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Biodiversity Potential in Brazilian Medium-sized Cities through Human Access to Nature

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ABSTRACT

The paper examines the relationship between city and environment, assuming that contemporary urbanism and sustainability of urban environment do not dialogue. To this end, from analysis of urban biodiversity, cultural ecosystem services, urban design, biophilia and configurational accessibility, a sample of 21 medium-sized Brazilian cities is investigated. Methodology is structured in two sections: (a) categorization of settlements according to biodiversity potential; and (b) spatial analysis of cultural ecosystem services (CES) to verify human access. Results indicate that investigated settlements present: (i) urbanization advancing through vegetation areas, extensive agricultural areas and patches of tree vegetation, low presence of parks, squares and protected areas; (ii) high to medium potential for biodiversity, using this potential for ecosystem services of provisioning and regulation and; (iii) satisfactory levels of access to cultural ecosystem services that reflect human access to nature. In addition, it was found that the CES are located, based on Space Syntax, in potentially accessible urban areas with potential for social interaction.

KEYWORDS

Urban Biodiversity, Cultural Ecosystem Services, Biophilia, Brazilian Medium-Sized Cities, Configurational Accessibility.

1 INTRODUCTION

This paper explores the dialogue between cities and sustainability, interpreting it as a process and not a final state. The intention is to understand the relationships existing within the urban ecosystem between built-up area and nature, based on the services offered. The comprehension of urban ecosystem follows the understanding of Franco (2001) and Oliveira (2016), who assume the urban ecosystem as a set of species interacting in the same environment. This system is interdependent on other systems and intersect the surroundings of urban settlements, resulting in a complex base that maintains the structure of the city.

We seek to discuss the usefulness of nature in different urban agglomerations, as well as the presence of urban biodiversity and ecosystem services, analyzing how these agglomerations contribute to its maintenance. The ecosystem services considered are cultural, such as squares and parks that make up urban green areas.

Ecosystem services, according to the Millennium Ecosystem Assessment Report (Millennium Ecosystem Assessment, 2005), are interpreted as the benefits arising from the ecological structure that nature offers, while cultural ecosystem services comprise the non-material benefits that people obtain from ecosystems.

The problem identified in this field of study lies in the fact that little is known about the interactions and synergies in the demands for ecosystem services accessed by different socioeconomic groups in medium-sized urban agglomerations in Brazil. There is limited information about the needs and demands for ecosystem services in the urban environment. Similarly, the necessity of more knowledge about the range of action of urbanization on ecosystem services is also understood as an issue requiring investigation.

Based on these assumptions, the article is structured in four sections in addition to this introduction, in order to answer the following research questions: (1) to what extent do medium-sized Brazilian cities promote human access to nature and biophilia, which would allow qualifying them as more sustainable? (2) is it possible to relate cultural ecosystem services and urban design with regard to preservation?

2 CONCEPTUAL REVIEW

2.1 Urban Biodiversity

Cities are the largest construction ever made on Earth by a single species. Peri-urban areas were progressively cleared to make room for new developments. Over time, new urban habitats and ecosystems unmatched in the natural world were created by human intervention. This complex and rich variety of species, habitats and urban ecosystems, whose human interference is increasing, is now commonly defined as urban biodiversity (Ossola *et al.*, 2016).

Understanding urban biodiversity, especially patterns, involves the composition of three essential vectors – the value given to the landscape, the socioeconomic level and the stage of the city. The value given to the landscape includes its recognition and refers to patterns of richness and variety of species, habitats and the scales and spatial gradients of biodiversity. In the urban environment, the landscape is seen and valued especially as fragments of habitat embedded in a matrix of non-habitat.

The socioeconomic and cultural level of the neighborhood can play an important role in structuring patterns of urban biodiversity, regardless of the effects of population density or distance from the urban center. This level directly influences the collective conservation ethics and human-environmental relations philosophies, so that the lack of access to urban nature may originate from these ethics and relationships that develop (Kinzig *et al.*, 2005). Therefore, it is believed that it is necessary to increase natural capital in places where most people live and work today, in order to provide opportunities for interaction with nature.

