Environmental Protection Agency (US EPA) released new guidelines for the Chesapeake Bay watershed total maximum daily load (TMDL) program that provided nutrient and sediment load reduction credits for stream restoration (US EPA, 2010). As a result, the number of stream restoration projects focused on water quality improvement and channel stabilization increased within the US mid-Atlantic region to meet the TMDL load reduction requirements. At the same time, it was increasingly recognized that there are important feedbacks between the biotic and abiotic components of stream systems; therefore, stream restoration projects should focus on both physical and ecological processes, rather than just channel form (Noe et al., 2024). Research has shown that, to improve stream ecological functions, stream restoration needs to restore heterogeneity, connectivity, and both hydrologic and morphological dynamism (Gilvear et al., 2013), which are reduced when channel stability is prioritized.

Given that ecological uplift should be a primary focus of all stream restoration projects (Noe et al., 2024), stream restoration designs should focus on ecosystem processes rather than focusing only on channel stability. The concept of ecosystem services, the idea that nature supports human well-being, provides a useful framework for a wholistic assessment of stream restoration projects. The idea that functional ecosystems provide important goods and services to human society originated in the late 1960s, although the term "ecosystem services" was not used until the early 1980s (De Groot et al., 2017). Ecosystem services (ES) are defined by the Common International Classification of Ecosystem Service (CICES) as the "contributions that ecosystems make to human well-being." ES assessments, such as the UK National Ecosystem Assessment (UK National Ecosystem Assessment, 2011) are now used to assess and manage natural resources. These assessments can identify trade-offs among multiple management goals, as prioritization of one ES can lead to increases or reductions in other ES (De Groot et al., 2017). For example, managing a river for drinking water quality can increase the creation of riparian buffers, which also improves wildlife habitat and biodiversity.

The valuation of ES provides an effective method of communication for with various project stakeholders (Böck et al., 2015), as there is a lack of recognition for the wide range of ES that river restoration can provide (Gilvear et al., 2013). The motivation in valuation ranges from reaching policy goals, to monitoring ecological integrity (UN, 2024). The United Nations (UN) System of Environmental Economic Accounting (SEEA) monetarily values ES. However, ES can also be valued using non-monetary indicators, which was the target of this study. This study aimed to assess the intermediate and final ES of design options to provide a comprehensive overview of the ES that can be provided by different restoration techniques. Final ES were defined as the desired functions or services provided by the ecosystem. In contrast, the intermediate services support the processes needed to provide the final ES (Haines-Young, 2018).

An ES assessment tool can be used to inform and assess stream restoration planning and design (Everard and Moggridge, 2011). For example, the stream reach targeted for restoration could be assessed to determine the ES currently being supported and to establish project goals. Then, stream restoration techniques which increase limited ES could be used to implemented the overall function of the stream ecosystem. Following project completion, the ES assessment could be repeated to determine if the desired change in ecosystem function was achieved.

The goal of this systematic review (SR) was to provide an overview of the ES provided by streams that can be increased through stream restoration activities. This goal was addressed by answering the following five questions: 1) What are ES?; 2) What are the ES of small streams?; 3) What tools are used for ES valuation?; 4) What are the classification systems for ES?; and, 5) What are examples of ES used in stream restoration and management? These five questions were used to identify the ES provided by different stream restoration designs that are applicable within the Chesapeake Bay watershed. As the main focus of this paper was on the mid-Atlantic region of the US, the focus of this literature review was on perennial streams, including urban streams, small streams, and lowland streams, ES that are provided within the stream corridor (main channel and floodplain), and that are relevant ES for the US mid-Atlantic region.

2 Methods

2.1 Systematic Review PRISMA Document

This literature review was completed using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework, which is the most widely used and accepted SR framework. PRISMA provides flowcharts and checklists to ensure a SR is completed in systematic manner than can be easily replicated. (PRISMA, 2020). Two reviewers worked independently through this review process.

The review is completed using four steps: Identification, Screening, Eligibility, and Inclusion (Page et al., 2021). These steps provide a systematic methodology to obtain all the literature about the specified topic while avoiding bias in reference identification and selection. The first step in the process is identification, which is based on establishing consistent keywords or phrases to use for each database search (Page et al., 2021). In the screening step all the abstracts and titles of the literature collected from the databases are reviewed based on formally established exclusion criteria. For example, a criterion used within this study was "remove anything not in English." The removal of papers not in English does invoke language bias; however, the translation of journal articles can be complex the time and funding constraints for this study did not allow for the translation of papers. Eligibility is established through the full text screening of the identified papers (Higgins et al., 2024). Then, the final step in identifying resources for the literature review is inclusion, where the selected papers are reviewed in depth, through quantitative and qualitative assessments (Higgins et al., 2024). By following and communicating the results of each step, SRs provide unbiased information and are considered the gold standard of literature reviews. This SR was completed using an online SR tool called Covidence (Covidence, 2025).

2.2 *PRISMA Systematic Review: Identification*

To identify research literature addressing the review questions, two keyword strings were created. Given that the paper Ecosystem Services of Small Streams: An Overview was considered a sentinel article in this SR, the database search strings were adjusted until the search results identified this key paper. The final search strings were as follows:

1. "ecosystem service*" AND "stream*"
2. ("ecosystem service*") AND ("stream*" OR "river*" OR "watercourse*") AND ("classification" OR "management" OR "quantification").

The Boolean operator "AND" was used to connect the words; truncation "*" was used on both terms to ensure that all papers with the root of stream or service were included. The Boolean operator "OR" was used when two words were of interest and could be considered interchangeable (Collaboration, 2013). As every database requires a slightly different keyword format, there were slight adjustments to the search strings.

Box 1. Literature Review Sources

Primary Literature Sources

- ProQuest: Environmental Science Database & Index
- ProQuest: Biological Science Database & Index
- Web of Science: Web of Science Core Collection
- Web of Science: BIOSIS or landscape-scale

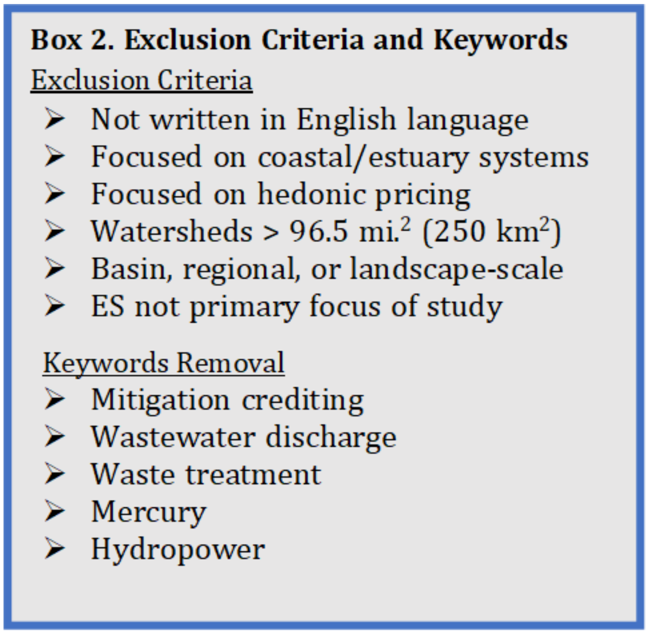
Secondary/Grey Literature Sources

- Google Scholar
- VoxGov

These two search strings were used to identify both primary and secondary sources. Primary literature is typically peer-reviewed literature from academic databases (Collaboration, 2013), while secondary or "grey" literature is obtained from non-academic sources such as a google searches, governmental agencies, nonprofits, and etc. (Collaboration, 2013). There were 862 studies obtained from the primary source databases identified in Box 1. Filters were applied to each database so that only journal articles, reports, and books were returned. Relevant "grey literature" was collected from a Google Scholar search of the National Oceanic Atmospheric Administration (NOAA) and the European Environmental Agency (EEA) governmental agency websites, the Government Documents Round Table (GODORT) database, and a governmental database called VoxGov. A total of 388 grey literature documents were retrieved, providing a total of 1,250 references from the primary and secondary literature searches (Box 1).

2.3 *PRISMA Systematic Review: Screening*

As a first step in screening, 540 duplicate articles were removed. Exclusion criteria were developed to identify and remove papers that were not applicable to stream restoration projects in the mid-Atlantic. For example, studies focused on the ES of large watersheds or regions, coastal or estuary systems, or rivers were excluded. Many papers were identified because the term "ecosystem services" was included in the abstract as a general term, rather than the focus of the study. The exclusion criteria for the screening process were formulated by the two literature reviewers and was shown in Box 2. The remaining 710 papers were reviewed based on these criteria; if any of the exclusion criteria were within the abstract or title, the document was removed from the study. An additional 643 papers were removed from the study during the screening process.



Box 2. Exclusion Criteria and Keywords

Exclusion Criteria

- Not written in English language
- Focused on coastal/estuary systems
- Focused on hedonic pricing
- Watersheds > 96.5 mi.^{2} (250 km^2)
- Basin, regional, or landscape-scale
- ES not primary focus of study

Keywords Removal

- Mitigation crediting
- Wastewater discharge
- Waste treatment
- Mercury
- Hydropower

2.4 *PRISMA Systematic Review: Eligibility*

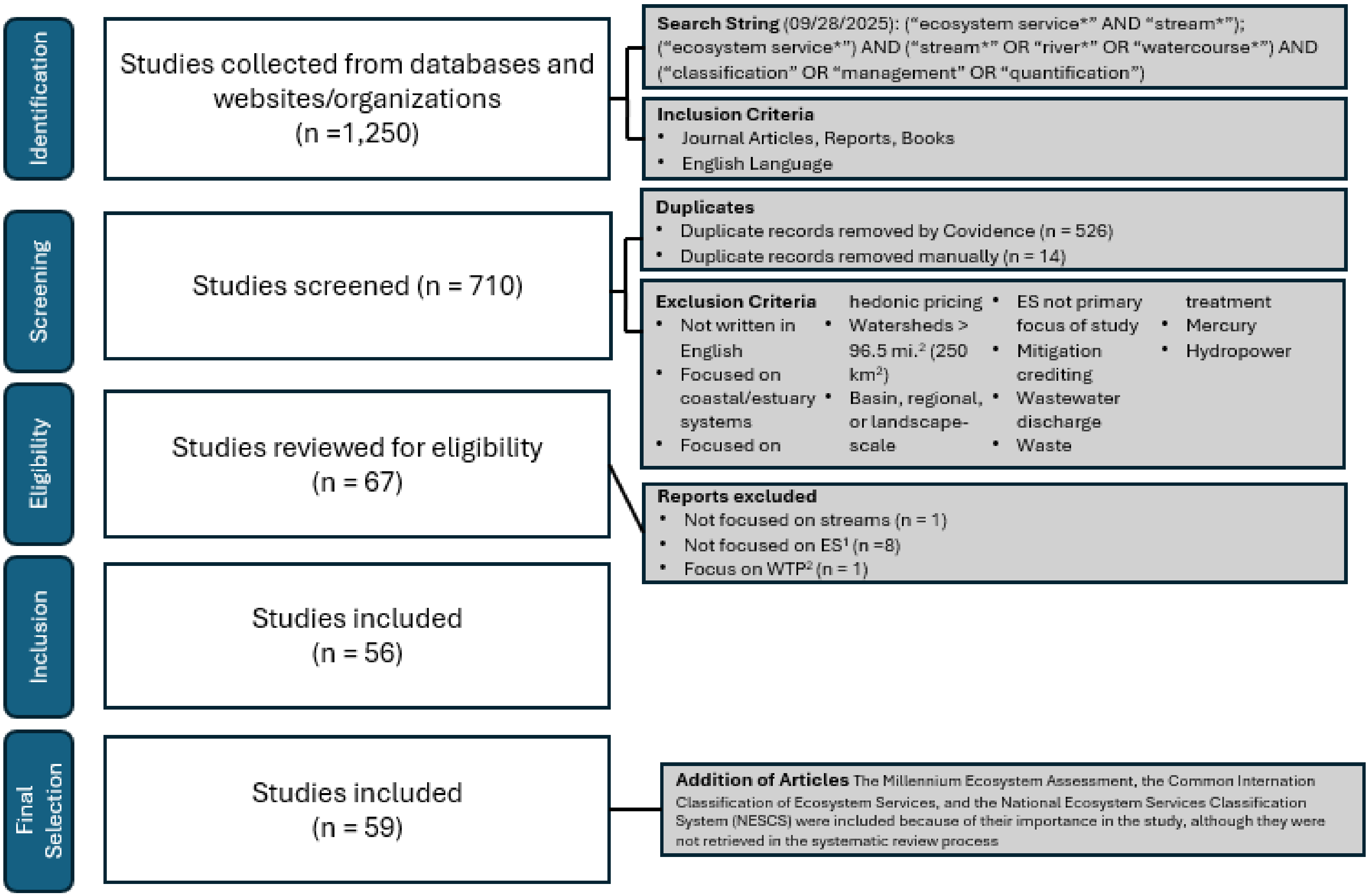
After the screening section was completed, the remaining 67 papers were assessed for eligibility by reviewing the full text of each paper. Papers that did not provide information relevant for the study questions were excluded from the literature review and a specific reason was provided each removal. There were eleven documents removed from the study after this step.

