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Urban stream assessment system (UsAs): An integrative tool to assess biodiversity, ecosystem functions and services

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ABSTRACT

Urban streams and ecosystems are highly affected by the intense development of cities and an increase of impervious surfaces. If these environments are close to their pristine state, they can be considered a nature-based solution promoting the integration of both green and blue elements in the cities, while providing a wide range of services (e.g. better aesthetics, air quality, leisure areas, and mitigation of climatic changes). In view of this, the current study aimed to develop a holistic assessment tool for urban streams that can be used to highlight their importance and support decision makers in the elaboration of measures to recover urban streams. The tool called Urban stream Assessment system (UsAs) includes the assessment of (1) biodiversity, (2) ecological functions and habitat that are inherent components of the ecosystems, and (3) provisioning, regulating, and cultural services, following The Millennium Ecosystem Assessment (MA) and the Common International Classification of Ecosystem Services (CICES). The tool includes 89 indicators belonging to 17 divisions (services and functions) selected from studies on urban areas and fluvial ecosystems. In addition, the tool introduces a method for the measurement of an indicator, rationale for the used indicator, positive and negative scope of the indicator, and reference to the proposed method. The tool incorporates also a step-by-step scoring system, which results in a global quality classification of streams. The UsAs tool was tested with a case study stream located in the city of Coimbra, Central Portugal. The final classification attributed to this stream was moderate, which is slightly higher than the ecological status, highlighting its potential ecosystem services (ES). However, the UsAs clearly showed a poor biodiversity (namely of aquatic invertebrates, amphibians, fish, aquatic mammals, and terrestrial insects), habitat conditions and the most compromised services that could be improved: water supply, air quality, health and well-being. The use of this novel tool supports also new research and knowledge on aquatic ecosystems and particularly urban streams by generating relevant data to answer and test important ecological questions, such as the influence of biodiversity in ecosystem functioning and services. Further investigation should focus more on tests in different types of urban streams, regions, and climates.

1. Introduction

Cities have become one of the most important habitats for humans. According to the UN, 68% of the world population is anticipated to live in cities by 2050 (United Nations, Department of Economic and Social Affairs, Population Division, 2019). As nature improves human well-being alongside urban liveability (Pickett et al., 2016), cities should not be considered as a secluded habitat from natural environment. Urban ecology as a field describes cities as socioecological systems where ecosystems and societies interact (Pickett et al. 2001). Amongst other ecosystems, urban freshwater ecosystems constitute dense networks within cities, composed often of a large river and several small streams. While globally land use has had the largest negative impact on freshwater ecosystems compared to other ecosystems (Díaz et al. 2019) in cities this impact is especially severe.

However, if preserved, these urban stream ecosystems can provide important services to modern cities such as improving aesthetics and air quality, establishing recreational areas, regulating microclimates and air humidity, reducing air temperature and promoting the well-being and health of populations (Haase, 2015; Carvalho-Santos et al., 2016; Hunter et al., 2019). Urban streams are also expected to have an important role in the mitigation of climate change by buffering extreme temperatures and as part of a strategy to prevent floods. They constitute a natural solution for draining the surface runoff of rainwater during

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extreme precipitation events expected under climate change in Southern Europe (Dadson et al., 2017; WWAP, 2018). This is relevant in urban areas where the infiltration capacity has been reduced due to the surrounding impermeable infrastructure (Zhang & Yang, 2011). In addition, urban stream ecosystems can constitute important and large reserves of biodiversity as they provide habitat for a wide diversity of species from birds (nesting and looking for refuge in the riparian vegetation), bats, terrestrial insects, mammals, reptiles, and amphibians, to aquatic insects, fish, algae and aquatic plants (Angold et al., 2006; Ferreira et al., 2016; Lepczyk et al., 2017).

Yet, urban growth comes at a high cost to these streams which become degraded by overexploitation of natural resources, pollution and disintegration of the land (Maes et al. 2011). This pressures cities to develop measures to conserve these valuable urban freshwater ecosystems and focus on long-term development (Porfiriev et al. 2017). In 2001 the United Nations initiated a program called Millennium Ecosystem Assessment (Millennium Ecosystem Assessment, 2005) with the aim of assessing how changes in the environment can influence human well-being. For rivers, several studies have been done over time (e.g. Vidal-Abarca and Suárez-Alonso, 2013; Dalal et al., 2018), and several indicators have been proposed for the assessment of their ecosystem services (ES) (e.g. Honey-Rosés et al., 2013; Trabucchi et al., 2014; Vollmer et al., 2016). Yet, for urban streams there was no known tool attending to the specificities of these systems, namely to their high embeddedness in the urban tissue, historical use, and potential ES.

Thus, we aimed to develop a holistic framework and assessment tool called Urban Stream Assessment system (UsAs) to assess biodiversity, ecosystem functions and habitat, and ES of urban streams. We considered three of the categories proposed by MA: provisioning, regulating, and cultural services. Provisioning services are products that are obtained from an ecosystem, and regulating services are mainly benefits derived from the sufficient biophysical ecosystem properties as well as regulation of urban streams. Cultural services refer to non-material benefits obtained from urban streams, including both physical and mental benefits for inhabitants (Millennium Ecosystem Assessment, 2005). Due to the special context of these streams in the urban environment, their services have a distinctive importance. Subjective data such as feelings and quantifiable benefit of streams for inhabitants become difficult to measure and are often not accounted for in scientific studies (Gross, 2013; Kochan, 2013). However, several studies were able to find metrics to analyse the psychological well-being gained from urban greenspaces (e.g. Sanesi et al., 2006; Dallimer et al., 2012; Hirons et al., 2016). Such cultural services were also contemplated by this study.