The stage of cities, in turn, is also related to the presence of biodiversity. The amount of time that has elapsed since an urban area was developed can influence the number and type of natural species found in that settlement through a diverse set of mechanisms that are linked to local rates of colonization and extinction. Older urban areas have had more time to ease the adverse impacts of urbanization, so a greater proportion of a city's extinction debt will have already been paid.

In addition to these three vectors, it should be taken into account that urban biodiversity already interacts, specifically through ecosystem services that regulate ecological processes, and sustains urban habitability and the resilience of modern cities.

2.2 Cultural Ecosystem Services

Ecosystem services are components of nature, directly appreciated, consumed or used to generate human well-being. What the concept brings, as a novelty, is the relevance of services that effectively sustain life on the planet, considered more important, much more because of the difficult to replacement, than because of the products generated.

The three main categories of ecosystem services under CICES (Common International Classification of Ecosystem Services) are provisioning (biomass, water, fiber); regulation and maintenance (soil formation and composition, pest and disease control, climate regulation, etc.); and cultural services (man's physical, intellectual, spiritual and symbolic interactions with ecosystems). Cultural ecosystem services (CES) are interpreted as the non-material benefits that people derive from ecosystems through spiritual enrichment, cognitive development, reflection, recreation and aesthetic experiences.

Concerning to this group, concept and understanding remain a residual category within the production of knowledge on the general theme of ecosystem services. Cultural service often refers to categories such as non-market, non-material, non-monetary, non-economic, and non-instrumental. In other words, cultural ecosystem services are about understanding the ways of life in which people participate, which constitute and reflect the values and stories people share and the places they inhabit.

2.3 Urban Design

Urban design can be defined as the spatial pattern of permanent physical objects in a city, the shape of this design being the result of the aggregation of more or less repetitive elements, that is, the union of many concept-elements that result in the urban pattern (Lynch, 2006). Urban patterns are largely composed of a limited number of relatively undifferentiated types of elements that repeat and combine. Specifically, the concept elements can be street patterns, block size and shape, street design, typical lot configuration, layout of parks and public spaces, and so on.

In essence, urban design is concerned with establishing the integrating fabric of urban areas allowing them to become real places for people, rather than simple collections of unrelated projects. It is interpreted that urban design has the responsibility to promote conviviality, including in public places; thinking about the urban and designing it involves providing open spaces for leisure and physical activities and understanding how this contributes to the population's quality of life. However, as Jacobs (2011) writes, public open spaces themselves are far from automatically promoting quality of life: on the contrary, it is open spaces that are directly and drastically affected by the way the neighborhood interferes with them.

It is somehow this interference that Hillier (2007) called “natural movement”, that is, the portion of movement (vitality) in a network of public spaces resulting from its configurational structure, regardless of the presence or absence of attractions. In fact, the configurational structure, which can be understood as urban configuration, involves the set of barriers and permeabilities that make up the physical structure of the space (Medeiros, 2013), in which the arrangement of the elements provides more or less facilities for the movement of people and performance of their activities.

Jan Gehl (2014) affirms that if we look at the history of cities, it can be clearly seen that urban design, together with urban structures and preceded by planning, influence human behavior and the ways in which settlements function. Therefore, the promotion of sustainable lifestyles in our urban agglomerations depends on the design of the physical environment and its capacity to provide social interaction, assuming that space affects society.

2.4 Biophilia

Biophilia can be understood as the innate and genetically determined affinity of human beings with the natural world, that is, the emotional and innate affiliation of human beings to other living organisms (Wilson, 1984). It's a recent concept coined by social psychologist Erich Fromm, who understood the consequences of being far from nature.