2.5 *PRISMA Systematic Review: Inclusion*

Using the 56 papers identified through the systematic selection process, the literature review was developed. The graphic for the PRISMA systematic review process was shown below in Figure 1.

2.6 *Additional Document Addition*

Through the literature review, three common classification systems were identified: the Millennium Ecosystem Assessment (MEA); Common International Classification of Ecosystem Services (CICES); and, the National Ecosystem Services Classification System (NESCS). To provide specific information about these classification systems, three additional governmental documents were added to this study. The addition of these



[1] Ecosystem Services (ES)
[2] Willingness to Pay (WTP)

Figure 1. PRISMA Systematic Review Flowchart (Adapted from Page et al., 2021; Sett et al., 2026)

papers was atypical in a SR, but these papers were added as they were foundational to ES classification.

3 Results/Discussion

The following sections summarize the identified research literature and reports to address the primary study questions.

3.1 What are ecosystem services?

While the definition of ES has changed over time, a more recent definition is "contributions that ecosystems make to human well-being" (Haines-Young, 2023). The benefit of using ES is that they act as a bridge between practitioners and the public by communicating and raising awareness of existing and future environmental conditions (Böck et al., 2018; Newcomer-Johnson et al., 2020). ES have been applied in multiple different biomes and contexts. For example, ES could be used to quantify the services that forests provide. For environmental management, the ES can be valued to assess the condition of the ecosystem or to assess trade-offs of different restoration practices or management strategies (Schuster et al., 2015). Both monetary and non-monetary methods are used to quantify ES. The valuation of ES can also be helpful in policy development (Haines-Young, 2012).

3.2 Ecosystem services classifications

Classification systems are used for ES studies to ensure consistency among and across studies. Three ES classification systems are the Common International Classification of Ecosystem Services (CICES), the Millenium Ecosystem Assessment (MEA), and the National Ecosystem Services Classification System (NESCS). These systems are similar, as the CICES and the NESCS were developed based on the MEA. While all the classification systems have similar goals, because the CICES system is used internationally and continues to be updated based on user-experience, the ES in this review will be classified according to the CICES system.

In the MEA, ES were defined by four categories: provisioning, regulating, supporting, and cultural. However, within the CICES, the supporting ES classified by the MEA were included in one of the three CICES categories, typically within the maintaining and regulating category. Figure 2 illustrates how ES are classified using the MEA system were recategorized under the CICES system. This section describes the three different ES classification systems and provides examples of these classification systems when available.

3.2.1 Millenium Ecosystem Assessment (MEA)

The original Millenium Ecosystem Assessment (MEA) was initiated by the United Nations (UN) Secretary, Kofi Annan, and was developed by a board of representatives from the Convention of Biological Diversity, the Convention to Combat Desertification, the Ramsar Convention on Wetlands, the UN convention on Migratory Species, governmental agencies, indigenous groups,

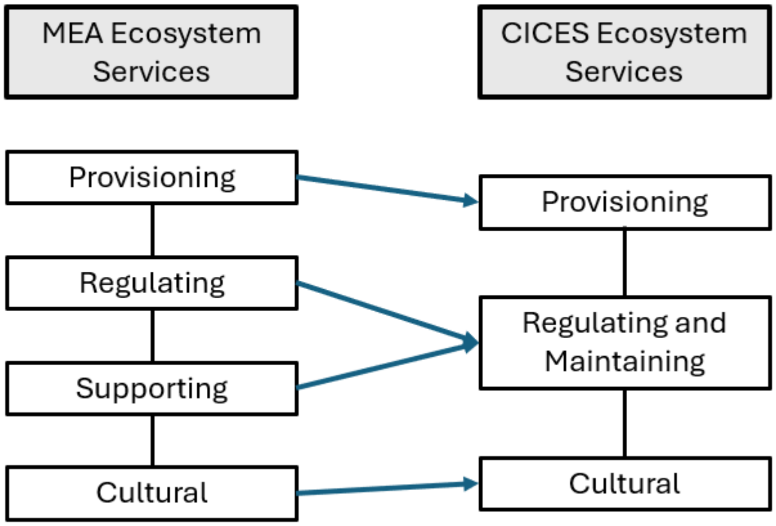


Figure 2. Connection between the categories in the Millenium Ecosystem Assessment (MEA) and Common International Classification of Ecosystem Services (CICES) classification systems (Haines-Young, 2023; MEA, 2005)

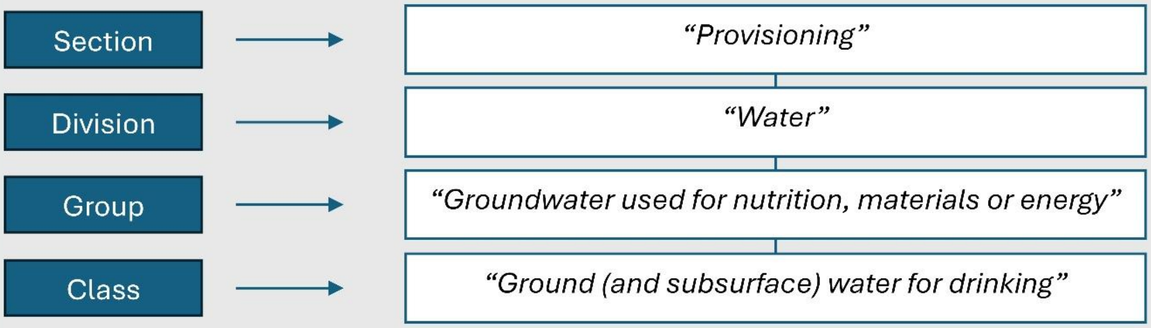
the private sector, and nongovernmental organizations; the final report was released in 2005. The MEA was developed to provide a method to assess the condition of the environment and actions that can be taken to improve the environment (MEA, 2005). The MEA defines ES as "the benefits people obtain from ecosystems" and divides ES into four categories: provisioning, regulating, supporting, and cultural. Unlike the CICES, the MEA does not follow a hierarchical structure. Within the MEA, provisioning ES are based on the supply of goods generated from the environment, whereas regulating conditions services are processes needed for ES outcomes. Biodiversity was considered a support to other ES, rather than a separate ES. The provision of cultural ES is difficult to assess, as the value of the cultural ES are subjective. The MEA suggested the use of indicators to assess the ES; indicators should use standardized methods so they are representative and reproducible. The use of data, models, and scenarios could also help to value ES (MEA, 2005).

An example of the application of the MEA system to an urban river restoration project is described by Everard and Moggride (2011). An ES assessment was used to determine the potential benefits of a project in Mayesbrook Park, East London. Study results indicated the project would likely have multiple significant benefits for the local community. Increases in regulating services (air and water quality, microclimate, flood risk, and sediment storage), supporting services (nutrient cycling and wildlife habitat), and cultural services (recreation, tourism, local revitalization, educational opportunities) were significant. In contrast, given that food, fiber, and fuel were not produced at the site originally and were not included in the project plan, provisioning ES were not expected to change. This application of ES showed that, even through urban streams experienced anthropogenic impacts, they were still able to provide goods and services for human well-being. The use of ES and the MEA enabled a structured assessment of the project benefits and impacts and improved communication with the public.

3.2.2 The Common International Classification of Ecosystem Services

The CICES was originally developed by the European Environment Agency (EEA) to facilitate ES accounting. Developed in 2009, the first version of the CICES was based on the MEA classification system (MEA, 2005). Unlike the MEA, the CICES was created with a hierarchical structure that is outlined in an Excel spreadsheet. The first tier of categorization is Sections, which are provisioning, regulation and maintenance, and cultural. The next classification tier is Division, followed by Group. The lowest classification level is Class (Appendix A). An example ES classification using the CICES is shown in Box 3.

Box 3. Application of CICES with Groundwater Provisioning (Haines-Young, 2023)



A common concern with ES classification is that some ES will be double-counted. For example, if a riparian area is used to graze beef cattle, double-counting can occur if the ES of the pre-restoration riparian area includes both the grass production and the beef production, since grass production is part of beef production. To minimize the likelihood of double-counting, the CICES was revised to differentiate between intermediate (grass production) and final (beef production) ES. The current (2026) version of the CICES is 5.2.

A study by Tujin (2020) provides an example of the use of the CICES for in watershed management. For this research, the authors compared the effects of four different weir heights using ES, as part of a plan for a reach of the Raam River in the Netherlands. The project goals included raising groundwater levels, decreasing flooding and enhancing biodiversity. Due to the surrounding land use the project also aimed to increase water retention, provide agricultural drainage, and reduce flood risk. Five ES were used to assess the alternatives within this study (ground water provisioning, flow control, crop and livestock provisioning, policy goals, and cultural); each of the ES were provided with the respective CICES code, except for policy goals, as that does not have a CICES code. The ES within this study were quantified using models such as iMOD, SOBEK Suite, WaterWijzer Landbouw, and TEEB-stad. Through this evaluation it was shown that the highest weir level provided the highest level of ES, despite a predicted reduction in crop yields.

3.2.3 National Ecosystem Services Classification System (NESCS)

Following the development of the MEA and CICES systems, the U.S. Environmental Protection Agency (EPA) developed the National Ecosystem Services Classification System (NESCS). The goal of this classification system is different from the MEA and CICES, as it aims to provide a more comprehensive classification system through the explicit separation of intermediate and final ES. The classification system uses universal terminology and organization, and includes extensive review of the ES (Newcomer-Johnson et al., 2020).