In addition, MA considers the supporting services which are necessary for the production of all other ES from the streams. Examples of supporting services are primary production, biodiversity and soil formation (Millennium Ecosystem Assessment, 2005). However, the Common International Classification of Ecosystem Services (version 5.1; Haines-Young and Potschin 2018) claims that these are indirect services including a variety of interacting and overlapping functions with other services. Considering them as ES could lead to double-counting some services that are already accounted for in other divisions such as regulating services (La Notte et al. 2017). Consequently, we opted to directly assess ecosystem functions and habitat, as well as biological communities, as inherent characteristics of the ecosystem, and we did not use the section of supporting services.

The component of biodiversity was considered following recent trends (Oliver et al., 2015; Ziter, 2015; Bongaarts, 2019). Biodiversity reflects the ecosystem's health and resilience to withstand and recover from a variety of disturbances (Harrison et al., 2014). One of the main criticisms to the ES approach is that the purely anthropogenic perspective of ES can result in a higher degradation of these systems, due to a more immediate need of populations (Moreno-Mateos et al., 2017). Thus, we included biodiversity (aquatic biological communities and terrestrial associated to the streams riparian areas) in this study, which together with ecosystem functions and habitat characterise the ecosystem and support ES. Finally, this leads to two separate assessments for ecosystem maintenance and ES. We assume that aquatic urban ecosystems, even if constrained by urbanisation, should aim to be as close as possible to the pristine state, supporting the expected biological communities and ecosystem functions for a given region and river type, following the principles of the Water Framework Directive (European Commission, 2000. The EU Water Framework Directive - integrated river basin management for Europe, December 2000).

Compared to ecological assessment of streams through biological indicators (*sensu* Water Framework Directive), this assessment intends to be more integrative and evaluate benefits of the services to human well-being, as well as contributing to conservation of biodiversity and more resilient urban ecosystems. A total of 124 studies and articles were reviewed for the framework to find the most suitable methodologies for the assessment of different indicators. A special attention is given to biodiversity, ecosystem functions and habitat, and cultural services, as these are often neglected in urban and/or riverine ES studies (Dalal et al. 2018). Although we propose a framework that can be used elsewhere to assess urban streams, reference values for biodiversity assessment should be adjusted at the regional level. Here, we tested the functionality of the UsAs tool with an urban stream from Coimbra city, central Portugal. We used adjusted values for biodiversity to the expected fauna and flora of the region and type of stream, according to published information and available data.

2. Methods

2.1. Main assessment categories and selection of services

The selection of relevant ES of urban streams for each of the three categories (provisioning, regulating and cultural) was based on an extensive search within publications and studies on riverine ES (e.g. Dalal et al., 2018; Riis et al., 2020) and on ES in urban areas (e.g. Gómez-Baggethun & Barton, 2013; Elmqvist et al., 2015; Garcia et al., 2016; Maes et al., 2016b; Brill et al., 2017; Chen et al., 2019). For each final service, we selected the most appropriate indicators that can directly affect the well-being of urban populations. Following this step, the evaluation tool was created by filling in ready-to-use methods.

Within the selected ES categories, provisioning services are more limited as urban streams in general do not yield an adequate number of products for self-sustaining the local populations. For instance, materials for biomass is a typical provisioning service, but since it is generally grown in cropland and forest ecosystems (Maes et al. 2016a), it was left out from the framework.

Regarding biodiversity, in addition to typical aquatic communities (e.g. invertebrates, algae, fish, aquatic fungi) we selected other taxonomic groups that could use the stream and associated riparian zone as habitat, including for feeding, refuge, or reproduction. These taxonomic groups are further divided into native and invasive species to highlight the need for an active management of invasive species for the preservation of biodiversity. Introduction and spread of invasive alien species can pose ecological, economic and social threats (Vilà & Hulme, 2017).

Considering all these factors the assessment framework resulted in five main sections and respective divisions:

1. Urban biodiversity (UB) - aquatic flora, fauna, fungi, invertebrates, terrestrial/semi-aquatic flora and fauna, and aerial fauna.
2. Ecosystem functions and habitat (EFH) - habitat availability, primary production, and nutrient cycling.
3. Provisioning services (PS) - water and food supply.
4. Regulating services (RS) - climate regulation, flood mitigation, air quality, water quality, carbon sequestration, and pollination.
5. Cultural services (CS) - education and cognitive development, tourism and recreation, heritage and prestige, amenity and aesthetic

enjoyment, therapeutic services and, health and well-being.

The proposed UsAs consists of eight columns: section, division, indicator, method, rationale, positive scope of service, negative scope of service / disservice, and reference to the proposed method.

As ES are often criticised for double-counting the services they produce **(e.g.** Fisher et al. 2009; Landers and Nahlik, 2013**)**, this study mitigates it by articulating the benefit of the service or function clearly in the rationale. Methods further explain what aspect of the service or function is measured. For instance, in UsAs, nutrient cycling can be studied by vegetated exposed substrate areas (island, side and point bars), and by measuring coarse organic matter decomposition (total and microbial). Supplementary material: UsAs 2020 Framework – EFH explains further the different aspects of nutrient cycling.

Primary production is assessed by measuring canopy cover by riparian trees. Canopy cover is particularly relevant in small streams, as the shade has the potential to reduce primary production **(**Kristensen et al., 2013**)**. In addition, primary production can be measured through photosynthesis by biofilms algal component, and sediment's respiration rate. Carbon sequestration on the other hand is studied by dissolved CO_2 in water, or optionally by carbon sequestration by sediment and/or vegetation in the riparian area.

Optional measures are considered important to the global assessment and can be measured to contribute to analysis of the stream and for comparative purposes (among urban streams of a given city/region). However, it will not add to the final scoring, as often a reference value is not established. In addition, indicators such as fish health based on endocrine disruptive chemicals **(**Ankley et al. 2009**)** require more advanced technology. They were also considered as optional measures, which would complete the information but are not obligatory for use of the classification system. The majority of the remaining indicators can be measured and/or observed in the field without the need for a specialist, and with common field equipment.

