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COMPOSITE-INDICATORS FOR URBAN ECOSYSTEM SERVICES AT SITE-LEVEL: A SYSTEMATIC LITERATURE REVIEW

INDICADORES COMPOSTOS PARA SERVIÇOS ECOSSISTÊMICOS URBANOS EM NÍVEL LOCAL: UMA REVISÃO SISTEMÁTICA DE LITERATURA

Valéria Letícia Marques Barbosa[1], Luiz Carlos de Faria[2], Eliana Cardoso-Leite[3]

ABSTRACT

Urban green areas, crucial components of green infrastructure, provide a variety of ecosystem services (ES) essential for enhancing the quality of life in cities. The quantity and quality of those ES are estimated and evaluated using indicators that serve as urban planning tools. However, these indicators are often challenging to generalize as they have been developed for specific locations and situations, frequently focusing on just one dimension - ecological, environmental, or economic. In this context, this study explored indicators for ES in urban green areas found in scientific articles from Scopus, Web of Science, and Scielo, through a Bibliometric Analysis and Systematic Literature Review following the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) protocol. Upon thorough examination of the 37 articles resulting from PRISMA, a predominance of indicators related to regulating services, particularly in urban parks, followed by cultural and supporting services, was observed. A diversity of indicators, methodologies, and analysis frameworks for ES was identified without a clear standardization, potentially complicating their application in urban green infrastructure planning and management. A research gap was noted regarding ES indicators studies in tropical and subequatorial urban environments, especially those that establish connections between ES and the necessary innovations to promote them.

Keywords: Urban Management; Urban Green Areas; Environmental Indicators.

RESUMO

As áreas verdes urbanas, partes essenciais da infraestrutura verde, fornecem uma variedade de serviços ecossistêmicos (SE) para a melhoria da qualidade de vida nas cidades. A quantidade e qualidade dos SE são avaliadas por meio de indicadores que servem como ferramentas de planejamento urbano. No entanto, muitas vezes, esses indicadores são difíceis de generalizar, uma vez que foram desenvolvidos para localidades e situações específicas, abrangendo frequentemente apenas uma dimensão - ecológica, ambiental ou econômica. Neste contexto, este estudo investigou indicadores para SE em áreas verdes urbanas encontrados em artigos científicos da Scopus, Web of Science e Scielo, por meio de uma Análise Bibliométrica e Revisão Sistemática de Literatura conforme o protocolo PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses). Após a leitura completa dos 37 artigos resultantes do PRISMA, observou-se a predominância de indicadores associados aos serviços de regulação, especialmente em parques urbanos, seguidos por serviços culturais e de suporte. Foi identificada uma diversidade de indicadores, metodologias e estruturas de análise para SE sem uma padronização clara, o que pode dificultar sua aplicação no planejamento e gestão da infraestrutura verde nas cidades. Foi identificada uma lacuna na pesquisa de indicadores de SE em ambientes urbanos tropicais e subequatoriais, especialmente naquelas que estabelecem conexões entre os SE e as inovações necessárias para promovê-los.

Palavras-chave: Gestão ambiental; Áreas verdes urbanas; Indicadores Ambientais.

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1 Ciências Biológicas. Bacharel. Mestranda (PPGSGA) em Universidade Federal de São Carlos. Sorocaba/SP. Email: valerialmb@estudante.ufscar.br

2 Engenharia Florestal. Doutorado em Recursos Florestais. Professor Associado (DCA-So/CCTS), Universidade Federal de São Carlos. Sorocaba/SP. lcfaria@ufscar.br

3 Bióloga. Doutorado em Biologia Vegetal. Professora Titular (DCA-So/CCTS), Universidade Federal de São Carlos. Sorocaba/SP. Email: eliana.leite@ufscar.br

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INTRODUCTION

Ecosystems provide essential benefits to human society, collectively referred to as ecosystem services (ES). The concept of ES was formulated to emphasize the increasing threats to ecosystems posed by human activities while underscoring the superior advantages of natural environments compared to deforested areas (PESCHE et al., 2012). In urban environments, urban forests play an essential role, offering a diverse range of ecological, social, and economic benefits. However, the management and conservation of urban forests present multifaceted challenges (LOCOSSELLI; BUCKERIDGE, 2023).

Urban forests contribute significantly to the four primary categories of ecosystem services (LOCOSSELLI; BUCKERIDGE, 2023; MEA, 2005): (i) cultural services: which encompass non-material benefits, such as education and recreation; (ii) provisioning services: which involve consumable products like food and water; (iii) regulating services: which include processes like climate amelioration; and (iv) supporting services: which maintain functional cycles such as nutrient cycling.

In addition to natural ecosystems, urban green areas (UGA) serve as vital green infrastructures (UGAs). The post-COVID-19 era has witnessed a substantial surge in demand for UGAs, emphasizing their critical role in providing local ecosystem services (KIM; SON, 2022). Each UGA offers unique sets of ecosystem services, and necessitates the development of effective assessment tools to aid landscape designers in their evaluation.