As with the CICES system, the NESCS has a hierarchical structure that classifies the environment, ecological goods, use, user, and beneficiary. The environment state is the general ecosystem type (aquatic versus terrestrial) where the ES is provided. Ecological goods are the tangible goods or services from the environment. For example, in a grassland environment the ecological end product could be the fauna. The direct use is then the “ecosystem service” or the service/good that the environment was providing, such as aesthetics. Finally, the direct user was the group of people that would be using the ES. In this example households are a user (Newcomer-Johnson et al., 2020). The beneficiary is used to combine the direct use and direct user into one category, such as farmers (Newcomer-Johnson et al., 2020).

Given the relatively recent development of the NECES, none of the research papers identified through the SR review applied this classification system. However, the NESCS is comparable to the CICES classification system and could be applied in a similar way.

3.3 Ecosystem services of small streams

As described in the River Continuum Concept (Vannote et al., 1980), characteristics of streams and rivers, such as discharge, channel morphology, and aquatic ecology, vary in predictable ways with watershed area. As a result, ES also vary with stream order, as described by Yeakley et al. (2016). While small streams provide all ES within a given reach, they support more regulating and maintenance services than larger systems, including water purification, water/nutrient cycling, and primary production. The provisioning services provide food, water, materials, and genetics, while the cultural ES include aesthetics, inspiration, recreation, education, and spiritual (Ferreira et al., 2023). In addition to spatial variations in ES, there is variation in the amount and type of ES provided by streams over time, such as those services related to recreation. The fluctuation in ES value occurs due to the change in seasons, as people may be more likely to go outside and use recreational infrastructure in temperate weather.

Although most management actions focus on rivers, lakes, and estuaries, first and second order streams constitute 70-90% of all river miles globally (Downing et al. 2012). Ferreira et al. (2023) conducted a review of the ES provided by small streams. These small water bodies occur in the upper reaches of watersheds and provide benefits to downstream waters, supporting the ES of receiving waterbodies. Therefore, quantifying and increasing the ES supported by small streams is critical. A summary of these ES and studies that assessed them are provided in Table 1.

3.4 Tools for ecosystem service valuation

There are both monetary and non-monetary methods for ES valuation. Monetary valuation methods typically require a non-monetary valuation of ES as an initial step before a monetary value can be assigned. Since one of the aims of stream restoration projects is to increase ecological integrity, quantifying the monetary value of ES is not necessary to compare stream restoration design options. However, some of the papers identified in the SR that used monetary valuation were retained for the literature review and are discussed in this section, as they provide useful information on non-monetary valuation methods.

Both monetary valuation and non-monetary valuation use indicators to assess the value of ecosystem services. Indicators are used to represent the condition or quantity of ES. An example ES indicator of fish provisioning is the abundance of fish species in number of individuals/hectare(ha) (Pastor et al., 2022). While there can be multiple different indicators for each ES, not all indicators will be applicable in every study and indicators should be selected on a case-by-case basis.

Indicators used for multiple different types of waterbodies were included in the summary of indicators, including intermittent rivers and ephemeral streams (IRES), rivers, urban streams, freshwater, small streams, floodplains, perennial coastal streams, and lowland streams. These indicators were grouped following the three CICES sections (provisioning, regulating, and cultural) and are summarized in Appendices B, C, and D, respectively. Where relevant, the units of each indicator were identified.

3.4.1 Provisioning Ecosystem Service Indicators

The provisioning ES are split into five major categories: food, water supply, agriculture, fiber and fuel, and other (Appendix B). The food indicators for the wild game and the fish are based on the number of species present as well as hunting/fishing licenses (Pastor et al., 2022). In contrast, the wild mushrooms and berries are based on the amount and density of the plants (Pastor et al., 2022).

Water supply contains the most ES indicators within the provisioning category. Water supply is split into two groups: water used for drinking and for non-drinking purposes. Based on the literature within this review, the most common uses besides drinking water are irrigation and industrial uses. The water supply ES has been quantified based on the number of people within communities, the quantity of groundwater supplied (gallons/day), and the quality of the supplied water (Pastor et al., 2022; Verdonschoot and Verdonschoot, 2023). For example, the Foundation for Applied Water Research (Stichting Toegepast Onderzoek Waterbeheer, STOWA) in the Netherlands studied the Raam River basin, using the iMOD groundwater model to estimate the available groundwater supply for the development of wetland regions (Tuijn, 2020). The agricultural ES from water supply consisted of crops and livestock. Indicators of the value of fiber and fuel produced by ecosystems can be quantified using the weight of material, the amount of forest, and/or the energy produced from hydropower (Pastor et al., 2022; Verdonschot and Verdonschot, 2023; Jakubínský and Cudlín, 2018). The “other” category quantifies ES for peat formation, provision of construction material, genetic material, and biochemical extract of medicine (Pastor et al., 2022).

3.4.2 Regulating and Maintenance Ecosystem Service Indicators

The regulating and maintenance indicators are split into 13 broad categories (Appendix C):

1. Biodiversity;
2. Carbon storage;
3. Climate regulation;
4. Erosion control;
5. Habitat provisioning;
6. Hazard mitigation;
7. Nutrients;
8. Organic matter breakdown;
9. Pest/disease control;
10. Sediment;
11. Stream metabolism;
12. Water purification; and,
13. Other.

Biodiversity was included as an ES in eight different studies, though it is not included in the CICES classification system. It could be categorized in the regulation and maintenance Section, with the other types of regulation and maintenance services by living processes Division, with a Group and Class of Other within the CICES classification system.

There were several studies identified through the literature review that assessed the regulating and maintenance ES of small streams; examples of commonly used indicators are provided in this section. The value of biodiversity in streams was measured using methods such as the average score per taxon (Michael-Bitton et al., 2025), Shannon-Wiener Index (Angela et al., 2015), and food web structure (Durance et al., 2016). Carbon storage was typically quantified by the % area of forest within the floodplain (Van Looy et al., 2017), while common indicators for climate regulation included air temperature (Calapez et al., 2023), humidity (Calapez et al., 2023; Van Looy et al.), and land cover present (Verdonschot and Verdonschot, 2023). Erosion control was quantified through the large wood present in the channel (Pastor et al., 2022), bedforms, valley slope, and bank conditions (Pastor et al., 2022), while hazard mitigation was assessed by evaluating flood magnitude and frequency using computer models (Tuijn, 2020; Pastor et al., 2022; Verdonschot and Verdonschot, 2023). Habitat provisioning within streams was evaluated based on the amount of different habitats available and the number of human structures blocking the stream, such as run-of-the-river dams (Jakubínský and Cudlín, 2018; Verdonschot and Verdonschot, 2023). Indicators such as nutrient uptake rates, floodplain connectivity, and presence of riparian buffers can be used to quantify stream nutrient processing ES (Pastor et al., 2022; Sweeney et al., 2004; Van Looy et al., 2017), while pest and disease control were assessed using taxonomic diversity, invasive species present, and yearly infection rates. Sediment indicators quantified sediment storage, decomposition, and formation, which were measured using microbial biomass, coarse particulate matter (CPOM), and leaf litter breakdown (Elosegi et al., 2017; Yates et al., 2019; Verdonschot and Verdonschot, 2023). Stream metabolism was assessed through the plant/algal biomass and the overall value of the stream metabolism (Yates et al., 2019; Schäfer et al., 2012). The extent of water purification was indicated using nitrogen and suspended soils concentrations, plant biomass, and groundwater levels.

3.4.3 Cultural Ecosystem Service Indicators

Cultural ES are typically considered the most difficult to estimate as the importance or meaning of a place is different for every person. As a result, cultural ES are rarely assessed using monetary valuation. Instead, multiple studies used surveys as a valuation method for cultural ES (Julian et al., 2018; Alvarado-Arias, 2023; Böck et al., 2015). The major categories within the cultural ES are aesthetics, education, recreation, spiritual/religious, and other (Appendix D).

Common valuation techniques for aesthetics are based on social media posts (Pastor et al., 2022), trails/recreation nearby (Jakubínský and Cudlín, 2018), and computer modeling programs such as: InVEST, and TEEB-stad (Tuijn, 2020). For example, Sanchez (2022) used social media as a method for determining popular recreation locations using geotags. Similarly, education value was quantified by the number of educational or research activities or studies occurring at the site. Frequently, recreation ES indicators were related to fishing (Yates et al., 2019; Pastor et al., 2022; Kok et al., 2025), such as the number of fishing licenses (Pastor et al., 2022), plant/algal biomass, taxonomic diversity, and number of visitors at specific locations (Yates et al., 2019). Indicators of the spiritual value of small streams have included quantification of the number of visitors to spiritual/religious locations (Chien and Satio, 2021) and surveys/interviews of residents and visitors (Verdonschot and Verdonschot, 2023; Pastor et al., 2022).

3.4.4 Monetary Valuation of Ecosystem Services

Though this study was focused on non-monetary valuation, there were multiple different papers using monetary assessment returned in the literature review. The main reason that studies from this SR used monetary valuation was for the accessible communication it allows between stakeholders. People who do not work in the field of streams/rivers will be able to understand the benefits of small streams as a monetary value (Böck et al., 2015).

Bräuer (2005) quantified the replacement cost for nutrient retention in the Jossa river where beavers had been reintroduced. The Jossa river is within the Spessart Mountains in Germany. The only ES quantified in this study was nutrient retention. The levels of nitrogen were estimated using a computer model that assessed the river area, runoff, hydraulic load, and flooded area present before and after beaver reintroduction. The introduction of beavers within this river system increased the water storage and flooded area. This resulted in improved nutrient retention. The cost of the sewage treatment that would be required for the removal of nutrients was used to quantify the monetary valuation of the ES provided by beaver dams. The monetary valuation was based on the change nutrient retention values estimated in the computer model after beavers had been reintroduced.

Honey-Rosés et al. (2013) took a slightly different approach to monetary ES valuation. In this study, the Stream Network Temperature Model (SNTEMP) was used to assess how the water temperature of Llobregat River in Spain changed as vegetation and discharge were altered. The study reach is located upstream of the Aigues TerLlobregat (ATLL) water treatment plant and downstream of a dam that could control the stream discharge. The goal of this stream management project was to create a stream restoration project that would save the ATLL water treatment plant money, with the hope that they will pay for the environmental services (PES). When the water temperatures were too high more disinfection byproducts were produced, so the expensive electrodialysis reversal treatment had to be used. The percentage area in forest cover along the banks was used to quantify shading coverage within the model. Through modeling it was assessed that the increase in shading would save the water treatment facility € 283,000 per year and an increase in discharge from the upstream dam would save the facility € 120,000 per year. It was determined that an increase in woody riparian vegetation would save the facility more money, but as the woody vegetation would have to grow it would take longer for the ecosystem to reach its total ES potential. In comparison, the increase in discharge could be nearly instant, but would not save the facility as much money.

Everard and Moggridge (2011) assessed the economic value of a previously restored urban stream restoration project in London. The restoration project provided no improvement in provisioning services, a gross annual benefit of £28,000 for the regulating services, and a gross annual benefit of £820,000 for the cultural services. Urban streams experienced anthropogenic impacts but through effective restoration projects the ES can be improved. This valuation was conducted after the restoration had already been completed, however, it shows how urban stream restoration projects can aid in improving cultural and regulating ES.