2.2. Selection of indicators (including scales of measurement)

2.2.1. Indicators

The indicators selected were considered the most informative and feasible to measure, in order to have a practical tool where evaluations would be the least dependent on the user, and could generate a global assessment with a great number of aspects.

Thus, more indicators per division give a more comprehensive idea of the local conditions. For example, habitat availability can be analysed through the instream habitats, large woody debris as habitat, or riparian zone conversion **(**Sweka & Hartman, 2006; Utz et al., 2016; Ramey & Richardson, 2017**)**. This set of indicators can cover the complexity and various aspects of one service, whereas a single indicator would only cover one part of the service. However, finding suitable indicators to address all the components of MA conceptual framework is a great challenge **(**Maes et al. 2016a**)**. For each service, a number of indicators is possible but some indicators have been extensively used, or do not concern the characteristics of the ecosystem **(**La Rosa et al., 2016; Maes et al., 2016a**)**.

ES can also generate problems for humans, especially within cities, which are known as disservices (Lyytimäki et al. 2008). Often the same ecosystem function can be beneficial and/or harmful even for the same receiver of the service **(**Blanco et al. 2019). It is important to integrate disservices in ES assessment to find the best management practices to minimise negative effects **(e.g.** Russo et al. 2017; Vaz et al., 2017; Blanco et al. 2019**)**.

UsAs introduces possible negative and positive scope of division for applicable indicators, which are later used as a base for the scoring of the indicator. For instance, tolerant invertebrates (Oligochaeta and *Chironomus* spp.) as a measure of water quality, are an important food source for amphibians, but can also indicate polluted and anthropogenically disturbed environment **(**Cranston, 1995**)**. Thus, presence or abundance of tolerant invertebrates results in a lower final score.

2.2.2. Methodologies

A wide array of methodologies (Supplementary material: UsAs 2020 Framework) has been proposed for the use of UsAs, according to the specific requirements of each indicator. Examples are the visual inspection of instream and stream margins, collecting water samples for chemical analysis, sampling aquatic benthic invertebrates with hand nets, or use of available databases, maps, or social media.

Both qualitative and quantitative indicators were used. Qualitative data are represented in both nominal and ordinal data range. A nominal scale includes observations at the field, such as visual observation for species (absent/present) and babbling of water (absent/present). Ordinal scales identify ranked data from inquiries, such as motivation to conserve the environment. Quantitative indicators consist of measured data such as air humidity or taxonomic identification.

To assess urban biodiversity, it is necessary to have adequate reference values. A maximum expected diversity for each selected taxonomic group was defined based on species databases and published information for streams in central Portugal **(**INAG, 2008; INAG, I.P. , 2009; A.P.H.A., , 2012; Feio et al., 2019**)**, the region where the stream Vale das Flores is located. Thus, the current thresholds apply to this study case and similar ones. These streams are characterised by temperate climate with a transition between Atlantic influence and Mediterranean climate, and the river type N1 $<$ 100 according to the WFD. Generally, measures for UB (as well as the biological quality indices obtained for water quality), such as on macroinvertebrates or diatoms, are the most demanding to examine. This is due to the need for specific approaches to sampling collection and laboratory processing, small size of individuals and/or for requiring specialists for the taxonomic identification and adequate taxonomic keys. On the other hand, some, such as the aquatic plants, fish and invertebrates are mandatory elements of ecological quality assessment of freshwater ecosystems in Europe (according to WFD) and other continents. In consequence, the information may already be available for certain areas and if not, the application of this tool will again promote their ecological classification according to European legislation.

2.2.3. Scales of measurement

For each indicator the stretch used for measurements varies according to their characteristics, from a given length (often 100 m or 500 m) to a buffer zone as well as the site of measurement, which could be either instream, in the margins, riparian zone, or drainage basin **(**Cochero et al. 2016**)**. A stretch of 100 m is relatively short but often contains a great variation in an urban stream and is a scale often used in the biological assessment of rivers for some quality elements (usually between 50 and 100 m). A stretch of 500 m represents a considerably large area for a small urban stream, and is often used in the hydromorphological assessment of rivers. The scale of measurement is mentioned in Supplementary material: UsAs 2020 – Scoring system for each indicator, and examples of given scales can be seen in Table 1.

2.3. Multi-criteria assessment scheme

A scoring system was developed based on a multi-criteria assessment to determine the impacts of a wide variety of parameters to urban ES. The scoring system was developed with the aim of assessing different indicators in a comparable manner. Thus, we built a scoring system, first organised at the section level (UB, EFH, and ES categories) and second, at the indicator level. The maximum points per section is 12, as it is the least common multiple based on the number of divisions per section (Table 2). Also, each division under the same section has an equal score. Maximum score per division is derived by:

$$\text{Maximum score per division} = \frac{Maximum\ score\ per\ section}{Number\ of\ divisions}$$

Table 1
Examples of different scales of measurement.

Section	Division (e.g. function, service)	Indicator	Assessment scale
UB	–	Macrophytes	100 *m*
EFH	Habitat availability	Streambed sedimentation	100 *m*
PS	Water supply	Transversal connectivity	500 *m*
PS	Water supply	Groundwater recharge	Whole stream
RS	Climate regulation	Air temperature variation	100 *m*
RS	Pollination	Nectariferous plants	500 *m*
CS	Education and cognitive development	Distance to urban stream from home	200 *m*

For instance, the final set of RS consists of six divisions (or services). Maximum score per division is derived by dividing the maximum score per section by the number of divisions (12/6) resulting in 2.00 points. Maximum score per indicator is derived similarly by dividing the maximum score per division by the number of indicators within the division:

$$\text{Maximum score per indicator} = \frac{Maximum\ score\ per\ division}{Number\ of\ indicators}$$

Consequently, one indicator in the final set is not valued more than another. This aims to mitigate subjective assessment and scientific errors. Ecosystem functions and biodiversity assessment follow the same principle.

