City biodiversity index and the cities-biodiversity relationship: a case study for Sorocaba, SP, Brazil

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Abstract
In order to adopt a strategic model which aims to mitigate the environmental pressures exerted by the process of unbridled urbanization, the Convention on Biological Diversity (CBD), an international agreement that permeates its conservation, the sustainable use of its resources and the equitable sharing of its resources, approved in 2010 the creation of the City Biodiversity Index (CBI), a political-legal instrument that aims to assess its management and progress. Later in 2016, the “Sorocaba: the city of biodiversity” program was launched by Secretariat for the Environment and Sustainability (SEMA), consisting of six specific objectives and among them, the establishment of criteria for the evaluation of conservation measures through indicators adapted from CBI, in order to propagate the urban ecology and ecosystems importance. Given the above, this study aimed to prove the compatibility between urban centers and biodiversity and to evaluate the environmental management of the city of Sorocaba, located in the interior of the State of São Paulo, through the application of 23 CBI indicators and semi-structured interviews with environmental technicians of the municipality, in order to raise possible strategies in the conservation of biodiversity. The sum of the indicators resulted in a value of 57 points out of a total of 92 (61.9%), showing that, although Sorocaba has a relevant biodiversity, the low score of many indicators implies a need for greater mobilization of government spheres and the successive application of the CBI, in order to expand the conservation and environmental management of the city agenda over the years, strategy agreed among the technicians interviewed.

Keywords City biodiversity index · Conservation · Local government · Urban biodiversity

Introduction
Currently, about 50% of the world population occupies large urban centers and the perspective is that this percentage will increase exponentially by the year 2030 (United Nations Population Fund 2007). Urbanization has been a driving force for changes in several essential ecosystem services, significantly affecting biological systems and factors such as climate and biodiversity, the latter in terms of species composition, wealth, abundance, and distribution (Shochat et al. 2006; Shochat et al. 2010). On the other hand, despite all the pressure exerted on the processes of biological diversity, a considerable number of species have their habitat areas inserted in urban perimeters (especially squares, parks, and gardens) as potential refuges due to the availability of food resources, abundance of habitats, ecological niches and, for the most part, the absence of natural predators (Angold et al. 2006).

Given all the problems inherent to urbanization processes, much is discussed about the difficulty in assigning a value
to urban biodiversity, characterized by the variety of living organisms inserted in urban bordering areas (Dearborn and Kark 2009; Laurila-Pant et al. 2015; Müller et al. 2013). In 2002 during the Convention on Biological Diversity (CBD), leaders of CBD signatory countries pledged to meet a goal of reducing biodiversity loss by 2010. However, a recent assessment using a couple of indicators showed a failure to achieve the objective and that the rate of biodiversity loss is the fastest ever observed (Secretariat of the Convention on Biological Diversity 2019; Smith et al. 2018).

Due to the results obtained, the CBD approved in 2010 a metric known as the “City Biodiversity Index” (CBI), an essential mark in the conservation of species and ecosystems (Cabral et al. 2012). This metric aims to assess the city’s efforts in the conservation of biodiversity and ecosystems and consists of 23 indicators that relate to various environmental aspects, such as green and permeable areas, species richness, public policies, education and others (CBI - City Biodiversity Index 2008), an essential mark in the conservation of species and ecosystems (Cabral et al. 2012). Also, the Convention Parties have established 20 new targets to be achieved by the year 2020, a fact that led the United Nations to name the period evaluated as “decade of biodiversity” (Mace et al. 2018; Secretariat of the Convention on Biological Diversity 2019). The strategy in question came to an end in October 2020 during the 15th Conference of the Parties (COP-15), reporting that many objectives have not been adequately achieved and adopting a new post-2020 approach that includes goals that aim to stop the loss of biodiversity and maintaining the integrity of ecosystems until 2030 (Hoban et al. 2020).

It is worth mentioning that natural degradation has adverse effects on humans and ecosystems, we can observe the homogeneity of biodiversity, and the (in)direct drivers change have accelerated in the past 50 years, actions need to ensure conserving goals due to the no/partially attendance of Aichi targets (such as policy responses, invasive alien species, action plans, etc.) and the Sustainable Development Goals in the current trajectories and insufficient progress (IPBES 2019). For the Aichi target, the main challenges are pointed out in the literature because of the gap and lack of integration with the landscape/seascape, insufficient progress on elements related to population density and urbanization, the need to address climate change and related risks, and the global need to improve the protection of biodiversity and refugia (Arneth et al. 2020; Buchanan et al. 2020; Meehan et al. 2020; Carrasco et al. 2021).