The biophilic hypothesis assumes that people need to have contact with nature and with the complex geometry of natural forms, as well as requiring nutrients and air for their metabolism to function. Thus, in an increasingly urban world, considering biophilia as the movement towards sustainable cities, an important change in urban construction thinking will be required, resulting in biophilic urbanism. The city should be understood as the seat of complex metabolic systems, with fluxes and cycles. For Beatley (2011), urbanism (biophilic) and urban design projects for sustainable cities should be created with a closed-loop philosophy, that is, converting linear flows into circular flows (closed loops), following the principles of natural systems.

The essence of biophilia is that physical and mental fitness and well-being continue to depend on the quality of connections to the world beyond the constructed, connections to the natural world, of which we continue and will continue to be a part. Contact with biodiversity and the ecosystem services it provides is much more important than inserting an aesthetic amenity into the urban environment.

3 DATASETS AND METHODS

Considering the fundamental concepts of the research and the structure presented in the introduction, in methodological terms the initial step consisted of selecting medium-sized Brazilian cities, based on four criteria: population size, municipality size, human development index (HDI) and social inequality measured by the Gini coefficient (Table 1). From a universe of 261 urban agglomerations, 21 settlements were selected (*Sudeste* Region – Bauru; Belford Roxo; Betim; Carapicuíba; Cariacica; Diadema; Jundiaí; Mauá; Mogi das Cruzes; Niterói; Santos; São João de Meriti; São José do Rio Preto; Vila Velha; Itaquaquecetuba; São Vicente. *Nordeste* Region – Campina Grande; Caruaru; Olinda. *Centro-Oeste* Region – Anápolis. *Sul* Region – Florianópolis). Due to the parameters, it was not possible to incorporate cities placed in the Northern Region of Brazil.

Table 1 – Criteria for selection of cities in the sample

population size	city size	human development index	social inequality (Gini)
Cities between 350.000 to 500.000 inhabitants.	Territorial area of up to 1.000 km^2.	Municipalities with similar Human Development Index, ranging from medium, high and very high.	Municipalities with Gini coefficient ranging from 0.3 a 0.5.

After the selection of the sample, the analysis steps consisted of: (1) categorization of medium cities by their biodiversity potential and (2) spatial analysis of cultural ecosystem services (CES) to verify human access.

Categorization (1) was carried out with the aim of detecting the proportion and distribution of the following elements: (a) built-up areas – a set of structures characterized by a marked density of buildings, with the presence of verticalization and almost absence of non-impermeable soil; (b) natural areas – a set of structures, outside the urban area, whose landscape and ecosystem conservation aspects are closer to the original; and (c) urban green areas – urban open areas or spaces composed of arboreal vegetation with free soil from buildings or waterproof coverings, with public access or not.

Within the categorization, the criteria used for judgment in the process of identifying the potential for biodiversity (Table 2) was adapted from the City Biodiversity Index (CBI), remarking the CBI, or Singapore Index (Chan *et. al.*, 2014), is a self-assessment tool that encourages cities to monitor and evaluate their progress in conserving and enhancing biodiversity. The index comprises 23 indicators in three components: native biodiversity, ecosystem services provided by biodiversity, and biodiversity governance and management.

Table 2 – Criteria for identifying biodiversity potential

built-up areas	natural areas	urban green areas
analysis coefficient: < 25% low; 25% a 50% medium; > 50% high.	analysis coefficient: < 25% low; 25% a 50% medium; > 50% high.	analysis coefficient: 1% a 6% low; 7% a 14% medium; 15% a 20% high

The way of calculating the categories was based on the following equations:

- Built-up area (BA): (total area of the urban area) ÷ (total area of the municipality) × 100%;
- Natural area (NA): (total area of the forest vegetation mosaic, agricultural area and protected area) ÷ (total area of the municipality) × 100%;
- Urban green area (UGA): (total area of squares, parks and arboreal vegetation patches) ÷ (total area of urban patch) × 100%

