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Ecosystem services assessment in urban green areas and urban forests: Rapid Assessment Protocol for cities

Avaliação de serviços ecossistêmicos em áreas verdes e florestas urbanas: Protocolo de Avaliação Rápida para cidades

Valéria Letícia Marques Barbosa[1], *Vanessa Peixoto Giacon*[2], *Eliana Cardoso-Leite*[1]

ABSTRACT

Urban planners must have a tool that communicates to stakeholders the benefits of green spaces in cities. Indicators ought to be economically feasible and easily understandable within a multidimensional perspective of ecosystem services. This study proposes an instrument that assesses the quality of ecosystem services supply in urban green areas and urban forests, evaluating the weaknesses and strengths of each area, quickly, simply, and still sensitively. We chose sensitive and application-friendly indicators, based on their applicability to Brazilian reality, in medium to highly urbanised areas. The indicators were ranked in four grades representing the ecosystem service supply in each area, from extremely unsatisfactory to extremely satisfactory conditions. After tests in different urban green areas and urban forests, in Sorocaba, São Paulo, Brazil, the protocol was calibrated, and indicators were adjusted to urban context and biome specificities. The calibrated and ready-to-use protocol was presented, assessing: five Cultural services with eight indicators, two Provisioning services with two indicators, four Regulating services with five indicators, and three Supporting services with three indicators. Qualitative and quantitative indicators were combined to comprehensively assess complex areas. The protocol contemplated all ecosystem service categories in order to respond to different management needs. Several indicators were tailored to urban contexts and local scale. Finally, cities may use this comprehensive list of ecosystem service indicators, already adapted for urban context, as an inspirational checklist for describing their urban green areas and urban forests' weaknesses and strengths.

Keywords: urban green spaces; urban green solution; green infrastructure; ecosystem services indices; composite indicators.

RESUMO

Planejadores urbanos devem ter uma ferramenta que comunique aos tomadores de decisões os benefícios dos espaços verdes nas cidades. Os indicadores devem ser economicamente viáveis e facilmente compreendidos em uma perspectiva multidimensional de serviços ecossistêmicos. Este estudo propõe um instrumento que avalie a qualidade do fornecimento de serviços ecossistêmicos em áreas verdes urbanas e florestas urbanas, avaliando pontos fortes e fracos de cada área, de forma rápida, simples, mas ainda assim sensível. Escolhemos indicadores sensíveis e de fácil uso, baseados na aplicabilidade na realidade brasileira, em áreas com médio a alto grau de urbanização. Os indicadores foram classificados em quatro níveis que representavam o fornecimento de serviços ecossistêmicos em cada área — de condições extremamente insatisfatórias até extremamente satisfatórias. Após testes em diferentes áreas verdes urbanas e florestas urbanas em Sorocaba, São Paulo, o protocolo foi calibrado, e os indicadores foram ajustados ao contexto urbano e às especificidades do bioma. O protocolo calibrado e pronto para uso foi apresentado, avaliando: cinco serviços Culturais com oito indicadores, dois serviços de Provisão com dois indicadores, quatro serviços de regulação com cinco indicadores, e três serviços de Suporte com três indicadores. Indicadores qualitativos e quantitativos foram combinados para avaliar áreas complexas de forma completa. O protocolo contemplou todas as categorias de serviços ecossistêmicos para atender às diferentes necessidades da administração. Diversos indicadores foram ajustados para o contexto urbano e escala local. Por fim, cidades podem usar esta abrangente lista de indicadores de serviços ecossistêmicos, já adaptados para o contexto urbano, como um *checklist* inspiracional para descrever as fraquezas e forças de suas áreas verdes urbanas e florestas urbanas.

Palavras-chave: espaços verdes urbanos; solução verde urbana; infraestrutura verde; índice de serviços ecossistêmicos; indicadores compostos.

[1]Universidade Federal de São Carlos – São Carlos (SP), Brazil.

[2]Universidade Paulista – Sorocaba (SP), Brazil.

Corresponding author: Eliana Cardoso-Leite – Universidade Federal de São Carlos – Rodovia João Leme dos Santos (SP 264), km 110 – Itinga – CEP: 18052-780 – Sorocaba (SP), Brazil. E-mail: eliana.leite@ufscar.br

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Introduction

Accelerated population growth results in small and sparse green areas, with lower quality (Shanahan et al., 2017). This process fragments natural environments, reduces biodiversity, creates a tension between urban expansion and nature conservation, and consequently leads to an 'extinction of nature experience' (Sandifer et al., 2015; Botzat et al., 2016; Calderón-Contreras and Quiroz-Rosas, 2017). Nevertheless, urbanisation can also be an opportunity to manage ecosystems closely (Schewenius et al., 2014).

When ecosystems are healthy, they deliver benefits, called ecosystem services (ES), which directly affect human well-being (MEA, 2005). Ecosystem services are clustered in four categories: Provisioning (e.g., materials as food and water), Regulating (e.g., climate or water regulation), Supporting (biogeochemical cycles maintenance), and Cultural (non-material benefits) (MEA, 2005).

In practice, conservation judgment relies on human values more than on scientific studies about biodiversity threats; therefore, an ES focus provides the scientific community an

assertion to base conservation decisions (Mace et al., 2012). The human well-being argument persuades more; hence, it helps validate public policies.

The urban context has received more attention recently, with an increased number in publications in the last years (Veerkamp et al., 2021), since people are prone to value more what is usable in their day-to-day lives and near their homes. This perspective claims urgency, as cities already face ES loss consequences, such as heat islands, water crisis, and atmospheric pollution. Thus, in this study, we considered urban green areas (UGA) as open spaces within the consolidated urban area with the presence of greenery, and urban forests (UF) as open areas with the presence of trees, also defined by Steenberg et al. (2019) as 'urban socio-ecological systems (...) with trade-offs between ecological and social functions'.