However, the maximum point per indicator for biodiversity is obtained directly by dividing 12 by the number of indicators (excluding invasive species and an optional measure). A negative score was attributed to the presence of invasive species considering that they can harm the existing natural resources. In case invasive species are present in a certain taxonomic group, a maximum of 0.45 points (75% of a total of 0.60) can be subtracted from the final score for UB. This will make a difference in the final scoring, where the deducted points for invasive species can add up to 3.15 points (7*0.45). In case invasive species are absent, no subtraction is needed.

2.3.1. Data metrics

Due to a lack of historical data that could be used to establish reference conditions, the scoring of the metrics had to be based on a customised ranking range, or data range based on existing literature and outcomes of field work. The data range was divided into 2–5 intervals depending on the following criteria: (1) the indicator can be assessed as a percentage of a reference value; (2) the indicator can be measured as absent or present; (3) values are compared against target water quality ranges (TWQR), as in the case of ecological quality which is measured in 5 classes (excellent, good, moderate, poor, bad), or simplified to > Good or < Good according to general standards; (4) quantity of an indicator is observed in the field as abundant, moderate, present, absent; and (5) indicator specific range (e.g. pH, temperature, safety of the area, flood capacity).

To make the values on different data ranges comparable, they are further converted into a percentage: 100%, 75%, 50%, 25%, and 0%. In this range, 100% is allocated to a high positive impact, and 0% is assigned where the indicator results in high negative impact (see Supplementary Material: UsAs Scoring system).

For instance, each indicator under water quality has a maximum score 0.40 (Table 2). Nutrients in water are assessed according to national standards established for ecological quality assessment following the Water Framework Directive and the final data range from > Good to < Good. In case the assessment leads to an unfavourable quality, the indicator is scored by multiplying the maximum score of the indicator by the corresponding percentage, which in this case is 0%.

2.3.2. Application of the scoring system

The use of the scoring system is divided into steps from A to E (Fig. 1). Table A (Supplementary materials: Scoring system - UsAs 2020) shows the basic structure of the assessment tool by showing the main section, the final set of services or functions, and their corresponding indicators. Table B (Supplementary materials: Scoring system - UsAs 2020 includes method specific information required in the field. Table C (Supplementary materials: Scoring system - UsAs 2020) contains conversion from the measured value within a given data range into a percentage. This percentage indicates the scale of performance, where 0% is negative and 100% a positive outcome. This percentage is then multiplied by the maximum score of the indicator. Steps D and E include the final scoring. First, Table D (Supplementary materials: Scoring system - UsAs 2020) includes the stages for obtaining the final score both per division and per section. The final classification is addressed for ecosystem maintenance and ES separately. When all points within a section are summed up, they can be converted into a final class (Table E - (Supplementary materials: Scoring system - UsAs 2020)) –

Table 2
Maximum score per section, division, and indicator.

Section	Maximum score per section	Number of divisions	Division	Maximum score per division	Number of indicators (exc. Optional measures)	Maximum score per indicator
UB	12	–	–	–	20	0.60
Invasive species					7	0
EFH	12	3	1. Habitat availability	4	5	0.80
			2. Primary production	4	1	4.00
			3. Nutrient cycling	4	1	4.00
PS	12	2	1. Water supply	6	3	2.00
			2. Food supply	6	4	1.50
RS	12	6	1. Climate regulation	2	2	1.00
			2. Flood mitigation	2	2	1.00
			3. Air quality	2	2	1.00
			4. Water quality	2	5	0.40
			5. Carbon sequestration	2	1	2.00
			6. Pollination	2	2	1.00
CS	12	6	1.Education and cognitive development	2	4	0.50
			2.Tourism and recreation	2	5	0.40
			3. Heritage and prestige	2	5	0.40
			4. Amenity and aesthetic enjoyment	2	2	1.00
			5. Therapeutic services	2	4	0.50
			6. Health and well-being	2	3	0.67

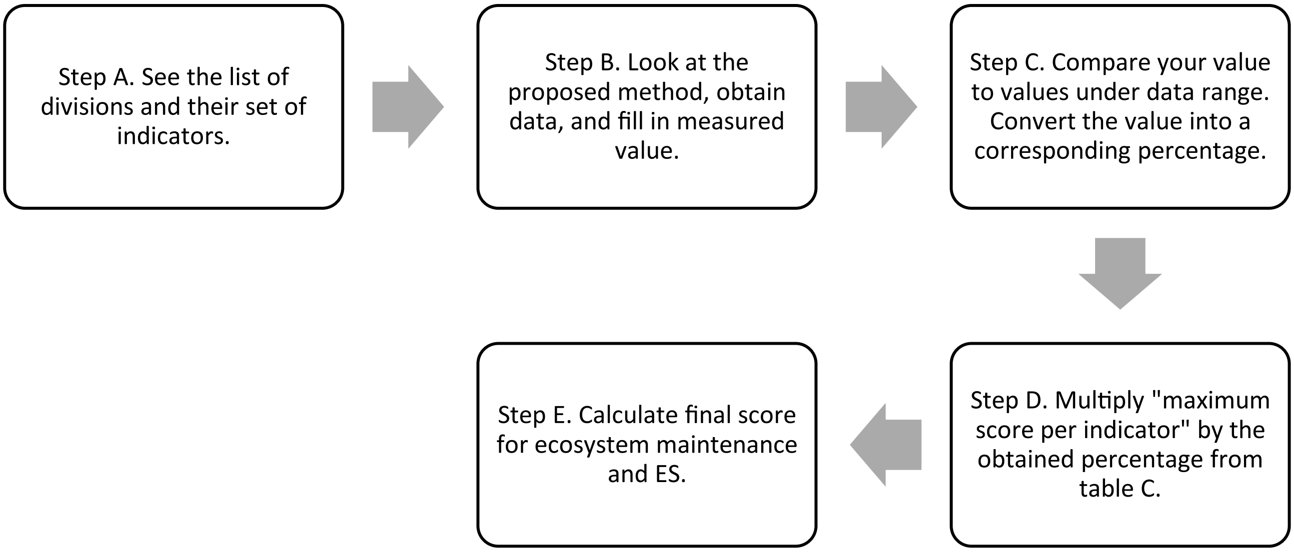

Fig. 1. Use of the scoring system from step A to step E.

firstly, for ecosystem maintenance (urban biodiversity and ecosystem functions and habitat), and second, for ES (PS, RS, and CS).