Indicators play a crucial role in simplifying the complexity of ecosystems (KELLY; HARWELL, 1990), facilitating the assessment of ecosystem services in UGAs. While economic frameworks have been popular for ecosystem services evaluation, they have faced criticisms regarding their applicability (ENGSTRÖM; GREN, 2017; BRZOSKA et al., 2021), advocating for the utilization of biophysical indicators, especially for non-cultural services (CORTINOVIS et al., 2021). Many services are economically incommensurable, and could not be charged, like the right to breathe fresh air.

Regarding to scale, a site-level assessment focus provides more detail about the ES supply in each UGA (DANIELS et al., 2018; BRZOSKA et al., 2021; VEERKAMP et al., 2021). Several ecological indicators assess ES, and studies in urban landscapes and UAs are increasing. However, those indicators are scattered in the literature, as most studies elaborate and test a single indicator (CHAROENKIT; KAMPANART, 2019). Likewise, when more than a single ES is analyzed, the ES usually belong to the same category (e.g. waste treatment and pollination, which are both regulating services). Nonetheless, a multidimensional approach for the supply of ES in UA areas is certainly useful for urban planning and design.

A composite-indicator solves the multifunctionality problem. Composite indicators combine sets of individual indicators into a single index (SAISANA, 2004; ALAM et al., 2016). Authors quantify ES in UGAs with diverse methodological approaches and give composite indicators different names: protocol, indexes, frameworks, or do not name them at all. Hence, there is neither standardization nor consensually accepted composite-indicators that comprehend all types of UGA, UA, ES or eco-regions (LONGSDON; CHAUBEY, 2013; PAKZAD; OSMOND, 2015; SZÜCS et al., 2015; BARTESAGHI KOC et al., 2018; VEERKAMP et al., 2021).

Therefore, this study aims to organize non-economic composite indicators designed for or tested in urban green areas at the site level. The specifics objectives are: (i) identify publication trends; (ii) compare different methodologies, indicators and indexes; (iii) identify what kind of ES categories, services and indicators are currently assessed in urban contexts; (iv) identify which green areas are focused; and (v) indicate future research directions.

MATERIALS AND METHODS

This Bibliometric Analysis and Systematic Literature Review adheres to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines, following the approach outlined by Page et al. (2021). The review criteria encompassed documents in English, Spanish, or Portuguese, with a special consideration for systematic reviews due to their efficiency in identifying aggregated environmental services and indicators. Eligibility criteria for papers included the presentation of non-economic indicators, expert-applied methodologies for assessing multiple ecosystem services, and a specific focus on urban green areas (UGAs), especially for urban forest, at the local level, in accordance with the criteria proposed by Robinson and Lundholm (2012).

Key inclusion criteria for selected articles were as follows: (i) the presentation of a composite index encompassing multiple ecosystem services, either through methodological innovation or by referencing existing works, with a clear definition of ecosystem services, such as pollination or recreation; (ii) the assessment of UGA's capacity to provide ecosystem services, excluding papers that did not correlate UGA characteristics with ecosystem service provision; (iii) the application of biophysical indicators by experts, directly related to ecosystem services, while excluding indicators focused on area design, perception, demand, or economic aspects; (iv) the individual assessment in urban contexts, excluding broader land cover comparisons or national-level analyses.

Data collection involved the identification of seminal articles by Dobbs et al. (2011), Gomez-Baggethun and Barton (2013) and Gaudereto et al. (2018), which proposed ecosystem services indexes for UGAs. Keywords derived from these studies were augmented to encompass broader terms, considering the variable use of 'environmental services' and 'ecosystem services' in the literature, as discussed by Lamarque et al. (2011) and Tancoigne et al. (2014). The final search string in English included terms such as 'indicators,' 'framework,' 'valuation,' and 'assessment,' without imposing date restrictions.

The search was conducted across Scopus, Web of Science, and Scielo databases on December 2022, with a focus on titles, abstracts, and keywords. Google Scholar was excluded due to its tendency to generate broad results and its limited filtering capabilities.

Data analysis involved exporting metadata for identified records in RIS format for import into Rayyan, a systematic review management tool (RAYYAN, 2022). Rayyan facilitated the identification of duplicates and initial labeling of papers. Two independent reviewers conducted abstract screening, with full reviews conducted for eligible texts.

The data analysis process included the extraction and coding of relevant information from eligible papers, including a pilot test on 10 papers to refine data coding. The extracted data covered publication trends, geographical patterns, categories of ecosystem services, indicators used, key aspects of documents, UGA assessment, and the structure of frameworks. All data were recorded in an Excel sheet for comprehensive analysis.

RESULTS AND DISCUSSION

The Bibliometric Analysis network visualization produced by VOSviewer (Figure 1) elucidates keyword clusters, where the colour of each circle signifies its cluster group, and circle size reflects the strength of interrelationships among keywords. This visualization provides a nuanced perspective on keyword interplay and their significance within the realm of ecosystem services in urban green areas.