UGA and UF are subject to environmental factors (e.g., soil, climate) and urbanisation/anthropogenic disturbances (as edge effect, which leads to biotic integrity and biodiversity loss, and exotic species; habitat fragmentation; pollution; amongst others) (Biondi, 2015; Giacon et al., 2022). Therefore, urban greenery differs structurally and ecologically from original forests, and cities may be considered a new and complex ecosystem, which has resulted from human-nature co-evolution and presents specificities according to urbanisation scales and stress factors (Ordóñez and Duinker, 2012; Marques et al., 2022).

Nevertheless, UGA and UF differ from each other. Their heterogeneous characteristics are reflexes of urbanisation patterns, land use and cover (at local scale, Giacon et al., 2022), history of management regime (which can promote its conservation or degradation), and original biomes altogether, and reverberate on the ES supply for each category.

UGA and UF present different vegetation compositions, ranging from the original biome composition, to ornamental, spontaneous (Breuste et al., 2013), or invasive species. Hence, it is pertinent to construct an instrument, such as a composite indicator or protocol, which assesses the ES supply in each area, according to its ecological and social characteristics.

Studies have analysed trends in international urban ecosystem services (UES) research (Haase et al., 2014; Schewenius et al., 2014; Botzat et al., 2016; Brzoska and Spāģe, 2020; Kleinschroth and Kowarik, 2020; Veerkamp et al., 2021; Marques et al., 2022; Jato-Espino et al., 2023; Barbosa et al., 2024; Ma and Yang, 2025) and in Latin America and South America urban green and ES research (Balvanera et al., 2020; Romero-Duque et al., 2020; Muñoz-Pacheco and Villaseñor, 2022). Those comprehensive literature reviews investigated different approaches, but their discussions converged to the evidence of common research limitations. Authors have created and tested tools to assess UES in European, Asian, and North American forests; however, those studies highlighted that whilst temperate regions are greatly represented and tropical regions have a scarcity of studies, as in developing countries of Latin America and Africa.

Urban planning in Latin American realities differs greatly from that of developed countries (Romero-Duque et al., 2020); however, Latin America contributes to a small fraction of global literature on ES (Balvanera et al., 2020) and even less to UES literature. Ma and Yang (2025) reviewed 862 studies about quantitative methods to assess UES, and Brazil only accounted for eight of them. Muñoz-Pacheco and Villaseñor (2022) investigated UES in South America and found that only a few studies in South America and Latin America were included in international reviews on UES. Marques et al. (2022) found that Latin American had low output and few citations regarding ES and urban planning. Barona et al. (2019) investigated trends in urban forestry research in Latin America and stated that, despite the increase in studies on urban forest ecosystem services, there is still little knowledge on the state of art and trajectories of the region.

Latin America has a predominantly tropical climate, high endemic biodiversity, and high demographic growth; nevertheless, it counts with scarce resources, poorly distributed to the environmental department, and bureaucratic public administration (Sinnott et al., 2010; Weyland et al., 2019; Balvanera et al., 2020). These climate regions have distinctive socio-ecological systems and need multidimensional studies to fill knowledge gaps in order to promote resilient cities, which are already facing climate change (Haase et al., 2014; Botzat et al, 2016; Muñoz-Pacheco and Villaseñor, 2022).

Notwithstanding the Constitution imposing protection for the environment and its ES (Brasil, 1988), ES loss due to urbanisation processes is felt by Brazilian biomes and ecotones (Ferreira et al., 2019). Hence, municipal environment secretaries must have the necessary means to assess their city green areas' ES supply to propose achievable goals and manage these areas with a plan of action for increasing ES supply (Caprioli et al., 2020).

Green areas assessment improves management efficiency and approximates underdeveloped countries to the United Nations' Sustainable Development Goals, such as '3. Good health and well-being', '11. Sustainable cities and communities', and '15. Life on land' (UN, 2017). Ecosystems manifest through their processes and functions (Veerkamp et al., 2021); thus, the expression of potential ES can be measured (Bastian et al., 2013).

Indicators simplify a complex reality into a manageable level; they find patterns and analyse ecosystems' viability to guide decision-making (Dobbs et al., 2011; Haase et al., 2014). Nonetheless, a study that covers more than one dimension of ES is rare (Haase et al., 2014); most studies focus on a single service, and the methods include less than ten indicators (Charoenkit and Piyathamrongchai, 2019; Barbosa et al., 2024).

Furthermore, monetary indicators predominate, which narrows human welfare to mere economic performance (Yang et al., 2018). Also, the assessment of regional scales may impair recognising which green infrastructure contributed to a certain ecological property (O'Sullivan et al., 2017; Brzoska et al., 2021). The local scale (e.g., urban parks) is directly perceived by residents and allows urban planners to design green infrastructure in detail (Brzoska and Spāģe, 2020; Brzoska et al. 2021; Cortinovis et al., 2021).

In order to compose a useful urban planning and management tool and communicate to stakeholders the benefits of green spaces in urban areas, the unified ES indicators must be accessible, easily understandable, and practical (Brzoska et al., 2021; Tudorie et al., 2019), as in a Rapid Assessment Protocol. This is an instrument designed to measure environmental quality (Guimarães et al., 2021). It gathers several indicators whose standardised evaluation methods identify which areas provide more services and why, transparently, as recommended by Brzoska et al. (2021).

Regarding UGA evaluation through ES composite indicators, Brazil contributes to only 5.3% of worldwide studies (Barbosa et al., 2024), despite its extensive area. Hence, this study objective was to elaborate an instrument (a rapid assessment protocol) to assess ecosystem services in UGAs.

The proposed instrument must evaluate the weaknesses and strengths of each area, with quick, simple and low-cost indicators, sensitively enough to a technician of a developing country's Municipal Environment Secretary — as the ones in Brazil — can potentially apply it, with less-extensive training levels, in medium to highly urbanised landscapes.

Methodological Procedures

In this study, a rapid assessment protocol was developed to evaluate ecosystem services provided by UGAs.