Despite the communication benefits of quantifying ES using monetary valuation, this valuation approach can increase error. There is always a certain amount of error when measuring indicators, and then when converting to a monetary value there is even more potential for introduced error (Honey- Rosés et al., 2013). Additionally, providing monetary valuation for some ES, specifically cultural, can be challenging. Due to these concerns, the use of monetary valuation for estimating ecosystem services should be conducted with careful consideration.

3.5 Case studies of ecosystem services assessment for stream management or restoration

ES can be used for water resources management and to assess the services provided before and after restoration. This section provides an overview of the use of ES to assess the quantity of stream ES currently supported in a municipality, as well as project assessment for stream restoration approaches. The types of restoration discussed below included: large wood (LW) addition, restoration/rehabilitation actions, Diversity of Upland Rivers for Ecosystem Service Sustainability (DURESS), and land cover change.

3.5.1 Ecosystems service accounting in a municipality

A study conducted by Calapez et al. (2023) assessed the existing ES of nine urban streams in Coimbra, Portugal. The study assessed 13 ES within the urban streams including two provisioning, five regulating, and six cultural ES (Table 2). The goal of the study was to understand the connection between biodiversity and ES in urban streams. The results showed provisioning and regulating and maintenance ES decreased as the impervious area increased. Similarly, stream biodiversity was low, as the measured benthic macroinvertebrate community consisted primarily of pollutant-tolerant species. The cultural ES were less quantifiable as the indicators were mostly focused on the potential of the streams to provide educational opportunities, quantified using the number of schools (or potential for) in an area as an indicator. The study concluded that ES that improve biodiversity within the stream reach should be prioritized over cultural ES that do not benefit the overall biodiversity of urban streams.

3.5.2 Addition of wood to streams

Three different restoration projects identified in the systematic literature review used the addition of wood as a restoration practice (Acuña et al., 2013; Elosegi et al., 2017; Tonkin et al., 2020). In the study performed by Acuña et al. (2013), the benefits and costs for active (constant addition of wood) and passive (natural addition of wood through riparian tree growth and loss) were assessed for four streams in the Añarbe reservoir watershed in northern Spain. Costs included the direct cost of the implementation and maintenance of the management actions, as well as a reduction in the ES of timber provisioning. Changes in fish provisioning, recreation, water quality, and erosion control were assessed. Study results showed fish provisioning and recreation ES losses outweighed the required maintenance cost for the low-ordered streams within the basin. Active restoration was more expensive than passive; however, the addition of wood naturally (and the associated benefits) takes longer to occur.

Working with the same four streams as Acuña et al. (2013), Elosegi et al. (2017) assessed the impact of wood additions on the ES of channel erosion reduction and the retention of sediment and organic matter. To quantify ES provision, the indicators of pool abundance, channel form, and sediment and organic matter storage were measured. Increasing the quantity of large wood in the study streams resulted in an increase in the number and size of pools, as well as an increase in both coarse particulate organic matter (CPOM) and sediment storage. While more organic matter storage occurred within the lower order streams, storage efficiency was higher in the higher order stream.

Table 1. Ecosystem services assessed in urban streams in Portugal (Calapez et al., 2023).

Section	Ecosystem Services
Provisioning	Water supply
	Food provisioning
Regulating	Climate regulation
	Flood mitigation
	Air quality
	Water quality
	Carbon storage
	Pollination
Cultural	Education
	Recreation
	Heritage
	Aesthetics
	Therapeutics
	Health

3.5.3 Selection of Stream Restoration and Rehabilitation Measures

Gilvear et al. (2013) developed an assessment tool to compare the cumulative changes in multiple ES resulting from different restoration strategies over both short and long timescales to help target restoration actions within a watershed. It is important to approach river management from a watershed-scale, because it allows multiple concerns to be addressed concurrently, ranging from biodiversity conservation to flood management. This assessment is unique in that it develops a score that integrates the effects over a time period of 25+ years.

The authors asserted that ES assessments should consider both the spatial and temporal effects of restoration actions. For example, dam removal at the mouth of a river will result in more significant uplift than a dam removed in the headwaters. On a temporal scale, these improvements will be realized in a short timespan as longitudinal connectivity will increase once the dam is removed. Additionally, the assessment highlights trade-offs among ES. If floodplain connectivity is increased along an agricultural stream, flood control, nutrient and sediment reductions, and habitat diversity will all increase; however, the provision of crop or forage production will decrease.

The tool focused on six ES that are targeted in many river restoration projects in Scotland:

1. Sustainable flood management (regulating)
2. Biodiversity conservation (supporting)
3. Physical habitat quality (regulating)
4. Fisheries enhancement (provisioning and cultural)
5. Nonpoint source pollution control (regulating)
6. Cultural

A total of 17 river restoration techniques were evaluated for ES provision, including the removal of hard structures (levees, culverts, dams, bank protection), invasive species removal, re-meandering, floodplain forest restoration, and the addition of large wood or beaver. For each of the 17 restoration techniques, the primary effect of the activity on the stream and the intermediate processes/form were identified (Figure 3). Each restoration technique was then evaluated using expert judgement to assign a score which indicated the effect of the technique on each ES. The scores ranged from 0 for no/weak/uncertain effect to 3 for strong effect.

The assessment tool ultimately provided two scores: A “total ecosystem service score” of 0-18 and a “number of ecosystem improvement score” of 0-6. For projects in Scotland, re-meandering, floodplain forest re-establishment, and landuse change had the highest total ES scores, while landuse change and beaver introduction affected the greatest number of ES. The assessment tool also included adjustments of up to 1 point for each ES to adjust the score for the local significance of that ES to the river or to emphasis/de-emphasis the watershed-wide impact of the restoration action. For example, invasive species removal may be a priority management consideration for one watershed while biodiversity may be more important in another catchment. The authors also noted that professional judgement would be required to develop these adjustments to the scores for watershed-scale considerations.

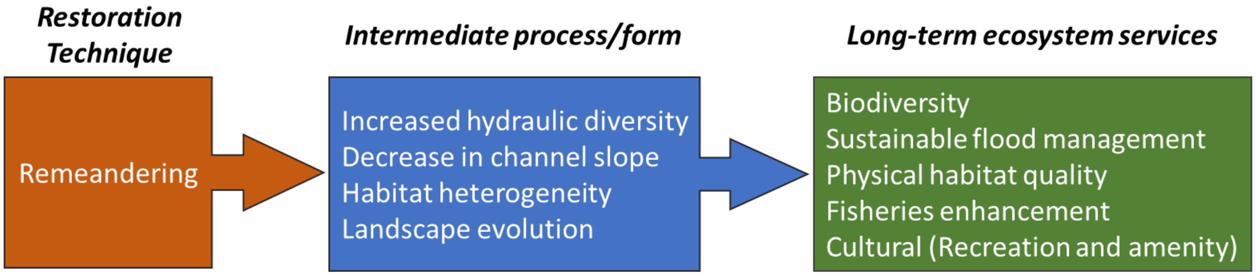


Figure 3. Example linkage between an example restoration technique, impacts to intermediate processes or forms, and long-term ecosystem services.

Once developed, the assessment tool was applied to Eddleston Water, a 25 mi.^{2} watershed in southern Scotland. While water quality was good in the stream, the ecological statis did not meet regulatory goals. The stream was experiencing ecosystem impairments due to prior straightening and levee construction. Flooding of downstream developed lands was also a concern. To address the ecological concerns, three restoration actions were considered for the middle reaches of the main stem: re-meandering; levee setback; and, floodplain forest creation. Additionally, the creation of woody riparian buffers throughout the watershed, large wood additions in an upstream tributary, and the removal of a run-of-the-river (RoR) dam in the lower reaches were evaluated.

The scores for each of these six techniques were then adjusted as a function of the spatial scale of the effect. For example, the re-meandering score was decreased by 1 for the biodiversity ES since it would only improve part of the watershed, while the floodplain reforestation score was increased 1 point for the ES of floodplain management, given that the actions were located where flooding was occurring. However, the biodiversity and physical habitat ES scores were each decreased by 1, since the reforestation project would only affect 1/3 of the watershed. Ultimately, floodplain reforestation was the highest ranked restoration action to achieve the goal of improved ecological health of Eddleston Water over the long term and dam removal was ranked lowest. In contrast, if a 5-yr timeframe is considered, the recommended actions reverse, with dam removal ranked highest and floodplain planting scored lowest. The authors noted that the assessment scores should only be used for planning purposes and for communication with stakeholders.

Similar to Gilvear et al. (2013), Hornung et al. (2019) developed the River Ecosystem Service Index (RESI), an ES assessment framework to inform river and floodplain management in central Europe. The assessment tool included 17 "management measures" (MM, Table 3) and 23 ES (Table 4) to provide a comprehensive understanding of the effects of different MM, particularly in light of multiple EU legislative directives targeted at water and flood management, habitat protection, and agricultural policy.

Unlike the work by Gilvear et al. (2013) this study combined information from the scientific literature with expert review and opinion to develop the linkage between the selected MM and ES. The authors first conducted a literature review of both peer-reviewed and "grey" literature to develop a draft assessment. Then, 17 experts were enlisted to rank the impact of the MM on ES from strong negative to strong positive, in addition to no linkage. Finally, the experts compared the two assessments and resolved differences between the scientific literature and the expert opinions to develop the final assessment matrix (Table 5).

Table 3. Management measures assessed for ecosystem service provision by Hornung et al. (2019).

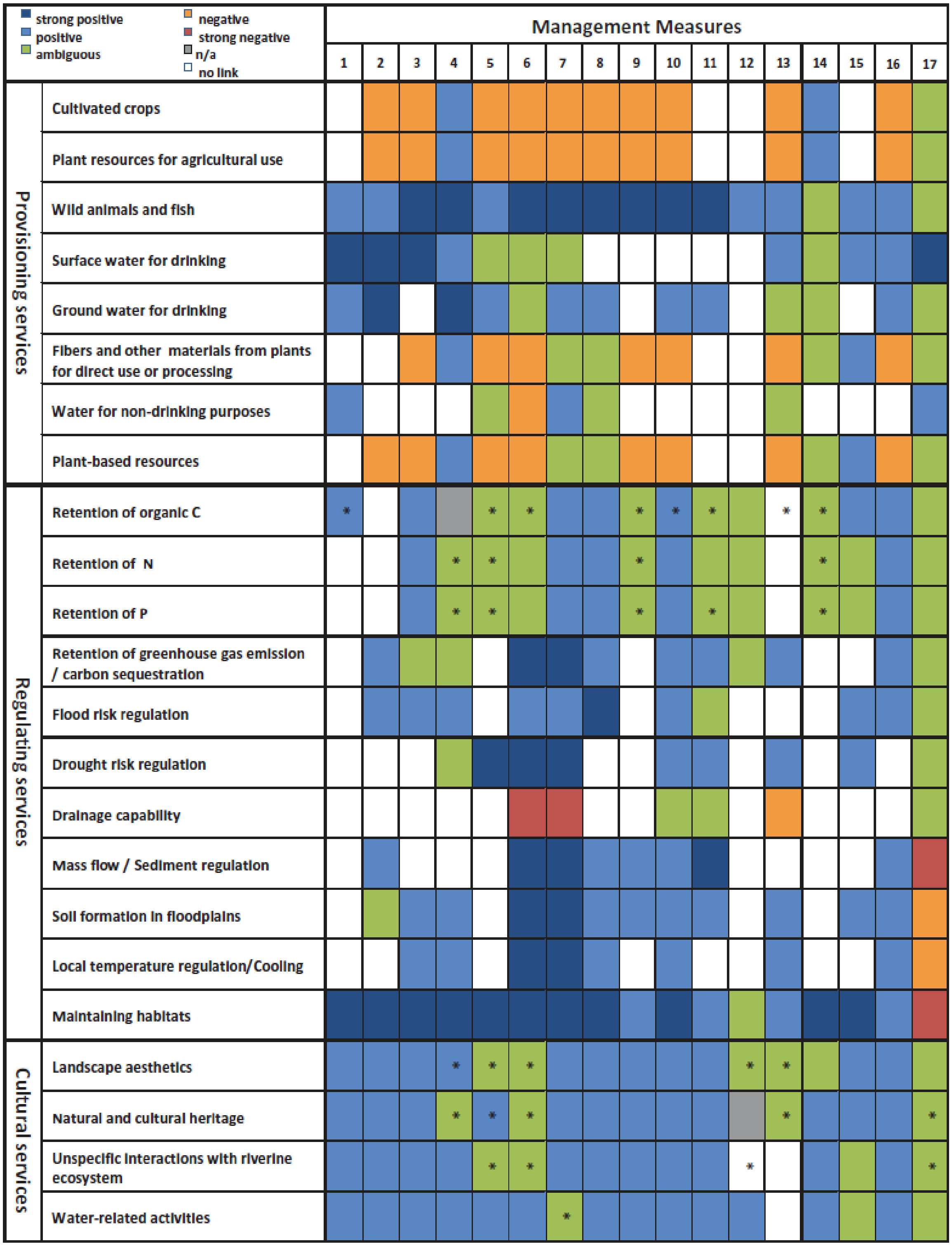
Number	Management Measure
1	Wastewater treatment plant construction or upgrades
2	Agricultural best management practices
3	Riparian buffer zone creation
4	Counteract acidification from conifer plantations
5	Reduce water withdrawals
6	Restore natural flow regime
7	Floodplain restoration
8	Levee setback, notching or removal
9	Increase aquatic organism passage
10	Habitat improvement
11	Gravel augmentation
12	Fish stocking
13	Remove floodplain drainage
14	Invasives species control
15	Prevent/control recreation impacts
16	Agroforestry practices for flood risk reduction
17	Flood retention areas and dams