To take the biological diversity present in cities as a basis for the proper functioning of the urban environment is still a somewhat unusual practice, given that the approach and planning for biodiversity conservation are challenging actions for local governments (Pierce et al. 2020). It is necessary to understand that it is possible to link biodiversity conservation actions with the development of the urban environment and that its success is intrinsically linked to the people-nature intersection, since the population benefits from a wide range of cultural services, from regulation, provision, and support from ecosystems (Kowarik et al. 2020; de Almeida Sinisgalli and de Sousa 2020).

Under a more local picture, the creation of Secretariat for the Environment and Sustainability (SEMA) in the city of Sorocaba, located in the interior of São Paulo State, was a driving force for discussions and projects aimed at the good management of biodiversity. Like the publication of two editions of the book “Biodiversidade no Município de Sorocaba” (Smith et al. 2014; Smith 2020), consisting of an inventory of animal and vegetable species in the city, and the presence of 33 parks in the municipality, eight of which classified as “natural” (of which many hosted environmental education activities).

Even though the municipality of Sorocaba is moving towards effective results concerning the protection of biodiversity, such effects must persist so that it is possible to provide faster responses about environmental protection and, consequently, population well-being (Smith et al. 2016). In this context, this study aimed to prove the compatibility between cities and biodiversity and expose the importance of green areas for it, as well for urban centers, aiming to evaluate the level and management of biodiversity in the municipality of Sorocabawith the subsidy of 23 indicators included in the CBI, being extremely relevant for the city and the first Picture of urban biodiversity through the index in question.

Material and methods

Study case

The choice of the municipality is due to technical criteria such as having a environment municipal office, developing an extensive environmental agenda and presenting public policies aimed at the conservation of biodiversity in the last 10 years. Sorocaba municipality is located in the interior of São Paulo State (S latitude: 23° 21’ and 23° 35’; W longitude: 47° 17’ and 47° 36’), being an important industrial pole due to its two main highways, Raposo Tavares (SP-270) and Castelo Branco (SP-280) (Emplasa – Empresa Paulista de Planejamento Metropolitano 2018). Has an area of approximately 450 km², with an average altitude of 600 m above sea level and has more than 600,000 inhabitants (SEMA 2016). The city’s climate is characterized by Cwb (hot subtropical) according to Köpen climatic classification, with an average monthly temperature that reaches less than 22 °C and precipitation of approximately 1408.4 mm per year (Cepagri – Centro de Pesquisas Meteorológicas e Climáticas
Aplicadas à Agricultura 2018). The declivity is between 0 and 15°, with more variations in the southeast portion. Is established in UGRHI-10 (The Water Resources Management System of the State of São Paulo) Sorocaba and Middle Tietê, encompassing 33 other municipalities (Bortoleto and Silva 2020).

Concerning its green area, the predominant and original vegetation of the city is characterized as Seasonal Semideciduous Forest with transition zones (ecotones) between Cerrado and Atlantic Forest, which contributes to the biodiversity conservation strategy, given that the municipality presents higher common species richness to the two biomes (Smith et al. 2016). Although it is quite fragmented, the Remaining Natural Vegetation (RNV) of the city corresponds to about 22% of the entire area, and 90% of your green areas are occupied by municipal parks, squares and public gardens (Fig. 1) (Smith et al. 2016).

Methodology

Urban indicators need to consider the final elements of the decision-making process, the results are conducive to response and sustainable development, and response directly affects the decision-making framework and sustainable participation (Tatham et al. 2014). The methodology employed in this work was based on 23 indicators belonging to City Biodiversity Index (CBI), divided into three categories: Biodiversity (10 indicators), Ecosystem Services (4) and Governance and Management (9) (Table 1). According to Deslauriers et al. (2018), CBI or Singapure Index on Cities’ Biodiversity was developed in 2008 to the monitoring and evaluation of biodiversity in cities, aiming to enhance conservation efforts front a scenario of increasing rates of biodiversity loss and urbanization. CBI aims the sustainable management of biodiversity, the evaluate aspects enables the understanding of biodiversity in urban areas (Uchiyama et al. 2015). It is worth mentioning that the development of CBI involves the participation of the Convention on Biological Diversity (CDB) and global partnerships; the first experience involving CBI occurred in Singapore in 2009 (Kohsaka et al. 2013). CBI is a good framework for urban planning related to biodiversity (Pierce et al. 2020). Kohsaka et al. (2013) pointed out that CBI is a simple indicator with scientific credibility and easy to apply. To each of the indicators