The instrument consists of a composite-indicator with application-friendly methodological procedures, represented as indicators, and their respective evaluation classes, represented as grades. To create the rapid assessment protocol, we followed three steps: indicators selection, protocol construction, testing, and calibration.

Indicators Selection

To select the indicators, a comprehensive literature review was carried out. Studies utilise diverse metrics, indicators and methodologies to quantify ES in UGA (Veerkamp et al., 2021). Therefore, we screened peer-reviewed articles on ISI Web of Knowledge and Google Scholar databases, along with journals linked to environmental indicators, ecosystem services, or urban planning. The keywords used for searching were 'urban ecosystem services', 'ecosystem services indicators', and 'urban green areas', along with the corresponding terms in Portuguese and Spanish, since much research conducted in America Latina is written in these languages.

A total of 451 studies were selected and screened. In addition, as much information about green areas administration is published in non-scientific literature, we also analysed the grey literature and, if available, consulted its scientific references within. All indicators were listed and analysed.

Tools must be adapted to the local context, and their construction considered the expertise required, the affordability, and the scalability needed (Almeida et al., 2018; Delpy et al., 2021). Therefore, so as to be applied in Brazilian urban areas, considering a low-budget scenario, the indicators must comply with the following inclusion criteria:

i. Represent a relevant ES according to MEA (2005);
ii. Are low-cost and easily applicable;
iii. Apply to urban context;
iv. Provide quantitative cultural and biophysical assessment; and
v. Apply on a local scale, with site-specific inputs.

If the studies and their indicators did not meet the inclusion criteria, they were excluded, for example, in cases where the indicator: (i) was related to a service not listed on MEA (2005); (ii) needed laboratory analysis, high-trained personnel, expensive instruments or charged software; (iii) was only related to forest or rural landscapes; (iv) only provided monetary or subjective social/perception values; and (v) applied only to regional or less-specific inputs, that is, could not be measured by a technician in field.

Protocol Construction

The protocol construction was carried out from 2020 (preliminary protocol) to 2024 (final protocol), and all ES categories were contemplated to respond to the different needs of urban green space management (Gómez-Baggethun and Barton, 2013). Qualitative and quantitative indicators were combined to comprehensively assess complex areas (Wang and Foley, 2021).

For each ES included, the protocol contained: its category according to MEA (2005) (Cultural, Supporting, Provisioning, and Regulating); indicator(s) and respective descriptors (what was going to be measured) and methodologies; and four classes, which ranked each ES supply condition.

Those classes represented intervals that measured desired characteristics by using grading scales. The classes used the scale: 'I. very unsatisfactory', for the worst scenario found within the study reality; 'II. unsatisfactory'; ' III. satisfactory'; and 'IV. very satisfactory', considered the best possible scenario for that indicator. It is possible to adapt each class range to other realities. Those established reference values were set in standards to be achieved in UGA management, which could be used as a tool for comparing the quality of ES supply. No weighting system was employed; therefore, all indicators contributed the same to the final score. Weights were not attributed so as to remain neutral.

The reference values for quantitative indicators were derived from a min-max normalisation, based on the poorest and highest performances found in the study area (calibration) (Charoenkit and Piyathamrongchai, 2019). Parameters were generated from field measurements. For example, for 'carbon storage', it is estimated that, for each hectare of semideciduous seasonal forest standing, 108 tC/ha are stored in the aerial part and more 120 tC/ha in the soil (Lemos et al., 2010). Also, Galvani et al. (2020) stated that UF remnants with less than 5 ha cannot maintain biotic integrity in the long term; in opposition, remnants with more than 20 ha can maintain biotic integrity. Then, these values were established as minimum and maximum, respectively, and the average was calculated between them to determine medium-class values. For fruit trees and flowers, the minimum and maximum were identified in the field. For percentages (e.g., canopy cover or covered surface), the values expected for UGA or UF were established based on Mota et al. (2016), which classified UGAs according to their management objectives.

Quali-quantitative indicators (as some Cultural services, e.g., aesthetic and education) were included. For those that could not be counted, the presence and maintenance parameters were set; as e.g., for walking trails the parameter was the presence of hazardous stretches: 'how severe the hazard was, how many hazardous stretches there were in the field, which group of people could not utilise the trail and enjoy the park'. In those cases, besides literature, authors' and co-authors' academic education (Architecture and Biology) and previous experiences (Mello et al., 2016; Mota et al., 2016; Galvani et al., 2020; Giacon et al., 2022) were crucial to establish the intervals that defined each class. Experts' opinion, combined with literature consultation, is the most common method to establish intervals amongst classes and respective grades, and does not substantially differ from traditional statistical methods (Burkhard et al., 2014; Campagne et al., 2020).

Protocol Calibration

Firstly, a preliminary protocol was created (in 2020), based on theoretical key-findings in the literature, which stated each service's importance. Secondly, the protocol template was tested to evaluate the indicators' sensitivity and adjust the classes.

The test was conducted in areas of Sorocaba, a city located at approximately 230º 30' S and 470º 27' W in the state of São Paulo, Brazil. The city was chosen to represent a place of medium to large area and demographic density. Sorocaba has a population of 723,682 inhabitants with a population density of 1,608.64/km² (IBGE, 2022). The climate is humid subtropical, and its predominant original biome is Atlantic Forest, especially represented by semideciduous seasonal forest, despite presenting specific elements of Cerrado (Savannah). The city holds more than 30 heterogeneous green areas (Mello et al., 2016), influenced by diverse urbanisation pressure degrees; those urbanisation pressures reflect on UGA and UF with different characteristics from their original biomes, with native and exotic (introduced and invasive) species combined.

Most UGA and UF in Sorocaba were visited and checked (approximately 30 areas) to verify each indicator's existence, frequency along with its methodology feasibility (economic and temporal), if it was suitable for urban context, and if the data it conveyed could be easily measured and analysed. Many indicators commonly cited in literature had to be excluded as their methodologies were not applicable by Brazilian environmental secretaries, as they involved complex mapping or modeling methods.