Table 4. Ecosystem services assessed for 17 management measures (Hornung et al., 2019).

Section	Ecosystem Services
Provisioning	Crops
	Plants for agriculture
	Fish/animal provisioning
	Drinking water (surface)
	Drinking water (groundwater)
	Materials/Plant provisioning
	Water for non-drinking
	Plant resources
Regulating	Organic carbon retention
	Nitrogen retention
	Greenhouse gas/carbon sequestration
	Flood regulation
	Drought regulation
	Drainage ability
	Flow/sediment regulation
	Soil formation
	Microclimate control
	Habitat maintenance
Cultural	Aesthetics
	Ecosystem interaction
	Heritage
	Water activities

Study results showed the actions with the greatest increase in ES were habitat creation, floodplain restoration, and agroforestry practices for flood risk reduction; however, these gains were frequently at the cost of the agricultural provisioning ES. The use of both scientific literature and a structured expert panel review permitted transparent reporting of the basis for the linkages and helped reduce expert bias. Additionally, the authors were able to distinguish knowledge gaps for linkages from a lack of linkage between the MM and ES. The most notable research gap was for the impact of the MM on the regulating ES of nutrient and organic carbon retention and cultural ES. Use of this assessment framework can support restoration decision-making by identifying potential unintended consequences, illustrating additional values of MM, and informing conversations with stakeholders.

Table 5. Assessment of stream restoration management measures (Table 3) for the provision of selected ecosystem services (Table 4). Asterisks indicate scientific uncertainty in the linkage between the management measure and the ecosystem service. From Hornung et al. (2013), copyright license Creative Commons CC BY.



■ strong positive 🟦 positive 🟩 ambiguous 🟧 negative 🟥 strong negative ▨ n/a □ no link		Management Measures																
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Provisioning services	Cultivated crops	□	🟧	🟧	🟦	🟧	🟧	🟧	🟧	🟧	🟧	□	□	🟧	🟦	□	🟧	🟩
	Plant resources for agricultural use	□	🟧	🟧	🟦	🟧	🟧	🟧	🟧	🟧	🟧	□	□	🟧	🟦	□	🟧	🟩
	Wild animals and fish	🟦	🟦	■	■	🟦	■	■	■	■	■	■	🟦	🟦	🟩	🟦	🟦	🟩
	Surface water for drinking	■	■	■	🟦	🟩	🟩	🟩	□	□	□	□	□	🟦	🟩	🟦	🟦	■
	Ground water for drinking	🟦	■	□	■	🟦	🟩	🟦	🟦	□	🟦	🟦	□	🟩	🟩	□	🟦	🟩
	Fibers and other materials from plants for direct use or processing	□	□	🟧	🟦	🟧	🟧	🟩	🟩	🟧	🟧	□	□	🟧	🟩	🟦	🟧	🟩
	Water for non-drinking purposes	🟦	□	□	□	🟩	🟧	🟦	🟩	□	□	□	□	🟩	□	□	□	🟦
	Plant-based resources	□	🟧	🟧	🟦	🟧	🟧	🟩	🟩	🟧	🟧	□	□	🟧	🟩	🟦	🟧	🟩
Regulating services	Retention of organic C	🟦*	□	🟦	▨	🟩*	🟩*	🟦	🟦	🟩*	🟦*	🟩*	🟩	□*	🟩*	🟦	🟦	🟩
	Retention of N	□	□	🟦	🟩*	🟩*	🟩	🟦	🟦	🟩*	🟦	🟩	🟩	□	🟩*	🟩	🟦	🟩
	Retention of P	□	□	🟦	🟩*	🟩*	🟩	🟦	🟦	🟩*	🟦	🟩*	🟩	□	🟩*	🟩	🟦	🟩
	Retention of greenhouse gas emission / carbon sequestration	□	🟦	🟩	🟩	□	■	■	🟦	□	🟦	🟦	🟩	🟦	□	□	🟦	🟩
	Flood risk regulation	□	🟦	🟦	🟦	□	🟦	🟦	■	□	🟦	🟩	□	□	□	🟦	🟦	🟩
	Drought risk regulation	□	□	□	🟩	■	■	■	□	□	🟦	🟦	□	🟦	□	🟦	□	🟩
	Drainage capability	□	□	□	□	□	🟥	🟥	□	□	🟩	🟩	□	🟧	□	□	□	🟩
	Mass flow / Sediment regulation	□	🟦	□	□	□	■	■	🟦	🟦	🟦	■	□	□	□	□	🟦	🟥
	Soil formation in floodplains	□	🟩	🟦	🟦	□	■	■	🟦	🟦	🟦	🟦	□	🟦	□	🟦	🟦	🟧
	Local temperature regulation/Cooling	□	□	🟦	🟦	□	■	■	🟦	□	🟦	□	□	🟦	□	□	🟦	🟧
	Maintaining habitats	■	■	■	■	■	■	■	■	🟦	■	🟦	🟩	🟦	■	■	🟦	🟥
Cultural services	Landscape aesthetics	🟦	🟦	🟦	🟦*	🟩*	🟩*	🟦	🟦	🟦	🟦	🟦	🟩*	🟩*	🟩	🟦	🟦	🟩
	Natural and cultural heritage	🟦	🟦	🟦	🟩*	🟦*	🟩*	🟦	🟦	🟦	🟦	🟦	▨	🟩*	🟦	🟦	🟦	🟩*
	Unspecific interactions with riverine ecosystem	🟦	🟦	🟦	🟦	🟩*	🟩*	🟦	🟦	🟦	🟦	🟦	□*	□	🟦	🟩	🟦	🟩*
	Water-related activities	🟦	🟦	🟦	🟦	🟦	🟦	🟩*	🟦	🟦	🟦	🟦	🟦	□	🟦	🟩	🟦	🟩

3.5.4 DURESS restoration project

The DURESS project was conducted using an integrated approach in the United Kingdom (UK) with the goal of restoring stream ES. The study was focused on upland river systems as these streams have increased intrinsic value and a large impact on receiving bodies of water. An integrated approach was used to understand the physical, biological, and social contributions of the stream. The main tool used to assess ecosystem services within the DURESS project was food webs, and there were 20 representative sites used to determine the interactions present within upland food webs. Food webs help to provide information about the movement of energy within an ecosystem. It is shown that an improvement in energy efficiency within the food web increased fish and bird populations. DURESS also used market, economic valuation, and non-market values, non-monetary valuation to assess the value of ES (Durance et al., 2016).

3.5.5 Land Cover Change

Two studies that used models to determine how a change in land cover can impact ES (Singh et al., 2018; Renz et al., 2025). Renz et al. (2025) studied three streams in the Oslofjord region of Norway, using QGIS to assess how potential land cover change would affect the provision of crops, materials, wood provisioning, wild animal provisioning, foraging, carbon storage, flood resilience, erosion control, phosphorus retention, recreation, hunting and non-use value ES. The land cover change scenarios ranged from increased agricultural land to a full focus on biodiversity and sustainability within the watershed. In the scenario focused on biodiversity and sustainability, all agricultural land was converted to native vegetation. This scenario predicted an increase in cultural ES but a decrease in provisioning services. In a study conducted by Singh et al. (2018), a 1-D Hydrologic Engineering Center River Analysis System (HEC-RAS) model was used to assess how the changes in vegetation and floodplain level impact the ES in a Vermont basin. There were three scenarios tested: REVEG (revegetation of the floodplain to a manning's roughness of 0.182), CRVEG (revegetation to n = 0.182 and lower floodplain), and CBVEG (lower the floodplain with baseline vegetation). The revegetation scenarios use dense herbaceous vegetation whereas the baseline vegetations was the existing vegetation. The model demonstrated increased vegetation and a lowered floodplain, resulting in an increase in the water quality ES in the basin (Singh et al., 2018). In both studies models were used to assess the ES present within the area.

4 Conclusions

While several definitions have been used, ecosystem services are generally defined as “"the contributions that ecosystems make to human well-being" (Haines-Young, 2023) and are broadly classified as provisioning, regulating and maintenance, and cultural services. Ecosystem services of small streams that could be impacted by stream restoration include the provisioning of plants, animals and fish, genetic resources, and water quality. The retention of carbon, sediment, and nutrients, local climate regulation, habitat provisioning and maintenance, and both lateral and longitudinal connectivity are the regulating and maintenance services provided by functioning stream ecosystems. High quality streams also provide cultural ecosystem services, such as scenery, a sense of place, recreation, and education and research.

To ensure consistency and avoid duplication of ES, several classifications have been developed. Created for the United Nations, the Millennium Ecosystem Assessment (MEA) was among the first ES classification systems and was used by nations internationally to quantify their national capital. Two additional classifications include the Common International Classification of Ecosystem Services (CICES) and the National Ecosystem Services Classification System (NESCS), both of which were developed based on the MEA. The CICES system is widely used and was recently updated based on user-feedback. Developed by the US EPA, the NESCS is a newer classification system that has not been broadly used.

There are several published examples of ES assessment tools that have been used to inform stream management and restoration decision-making in the UK and Europe. The tools are generally developed by selecting commonly used restoration techniques and then determining the impact of those techniques on stream ES. The linkage between the restoration actions and ES can be developed using expert opinion, published information from the scientific literature, or a combination of both. These assessment tools allow an objective comparison of different restoration actions by providing a wholistic view of the benefits of each action and potential trade-offs. Based on these examples, an assessment framework could be developed for the Chesapeake Bay watershed to improve the design and assessment of stream restoration projects and to improve communication with stakeholders.