Final classification follows the scale used for the Ecological status classification of surface water bodies in EU (European Commission, 2000. The EU Water Framework Directive - integrated river basin management for Europe, December 2000**):** bad (0–20), poor (21–40), moderate (41–60), good (61–80), high (81–100). The final class can be obtained as such:

$$Final\ classification = \sum \frac{F_{us} \times 100}{F_{max}}$$

F_{us} = Final score of ecosystem maintenance or ES sections
F_{max} = Maximum score (sum of the related sections)

In case an indicator cannot be applied to the stream or measured locally due to other restrictions, this indicator can be neglected. The scoring system allows the user to also modify the set of indicators. For instance, in case food supply under PS cannot be applied to urban orchards, it can be disregarded. This results in fewer indicators in the set, which consequently results in a higher maximum score of the rest of the indicators within the set. Maximum score for food supply in this case would be substituted for 3 instead of 4 indicators (Table 2), which results in a maximum score of 2.00.

2.4. Assessment of a test site – The urban stream Vale das Flores

To test UsAs, especially the applicability of the indicators and feasibility of obtaining values and scores, we used a known urban stream as a test site. Vale das Flores (Fig. 2) is located in the city of Coimbra, central Portugal (> 150 000 inhabitants), where previous studies have been undertaken by the team **(**Serra et al., 2019**)**. The stream is approximately 3.1 km long and runs underground for most of its length. It becomes uncovered approximately 1 km before it discharges into the River Mondego.

Vale das Flores is an example of a highly modified urban stream, with poor water quality and vast cuts of native riparian vegetation. It flows at a central location of the city and is surrounded by heavy infrastructure, such as roads, private residence and businesses. We considered the whole stream for most of the indicators, except for the ones that could only be observed on the reaches that are aboveground.

The stream is mostly linear with some meanderisation and small riffles. There is some riparian vegetation including autochthonous species (e.g. *Salix* spp.*, Alnus glutinosa, Rubus sp.*) but also several invasive weeds and macrophytes, such as *Arundo donax, Cortaderia selloana, Tradescantia fluminensis, Ailanthus altissima, Ipomoea indica, Phytolacca americana,* and *Oxalis pes-caprae* **(**Serra et al., 2019**)**.

Fig. 2. Vale das Flores is an example of an urban stream that is surrounded by heavy infrastructure.

There are a number of bridges crossing the stream, from small pedestrian bridges to larger bridges and the uncovered stretch is mainly surrounded by unconsolidated walls. An artificial metallic mesh covers the stream bottom for erosion prevention and stabilising natural substrates. Previous works have shown that the ecological quality of the stream is poor with an impoverished aquatic invertebrate community composed mainly of insensitive species, such as Diptera Chironomidae, Oligochaeta and Gastropoda **(**Serra et al., 2019**).**

For biodiversity indicators existing data on diatom and invertebrate communities was used as well as physico-chemical parameters from **(**Serra et al., 2019**)**. The remaining indicators were filled according to field observations and measurements.

3. Results

After extensive bibliographic revision, 124 studies were included in UsAs, and a total of 87 potential indicators were selected to characterise and assess urban stream ecosystems and services (Supplementary material: UsAs 2020 – Framework and UsAs 2020 Scoring system). To elucidate the structure of the measurements and identification of UB (Table 3) the framework was divided into three different states in stream ecosystems; aquatic – in water, terrestrial – in the margins and,

Table 3
Final set of indicators for urban biodiversity and corresponding number of expected taxa at a site for urban streams of Central Portugal based on existing literature and available data. If no reference conditions can be given locally, the indicator can be assessed as present/absent.

Urban biodiversity			Number of expected taxa at a site / autochthonous species expected at a given region and stream type - reference conditions	Data range
Aquatic	Plants	Leaves from riparian trees	Number of leaves	0,1,2,3, ≥4
		Diatoms	126 species	0–100% of the species
		Macrophytes	209 species	0–100% of the species
		Invasive macrophytes	4 species	> 1, 1, 0
		Endangered macrophytes	–	Present/absent
	Animals	Native mammals	4 species	0,1,2,3, ≥4
		Invasive mammals	*Neovision vision*	> 1, 1, 0
		Endangered mammals	*2 species*	Present/absent
		Native fish	20 species	0–100% of the species
		Invasive fish	10 species	> 1, 1, 0
		Endangered fish	6 species	Present/absent
		Native invertebrates	120 species	0–100% of the species
		Invasive invertebrates	–	> 1, 1, 0
		Endangered invertebrates	–	Present/absent
	Fungi	Hyphomycetes	102 species	0–100% of the species
Terrestrial / Semi-aquatic	Plants	Native riparian trees	9 species	0–100% of the species
		Invasive trees	–	> 1, 1, 0
		Endangered trees	–	Present/absent
	Animals	Amphibians	9 species	0–100% of the species
		Invasive amphibians	4 species	> 1, 1, 0
		Endangered amphibians	4 species	Present/absent
		Optional measure: Invasive mammals (households with cats)	–	Number of households with a cat via inquiry
Aerial	Animals	Birds	17 species	0–100% of the species
		Invasive birds	–	> 1, 1, 0
		Endangered birds	–	Present/absent
		Endangered bats	–	Present/absent
		Butterflies	12 species	0–100% of the species
		Dragonflies (endangered species, aerial phase)	8 species	0–100% of the species

aerial – in the air, in the riparian zone. Species can be found in Supplementary material: Species lists.