The indicators included in the present study used field surveys, defined as 'collection of biophysical data or environmental performance' (Charoenkit and Piyathamrongchai, 2019), but also used spatial mapping to measure vegetation areas and distance to green spaces.

Several services are difficult to measure with direct indicators; thus, many of them were transformed into proxy indicators, defined by Charoenkit and Piyathamrongchai (2019) as 'any tangible piece of evidence inferring the interested benefits (ES), which substitute the assessment of the benefits themselves. In this study, proxies were established based on facilities provided in green areas (e.g. aesthetic values were based on the UGA physical features and appealing biodiversity) or distant from them.

All indicators were adapted, and the protocol was reconstructed (2021) along with a series of empiric tests in the areas. Each remaining indicator: 1. was tailored to better address urban contexts (substituting elements or quantitative parameters more common to mature forests or rural landscapes for elements and parameters found within UGAs); and 2. had its methodology simplified to attend to our protocol objectives.

Then, intervals amongst grades were defined with minimum, medium, and maximum values, consonantly with the results obtained from the preliminary protocol. Each criterion was detailed to clarify classes and avoid subjectivity, even for qualitative indicators (Tables 1, 2, and 3).

Next, the criterion was tested four more times (in 2022 and 2023) after the COVID-19 pandemic lockdown, along with the park's staff, to test if the indicators could be understood and applicable after short instructions.

Finally (in 2024), the classes were refined (final calibration), especially in quantitative indicators, based on the tests conducted in eight selected areas with distinctive characteristics, as: vegetation naturalness (natural, exotic, or a mix of both); area size (from 1.79 to 60 ha); vegetation patch size (from 0.32 to 31 ha); and the presence (or not) of infrastructure (e.g., leisure, recreation, and sports practice, along with bathrooms and drinking fountains). The areas were public and located within the anthropized matrix.

Table 1 – Selected Cultural ecosystem service indicators and evaluation procedures.

Indicator	Indicator's field guide
Aesthetic (Water)	Verify the presence and maintenance of natural water bodies (m.p.) (e.g., rivers, ponds). Under 'extremely unsatisfactory conditions' the water body presents no maintenance such as the presence of anthropogenic waste, organic matter decomposition, or aquatic macrophytes infestation. On the contrary, 'extremely satisfactory conditions' mean those items are almost or completely absent. 'Satisfactory' is the condition for intermediary classes, e.g. when quantifying the extent of degradation — if a pond presents relevant macrophyte infestation in 30%, and 70% is preserved and maintained (m.p.=70%).
Aesthetic (Flowers)	Quantify species and individuals with coloured and 'showy' flowers. Trees, bushes, epiphytes, and flowerbeds (with at least 0.25 m²) can be considered.
Aesthetic (Attractive animals)	Quantify species of birds and butterflies. Discriminate without a field guide. Do not count too tiny and camouflaged butterfly species or domestic pigeon (*Columba livia*), as they are not considered aesthetically appealing nor arouse curiosity.
Comfort (Accessibility)	Google Earth: Calculate the distance to the nearest residential area. Verify if the urban green area has time restrictions and/or visitation limitations.
Recreation (Activities and events)	Verify event signalling *in loco* (posters, chat with visitors or neighbourhood residents) or virtually (search providers, official and unofficial city's Instagram, etc.). Events can include: a) cultural exhibitions (e.g., theatre, music shows, dance); b) celebrations (e.g., LGBT parade, Halloween, Carnival); c) organised social encounters; and d) fairs (e.g, handicraft, adoption of puppies, organic food); and others.
Health (Walking trails)	Hazardous stretches may not attend the physically disabled or the elderly, as visitors must maintain body balance and have strong legs so as not to stumble while walking on them. Distinguish if walking paths are suitable for walking and exercising, or if they present hazardous stretches (steep, craggy, or narrow stretches; large roots, stones, and erosion furrows which uneven the ground, etc.). Verify the extent (m.p.) of trails that can be accessed by anyone, that is, presents no hazards and does not impair the visitation in some areas of the park
Health (Bird vocalizations and water sounds)	Quantify bird species by distinguishing their vocalizations, either songs or calls. Birds usually sing at dawn and sunset — choose one time set and delimit a two-hour period to listen. Also listen to running water sounds (presence or absence).
Education Guided visitation)	Verify school-visitation frequency and/or if there are environmental tutors available to guide the lay public. Also search for different interpretative signs related to environmental education, e.g., springs' location, list of species of animals or plants found in the park, curiosities about recycling near trash bins, curiosities about ecological processes, etc. Do not count signs of identification (name of the park), directions, or facilities (e.g., bathrooms, drinking fountains).

m.p.: maintenance percentage;

Table 2 – Selected Provisioning ecosystem service indicators and evaluation procedures.

Food (Fruit trees)	Quantify fruit tree richness and abundance. They will not always carry fruits during data collection; count the trees with or without fruits. Most fruit tree species planted are exotic. A simple previous training for this indicator may include the region most common fruit trees (natives and exotics) naturally found or planted.
Water (Springs)	Verify springs presence and maintenance. A degraded spring is worse than the absence of springs. If water comes out, it is functional.

Table 3 – Selected Regulating ecosystem service indicators and evaluation procedures.