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6. Appendix A. Ecosystem services (ES) of the Common Internation Classification of Ecosystem Services (CICES)

Division	Group	Class
Section: Regulation & Maintenance		
Transformation of biochemical or physical inputs to ecosystems	Mediation of waste, toxics and other nuisances by non-living processes	Dilution or transport of wastes by freshwater and marine ecosystems
		Dilution or transport of wastes by atmosphere
		Mediation of wastes by other chemical or physical means (e.g. via Filtration, sequestration, storage or accumulation)
		Geological structures and deposits for storage of anthropogenic wastes
	Mediation of nuisances of anthropogenic origin	Mediation of nuisances by abiotic structures or processes
Regulation and maintenance of geophysical	Regulation of baseline flows and extreme events	Abiotic regulation of mass flows
		Abiotic regulation of liquid flows
		Abiotic regulation of gaseous flows
	Maintenance of physical, chemical, abiotic conditions	Maintenance and regulation by inorganic natural chemical and physical processes of fresh or salt waters
		Maintenance and regulation by inorganic natural chemical and physical processes of atmosphere
Transformation of biochemical or physical inputs to ecosystems	Reduction of nutrient loads and mediation of wastes or toxic substances of anthropogenic origin by living processes	Bio-remediation by micro-organisms, algae, plants, and animals
		Filtration/sequestration/storage/accumulation by micro-organisms, algae, plants, and animals
	Mediation of nuisances of anthropogenic origin	Noise attenuation
		Visual screening

Division	Group	Class
Regulation of baseline flows and extreme events	Erosion control	Control of water erosion rates
		Control of wind erosion rates
	Hydrological cycle and water flow regulation	Regulation runoff and base flows
		Regulation of peak flows
	Hazard mitigation	Buffering and attenuation of mass movement
		Surge and flood wave mitigation
		Wind protection
		Fire protection
Regulation of physical, chemical, biological conditions	Lifecycle maintenance, habitat and gene pool protection	Pollination (or 'gamete' dispersal in a marine context)
		Seed dispersal
		Maintaining or regulating nursery populations and habitats or breeding grounds (Includes gene pool protection)
		Maintaining or regulating refuge habitats
		Maintaining or regulating feeding grounds
	Pest and disease control	Pest control (including invasive species)
		Disease control
	Regulation of soil quality	Biologically mediated weathering processes and their effect on soil quality
		Decomposition and fixing processes and their effect on soil quality
		Maintenance of soil structure by biological agents and ecological processes
	Water conditions	Regulation of the chemical condition of macronutrients in freshwaters by living processes

Division	Group	Class
Regulation of baseline flows and extreme events	Erosion control	Control of water erosion rates
		Control of wind erosion rates
	Hydrological cycle and water flow regulation	Regulation runoff and base flows
		Regulation of peak flows
	Hazard mitigation	Buffering and attenuation of mass movement
		Surge and flood wave mitigation
		Wind protection
		Fire protection
Regulation of physical, chemical, biological conditions	Lifecycle maintenance, habitat and gene pool protection	Pollination (or 'gamete' dispersal in a marine context)
		Seed dispersal
		Maintaining or regulating nursery populations and habitats or breeding grounds (Includes gene pool protection)
		Maintaining or regulating refuge habitats
		Maintaining or regulating feeding grounds
	Pest and disease control	Pest control (including invasive species)
		Disease control
	Regulation of soil quality	Biologically mediated weathering processes and their effect on soil quality
		Decomposition and fixing processes and their effect on soil quality
		Maintenance of soil structure by biological agents and ecological processes
	Water conditions	Regulation of the chemical condition of macronutrients in freshwaters by living processes

Division	Group	Class
		Regulation of the chemical condition of macronutrients in salt waters by living processes
	Atmospheric composition and conditions	Regulation of chemical composition of atmosphere and oceans, and the maintenance of continental atmospheric/oceanic circulation patterns
		Regulation of temperature and humidity, including ventilation and transpiration at local scales
Section: Provisioning		
Water	Surface water used for nutrition, materials or energy	Surface water for drinking
		Surface water used as a material (non-drinking purposes)
		Freshwater surface water used as an energy source
		Coastal and marine water used as energy source
		Ground (and subsurface) water for drinking
		Ground water (and subsurface) used as a material (non-drinking purposes)
		Ground water (and subsurface) used as an energy source; regulation of heating and cooling.
Non-aqueous natural abiotic ecosystem outputs	Mineral substances used for nutrition, materials or energy	Mineral substances used for nutritional purposes
		Mineral substances used for material purposes, including geophysical support (foundations).
		Mineral substances used for as an energy source
	Non-mineral substances or ecosystem properties used for nutrition, materials or energy	Non-mineral substances or ecosystem properties used for nutritional purposes
		Non-mineral substances used for materials

Division	Group	Class
		Wind energy
		Solar energy
		Geothermal from earth or stored solar energy
Biomass	Cultivated terrestrial plants for nutrition, materials or energy	Cultivated terrestrial plants (including fungi, algae) grown for nutritional purposes
		Fibres and other materials from cultivated plants, fungi, algae and bacteria for direct use or processing (excluding genetic materials)
		Cultivated plants (including fungi, algae) grown as a source of energy
		Plants cultivated by in-situ aquaculture grown for nutritional purposes
		Plants cultivated for fibres and other materials by in-situ aquaculture for direct use or processing (excluding genetic materials)
		Plants cultivated by in-situ aquaculture grown as an energy source
	Reared animals for nutrition, materials or energy	Animals reared for nutritional purposes
		Fibres and other materials from reared animals for direct use or processing (excluding genetic materials)
		Animals reared to provide energy (including mechanical)
		Animals reared by in-situ aquaculture for nutritional purposes
		Fibres and other materials from animals grown by in-situ aquaculture for direct use or processing (excluding genetic materials)
		Animals reared by in-situ aquaculture as an energy source
	Wild plants (terrestrial and aquatic) for nutrition, materials or energy	Wild plants (terrestrial and aquatic, including fungi, algae) used for nutrition
		Fibres and other materials from wild plants for direct use or processing (excluding genetic materials)

Division	Group	Class
		Wild plants (terrestrial and aquatic, including fungi, algae) used as a source of energy
	Wild animals (terrestrial and aquatic) for nutrition, materials or energy	Wild animals (terrestrial and aquatic) used for nutritional purposes
		Fibres and other materials from wild animals for direct use or processing (excluding genetic materials)
		Wild animals (terrestrial and aquatic) used as a source of energy
Genetic material from all biota	Genetic material from plants, algae or fungi	Seeds, spores and other plant materials collected for maintaining or establishing a population
		Higher and lower plants (whole organisms) used to breed new strains or varieties
		Individual genes extracted from higher and lower plants for the design and construction of new biological entities
	Genetic material from animals	Animal material collected for the purposes of maintaining or establishing a population
		Wild animals (whole organisms) used to breed new strains or varieties
		Individual genes extracted from organisms for the design and construction of new biological entities
Section: Cultural		
Physical and experiential interactions with biophysical environment	Direct, in-situ and outdoor interactions with geophysical systems	Characteristics of geophysical systems that enable activities promoting health, recuperation or enjoyment through active or immersive interactions
		Characteristics of geophysical systems that enable activities promoting health, recuperation or enjoyment through passive or observational interactions
		Elements of geophysical systems that enable scientific investigation or the creation of traditional ecological knowledge
		Elements of geophysical systems that enable education and training

Division	Group	Class
		Elements of geophysical systems that are resonant in terms of culture or heritage
		Elements of geophysical systems that enable aesthetic experiences
	Indirect interactions with geophysical systems	Elements of geophysical systems used for entertainment or representation outside the setting concerned
		Elements of geophysical systems that have symbolic meaning
		Elements of geophysical systems that have sacred or religious meaning
	Other biophysical elements appreciated by people	Elements or features of geophysical systems whose contemporary existence or conservation is important to people
		Elements or features of geophysical systems whose inter-generational existence or conservation is important to people
Physical and experiential interactions with natural environment	Direct, in-situ and outdoor interactions with living systems	Elements of living systems that enable activities promoting health, recuperation or enjoyment through active or immersive interactions
		Elements of living systems that enable activities promoting health, recuperation or enjoyment through passive or observational interactions
		Elements of living systems that enable scientific investigation or the creation of traditional ecological knowledge
		Elements of living systems that enable education and training
		Elements of living systems that are resonant in terms of culture or heritage
		Elements of living systems that enable aesthetic experiences
	Indirect interactions with living systems	Elements of living systems used for entertainment or representation outside the setting concerned
	Indirectly appreciated living system elements	Elements of living systems that have symbolic meaning
		Elements of living systems that have spiritual or religious meaning

Division	Group	Class
	Other characteristics of living systems	Elements or features of living systems whose contemporary existence or conservation is important to people
		Elements or features of living systems whose inter-generational existence or conservation is important to people

7. Appendix B. Provisioning ecosystem services of streams

Ecosystem Service	Indicator	Units	References
Food			
Food supply	Natural plants with a nutritional, aromatic, medicinal value	–	Calapez et al., 2023
	Fish	–	Calapez et al., 2023
	Urban orchards	–	Calapez et al., 2023
	Other aquatic animals with nutritional value	–	Calapez et al., 2023
Fish	Aquaculture farms	number/ha	Pastor et al., 2022
	Fishing licenses	number/ha/year	Pastor et al., 2022
	Abundance of fish species	individuals/ha	Pastor et al., 2022
Berries and Mushrooms	Density of different edible wild plants in riparian/floodplain	individual/ha	Pastor et al., 2022
	Coverage of different edible wild plants in riparian/floodplain % Pastor et al., 2022		
	Distrubtion and richness of edible riparian plants estimated from modeling	species/ha	Pastor et al., 2022
	Production of wild plants in riparian and floodplain	kg/ha/year	Pastor et al., 2022
Wild Game	Kills	kill/ha/year	Pastor et al., 2022
	Hunting licenses	number/ha/year	Pastor et al., 2022
	Population size of species of interest	individuals/ha	Pastor et al., 2022
Water Supply			
Surface water non-drinking	Hydropower plants	number/IRES length	Pastor et al., 2022
	Installed capacity of hydropower plant generators	MW	Pastor et al., 2022
	Annual power generation	GWh/year	Pastor et al., 2022
	Water abstracted for energy production	m^3/ha	Pastor et al., 2022
	Labor force of industry full-time equivalent	–	Pastor et al., 2022