Thus, the logic in classifying the cities in each of the three categories created followed the line of reasoning described below (Table 3):

Table 3 – Categorization for analysis of biodiversity potential

CATEGORY 1	CATEGORY 2	CATEGORY 3
Average/high percentage of built-up area, low/medium urban green area percentage and low/medium percentage of natural and/or protected areas.	Percentage of built-up area low/medium, percentage of urban green area low/medium and percentage of natural and/or protected areas, medium/high.	Percentage of low/medium built-up area, percentage of medium/high urban green area and medium/high percentage of natural and/or protected areas.
BUILT AREA predominates	**NATURAL/PROTECTED AREA** predominates	**URBAN GREEN AREA** predominates

The spatial analysis of CES (2) to verify human access, considered: (a) the number of CES from the total of accessible urban green areas per inhabitant in square meters; and (b) the distribution of CES, according to the total of urban green areas – squares and parks – arranged by the urban sprawl area. The access level criteria was adapted from the studies by Miller (2001) and Farr (2013), according to the following judgment: above 70% – excellent; from 30% to 70% to – satisfactory; 10%-30% – minimum; and less than 10% – insufficient.

The calculation method for the level of human access to nature resulted from the following procedures:

- Quantity of cultural ecosystem services (total area of parks and squares, in m^2) ÷ (total population) = accessible cultural ecosystem service per inhabitant.
- Distribution of cultural ecosystem services by urban area (total area of parks and squares, in m^2) ÷ (urban area) = area of the city destined to accessible cultural ecosystem services.
- Total number of people served by cultural ecosystem service (squares and parks) within a radius of 400 meters (total population within 400 meters of parks and squares) ÷ (total population of the municipality).

After inferring the level of access, two average cities in the sample were selected, one with the highest level and other with the lowest one, specifically within a radius of 400 meters, equivalent to a ten-minute walk. This subgroup was evaluated according to the spatial modeling associated with the Theory of the Social Logic of Space – Space Syntax (Hillier, 2007), aiming at investigating, from axial maps, the topological accessibility concerning the variables global integration and local integration. The intention was to identify the spaces with the greatest potential for co-presence, that is, potential accessibility resulting from the configuration of the place.

4 RESULTS

4.1 Biodiversity Potential

Regarding the first stage of analysis (categorization of medium-sized cities by biodiversity potential), the execution of criteria and calculations resulted in the identification of seven cities in category 1 (low biodiversity potential), twelve in category 2 (high biodiversity potential) and two in category 3 (average biodiversity potential).

For category 1 (C1), the cities included were: Belford Roxo, Carapicuíba, Diadema, Mauá, São João de Meriti, Itaquaquecetuba and Olinda. These settlements have low to very low biodiversity potential. The built-up area presented a percentage value of 77.57%, indicating a high level. The indexes for the natural areas category reached 22.43%. The measure for the presence of natural areas was considered low. The third categorization criterion – urban green areas – reached 8.84%, a value qualified as medium.

In turn, for category 2 (C2), the cities of Anápolis, Bauru, Betim, Cariacica, Campina Grande, Caruaru, Jundiaí, Mogi das Cruzes, Santos, São José do Rio Preto, Vila Velha and São Vicente were classified. The set comprises settlements with medium to high biodiversity potential. As for the evaluation criteria, the first – built-up area – presented the percentage of 13.64%, classified as low level. In relation to natural areas, the values reached 86.36% of the municipality territory, considered high. With regard to urban green areas, for this group it comprised 6.04% of the territory, a low value.

The cities of Niterói and Florianópolis were identified for category 3 (C3), settlements with medium potential for biodiversity. It was observed as an outstanding feature the fact that both the presence of a natural area and the entire urban green area were registered with valuation from medium to high. As for the categorization criteria, the constructed area presented the percentage of 28.85%, indicating an intermediate level. The values for natural areas resulted in 71.16%. The third categorization criterion – urban green areas – reached an average of 17.13%, qualified as high, according to the parameters adapted from the Urban Biodiversity Index.