Global climate mitigation (Carbon sequestration)	Calculate, in absolute values, the canopy cover, in hectares.
Local climate amelioration (Temperature)	Assess the temperature with a thermometer.[1] First, measure the temperature inside the tree coverage (patch core); then measure the park surroundings, under direct solar radiation. Subtract the temperature measured inside the patch core from that outside the park. The equipment may be more or less sensitive, but must be able to capture the difference of temperature in and outside the forest patch.
Local climate amelioration (Shading)	Google Earth: Calculate the percentage of tree canopy coverage relative to the total terrestrial area (water areas excluded).
Erosion control (Protected soil)	Assess the percentage of terrestrial surface covered with vegetation (both herbaceous or trees). Soil furrows and ravines may indicate mass movement.
Flood prevention (Draining soil)	Assess the percentage of the park (land and water) with permeable surface. The surface is considered permeable if non-sealed (not paved), or if the exposed soil is not compacted (e.g., due to excessive trampling).
Noise pollution reduction (Noise)	Measure decibels outside the park, next to the street, and then measure decibels inside a robust vegetation patch, at 25 m from the first spot. To eliminate variables, leave a device emitting sound in the amplitude of 70–80 dBs next to the street. Wait three minutes and register the highest value (as a car honk or a racing lorry) shown in a decibel meter.[2] The difference between the two spots is the value of insertion loss.[3]

[1]In this study, we used a THAL-300 thermo-hygro-anemo-luxmetre (Instrutherm). [2]In this study, we used a mobile phone application named 'Sound Meter' as a decibel meter. [3]Insertion loss: noise-level difference measured before and after a vegetation barrier insertion.

Hence, the protocol was calibrated according to parameters of semideciduous seasonal forest areas in medium to highly urbanised landscapes.

To avoid bias when calculating intervals amongst classes, field visits occurred in Spring mornings, and temperatures were measured between 12:00–13:00 h. It was verified that the necessary equipment was carriable and easily affordable, and the entire field data (for each area) could be collected within an interval of four hours.

For indicators that required satellite images analysis, we chose simple indicators, attended by Google Earth, which is trustworthy, frequently updated, free for everyone, and requires little training to manipulate tools and interpret results (Leinonen et al., 2018; Pereira et al., 2018; Araújo Junior et al., 2021).

The final indicators list met the criteria for relevant and achievable ES indicators recommended by van Oudenhoven et al. (2018) and Dushkova et al. (2021): relevance to local reality, easily comprehended methodology, results credibility, and budget-feasibility. The indicators had stable parameters and related to one or more ES. Likewise, an ES could be assessed by more than one indicator.

Results

Indicators and ES were selected according to key aspects of relevance found in specialised literature, which are listed on the Supplementary Document (Appendix 1). Indicators were adapted to suit the prerequisites of the study: low-cost analysis, applicability in urban areas, minimum need of equipment, and specialised or charged software. Each area required a single day of work for data gathering (field visit+-geoprocessing in software), plotting, and analysis.

The protocol suffered many modifications before its final version, including indicators and services addition, removal, modification, and unfolding. Removal, modification, and unfolding examples are as follows:

a) Removal: The first protocol had janitorial indicators for Cultural ES (e.g., existence and maintenance of bathrooms, playgrounds, exercise bars, etc.); however, as those indicators were only indirectly related to ES, they were removed. Some services such as 'disease control' were also removed, since their indicators could not be transformed into non-expensive and application-friendly tools that still maintained accuracy and reliability in urban contexts.
b) Modification: The first version also had geoprocessing indicators that used ArcGIS, which were substituted for QGIS (free-of-charge) indicators, and then Google Earth, which was proven to be the most application-friendly software. Some services as 'urban gardens and orchards' suggested by the literature were not found in our reality and were substituted for 'fruit trees'. Also, some classes had to have their intervals adjusted, as 'attractive animals' and 'fruit trees'.
c) Unfolding: The health service indicator included only birds and was unfolded to embrace water sounds as well. Similarly, the education service indicator was unfolded to include interpretative signs along with environmental science tutors; therefore, Environmental Secretariats with fewer human and financial resources, unable to pay for tutors in urban parks, may supplement this demand with fixed environmental education key aspects related to the park.

The list of ES followed MEA (2005) to avoid misinterpretation; e.g., even though microclimatic amelioration and noise reduction are related to comfort (Cultural ES), they were categorised as Regulating ES, since they belong to this category according to MEA's official list.

The final result (calibrated protocol) is presented in Table 4 and gathered sensitive and application-friendly indicators.

As the protocol configures a lean tool, printable on a single page that can be attached to a clipboard and taken to the field, this table details each indicator guide, including discrimination of qualitative indicators classes. The instruments used (as thermometer and decibel meter) must be the same for all areas, to avoid distortion and bias. Tables 1, 2, 3, and 5 quickly describe the recommended procedures for measuring each of the indicators/descriptors.

Field indicators were calibrated for Spring season tests. To conduct tests in other seasons, some classes may need re-calibration, e.g., 'Aesthetic – Water' (in Summer, with rains, water may seem clearer and cleaner) or 'Aesthetic – Flowers' (different flowers bloom in Summer, e.g., *Ceiba speciosa*, or in Winter, e.g., *Handroanthus impetiginosus*). Seasons do not influence software indicators; therefore, they can be tested separately.

Google Earth is faster and more intuitive than QGis. It has an easy interface to create perimeters, calculate each area sizes and modify polygons. However, some Environmental Secretariats staff are graduated technicians who may have previous experience with geoprocessing and might rather use QGis. QGis is more indicated to organise polygons inside a single UGA, especially for areas which encompass many isolated trees instead of a single 'solid' vegetation patch. QGis is also indicated for areas with 'hollow' cores in satellite data, representing clearings; in those cases, for greater accuracy, use the 'Erase' tool to remove an area inside the polygon.

To apply the protocol, it is recommended to walk inside and around each UGA using comprehensive paths to collect all field data. Then, area attributes must be calculated with Google Earth (or QGis). If more than one area is visited, all of them must be visited within a short period of time, to avoid bias in comparisons.

After all data gathering, data plotting can be performed on sheets (as Google Sheets, a free-of-charge tool). Finally, the results are calculated. Some services have more than one indicator (e.g., primary production); the two indicators of arithmetic average must be calculated to define the ES grade. For each ES class (Cultural, Provision, Regulating, and Supporting), individual indicator grades (1–4) are summed and then divided by the number of services of the class to have an arithmetic average. Afterwards, each class arithmetic average is summed, and each UGA can score from 4 points (equivalent to an ES supply of 0%) up to 16 points (equivalent to an ES supply of 100%).