Ecosystem Service	Indicator	Units	References
Groundwater Provisioning	Industrial plants	number/ha/sector	Pastor et al., 2022
	Water abstracted for industrial use	m^3/basin ha	Pastor et al., 2022
	Groundwater bodies	m^3/basin ha	Pastor et al., 2022
	STOWA	–	Tuijn, 2020
	IMOD	–	Tuijn, 2020
	Ground water availability / sub-surface retention	–	Tuijn, 2020
Surface water for drinking	Water exploitation index % Pastor et al., 2022		
Water Supply	Total irrigated land, if possible, per crop	ha	Pastor et al., 2022
	Water extracted for agricultural use	m^3/basin ha/year	Pastor et al., 2022
	Permanent and non-permanent population within floodplain	inhabitants/ha	Pastor et al., 2022
	Irrigation intensity	m^3/ha/crop	Pastor et al., 2022
	River water quality indicator	–	Chien and Satio, 2021
	River water quality indicator	–	Chien and Satio, 2021
	SWAT	mm	Angela et al., 2015
	Irrigation of crops	–	Ranta et al., 2021
	Irrigation of crops	–	Calapez et al., 2023
	Groundwater recharge	–	Calapez et al., 2023
	Transversal connectivity (water from channel to the margins)	–	Calapez et al., 2023
	Amount of water withdrawals from the riverbed used for economic & purposes (irrigation, industry, etc.)	–	Jakubínský and Cudlín, 2018
	Chemical surface water quality	–	Verdonschot and Verdonschot, 2023
	Ground water quality and sustainable available quantity	–	Verdonschot and Verdonschot, 2023
	Water quality (chemical and biological indicators) Amount of water withdrawals used for drinking purposes (ground water and surface water)	–	Jakubínský and Cudlín, 2018
	Ecological water quality	–	Verdonschot and Verdonschot, 2023

Ecosystem Service	Indicator	Units	References
Agriculture			
Agricultural water use	Chemical surface water quality and sustainable available quantity	–	Verdonschot and Verdonschot, 2023
Crop and livestock provisioning	InVEST	–	Tuijn, 2020
	WaterWijzer Landbouw	–	Tuijn, 2020
	Crop yield / livestock produce	–	Tuijn, 2020
Grains	Area used for crop production for food and feed	ha	Pastor et al., 2022
	Grain species produced for food and feed	number/ha	Pastor et al., 2022
	Yield of food and feed crop species	kg/ ha/year	Pastor et al., 2022
Fiber & Fuel			
Fiber & Fuel	Surface of exploited wet forests and reeds	ha	Pastor et al., 2022
	Firewood produced by riparian forests	t or m3/ha/year	Pastor et al., 2022
	Number of collectors/consumers/beneficiaries	number/basin ha or IRES km	Pastor et al., 2022
	Weight of material from floodplain	t/ha/year	Pastor et al., 2022
	Volume of inorganic matter extracted	m^3/IRES km/year	Pastor et al., 2022
	Inland salt production	t/ha/year	Pastor et al., 2022
	Surface area of forest under	–	Verdonschot and Verdonschot, 2023
Other			
Biochemical extract of medicine	Diversity and quantity of plant elements extracted in the fluvial area	number of plant elements/ha	Pastor et al., 2022
	Coverage of aquatic and riparian plant species with medical applications	species richness/ha	Pastor et al., 2022
	Coverage of aquatic and riparian plant species with medical applications	%	Pastor et al., 2022
	Quantity of fish harvested for consumption	kg/ha/year	Pastor et al., 2022
Biomass production	Dry residual biomass harvested from natural ecotopes	t/y	Kok et al., 2025

Ecosystem Service	Indicator	Units	References
Energy	Amount of energy provided by the hydropower plants.	–	Jakubínský and Cudlín, 2018
Genetic material	Provision/extraction of genetic material from flora and fauna for use in non-productive	biomass	Pastor et al., 2022
	Water abstracted for drinking purposes	m^3	Pastor et al., 2022
Peat formation	Surface area of wetland with C-storage potenital	–	Verdonschot and Verdonschot, 2023
Provision of construction material	Extracted construction material (sand, gravel& clay) during works	t	Kok et al., 2025

8. Appendix C. Regulating and maintenance ecosystem services of streams.

Ecosystem Service	Indicator	Units	References
Biodiversity			
Biodiversity	Shannon-Wiener Index	Shannon-Wiener index mean value for macro-invertebrates and macroscopic algae	Angela et al., 2015
	Food Webs	–	Durance et al., 2016
	Indices of biodiversity and food web structure	–	Verdonschot and Verdonschot, 2023
	Average Score Per Taxon (ASPT)	–	Michael-Bitton et al., 2025
Habitat provision	Riparian/riverbank woodland	–	Van Looy et al., 2017
	Risk of channel rectification	–	Van Looy et al., 2017
	Floodplain forest	–	Van Looy et al., 2017
	PAGW policy achievement index: similarity index (0–1) based on # ha of natural ecotopes with # ha as stipulated in policy	Kok et al., 2025	
	Structural heterogeneity	–	Verdonschot and Verdonschot, 2023
	Number of migration barriers in the riverbed (weirs, dams, etc.)	–	Jakubínský and Cudlín, 2018
Regulation of physical, chemical, biological conditions	Regulation of physical, chemical, biological conditions	# of biodiversity in river or riverbank	Chien and Satio, 2021
Riparian Buffer Zone	Riparian Buffer Zone	NDVI values	Michael-Bitton et al., 2025
Climate Regulation			
Climate Regulation	Air humidity variation	–	Van Looy et al., 2017
	Change of air temperature	River bank/corridor vs rest of the catchment (◦C)	Ranta et al., 2021
	Area of wooded riparian and forested floodplain	–	Verdonschot and Verdonschot, 2023
	Change of air humidity	river bank/corridor vs rest of the catchment (%)	Pastor et al., 2022
	Character of vegetation cover within the river landscape (esp. size of shade areas)	–	Jakubínský and Cudlín, 2018
	Air humidity variation	–	Calapez et al., 2023
	Air temperature variation	–	Calapez et al., 2023
Microclimate control	Air temperature variation	–	Calapez et al., 2023
	Riparian/riverbank woodland (10 m buffer)	–	Van Looy et al., 2017
	Upstream continuity (density gaps)	–	Van Looy et al., 2017
	Buffer continuity: length gaps (max per reach)	–	Van Looy et al., 2017

Ecosystem Service	Indicator	Units	References
Air quality (AQ)	Integrity of the riparian corridor	–	Calapez et al., 2023
	Lichen functional groups	–	Calapez et al., 2023
Erosion Control			
Erosion Control Erosion Regulation	Processes of bank retreat; presence of a potentially erodible corridor	–	Pastor et al., 2022
	Bed configuration – valley slope	∘	Pastor et al., 2022
	Bed configuration – valley slope	%	Pastor et al., 2022
	Planform pattern	multi-thread, single-thread, transitional	Pastor et al., 2022
	Presence of typical fluvial land forms in the flood plain	Meanders, oxbow lake	Pastor et al., 2022
	Variability of the cross-section	–	Pastor et al., 2022
	Wood removal	t/km or t/ha	Pastor et al., 2022
	Presence of in-channel large wood	presence/absence matrix	Pastor et al., 2022
	Loss of soil particles	t/ha/year	Pastor et al., 2022
	Upstream alteration of flow	number of structures upstream	Pastor et al., 2022
	Bank protections	presence/absence matrix; alternatively km of protections	Pastor et al., 2022
	Structure of the channel bed	armouring, clogging, natural heterogeneity	Pastor et al., 2022
	Vegetation cover	%	Pastor et al., 2022
	Alteration of sediment discharge	–	Pastor et al., 2022
	Floodplain area protected against soil erosion and peak flows (see flood control)	–	Verdonschot and Verdonschot, 202
	Rosgen Classification	Rosgen's classification	Angela et al., 2015
Carbon Storage			
Carbon Sequestration	Lateral (floodplain) contact (risk alteration)	–	Van Looy et al., 2017
	Slope (retention capacity)	–	Van Looy et al., 2017
	Floodplain forest	–	Van Looy et al., 2017
	Tonnes C/ sequestered	floodplains/y	Kok et al., 2025
	Dissolved CO2 in the water	–	Calapez et al., 2023
Nutrients			
Nutrient cycling regulation	Drying-flowing oscillation	–	Pastor et al., 2022

Ecosystem Service	Indicator	Units	References
	Presence of geomorphological elements	–	Pastor et al., 2022
	Presence of riparian forest	–	Pastor et al., 2022
	Ecological status according to the WFD	–	Pastor et al., 2022
	Transport of nutrients and pollutants	–	Pastor et al., 2022
	Self-purification capacity	–	Pastor et al., 2022
	Physicochemical indicators (e.g., NO3, PO43-, total N, total P)	–	Pastor et al., 2022
	Patchiness of morphological units	–	Pastor et al., 2022
	Fluxes of POC and CO2	–	Pastor et al., 2022
	Presence of dams or other storage constructions	–	Pastor et al., 2022
	Presence of woody debris	–	Pastor et al., 2022
	Presence of L-gradient, broad valley bottoms	–	Pastor et al., 2022
	Connectivity with the floodplain	–	Pastor et al., 2022
	Nutrient Uptake	–	Sweeney et al., 2004
Nutrient retention	Riparian (30 m buffer) woodland	–	Van Looy et al., 2017
	Buffer continuity: frequency gaps	–	Van Looy et al., 2017
	Lateral (floodplain) contact (risk alteration)	–	Van Looy et al., 2017
	Stream profile (Width:depth risk alteration)	–	Van Looy et al., 2017
Water Purification			
Water Purification	Water filtration rate	–	Yates et al., 2019
	Filter feeder biomass	–	Yates et al., 2019
	Uptake lengths	–	Yates et al., 2019
	Denitrification	–	Yates et al., 2019
	Macrophyte biomass	–	Yates et al., 2019
	Microbial transformation	–	Yates et al., 2019
	Retention of Nitrogen (N) from point and diffuse sources	kg N year-1	La Notte et al., 2017
	TN concentration	–	Michael-Bitton et al., 2025
	TN/TSS Flux	mg/s	Palmer et al., 2014
	Algal species diversity	–	Yates et al., 2019
	Rooted macrophyte biomass	–	Yates et al., 2019
	Width of functional vegetation and linear extension of functional vegetation	m	Pastor et al., 2022
	Carbon stored and sequestered on four different carbon pools	–	Pastor et al., 2022
	CO2 emissions from a dry bed	t/ha	Pastor et al., 2022

Ecosystem Service	Indicator	Units	References
	Presence of riparian forest	ha	Pastor et al., 2022
	presence of emergent and floating aquatic macrophytes	number of species	Pastor et al., 2022
	Presence of riparian forest	m	Pastor et al., 2022
	Natural bed substrate (risk alteration)	–	Van Looy et al., 2017
	Uniformity sinuosity (rectification rate	–	Van Looy et al., 2017
	Healthy ecological functioning	–	Verdonschot and Verdonschot, 2023
	Retention time in the catchment (water balance)	–	Verdonschot and Verdonschot, 2023
	Tonnes N captured	floodplains/y	Kok et al., 2025
Water Quality	Nutrients in the water	–	Calapez et al., 2023
	Acidification	–	Calapez et al. , 2023
	Total suspended solids	–	Calapez et al., 2023
	Ecological quality	–	Calapez et al., 2023
	Tolerant invertebrates	–	Calapez et al., 2023
	Physiochemical properties FC/FE	–	Angela et al., 2015
Water Regulation	Groundwater recharge rate	mm/ha/year	Pastor et al., 2022
	Groundwater level	m per surface	Pastor et al., 2022
	Alteration of flow in the reach	–	Pastor et al., 2022
Diease/Pest Control			
Diease/Pest Control	Soil depth and litter cover	cm	Pastor et al., 2022
	Structure of the channel bed	–	Pastor et al., 2022
	Bed configuration - valley slope	%	Pastor et al., 2022
	Wastewater treatment plants - WWTPs	–	number Pastor et al., 2022
	Patchiness of morphological units	–	Pastor et al., 2022
	Nutrient excess	–	Pastor et al., 2022
	presence of emergent and floating aquatic macrophytes	number of species	Pastor et al., 2022
	Width of functional vegetation and linear extension of functional vegetation	m	Pastor et al., 2022
	Earthworms	number or mass/m2	Pastor et al., 2022
	Presence of emblematic riverine species	–	Pastor et al., 2022
	Bed configuration - valley slope	°	Pastor et al., 2022
	Yearly infection rates	–	Verdonschot and Verdonschot, 2023
	Taxonomic diversity	–	Yates et al., 2019
	Trait diversity	–	Yates et al., 2019