With regard to biodiversity potential, C1 cities reflected low potential for natural areas, percentages that remained with low variation for the forest vegetation mosaic, for protected areas and for agricultural areas. In contrast to the scarcity of natural areas, the breath is found in urban green areas, which obtained an average value. Indeed, in the medium-sized cities categorized as C1 the ecosystem services can be considered inactive. Although it was identified that this low biodiversity potential when is used, generally is used for regulatory ecosystem services and to a lesser extent in cultural ecosystem services.

In turn, cities C2 pointed to a picture of high potential for biodiversity in the high percentages of forest vegetation and agricultural areas, components that, together with protected areas, form natural areas. However, the high potential is not being reflected in the urban sprawl. The use of this high potential seems to focus on ecosystem services of provision and regulation.

C3 cities reflected the average biodiversity potential in the values for the presence of natural areas, used basically to regulatory ecosystem services. Within the established context, it was conjectured that the values for urban green areas could be high, which in fact happened. However, there is a caveat for the presence of squares and parks that within the urban area presented values lower than those found in cities C1 and C2.

It is important to consider that this is an exploratory work in the field of identifying the potential of urban biodiversity. Studies on this topic are still incipient and the results and data achieved here, which join the work of Cardoso (2011), in the selection of indicators of urban biodiversity for the city of Lisbon, and of Uchiyama *et al.* (2015), in the identification of urban biodiversity in

Japanese cities, could be used, in the near future, to create a global index regarding the potential of urban biodiversity.

4.2 Cultural Ecosystem Services and Human Access

For the investigation of the second analysis criterion (spatial analysis of cultural ecosystem services to verify human access), we sought to identify which fraction is destined, within the urban area, for cultural ecosystem services - urban squares and parks - and check which part of the population would have access to these areas. From the analysis of the quantity of accessible urban green areas in the sample of 21 cities, an average of 478.595 m^2 of accessible CES was identified, of which 235.976 m^2 are square areas and 242.619 m^2 are parks.

Bauru was identified as the one with the largest area for squares, 577.000 m^2, and parks, 1.307.000 m^2. Campina Grande and Betim also stand out, respectively with 428.000 m^2 and 410.000 m^2. Carapicuíba and Jundiaí presented a prominent value for the total area destined to the parks, 744.000 m^2 and 564.000 m^2. In contrast, the cities with the smallest area for squares were Itaquaquecetuba (66.000 m^2), São João de Meriti (89.000 m^2) and Caruaru (99.000 m^2). Regarding parks, São João de Meriti had the smallest area, 14.000 m^2, followed by Caruaru (31.000 m^2) and Vila Velha (51.000 m^2).

As for the amount of accessible cultural ecosystem services, the sample of cities had an overall average of 1.18m^2 of accessible green area per inhabitant, of which 0.57m^2 of squares per inhabitant and 0.61m^2 of parks. Silva *et al.* (2016) recommend that accessible urban green areas should be at least 6m^2 per inhabitant: the obtained values are significantly lower. In the overall picture, the cities with the largest CES accessible area per inhabitant were Bauru and Carapicuíba, with 5.07m^2 and 2.26m^2 respectively. Of the sample, the smallest were São João de Meriti and Itaquaquecetuba, with 0.22m^2 and 0.18m^2 respectively (Figure 1).