Table 4 – Ecosystem services assessment protocol.

Service	Indicator	Verify	I	II	III	IV
Cultural						
Aesthetic	Water	ssdWater bodies presence and maintenance	Extremely unsatisfactory condition (m.p. up to 25%)	Absent/ unsatisfactory condition (m.p. up to 50%)	Satisfactory condition (m.p. up to 75%)	Extremely satisfactory condition (m.p. more than 75%)
	Flowers	Quantity (spp. or indiv.)	Up to 9 spp. or 25 indiv.	10–14 spp. or 25–34 indiv.	15–19 spp. or 35–45 indiv.	>20 spp. or >45 indiv.
	Attractive animals	Quantity (birds and butterflies spp.)	Up to 12	12–14	15–18	19+
Comfort	Accessibility	Distance to the nearest residential area; access restriction	More than 500 m, restricted	More than 500 m, open	Up to 500 m, restricted	Up to 500 m, open
Recreation	Activities and events	Types and frequency	Absent or without records	one event type, rare or that happened once	one event type, traditional (recurrent)	More than one recurrent event and/ or at least one frequent event
Health	Walking trails	Presence and maintenance	Mostly in hazardous conditions (m.p. up to 30%)	Large stretches in hazardous conditions /Absent (m.p. up to 60%)	Some stretches in hazardous conditions (m.p. up to 90%)	Without hazardous stretches, adapted to all publics (m.p. more than 90%)
	Birds (vocalization) and water sounds	Identification of different songs or calls (spp.) (SOC) and flowing water Sounds	Up to 7 SOC, without water sounds	More than 7 SOC, without water sounds	Up to 7 SOC, with water sounds	More than 7 SOC, with water sounds
Education	Guided visitation	School-visit frequency and tutors offering help	Absent or without records	Some school visits and/or up to 1 interpretative sign	Frequent school visits and/or up to 2 interpretative Signs	Environmenta l tutors and/or 3 or more interpretative signs
Provisioning						
Food	Fruit trees	Quantity (spp. or indiv.)[1]	Up to 10 spp, / 25 indiv.	11–14 spp. / 26–50 indiv.	15–18 spp. / 51–75 indiv.	19+ spp. 75+ indiv.
Water	Springs	Presence and conservation	Degraded	Absent or non-functional	One, regular condition	More than one, regular condition
Regulating						
Global climate mitigation	Carbon storage	Forested patches (ha)[2] / tC storage[2]	<5 / <529 tC	5.1–12.5 / 550–1,350 tC	12.6–20.0 / 1,360–2,160 tC	>20 / >2,160 tC
Local climate amelioration	Temperature	Reduction (°C)	Up to 1	>1.0–2.5	>2.5–4.0	>4.0
	Shading	Canopy cover (terrestrial)	Less than 50%	>50–70%	>70–85%	>85%
Erosion control	Protected soil	Area covered with vegetation	Less than 70%	70–80%	>80–90%	>90%
Flood prevention	Draining soil	Permeable area	Less than 75%	75–85%	>85–95%	>95%
Noise pollution reduction	Noise	Reduction in dB[3]	None (up to 20 dB)	Up to 10 dBs (21–30)	11-20 dBs (>30–40)	More than 20 dBs (>40)
Supporting						
Water cycle maintenance	Canopy coverage	Area covered with trees (%)	Less than 40%	40–60%	61–80%	>80%
Nutrient cycling	Litterfall	Area percentage with remaining litterfall under the canopy	Less than 30%	30–70%	>70%, single layer	>70%, overlapping layers (at least 6 cm)
Habitats and niches	Stratification	Strata number	0 (isolated trees)	1	2	3 or more

spp.: number of species; indiv.: number of individuals; m.p.: maintenance percentage; SOC: songs or calls. [1]When ranks diverge, apply the arithmetic average to the grades (not the interval within each grade), rounding up. [2]For semideciduous seasonal forest. [3] Without obstacles, 20 dBs was established as the average distance loss. Higher values are due to insertion loss.

Table 5 – Selected Supporting ecosystem service indicators and evaluation procedures.

Water cycle maintenance (Canopy)	Google Earth: Calculate the percentage of tree canopy coverage relative to the total area (both water and land areas included).
Nutrient cycling (Litterfall)	Assess the percentage of area that maintains litterfall under the tree canopy cover without human management.
Habitats and niches (Stratification)	Verify the number of strata composing the densest forested patch.

Discussion

Large green remnants in the middle of urbanised areas are rare. To compare large and small parks, we adapted indicators to use relative values (percentages) instead of absolute values (except for carbon storage). Theoretically, larger parks can embrace more plants and animals. Nevertheless, our tests proved that small areas can provide a high supply of services, even more than some larger areas, according to location and management. Other services are size-neutral, e.g., Accessibility or Education — area size is irrelevant for environmental education.

Model methods are available to estimate ES as inVEST, i-Tree CITYgreen, and UFORE. Nonetheless, modelling approaches may present common limitations (Charoenkit and Piyathamrongchai, 2019). Firstly, indicators involved in these models are limited mainly to Regulating services (Duan et al., 2025). Then, software as inVEST (which is free) and i-Tree may be accurate for some services; however, they require setting values for many parameters and intensive training, otherwise, the results may be biased (Ma and Yang, 2025).

Field surveys at site-specific areas are required to analyse species diversity (Charoenkit and Piyathamrongchai, 2019). Most studies in Latin America collect data through field surveys (Barona et al., 2019; Romero-Duque et al., 2020). There are still no models or software that allow for precise estimation of biodiversity and some cultural services, which are the reasons why we chose the field survey as the main method. Usually, an empirical approach is time consuming and resource intensive (Charoenkit and Piyathamrongchai, 2019); that is why we excluded indicators that needed testing of water or air quality or gathering soil samples.