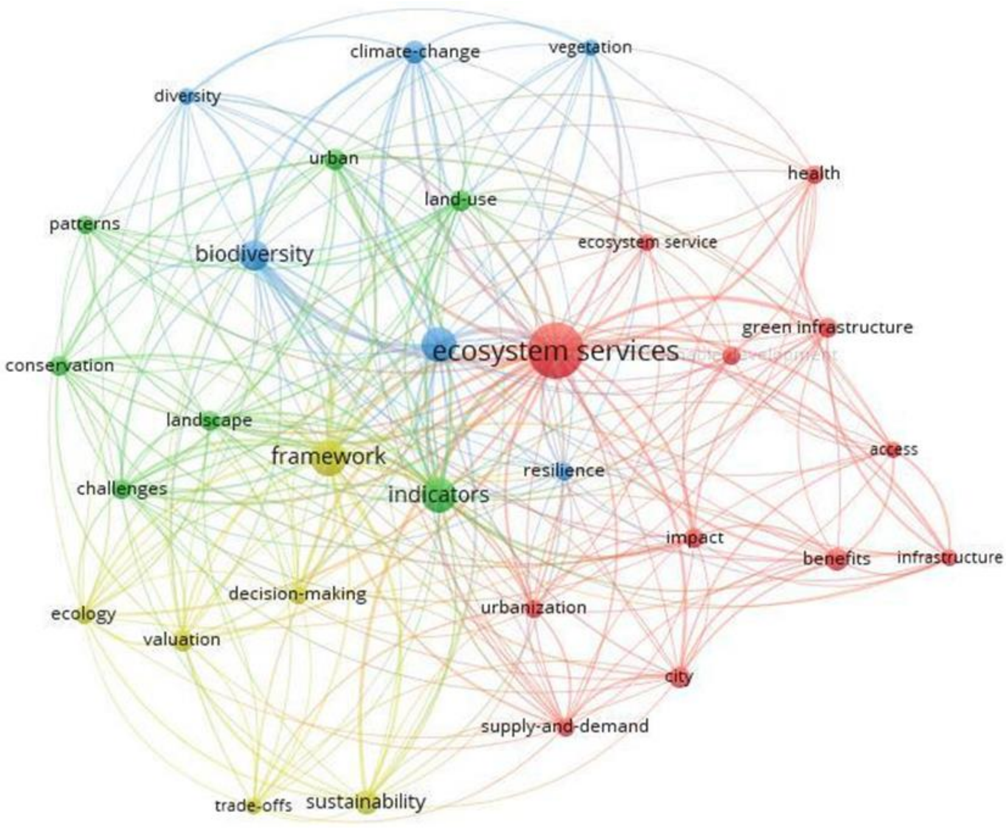

Figure 2. Keyword Network Map.
Figura 2. Mapa de rede de coocorrência de palavras-chave.

Our comprehensive search across databases yielded a total of 1209 records. Following the process of duplicate removal and assessment against inclusion criteria using the Rayyan software, we retained 37 studies for the final analysis, as depicted in Figure 2. Importantly, this figure provides a detailed breakdown, shedding light on the specific exclusion criteria that led to the omission of certain studies, ensuring transparency in our selection process.