Ecosystem Service	Indicator	Units	References
Pollination			
Pollination	Bees	–	Calapez et al., 2023
	Nectariferous plants	–	Calapez et al., 2023
	Number of mammals using the stream	–	Pastor et al., 2022
	Presence of exotic and invasive riverine species	–	Pastor et al., 2022
	Abundance of mosquitoes	–	Pastor et al., 2022
	Visitation rate of aquatic insects	–	Pastor et al., 2022
	Pollination Sustainability Index for Riverine Landscapes	–	Pastor et al., 2022
	Percentage of aquatic prey in the diets of terrestrial arthropod predators	%	Pastor et al., 2022
Hazard Mitigation			
Natural Hazard Regulation	Morphological type of the reach	–	Pastor et al., 2022
	Longitudinal continuity in sediment and wood flux	–	Pastor et al., 2022
	Number of floods	–	Pastor et al., 2022
	Vegetation management	–	Pastor et al., 2022
	Artificial changes of the river course	–	Pastor et al., 2022
	Sediment and wood removal	–	Pastor et al., 2022
Flood Mitigation	Number, frequency and magnitude of floods and droughts	–	Verdonschot and Verdonschot, 2023
	Floodplain connectivity scale	–	Michael-Bitton et al., 2025
	Flood capacity	–	Calapez et al., 2023
	Floodplain availability	–	Calapez et al., 2023
	Soil water retention capacity of the river landscape Extent of the natural inundation areas along the streams	–	Jakubínský and Cudlín, 2018
Hydraulic cycle and flow control	InVEST	–	Tuijn, 2020
	Surface retention / avoided flood damages	–	Tuijn, 2020
	STOWA	–	Tuijn, 2020
	Riparian shade model Tauw	–	Tuijn, 2020
	SOBEK Suite	–	Tuijn, 2020
Sediment			
Decomposition/soil formation	Litter break-down rates	–	Yates et al., 2019
	Burrower biomass	–	Yates et al., 2019
	Litter break-down rates	–	Yates et al., 2019

Ecosystem Service	Indicator	Units	References
Regulation/Storage	Microbial biomass and diversity	–	Yates et al., 2019
	Shredder/collector biomass and diversity	–	Yates et al., 2019
	Net Ecosystem Respiration	–	Yates et al., 2019
	Soil condition	–	Verdonschot and Verdonschot, 2023
	Universal Soil Loss Equation	ton/ha/year	Angela et al., 2015
	Coarse particulate organic matter (CPOM)	g/m2̂	Elosegi et al., 2017
Stream Metabolism			
Stream Metabolism	Stream Metabolism	–	Schäfer et al., 2012
	Plant biomass	–	Yates et al., 2019
	Algal biomass (chlorophyll a)	–	Yates et al., 2019
	Stream Metabolism	–	Schäfer et al., 2012
Organic Matter Breakdown			
Organic Matter Breakdown			
	Breakdown of organic matter	–	Schäfer et al., 2012
	Dissolved Organic Matter	–	Sweeney et al., 2004
	# of wetlands Variety of algae, plants	–	Chien and Satio, 2021
Floodplain			
Connectivity			
	Continuity riparian forest: fragmentation	–	Van Looy et al., 2017
	Upstream continuity (mean # gaps)	–	Van Looy et al., 2017
	Dam density (risk alteration)	–	Van Looy et al., 2017
	Infrastructure/urbanization	–	Van Looy et al., 2017
Odor			
Odour reduction, noise attenuation, visual screening	Presence of a modern floodplain	–	Pastor et al., 2022
	Crossing structures, other bed stabilization structures	–	Pastor et al., 2022
	Bank protections	–	Pastor et al., 2022
	Hillslope – river corridor connectivity	–	Pastor et al., 2022

9. Appendix D. Cultural ecosystem services for streams from the literature in the systematic review

Ecosystem Service	Indicator	Units	References
Aesthetic			
Aesthetic & Local Ecological Knowledge	Number of “viewer days” per year	–	Pastor et al., 2022
	Social media photos number of photos	–	Pastor et al., 2022
	Scenic/panoramic trails km Pastor et al., 2022		
	Index of Natura 2000	sites/UNESCO	Pastor et al., 2022
	Index of Natura 2000	sites/UNESCO	Pastor et al., 2022
	Number of “viewer days” per year	–	Pastor et al., 2022
	Social media photos	–	Pastor et al., 2022
	Scenic/panoramic trails	–	Pastor et al., 2022
	# people attracted to river-related outdoor events	–	Chien and Satio, 2021
	Survey under residents on perception and use	–	Verdonschot and Verdonschot, 2023
	Number of recreational facilities close to the river landscape (in max. distance of 1 km from the river) Length of hiking trails in the river landscape	–	Jakubínský and Cudlín, 2018
Cultural and Aesthetic Values	Property value	–	Tuijn, 2020
	InVEST	–	Tuijn, 2020
	AVANAR	–	Tuijn, 2020
	NC-model	–	Tuijn, 2020
	TEEB-stad	–	Tuijn, 2020
Cultural			
Cultural heritage	Inventory of historical ‘objects’	–	Verdonschot and Verdonschot, 2023
	Qualitative interviews and photo elicitation	–	Verdonschot and Verdonschot, 2023
	# people attracted to river-related outdoor events	–	Chien and Satio, 2021
Therapeutic services	Calm and tranquil locations	–	Calapez et al., 2023
	Birdsong	–	Calapez et al., 2023
	Babbling of water	–	Calapez et al., 2023
	Temporal getaway	–	Calapez et al., 2023
Heritage and prestige (H)	Water wheel/mill	–	Calapez et al., 2023
	Washhouses	–	Calapez et al., 2023
	Historical bridges	–	Calapez et al., 2023
	Restoration projects by institutions	–	Calapez et al., 2023
	Naturalness of the streams	–	Calapez et al., 2023

Ecosystem Service	Indicator	Units	References
Health and Well-being	View to a stream from home/workplace	–	Ranta et al., 2021
	Jogging, football, other sports	–	Calapez et al., 2023
	View to a stream from home/ workplace	–	Calapez et al., 2023
	Feeling of safety	–	Calapez et al., 2023
Direct, in-situ and outdoor interactions with passive or observational interactions	# people attracted to river-related outdoor events	–	Chien and Satio, 2021
	Flood frequency/by depth/ volumes	–	Chien and Satio, 2021
	# people attracted to riverrelated outdoor events	–	Chien and Satio, 2021
Entertainment or representation	# people attracted to river-related outdoor events	–	Chien and Satio, 2021
Existence value	# people attracted to river-related outdoor events	–	Chien and Satio, 2021
General	Perceived social importance	–	Pastor et al., 2022
	Improved wellbeing, happiness and Quality of life indicators and scales	–	Pastor et al., 2022
	Perceived location (in a map) of supply and demand of ecosystem services	–	Pastor et al., 2022
Nature policy goals	Completion policy goals / success chance of the development of target vegetation/nature as outlined by policy	–	Tuijn, 2020
Riverine Landscape Pleasure	Perception scores from nine Likert items	–	Michael-Bitton et al., 2025
Symbolic meaning	# people attracted to river-related outdoor events	–	Chien and Satio, 2021
Traditional ecological knowledge	# people attracted to river-related outdoor events	–	Chien and Satio, 2021
Fish			
Fisheries and recreation	Rooted macrophyte and bryophyte biomass	–	Yates et al., 2019
	Taxonomic diversity	–	Yates et al., 2019
	Trait diversity	–	Yates et al., 2019
	Gross Primary Production	–	Yates et al., 2019
	Algal quality	–	Yates et al., 2019
	Invertebrate density	–	Yates et al., 2019
	Bivalve biomass	–	Yates et al., 2019
	Filamentous algae biomass	–	Yates et al., 2019
	Ash-free dry mass of periphyton	–	Yates et al., 2019
	Community Stability Trophic metrics	–	Yates et al., 2019

Ecosystem Service	Indicator	Units	References
	Net Ecosystem Respiration	–	Yates et al., 2019
Education			
Educational and Research	Distance from school to a stream	–	Calapez et al., 2023
	Environmental volunteer projects to rehabilitate and restore the stream	–	Calapez et al., 2023
	Excursions by schools (annually)	–	Calapez et al., 2023
	Distance to an urban stream from home	–	Calapez et al., 2023
	# people attracted to river-related outdoor events	–	Chien and Satio, 2021
	Number of formal and informal education activities	–	Pastor et al., 2022
	Number of scientific studies	–	Pastor et al., 2022
	Number, extent and density of sacred/religious sites	–	Pastor et al., 2022
	Number of educational programmes	–	Verdonschot and Verdonschot, 2023
Spritual			
Spiritual, Religious And Therapeutic Services	Survey under residents on perception and belief	–	Verdonschot and Verdonschot, 2023
	Number and origin of participants in pilgrimages, festivals or rituals associated with sacred and therapeutic places	–	Pastor et al., 2022
	Number of 'nature on prescription' schemes that include IRES	–	Pastor et al., 2022
	Number, length and extent of IRES for which environmental flows (eflows) or "cultural flows" targets have been developed and adopted	–	Pastor et al., 2022
	Number, length and extent of IRES in watersheds granted legal personhood	–	Pastor et al., 2022
	Positive health outcomes	–	Pastor et al., 2022
	Visitor statistics to places where springs and streams heal them or religious sites	–	Pastor et al., 2022
	Number of ecotherapy prescriptions	–	Pastor et al., 2022
	Number of flora and fauna of symbolic, mythic or totemic significance	–	Pastor et al., 2022
	Nature connectedness to, and derived from IRES	–	Pastor et al., 2022

Ecosystem Service	Indicator	Units	References
	# people attracted to river-related outdoor events	–	Chien and Satio, 2021
Recreation			
Recreation	Number & type of activities e.g., walking, hiking, picnics, birdwatching	–	Pastor et al., 2022
	Fishing licenses	number/km	Pastor et al., 2022
	Number of cultural organizations	number/ha	Pastor et al., 2022
	Number of visitors for recreational purposes	–	Pastor et al., 2022
	Spread of person-days of recreation Visitation rate based on geotagged photos	–	Pastor et al., 2022
	Maps of trails	km	Pastor et al., 2022
	Number of recreational activities	–	Michael-Bitton et al., 2025
	Recreational and tourism economic benefits	–	Verdonschot and Verdonschot, 2023
	# of accessible sport fishing locations	–	Kok et al., 2025
	Average supply of walking opportunities/ha	–	Kok et al., 2025
Tourism	Scouts activity	–	Calapez et al., 2023
	Recreational fishing	–	Calapez et al., 2023
	Museums	–	Calapez et al., 2023
	Touristic activity + water based activities	–	Calapez et al., 2023
	Restaurants, cafes, shops	–	Calapez et al., 2023