Some studies propose protocols, but do not perform empirical tests to verify reliability. Barbosa et al. (2024) stated that each phytophysiognomy and socioeconomic region requires specific evaluation criteria; therefore, each criterion must be empirically validated and described on tables to compose a clear and objective practical tool. Also, most indicators found in our literature review were not highly relevant for urban context, similar to the review of Cultural indicators by La Rosa et al. (2016). The different assessment methods and scoring systems found in UES literature are mostly derived from non-urban ecosystem evaluations and may not be suitable for this environment (Charoenkit and Piyathamrongchai, 2019; Ma and Yang, 2025).

Furthermore, the few multifunctional, expert-based and fine-scale studies present in literature for urban contexts assemble indicators which, although reliable, are unfeasible, since they usually demand resources that conflict with a lack of personnel and of economic reserves (Grunewald et al., 2021).

Frameworks for assessing UES through an economic perspective are available. Duan et al. (2025) chose indicators suitable for urban green spaces, according to experts; however, their approach included complex mathematical calculations such as ‘negative ion supply’, ‘pollutant absorption’, ‘dust PM10 and PM2.5’, etc., which requires a background in engineering, and calculus of Shannon-Wiener Diversity Index combined with even more variables, which requires an extremely specialised botanical taxonomist.

Yang et al. (2018) used emergy methodologies to build indicators mainly for Regulating and Supporting services such as net primary production, carbon sequestration, soil building, groundwater recharge, and others. However, emergy calculations involve complex formulas. Additionally, the authors assessed cultural services from tourism values, but UGAs are designed to be accessed by neighbourhood residents, not by tourists.

Studies with many calculi and sampling collection are extremely reliable, but economically unfeasible and extremely time-consuming, which would need several days to achieve results for a single area. Those studies may be conducted by academics, and the results can then be presented to decision-makers; however, secretaries might not have the time, personnel, or budget to conduct those methodologies themselves, becoming dependent on other researchers.

Other studies attempt not to attribute economical values in the assessment of UES. For instance, Dobbs et al. (2011) selected high-complexity indicators which needed laboratory analysis (as organic matter, pH, bulk density, nutrients, and metals, etc.), high-complexity calculus (as diversity index, biomass conversion, real state values, air pollutant removal in tons/year, etc.) and did not established classes with optimal intervals.

Brzoska et al. (2021) developed a standardized and application-friendly protocol, with clear evaluation classes and gave feedback about ES optimisation in each UGA; yet the protocol still needed thoroughly trained mappers, some from research institutes, to analyse geodata. Either Dobbs et al. (2011) and Brzoska et al.’s (2021) studies were conducted in first-world countries (respectively, the United States and Germany) and had environmental agencies cooperation.

Those indexes and protocols built in first-world countries are robust and could provide extremely reliable data. The fact is, most cities in Brazil would need financial aid programs and cooperation with research institutions (such as universities) to apply those indicators, and our objective was to design an independent tool.

Latin America overall faces significant limitations. As reported by Balvanera et al. (2020), 'funding for research in LA and the Caribbean is nearly three times lower than the global average'. Moreover, according to Weyland et al. (2019), Latin America 'has institutional instability, a tendency of lack of commitment with agreements and short-term policies'; hence, solutions need to be rapid, before government terms end.

Sorocaba is located in the richest state of Brazil (São Paulo), has a gross domestic product of R$36.7 billion, and a Human Development Index (HDI) greater than Brazil's average (0.798) (IBGE, 2022; PCS, 2024). Additionally, the city achieved the first position on the Blue-Green Cities Program (Programa Município VerdeAzul) for its group (SEMIL, 2023). Still, the Sorocaba Environmental Secretariat faces spending cuts and human resources deficits, as do other medium to large cities' Secretariats in Brazil.

Gaudereto et al. (2019) first attempted to address the Latin America reality and proposed an Index of Ecosystem Services for Green Areas (ISEAV), whose Regulating and Supporting indicators inspired some indicators in the protocol presented herein (e.g., canopy cover, green cover, pervious area, and burlap — here presented as litterfall).

Nevertheless, some of their proposed indicators might be unreasonable in urban contexts, as 1. 'Native/Exotic Species Proportion' (as urban areas frequently present exotic species); 2. 'Feeding and Raw Materials' assessed with 'scale of use' (which would be difficult to apply without behavioural studies to identify patterns of use, and urban scales rarely permit UGA commercial exploitation); and 3. 'Medicine Materials' that were not identified in neither of the 30 UGAs analysed. The authors tested their index in a metropolis (São Paulo) and did not find some of the proposed Provisioning indicators. Furthermore, authors stated that ISEAV presents a limitation: the lack of cultural ES assessment. Hence, in our protocol, we included Cultural ES, adapted Provisioning services, and adapted some of the Regulating and Provisioning services, presenting a complete tool.

The lack of Cultural ES assessment reflects a major pattern in Latin American literature (Barona et al., 2019). Cultural ES quantification challenges researchers. Ideally, Cultural ES in UF assessment would include ecology, economics, and social sciences approaches combined (La Rosa et al., 2015), connecting ecological dynamics and socio-cultural aspects. Recent studies (Cebrián-Piqueras et al., 2020; Zhang et al., 2021; Thiemann et al., 2022; Barreira et al., 2023; Thapa et al., 2023) reveal that socio-cultural elements influence the perception of local population (users) about ES; hence, population perception must be taken into account in the management of green/protected areas, as perception studies reflect the extent to which green infrastructure fulfil a societal demand or need (Veerkamp et al., 2021). Despite its importance, we did not include users' perception, as perception studies require specific methodologies (Arias-Arévalo et al., 2017; Cebrián-Piqueras et al., 2020), which are beyond our scope of study.