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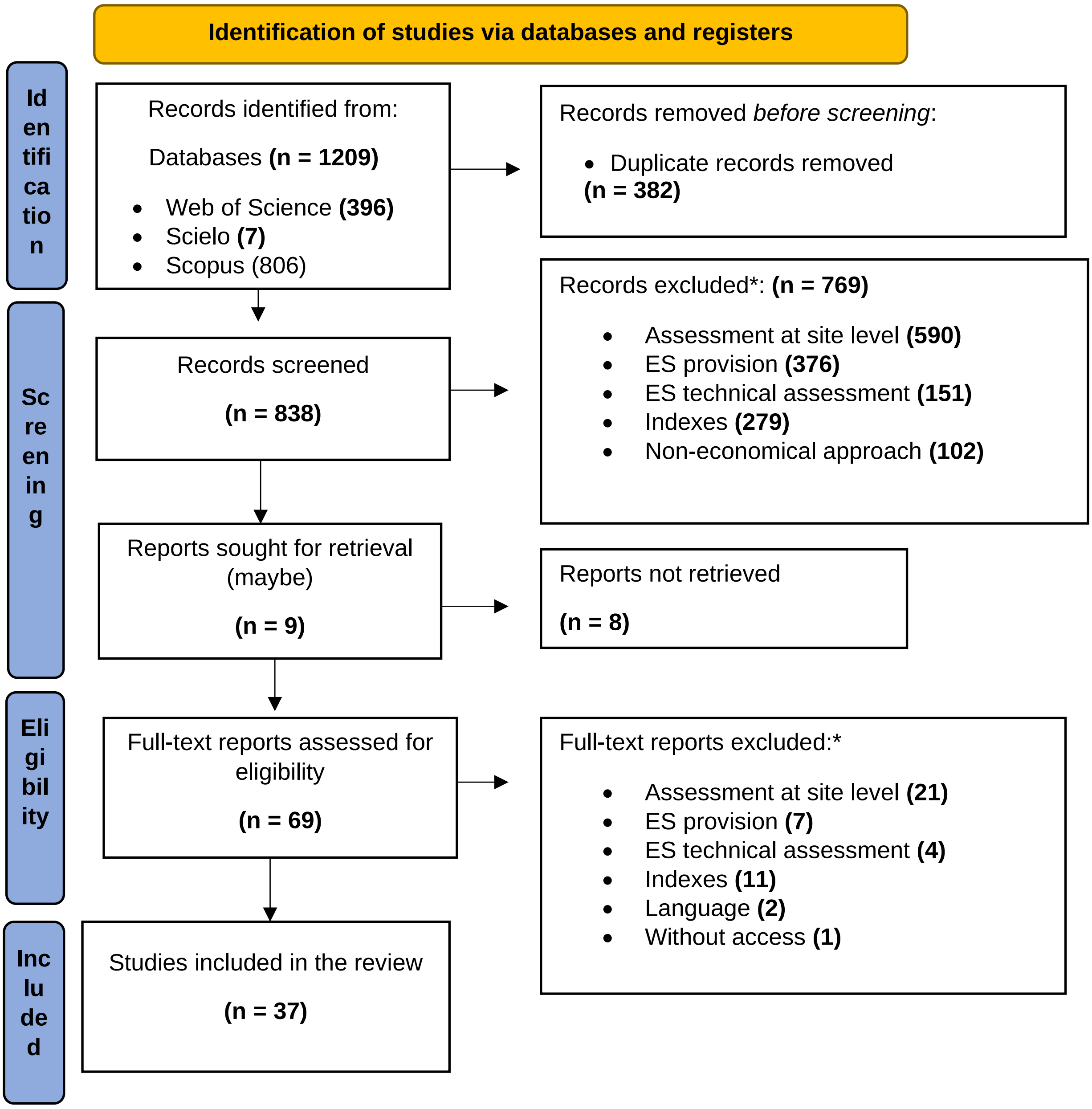

* A single study may have reached more than one exclusion criteria.

SOURCE: Adapted from PRISMA (2023)

Figure 2. PRISMA Flow Diagram — Study selection stages on the left, numbers of identified and excluded studies on the right.

Figura 2. Diagrama de fluxo PRISMA — Etapas de seleção do estudo à esquerda, números de estudos identificados e excluídos à direita.

The study's analysis of publication patterns underscores the distinctive focus of this study on composite indicators at the site level, distinguishing it from prior research that explored general knowledge and publication trends in urban ecosystem service assessments (HAASE et al., 2014; BRZOSKA; SPĀGE, 2020; MUÑOZ-PACHECO; VILLASEÑOR, 2022). Most of the literature consists of papers, complemented by two conference papers, a chapter in a series, and an annual congress report. 'Ecosystem Services' emerges as the predominant publication theme, followed by 'Ecological Indicators' and 'Science of the Total Environment', all of which are published by Elsevier. The alignment of these journals with our search terms underscores their relevance to the study's focal point.

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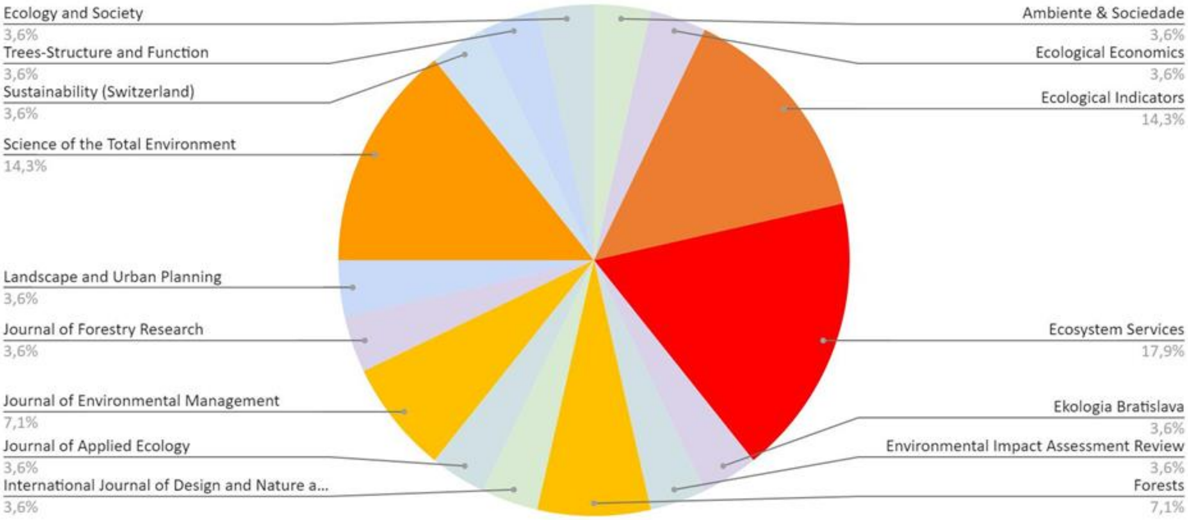

Figure 3. Distribution of Publications in Journals for the Included Studies in the Systematic Review.
Figura 3. Distribuição das Publicações em Revistas dos Estudos Incluídos na Revisão Sistemática.