Fig. 1 Geographic location of the Brazilian municipality of Sorocaba (SP) and some of its main green areas
| Categories | CBI indicators | Adapted indicators | Methods of obtaining data | Score |
|------------|----------------|--------------------|---------------------------|-------|
| 1. Proportion of natural areas in city | Proportion of green areas in relation to total area | (Green areas) / (City area) x 100 | 0 points: < 1.0% 1 point: 1.0%–6.9% 2 points: 7.0%–13.9% 3 points: 14.0%–20.0% 4 points: > 20.0% |
| 2. Connectivity measures | Check for connectivity between different green spaces | Bibliographic consultation (Bortoleto 2019) | 0 points: < 200 ha 1 point: 201–500 ha 2 points: 501–1000 ha 3 points: 1001 – 1500 ha 4 points: > 1500 ha |
| 3. Native biodiversity in built up areas (bird species) | Check for number of bird species in built up areas | Field surveys and Bibliographic consultation (Piratelli et al. 2016; Prefeitura Municipal de Sorocaba 2019) | 0 points: < 19 bird species 1 point: 19–27 bird species 2 points: 28–46 bird species 3 points: 47–68 bird species 4 points: > 68 bird species |
| Biodiversity | 4. Change in number of vascular plant species | Change in number of vascular plant species | 2014 and 2020 inventories (Smith et al. 2014; Smith 2020) | 0 points: the number of species remains the same or decreases 1 point: increase in 1 species 2 points: increase in 2 species 3 points: increase in 3 species 4 points: increase in 4 species or more |
| 5. Change in number of bird species | Change in number of bird species | 2014 and 2020 inventories (Smith et al. 2014; Smith 2020) | 0 points: the number of species remains the same or decreases 1 point: increase in 1 species 2 points: increase in 2 species 3 points: increase in 3 species 4 points: increase in 4 species or more |
| 6. Change in number of butterfly species | Change in number of butterfly species | 2014 and 2020 inventories (Smith et al. 2014; Smith 2020) | 0 points: the number of species remains the same or decreases 1 point: increase in 1 species 2 points: increase in 2 species 3 points: increase in 3 species 4 points: increase in 4 species or more |
| 7. Change in number of any other taxonomic group selected by the city | Change in number of amphibian species | 2014 and 2020 inventories (Smith et al. 2014; Smith 2020) | 0 points: the number of species remains the same or decreases 1 point: increase in 1 species 2 points: increase in 2 species 3 points: increase in 3 species 4 points: increase in 4 species or more |
| Categories | CBI indicators | Adapted indicators | Methods of obtaining data | Score |
|------------|----------------|--------------------|---------------------------|-------|
| 8. Change in number of any other taxonomic group selected by the city | Change in number of mammal species | 2014 and 2020 inventories (Smith et al. 2014; Smith 2020) | 0 points: the number of species remains the same or decreases 1 point: increase in 1 species 2 points: increase in 2 species 3 points: increase in 3 species 4 points: increase in 4 species or more |
| 9. Proportion of protected natural areas | Proportion of protected areas in relation to the total area | (Protected areas) / (City area)×100 | 0 points: < 1.4% 1 point: 1.4%–7.3% 2 points: 7.4%–11.1% 3 points: 11.2%–19.4% 4 points: > 19.4% |
| 10. Proportion of invasive alien species | Proportion of invasive alien species and verification of their conservation status according to the Red List of Threatened Species | (Number of invasive alien species) / (Number of native species)×100 | 0 points: < 30.0% 1 point: 20.1%–30.0% 2 points: 11.1%–20.0% 3 points: 1.0%–11.0% 4 points: < 1.0% |
| 11. Regulation of quantity of water | Proportion of permeable and impermeable areas | (Permeable areas) / (City area)×100 | 0 points: < 33.1% 1 point: 33.1%–39.7% 2 points: 39.8%–64.2% 3 points: 64.3%–75.0% 4 points: > 75.0% |
| 12. Climate regulation | Proportion of tree cover | (City canopy cover) / (City area)×100 | 0 points: < 10.5% 1 point: 10.5%–19.1% 2 points: 19.2%–29.0% 3 points: 29.1%–59.7% 4 points: > 59.7% |
| **Ecosystems Services** | **Area of parks with natural areas / 1000 persons** | Obtaining the number of inhabitants by natural areas of the city per 1000 persons | (Green areas) / (Number of inhabitants)×100 | 0 points: < 0.1 ha / 1000 persons 1 point: 0.1 – 0.3 ha / 1000 persons 2 points: 0.4 – 0.6 ha / 1000 persons 3 points: 0.7 – 0.9 ha / persons 4 points: > 0.9 ha / 1000 persons |
| 14. Number of formal education visits per child below 16 years to parks with natural areas per year | Obtaining number of formal education visits per child below 16 years to parks with natural areas per year | Consult the database of the Secretariat for the Environment and Sustainability | 0 points: 0 formal education visits per year 1 point: 1 formal education visit per year 2 points: 2 formal education visits per year 3 points: 3 formal education visits per year 4 points: > 3 formal education visits per year |
| Categories | CBI indicators | Adapted indicators | Methods of obtaining data | Score |
|------------|----------------|--------------------|--------------------------|-------|
| 15. Budget allocated to biodiversity | Checking for budget allocated to biodiversity | (Environment-related settlement) / (Total settlement) × 100 (Prefeitura Municipal de Sorocaba 2019) | 0 points: <0.4% 1 point: 0.4%–2.2% 2 points: 2.3%–2.7% 3 points: 2.8%–3.7% 4 points: >3.7% |
| 16. Number of biodiversity projects implemented by the city annually | Verify number of biodiversity projects implemented by the city annually | Consult the database of the Secretariat for the Environment and Sustainability | 0 points: <12 programs/projects 1 point: 12–21 programs/projects 2 points: 22–39 programs/projects 3 points: 40–71 programs/projects 4 points: >71 programs/projects |