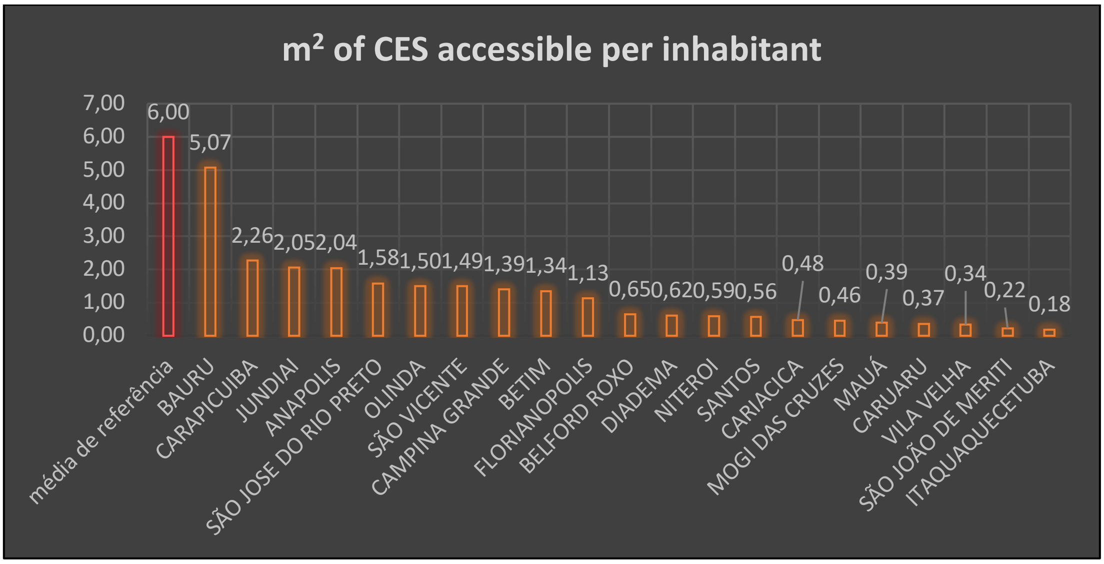

Figure 1 – Quantity (in m^2) of accessible CES areas per inhabitant.

Regarding human access to nature within 400 meters, or access to CES within a ten-minute walk, it was observed that 60.93% (4.950.558 inhabitants) have access to nature, a level considered satisfactory. Exploring the composition of the measure, it was identified that within the sample of 21 cities, 7 had an excellent level and 14 had a satisfactory pattern. Municipalities with minimum and insufficient levels were not found.

Considering the example of the city of Diadema, framed at excellent level, it was found that the municipality has 295.494 inhabitants with access to up to 400 meters to the 62 identified cultural ecosystem services. By analyzing the distribution of CES by neighborhoods, it was identified that all of them have cultural ecosystem services, so that 16.31% of the inhabitants have access to parks and 73.20% have access to squares within a ten-minute walk (Figure 2).