A temporal analysis of publication trends, presented in Figure 4, reveals a noteworthy surge in publications during 2021. This surge aligns with the evolving dynamics in the field of ecosystem services, particularly in the context of urban green areas, which Jato-Espino et al. (2023) identify as increasingly significant in contemporary and future urban planning. The increased volume of publications in 2021 can be attributed to two factors: first, an escalated academic interest in exploring the multifunctionality of ecosystem services, in contrast to the previous year's emphasis on single-indicator studies, and second, the potential filling of gaps in multifunctional studies that did not meet all inclusion criteria in other years, now being addressed.

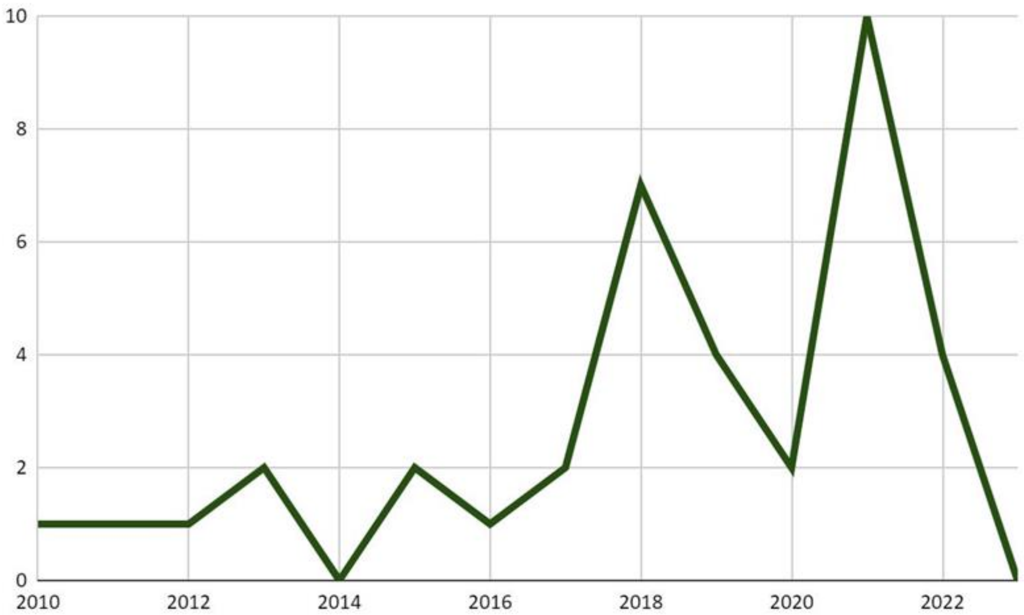

Figure 4. Timeline of publication for Studies Included in the Systematic Review.
Figura 4. Cronologia de publicação dos estudos incluídos na Revisão Sistemática.

In line with the findings of Haase et al. (2014) and Brzoska and Spāģe (2020), Europe stands out as the leader in the development of composite indicators for ecosystem services, followed by Asia and North America (Figure 5). The prolific contributions from individual countries mirror this trend, with Germany, China, and the United States taking the lead. Notably, the representation of studies is limited in Africa, with Brazil being the sole representative from South America, and New Zealand representing Oceania. A significant portion of studies (23.7%) introduced theoretical protocols without empirical testing, categorizing them as non-empirical.