The final framework was organised as such: 28 indicators for UB; three divisions for ecosystem functions and habitat (habitat availability, primary production, and nutrient cycling); two for provisioning services (water and food supply); six for regulating services (climate regulation, flood mitigation, air quality, water quality, carbon sequestration, and pollination); six for cultural services (education and cognitive development, tourism and recreation, heritage and prestige, amenity and aesthetic enjoyment, therapeutic services, and health and well-being).

In EFH, habitat availability can be measured by a set of five indicators: instream habitat / substrate type distribution, streambed sedimentation, large woody debris as habitat, natural undisturbed area, and riparian zone conversion. Primary production can be measured by shading, or by two optional measures: photosynthesis by biofilms and sediment's respiration rate. Nutrient cycling can be measured by a set of two indicators: vegetated exposed substrate areas (island, side and point bars), and optionally by measuring coarse organic matter decomposition (total and microbial). Pollination can be measured by the presence of bees and nectariferous plants. Corresponding methods for the assessment of ecosystem functions can be found in the Supplementary Material: UsAs – Framework, EFH.

Supplementary material: UsAs – Framework, PS includes two divisions for PS. Water supply can be assessed with three indicators, including irrigation of crops, groundwater recharge, and transversal connectivity (water from channel to the margins). Food supply can be measured by four indicators; natural plants (with nutritional, aromatic, medicinal value), species richness of fish, other aquatic animals with nutritional value, and presence of urban orchards in the riparian area. An optional measure is to measure Endocrine disruptive chemicals in fish. Data for food supply can be also obtained from the assessment of UB for fish species and aquatic animals, such as bivalves and crayfish.

Under RS, climate regulation can be measured by air temperature and air humidity variations. This is done by comparing the instream conditions to the conditions outside the riparian zone. Flood mitigation includes flood capacity and floodplain availability, and air quality is measured by integrity of the riparian corridor (margins with no vegetation cuts) and presence of lichens. An optional measure is to study all primary air pollutants as a standard air quality measure in the riparian area. Water quality has five indicators: nutrients in the water, presence of tolerant invertebrates, ecological quality according to WFD, total suspended solids, and pH. An optional measure includes *E. coli* contamination.

CS consist of 25 indicators, such as restoration projects by institutions, babbling of water, and distance to an urban stream from home. Information can be obtained by field surveys, from web searches, via inquiries to the population or to some entities of local political power, or by visual observation. The use of inquiries in UsAs was however restricted to few to facilitate the application of the framework.

3.1. Structure of the UsAs

The final structure of UsAs is displayed in Table 4. The final choice of indicators varies between one and six for each service. The recommended method of measurement is shown in the next column. Following the suggested method of measurement, the rationale explains why this specific indicator is important in assessing urban streams. A recap of the importance of the indicator is shown as well as a potential disservice. The last column indicates bibliography with the justification for the use of a given indicator or more details on the methods.

3.2. Assessment of a test site – The urban stream Vale das Flores

The application of the UsAs framework was relatively simple, although it was time-consuming. The field survey requires approximately three hours in this quite simplified ecosystem and it is expected to take

Table 4
Examples of a division and an indicator of the final framework.

Section	Division	Indicator	Methods	Rationale	Positive scope	Disservice	Reference
UB	–	Leaf diversity	Count of different riparian tree species based on the leaves found in the stream channel or banks. Hand-picking of fallen leaves or observation of leaves in the trees and other plants.	Leaf litter provided by riparian vegetation can be used as an indicator of diversity of riparian plants. Riparian tree diversity is essential for the maintenance of ecosystem functioning, namely to decomposition processes. Also, riparian trees provide support to stream banks, are a natural filter of nutrients and contaminants, contribute to cool down air and water temperature, and minimise eutrophication amongst others.	Decomposed leaves are a source of organic matter and energy to stream ecosystems.	–	Jackrel & Wootton, 2015
EFH	Habitat availability	Instream habitat / substrate type distribution	Within a 100-metre stretch, number of substrate types (8) available: rocks and blocks, stones/gravel, coarse sand, fine sediment (mud), coarse organic matter deposits (e.g., leaves), macrophytes and algae, pools, riffles	Preservation of natural habitat that is often degraded or disappears in an urban environment. The loss of natural systems reduces the potential existence of many aquatic species.	Safety for different organisms, conservation of natural habitat	–	Salant et al. 2012
PS	Water supply	Irrigation of crops	Number of water captions, visual observation. Scale: consider a transept of 10 × stream width over a 500 m stretch	Water captions provide water supply for irrigation of crops. However, they might reduce the water available in the stream for biodiversity and services.	Independency of remote sources; reduction of GHGs	Lowering of water table, reducing habitat for aquatic flora and fauna, increase potential for eutrophication and noise	Wakode et al., 2018
RS	Climate regulation	Air humidity variation	Two measurements (M_o, M_i): % humidity in the margins, outside the riparian zone compared to the instream air humidity. Scale: 100 *m*	Streams and respective riparian zones provide humidity to cities' air on the contrary, constructed areas and traffic raise air temperature and decrease humidity.	Human well-being	High humidity can cause problems with constructions, rheumatic diseases	Lourenço et al. 2006; Freitas et al., 2009
CS	Health and well-being	View to a stream from home/ workplace	Number of windows that can be viewed from the stream. Count along a 100m stretches of the stream.	The number of residents with a view to a greenspace/urban stream can be measured by counting the windows. A view to nature is an important factor for residents' well-being.	Relaxation, aesthetics	–	Gilchrist et al. 2015

Table 5
Results of the assessment of Vale das Flores with the UsAs.