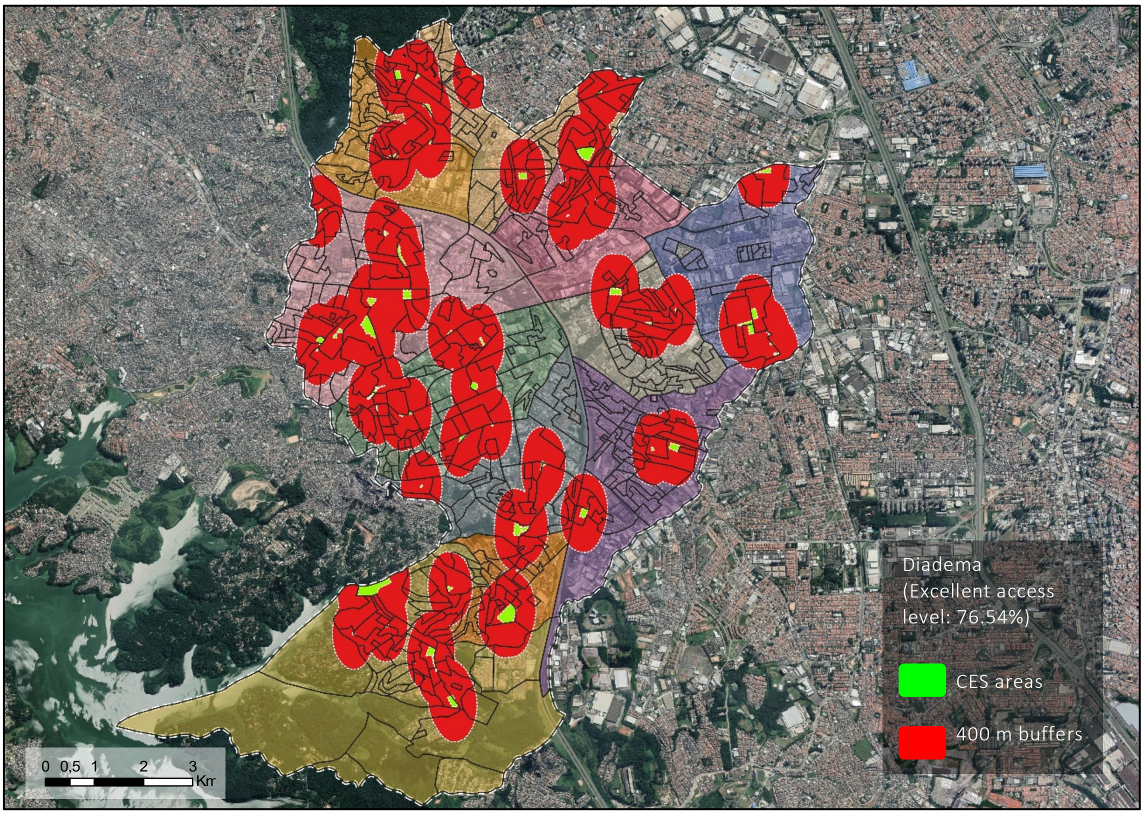

Figure 2 – Cultural Ecosystem Services spread across the city of Diadema.

4.3 Social Interaction Potential

To identify the social interaction potential, the urban space was investigated by means of axial maps (Medeiros, 2013). The relationship between human access and the social interaction potential was explored considering the medium-sized city with the highest level of human access to nature (Bauru: excellent level of access up to 400 meters, accessible to 88% of the population) and the one with the lowest one (Vila Velha: human level below 400 meters, accessible to 37% of the population).

In the analysis, it was decided to consider the global integration measure (which relates all the axial lines of the system to each other, demonstrating the relationship between the configurational structure of the urban grid and the urban movement, helping to identify the morphological center); and local integration variable (which, in most cases, coincides with the potential local properties of configuration, that is, it is suitable for analysis of local centralities or neighborhoods). The stage comprised the interpretation of the location of CES and the relationship with the area's potential configuration.

The global integration of the city of Bauru reached an average of 0.42, while that of Vila Velha of 0.28, numbers that characterize a preponderance of a dispersed urban fabric associated with a conformation tending to labyrinth, despite the apparent regularity of the fractions/neighborhoods. The values of urban systems are significantly lower than the Brazilian average of 0.76 (Medeiros, 2013). The local integration of cities in turn, for both cities, allowed to identify the local centralities spread along the urban grid.

The results indicate that of the total CES in Bauru (229), 7% are located in segregated areas while 93% are in more integrated zones. For Vila Velha, for a total of 28 CES, 4% of the areas are segregated and 96% are in the more integrated spaces (Figure 3). The findings show that the CES are predominantly located in more accessible areas, that is, potentially easier to be reached both locally and globally. It is inferred that the strength of integration identified through axial maps and positively associated with CES is an important factor for the sustainability of cities, as nature must be present where the greatest number of people is supposed to be.