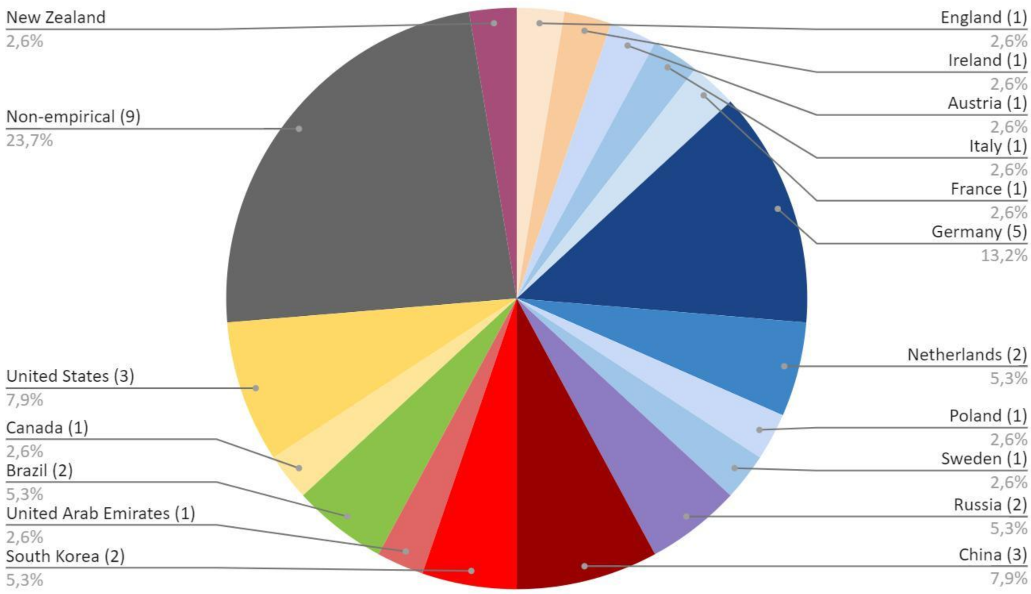

Figure 5. Geographic distribution of study locations by countries.
Figura 5. Distribuição Geográfica dos Locais dos Estudos por países.

We observed an increasing interest in other continents, contrastingly to previous research where European cities dominated (73.3%) as in Brzoska and Spāģe (2020). However, tropical and developing regions remain underrepresented, indicating a substantial knowledge gap, as highlighted by Haase et al. (2014), Brzoska and Spāģe (2020), Muñoz-Pacheco and Villaseñor (2022), and Jato-Espino et al. (2023).

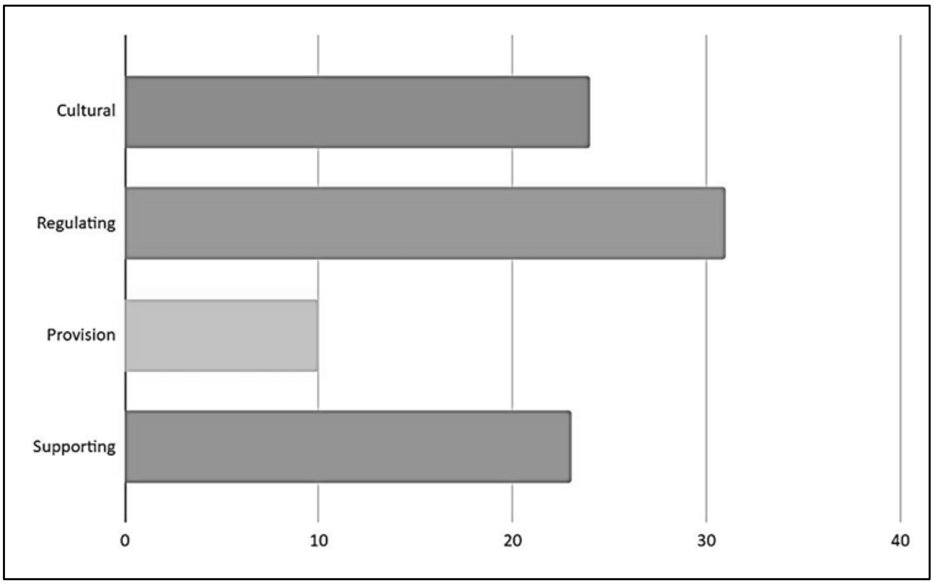

Figure 6: Types of Ecosystem Services Found in the Systematic Literature Review.
Figura 6: Tipos de serviços ecossistêmicos encontrados na Revisão Sistemática de Literatura.

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It is essential to clarify that, for consistency and standardized analysis, we adopted the categorization framework established by the Millennium Ecosystem Assessment (MEA, 2005) for 'Supporting' services.

Our analysis of ecosystem service categories (Figure 6) reveals a significant focus on 'Regulating' services. The dominance of 'Regulating' services in the literature can be attributed to the presence of urban forests and parks within anthropized environments, where urbanisation amplifies vulnerability to hazardous events (JATO-ESPINO et al., 2023). Researchers have focused on understanding the roles of these services in mitigating the impacts of climate change, including the control of extreme weather events, reduction of atmospheric and noise pollution, waste hazard mediation, and soil conservation (SUTHERLAND et al., 2018; JATO-ESPINO et al., 2023).

Regulating services were followed closely by 'Cultural' services, with 'Supporting' services also receiving considerable attention. It is noteworthy that some studies exclusively concentrated on either 'Regulating' or 'Cultural' services. Notably, UGAs play a pivotal role in enhancing public health, a prolific branch of ecosystem services (ES) research, often encompassing terms like 'recreation,' 'physical activity,' 'walking,' and 'sports' (JATO-ESPINO et al., 2023). Additionally, Cultural ES assessments frequently adopt non-monetary frameworks (DICKINSON; HOBBS, 2017), which can impact the number of publications included in this review.

City residents face limited opportunities for nature interaction and the associated benefits, including leisure, education, and contemplation (DICKINSON; HOBBS, 2017). Consequently, the findings presented in Figure 6 underscore the significance of urban green areas (UGAs) in comparison to protected areas (PAs), such as National or State Parks (IUCN, 1994), primarily due to the greater accessibility and visitation potential of UGAs.