	Division	Final points per division	Maximum	Final score	Classification
Ecosystem maintenance	**UB**	1.35	12.00	25.21	Poor
	EFH	4.70	12.00		
	Total	**6.95**	**24.00**		
Ecosystem services	**PS**	7.00	12.00	57.17	Moderate
	RS	8.05	12.00		
	CS	5.53			
	Total	**20.08**	**36.00**		

longer at a larger stream with a better-preserved ecosystem supporting a higher biodiversity. Approximately five days were spent in the lab (for water filtration, leaf litter decomposition experiment preparation and processing, sporulation of fungi, identification of invertebrates, diatoms and hyphomycetes) and approximately one day to search for other information in the office (web, books, papers). To perform the litter decomposition experiment it was necessary to wait for four weeks before retrieving the mesh bags from the stream. In addition, some days are required for contact with the local political power, associations, schools or museums to clarify certain aspects (e.g. count of excursions to the stream, rehabilitation projects or actions from NGOs etc.).

After applying the calculations, we obtained a partial score of 1.35 for UB, 4.70 for EFH, 7.00 for PS, 8.05 for RS and 5.53 for CS (Table 5). The final score of 25.21 for ecosystem maintenance corresponds to a poor condition on the classification scale, and 57.17 for ES to a moderate condition.

The final classification attributed to this stream is slightly better than previous results from ecological assessment of the stream. Here, the evaluation with UsAs indicated poor biodiversity. Presence of invasive species, such as *Physa fontinalis, Potamopyrgus antipodarum, Procambarus clarkii*, cause a decrease in native biodiversity, and tolerant invertebrates (Lumbriculidae and Tubificidae) that are abundant (Serra et al., 2019) imply poor quality of the stream. Lack of shelter (e.g. absent woody debris as habitat and lack of natural undisturbed area) can play a role in poor biodiversity and consequently impact fish communities that are absent in the stream.

In addition, the UsAs highlighted a poor value of the cultural services provided by this stream, although there is high potential to increase this value due to proximity to many residential buildings, walking paths, and sidewalks near the stream. Presently however, the stream does not offer a great variety of recreational activities and elements of cultural heritage, such as historical bridges, waterwheels, washhouses, and museums. Therapeutic services such as babbling of water and birdsong are, however, present.

Flood mitigation measured by Manning's equation, carbon sequestration and climate regulation (measured by comparing the instream and outside riparian temperature and humidity) performed well. The stream has also an effective primary production (measured by shading) and pollination capacity due to presence of bees and nectariferous plants.

4. Discussion

Of all continental aquatic ecosystems, impacts of anthropogenic disturbances are especially strong in urban streams. These aquatic ecosystems have a high potential to provide citizens with a better quality of life, including recreational areas, leisure, and psychological stability (Díaz et al. 2018), but are often neglected by stakeholders and excluded from regular ecological monitoring. Still, monitoring nature and defining strategies to protect it, is increasingly important in the rapidly changing urban environments (Connop et al., 2016; Raymond et al., 2017). In addition, open communication and interactive decision-making amongst several experts on urban stream ecology and ES can benefit both local population and ecosystems (Bennett et al., 2015; Nesshöver et al., 2017).

Despite the vast bibliography on monitoring strategies and programs to evaluate the quality of rivers (e.g. WFD and American Public Health Association, APHA) there is no framework that reflects the uniqueness of the urban aquatic ecosystems from the perspective of their capacity to provide ES. The proposed Urban stream Assessment system (UsAs) is an ideal tool to summarise and collect the baseline information to promote this dialog based on solid knowledge of these ecosystems and their potential services to the population. The result of the assessment is converted into a final class for maintenance of the ecosystem and ES according to WFD (high, good, moderate, poor, bad). It demonstrates the condition of a stream in a comparable manner that can provide insight to local management of urban streams with special attention to environmental quality.

The information gathered in UsAs is very global, covering diverse areas of expertise from ecology to hydraulics, as well as economic activities and cultural heritage, in a relatively simple manner. These methods can provide a useful base for the multidisciplinary evaluation of urban streams. The application of UsAs to Vale das Flores in this study showed that the set of proposed divisions and indicators complemented each other and provided an integrative description of the state of Vale das Flores, beyond existing ecological information (Serra et al., 2019).

Comparatively, and in spite of some missing data, the application of the UsAs showed a poor performance of Vale das Flores stream site regarding cultural services and urban biodiversity, while regulating services performed better. Overall there is a great need for improvement of all divisions. This means that rehabilitation of this stream is highly needed and renaturalisation of the stream should be the key focus. Successful improvement of the characteristics inherent to an ecosystem (e.g. habitat diversification, shading through riparian vegetation or nutrient cycling) should also lead to an enhancement of biodiversity and other services (**e.g.** Connop et al. 2016; Bongaarts, 2019). Presently, the stream is neglected by the local population, although some cultural services could be recorded (namely a view to the stream from several homes and workplaces, existence of pedestrian passages, and field trips from local schools). The results show that in case the stream is rehabilitated (with a special focus on riparian vegetation and instream habitats), these services could be exponentially improved. As the stream is located in a highly urbanised area, it could provide much better aesthetics, air quality, and leisure activities. This highlights one important aspect to be considered by urban managers: while urban streams are presently amongst the most damaged **ecosystems** (Pickett et al. 2001; Walsh et al., 2005), if recovered to a more natural state, they have not only a high transformative potential of the urban landscape, but also a high potential to maintain biodiversity and deliver important services to inhabitants. This implies, however, a great number of changes in current practices and ideas: promotion of the value of these ecosystems to local populations and stakeholders while facing numerous technical and political challenges is needed (Connop et al., 2016; Bush, 2020).