Authors have adopted proxy methodologies to assess cultural ES such as the presence of particular physical features or infrastructure, e.g., benches, walking trails, interpretative signs, public accessibility, recreational infrastructure, history of use for educational purposes, scenic quality, tree cover, etc. (La Rosa et al., 2015). Notwithstanding this variety, no Cultural ES indicators were found to be of 'high relevance for urban context' (La Rosa et al., 2015). Hence, we tried to tailor indicators to assess cultural services through measurable community-engagement parameters as Events and Guided Visitation, which could be analysed through a technical-scientific point of view; this approach, albeit limited, permits the construction of a multifunctional protocol (with all ESs).

Ma and Yang (2025) reported an urge to develop methods and indicators that explicitly quantify UES. Nonetheless, ES scientific information is often codified in a complex language, not understandable to the political sector and, as a result, theoretical studies are rarely implemented in practice (Weyland et al., 2019). Some techniques may only be carried out by researchers and for academic purposes, as 'many low administrative levels (as municipalities) find it difficult to follow strict protocols due to technical (and financial) impediments' (Weyland et al., 2019).

Hence, we adjusted all indicators to fit in urban context, and tailored the methodologies.

For example, theoretical studies and indicators were transformed into a tool with usable results, due to its accessible language and technical and financial feasibility (simplicity of operation and low data gathering requirements), to attend to the reality of countries such as Brazil.

During the tests in some visits, we were assisted by the park's staff: men aged from 50 to 65, with no formal education. They were able to understand the indicators, their methodologies, and importance with little explanation. Therefore, the protocol was proven user-friendly.

User-friendly technical solutions permit non-scientific operators to continuously collect data and monitor the progress of policy targets (Matasov et al., 2020). Municipal decision-makers could manage the data provided by the proposed protocol and monitor the progress of environmental targets (e.g., determined ES supply increase, or attendance to Sustainable Development Goals).

Ecosystems are complex; therefore, indicators had to be simplified to achieve our objectives. Thus, we do not recommend the protocol utilisation to gather comparative data in national or international scenarios. The instrument provides the means for local comparisons. For intermunicipal comparisons, both cities must present the same biome and similar urbanisation processes and stages.

Simplifications may struggle to promptly capture ecosystem changes; nonetheless, it is sometimes desirable because 'assessing the relative values of UES by using simple equations is more critical than achieving absolute accuracy, as those relative values are helpful for decision-makers to evaluate specific land uses or management options' (Ma and Yang, 2025). In this study, the simplification of methods was a choice for suitability, as the protocol's main objective was to facilitate data collection in cities that had lack of personnel or resources. Being a local tool, it can be used by Environmental Secretaries/Agencies to give insight about how to improve its UGA, in order for the population to benefit more and better. It's a major challenge to apply complex models in real-world scenarios. Synthesising multiple ES in a single study, with reduced complexity, reduces the burden for decision-makers (Cortinovis et al., 2021).

Indicators permit the appointed technician to analyse details of each area *in loco*, and thus suggest a personalised and assertive management strategy. As city residents have contact with nature at local sites, planning decisions improve urban environmental quality better when addressing the local level (La Rosa et al., 2016; Brzoska et al., 2021). Stakeholders may perform an initial diagnosis to identify the UGA weak points, to improve and monitor their characteristics. For example, if the 'Provisioning – Food' service presents a low score in a specific UGA, managers can plant fruit trees; if the 'Regulating – Flood prevention' service presents a low-score in every UGA in the city, managers may design an UGA to prevent floodings in critical points of the city.

There is no consensus about how to quantify ES in cities, and several different indicators and methodologies are found in literature, which may serve different purposes (Veerkamp et al., 2021). Depending on the outcomes and necessities, it may support funding requests for the development of more profound protocols that involve highly qualified professionals, more extensive field experiments, advanced technologies, and community engagement.

ES are particular to each context, and it is unwise to assess them with a universal methodology (Burkhard et al., 2014). Hence, cities may use this comprehensive list of ES and indicators, already adapted for urban context, as an inspirational checklist for describing their UGA weaknesses and strengths.

A panel of experts may tailor the protocol to attend to their own city specificities, according to its natural, economic, political, and cultural contexts, purposes, and challenges (Campagne et al., 2020; Caprioli et al., 2020; Dushkova et al., 2021). Therefore, both smaller and bigger cities can refer to the same framework, with proper adjustments to their realities.

Conclusions

The proposed protocol novelty resides in the synthesis of all ES categories in a single instrument, with indicators tailored to medium-to-large cities with lesser budget and human resources. Technicians can utilise the proposed protocol with minimal training (application with low costs and brief duration). Notwithstanding its feasibility, it demonstrated sensitivity to detect differences among the areas and provide a preliminary assessment of ecosystem services in the evaluated area, potentially supporting, if necessary, the funding of more comprehensive studies. It seeks to offer initial data to underpin public policy decisions, especially in resource-limited contexts, common in developing countries.

The protocol may be adapted to assess other regions with different urbanisation historic and distinctive original biomes. We proposed a framework; in order to suit the methods to the local reality, technicians can discuss the proposed indicators, remove some, and include others. They can also adjust the boundaries that separate the grades (in I, II, III, IV). Therefore, technicians may apply this protocol to compare different UGA and improve their ES supplies.

The main limitation of this protocol is related to the methodology; since it was not the focus of this study, the perception of people (users) was not assessed. We recommend future studies to engage with the community and delve deeper into this topic, analysing how users of green areas and urban forests perceive their ES, especially for cultural services. We also encourage new research to apply the protocol in different cities; and propose new adapted indicators to each ES, with simple and feasible methodology, statistically validated, to different biomes and urbanisation processes.

Authors' Contributions

Barbosa, V.L.M.: data acquisition and curation, formal analysis, investigation, visualization, writing – original draft, writing – review & editing. **Giacon**, V.P.: project administration, supervision, writing – review & editing. **Cardoso-Leite**, E.: conceptualization and design, methodology, project administration, supervision, validation, writing – review & editing.

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