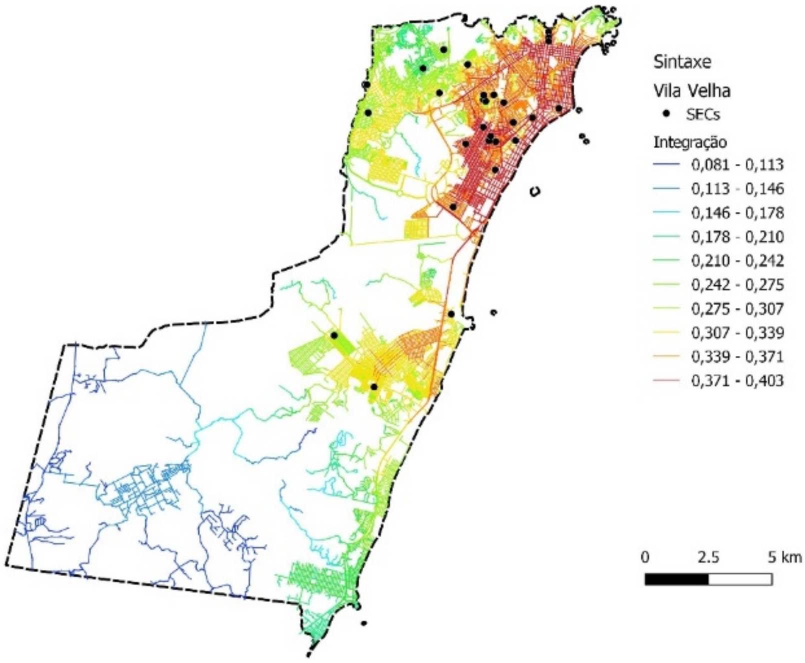

Figure 3 – Distribution of CES and relationship with the most integrated areas of the city of Vila Velha (axial map, global integration measure).

5 CONCLUSIONS

The paper sought to examine the relationship between city and environment, assuming the premise that contemporary urbanism and the sustainability of the urban environment do not dialogue. Throughout the sections, aspects of urban biodiversity, cultural ecosystem services, urban design and biophilia were discussed, using medium-sized Brazilian cities as a sample. Based on the methodology developed, we sought to identify the potential for biodiversity in cities through the investigation of human access to nature in 21 case studies, with the aim of contributing to the discussion on CES.

Regarding the first research question presented – to what extent do medium-sized Brazilian cities promote human access to nature and biophilia, which allows qualifying them as more sustainable? – the analysis of the results allowed us to conclude:

(i) most medium-sized cities had medium to high biodiversity potential (14 of the 21 analyzed);
(ii) the use of this potential has basically turned out to be aimed at ecosystem services of provisioning and regulating;
(iii) cultural ecosystem services are underestimated in these cities, mainly in C2 and C3 categories.

Although the results obtained allow us to arrive at a first panorama, it is known that the potential of biodiversity, in order to be maintained, depends on other factors and perceptions. It depends on a greater contact of people with the natural environment. It depends on biophilia and, above all, on the rise of cultural ecosystem services as factor that indeed contribute to people's relationship with nature.

With reference to the second question – is it possible to relate cultural ecosystem services and urban design with regard to preservation? – the results obtained presented some aspects:

(i) good coverage, in most cities analyzed almost 60% of neighborhoods have some type of CES, although the total area occupied by CES seems proportionally small;
(ii) satisfactory level of access of CES, regarding human access to nature within 400 meters: these spaces are reasonably distributed and accessible to most citizens;
(iii) based on the Theory of Social Logic of Space, it was observed for the selected cities that the CES are located in potentially accessible urban zones.

Indeed, obtained results for the sample point to the existence of a structure or network of spaces whose location and distribution are favorable to the promotion of an urban environment with a better relationship with nature. It remains, however, to qualify and expand it. Biophilia seems dormant and somehow repressed. It can be said, in this way, that medium-sized Brazilian cities are far from ideal, but they contain the spatial structure that can serve as a basis for transformation into biophilic cities.

At prospective view for future researches in this field is important, and necessary to, advance in the assessment to obtain data on the quality of CES in cities. As well is also important investigate if the biodiversity potential related to the provisioning ecosystem service not to be destined to monoculture or pasture, a fact that can undermine the efficiency and usefulness of this very important ecosystem service.

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