The development and test of this framework raised also a number of questions and highlighted some potential drawbacks. Among others, urban streams can have rapid fluctuations in water quality and flow as a result of their changing surroundings (Walsh et al., 2012; Serra et al., 2019). In addition, some taxonomic groups such as invertebrates and plants have seasonal life cycles, which also influence processes such as decomposition rates and primary production. These constrain the generalisation of results based on short or single field surveys, as well as the choice of reference values, which influence the outcome of the scoring system. To solve this, it is recommended to repeat some measures with potential temporal variations. This would nonetheless increase the time needed to complete assessment, which is already quite considerable for one stream (approximately five weeks).

Another difficulty is that many services come together with a disservice (Lyytimäki et al., 2008; Speak et al., 2018). This can make an objective assessment more difficult. Nevertheless, indicators that have both positive and negative scope of service highlight important issues that make the assessment more realistic and therefore worthwhile. Examples of this situation are aquatic plants that can provide local temperature regulation, air pollutant reduction, noise reduction, and better health for humans. Their presence overweighs their scope of negative service (e.g. competition for water uptake or occupation of the channel occulting in water).

Despite these potential drawbacks, the ES concept offers a comprehensive approach to ecologically sustainable city design. Compared to ES or ecological quality assessment (as that preconised by the WFD; European Commission 2000) the UsAs is more holistic. It also includes the assessment of local species diversity for a wide range of taxonomic groups that are part of stream ecosystems, including terrestrial and aerial species associated to water and riparian vegetation, such as amphibians, reptiles, or birds that are not contemplated by WFD. However, many studies indicate the potential of these groups as ecological indicators (namely birds and amphibians) which also depend on the integrity of riparian areas (Sekercioğlu et al., 2004; Aguiar & Ferreira, 2005). These groups have even been in monitoring programs around the world (e.g. Price et al., 2005; Kaiser, 2008; Schmeller et al., 2012).

Other relevant features of UsAs are the assessment of ecosystem functioning, as well as invasive and exotic species that are usually also not considered in the regular monitoring of rivers. They can even be accounted for in a positive way by indices, such as the multi-metric ones used for invertebrates that account for species richness (Feio et al., 2014; Feio et al., 2019). However, invasive invertebrates, fish or plants are often present in urban rivers, causing severe damages to ecosystems by competing for resources, damaging native species and decreasing aesthetic value of their green areas (e.g. Doherty et al. 2016 Gaertner et al. 2017). The collection of this information will contribute to improving mitigation measures, and to a more realistic panorama of the distribution of these species.

Concerning ecosystem functioning, the UsAs includes aspects such as primary production, decomposition rates of organic matter, and sediment's respiration rates. These parameters, although not yet present in official indicators of ecological quality, have been widely explored by the scientific community to assess ecosystem health (e.g. Feio et al., 2010; Imberger et al., 2010; Silva-Junior et al., 2014; Chauvet et al., 2016). They allow the evaluation to be more integrative than the measures strictly based on biological assemblages (Imberger et al. 2010). A potential difficulty in the implementation of this tool is to find adequate expertise for all taxonomic groups, which may be a constraint in some regions (Pyšek et al. 2013). Identification of species is required to obtain a maximum benefit of the assessment, but some of these measures can be more easily performed anywhere in the world and are more independent of taxonomic expertise. Also, lack of expertise does not prevent the correct application of the remaining sections.

Finally, the data gathered through the application of this tool can be used to provide insights on the relationship between biodiversity, ecosystem functions and habitat, and ecosystem services. It is widely agreed within the scientific community that biodiversity plays a fundamental role in ecosystem functioning, which is usually directly related to the potential of a stream to provide services (Ziter, 2015; Oliver et al., 2015; Díaz et al., 2019). Theoretically, the loss of biodiversity affects urban ES locally as well as globally, which can ultimately have a negative impact in sustaining the urban population (Alberti & Marzluff, 2004; Oliver et al., 2015). However, there is still not enough data to explore those relationships due to the complexity of these rapidly changing environments. The UsAs can strongly contribute to overcoming this gap, and improving scientific knowledge on aquatic ecosystems, as it systematically congregates a large number of aspects of urban streams.

5. Conclusions

Urban streams can provide important services to urban populations and host a wide diversity of species. In order to maximise the benefits of these urban environments we suggest the use of an ES-based Urban stream Assessment system including ecological functions and habitat as well as urban biodiversity.

Overall, this tool is able to provide two different types of information: (1) raw data of the environmental quality that will also be useful in ecological studies, and (2) intermediate scores and the final classification, which results in a simplified demonstration of a complex reality of an urban stream. This information is useful for urban designers and water managers, who can better understand where investments should be made to recover streams and maximise the services provided by these ecosystems to the population. In addition, it allows the establishment of priority areas for nature conservation, promoting green areas in a city and protecting land from increasing urbanisation.

Also, the collection of information on those divisions of the UsAs, that do not require a high scientific specialisation, such as pollination, therapeutic services, and tourism and recreation, could be made with citizen collaboration. Thus, this framework also becomes a tool for environmental education and citizen participation in the co-responsibility to keep urban rivers clean and healthy.

Finally, UsAs is intended to be a flexible tool where methods recommended are not intended to be fixed over time, but may evolve when more feasible and innovative methods appear. Future research should also focus on testing its adaptability to other regions of the world with different climates and ecological characteristics.

CRediT authorship contribution statement

Elina Ranta: Methodology, Writing - original draft. **Maria Rosario Vidal-Abarca:** Investigation. **Ana Raquel Calapez:** Validation, Writing - review & editing. **Maria João Feio:** Validation, Supervision, Writing - review & editing.

Declaration of Competing Interest

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

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Appendix A. Supplementary data

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