In contrast, 'Provisioning' services received less attention and were primarily integrated into broader frameworks, making them the least represented category in this review. The finding aligns with other reviews of urban ecosystem service assessments (BRZOSKA; SPĀĢE, 2020; HAASE et al., 2014; MUÑOZ-PACHECO; VILLASEÑOR, 2022). Brzoska And Spāģe (2020) posit that unlike other ES categories, Provisioning services can be imported into urban areas, diminishing their importance in city contexts. In contrast to Muñoz-Pacheco and Villaseñor's (2022) findings in South America, we did not observe a shortage of studies encompassing Supporting services. Some authors integrate Supporting and Regulating services within the same category, following the CICES framework, potentially leading to misinterpretations.

In the review, while some studies broadly define UGAs as urban green structures, urban vegetation, or urban green infrastructures (BRZOSKA; SPĀĢE, 2020; MUÑOZ-PACHECO; VILLASEÑOR, 2022), others focus primarily on parks, often exclusively (MUÑOZ-PACHECO; VILLASEÑOR, 2022).

Various typology of UGAs were assessed (Figure 7). Some studies concentrated on assessing individual UGA types, while others evaluated multiple UGA types to compare their ES

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delivery. Nine studies neither empirically tested their indices nor specified a particular UGA for testing. Seven studies tested their indices across multiple UGA types. Among UGAs, urban parks were the most frequently assessed, followed by forest fragments and gardens, which encompass public gardens, allotment gardens, or common gardens.

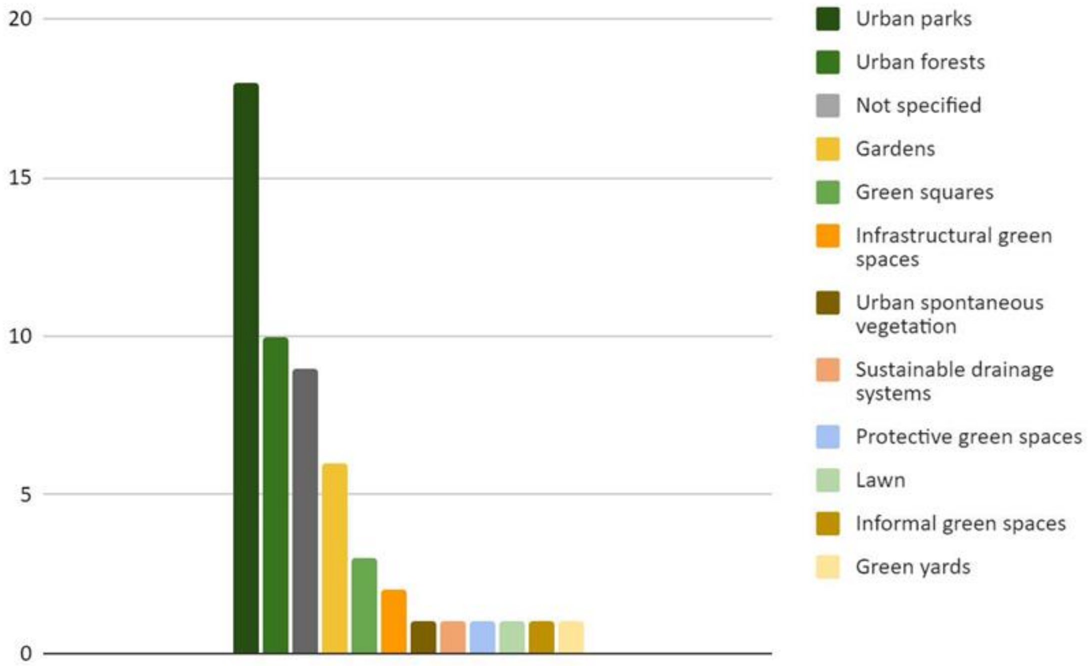

Figure 7. Types of green areas empirically assessed by the authors of articles included in the systematic literature review.
Figura 7. Tipos de áreas verdes avaliadas empiricamente pelos autores dos artigos incluídos na Revisão Sistemática de Literatura.

Urban parks, vital elements of landscape urbanism and recreational spaces, receive considerable attention in urban studies, possibly due to their standardized nomenclature, which is characterized by extensive greenery and designated public use areas. These attributes are of utmost importance in urban environments. However, it is worth noting that within the same study, different definitions of urban parks may coexist, as exemplified by Ungaro et al. (2022), who categorized urban parks based on land cover and urban soil types, highlighting variations in vegetation type, density, and the presence of amenities such as playgrounds or walkways.

Many excluded studies focused on landscape ES provision. For instance, Alam et al. (2015) proposed a composite indicator for urban ecosystem services, yet their tested indicators were limited to landscape metrics. Typically, authors rely on spatial proxy methods to estimate ES capacities, rather than collecting primary data through field observations (BRZOSKA; SPĀGE, 2020). While landscape studies are vital, many ES necessitate site-level measurements for accurate assessment.

Regarding framework, we found that only seven studies comprehensively covered all ES categories (ROBINSON; LUNDHOLM, 2012; GÓMEZ-BAGGETHUN; BARTON, 2013; SCHRAM-BIJKERK et al., 2018; KRAEMER; CHAROENKIT; KAMPANART, 2019; TUDORIE et al., 2019; SIKORSKI et al., 2021). Despite the acknowledged importance of multifunctionality in management, the literature predominantly consists of studies focusing on a single ES category (JATO-ESPINO et al., 2023).

The diversity in suggested indicators, methodologies, framework structures, and even nomenclature for ES is evident across studies, although certain indicators, such as Leaf Area Index (LAI), are consistently repeated. Standardized models for classifying ES, such as the Millennium Ecosystem Assessment (MEA) and the Common International Classification of Ecosystem Services (CICES), have gained widespread acceptance within the scientific community. Authors are encouraged to adhere to these established nomenclatures to facilitate cross-comparisons. A standardized framework, incorporating comprehensive indicators and detailed methods, should be selected, at least for specific UGA types or regional variations.

Some studies, exemplified by Dong and Liu (2019), proposed numerous indicators and subsets but focused solely on a single ES category, precluding classification as composite indicators.

Studies that merely list possible indicators without establishing comparative classes or field assessment criteria often result in weak and superficial frameworks. Notably, 23.7% of the studies did not empirically test their composite indicators, undermining their reliability. Recognizing that each phytophysiognomy and socioeconomic region may require specific evaluation criteria, these criteria should be empirically validated. A few studies omitted framework tables and described theoretical indicators within the text, rendering them theoretical rather than practical tools. To enhance clarity, frameworks should always be presented in tables, with further clarifications provided in the text. In contrast, studies like Gómez-Baggethun and Barton (2012) may not conduct empirical tests but present robust frameworks that include the ES, their descriptions, and numerous indicators or proxies, some of which are only measurable at the site level.

Authors should establish connections between ES provision and the innovations required to achieve it. This guidance can assist urban planners in integrating ES enhancement into infrastructure development routines and utilizing indicators in decision-making (CORTINOVIS; GENELETTI, 2019).

Well-defined and reliable ES indicators serve as valuable urban planning tools. Indicators link ecosystem processes, identify interconnected services, communicate benefits to stakeholders, and support management objectives (MÜLLER; BURKHARD, 2012; TUDORIE et al., 2019).

The UGA must be designed to encompass all aspects of ES, and a set of indicators that assesses all aspects at once saves time and money. Multifunctionality reveals synergies among ES and maximizes UGA benefits (CORTINOVIS; GENELETTI, 2019; JATO-ESPINO, 2023). A holistic approach to ES by municipal urban planners optimizes UGA design for multiple benefits, fostering sustainable cities (WANG; FOLEY, 2021; BELAIRE et al., 2022; CHEN et al., 2022; MUÑOZ-PACHECO; VILLASEÑOR, 2022; JATO-ESPINO, 2023). Managers can assess ES

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supply, compare UGA strengths and weaknesses, and make informed decisions using a qualified, active, and transparent tool (ANDERSSON-SKÖLD et al., 2018; BREUSTE et al., 2013; NUR et al., 2022).

Finally, it is essential to recognize that developing countries are currently in a vulnerable position concerning climate change. Hence, there is an imperative need for these countries to receive more substantial representation regarding the multifunctional aspects of their Urban Green Areas (UGAs). This representation will contribute to the harmonization of socioeconomic development and environmental protection efforts (JATO-ESPINO et al., 2023).

Our efforts to reduce bias encompassed the inclusion of comprehensive keywords in the search terms; nevertheless, certain terms, such as the ecosystem service categories (Supporting, Regulating, Provisioning, Cultural), were not searched for separately. Furthermore, article selection relied solely on the scientific judgment of a single author, considering articles published in known languages (Portuguese, English, and Spanish), potentially introducing geographical bias. Also, studies not archived in Scopus, Scielo, or Web of Knowledge were not included in this review. Lastly, it is evident that tropical and sub-climate countries lack adequate representation in the literature; given the distinct biodiversity and urban planning models in these regions, authors must address their peculiarities by developing compatible frameworks in future research efforts.

CONCLUSIONS

The study revealed that empirically tested indexes with indicators for Ecosystem Services (ES) strictly adapted urban green areas are still scarce, especially indexes which address a holistic approach OF ES and encompass all four categories. In regard to the empirically tested indexes, the most assessed urban green area type was ‘Urban park’.

Regulating ES were the most prominent among the articles analysed, followed by Cultural and Supporting services in similar proportions. It is worth highlighting that ES indicators in urban green areas still lack standardization in the scientific community, given the diversity of nomenclatures, methodologies, and assessment frameworks found. However, certain indicators, such as Leaf Area Index (LAI), are frequently encountered.

Lastly, European researchers stand out as leaders, followed by Asian and American researchers. Researchers from (Africa, South America, and Oceania) had little representation, presenting. The development of indicators and empirical testing in different regions, especially in tropical and subequatorial climate countries from South America, and Africa and Oceania, represent opportunities for future studies on the peculiarities of these locations.

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