| Governance and Management | 17. Existence of local biodiversity strategy and action plan | Verify existence of local biodiversity strategy and action plan | Consult the database of the Secretariat for the Environment and Sustainability | 0 points: absence of action plans and local strategies related to biodiversity 1 point: action plans and local strategies related to biodiversity being considered as part of the routine process 2 points: action plans and local strategies related to biodiversity being planned as part of the routine process 3 points: action plans and local strategies related to biodiversity in the implementation process as part of the routine process 4 points: existence of action plans and local strategies related to biodiversity |
| 18. Number of essential biodiversity-related functions | List essential biodiversity-related to biodiversity | Consult the database of the Secretariat for the Environment and Sustainability | 0 points: no biodiversity-related function 1 point: 1 function 2 points: 2 functions 3 points: 3 functions 4 points: >3 functions |
| 19. Number of city or local government agencies involved in inter-agency cooperation pertaining to biodiversity matters | Number of city or local government agencies involved in inter-agency cooperation pertaining to biodiversity matters | Consult the database of the Secretariat for the Environment and Sustainability | 0 points: cooperation of 1 or 2 agencies 1 point: cooperation of 3 agencies 2 points: cooperation of 4 agencies 3 points: cooperation of 5 agencies 4 points: cooperation of more than 5 agencies |
| Categories                                                                 | CBI indicators                                                                 | Adapted indicators                                                                 | Methods of obtaining data                                                                 | Score                                                                 |
|--------------------------------------------------------------------------|---------------------------------------------------------------------------------|------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------|-----------------------------------------------------------------------|
| 20. Existence of formal or informal public consultation process          | Verify the existence of public environmental policies                           | Consult the database of the Secretariat for the Environment and Sustainability     | 0 points: absence of public environmental policies related to biodiversity                |
|                                                                          |                                                                                 |                                                                                   | 1 point: public environmental policies related to biodiversity being considered as part of the routine process |
|                                                                          |                                                                                 |                                                                                   | 2 points: public environmental policies related to biodiversity being planned as part of the routine process |
|                                                                          |                                                                                 |                                                                                   | 3 points: public environmental policies related to biodiversity in the implementation process as part of the routine process |
|                                                                          |                                                                                 |                                                                                   | 4 points: existence of public environmental policies related to biodiversity             |
| 21. Number of agencies/ private companies/ NGOs/ academic institutions / international organisations with which the city is partnering in biodiversity activities, projects and programmes | Number of agencies/ private companies/ NGOs/ academic institutions / international organisations with which the city is partnering in biodiversity activities, projects and programmes | Consult the database of the Secretariat for the Environment and Sustainability       | 0 points: absence of partnership with agencies / private companies / NGOs / academic institutions / international organisations |
|                                                                          |                                                                                 |                                                                                   | 1 point: partnership with 1–6 agencies / private companies / NGOs / academic institutions / international organisations |
|                                                                          |                                                                                 |                                                                                   | 2 points: partnership with 7–12 agencies / private companies / NGOs / academic institutions / international organisations |
|                                                                          |                                                                                 |                                                                                   | 3 points: partnership with 13–19 agencies / private companies / NGOs / academic institutions / international organisations |
|                                                                          |                                                                                 |                                                                                   | 4 points: partnership with 20 or more agencies / private companies / NGOs / academic institutions / international organisations |
| Categories | CBI indicators | Adapted indicators | Methods of obtaining data | Score |
|------------|---------------|--------------------|--------------------------|-------|
| 22. Is biodiversity or nature awareness included in the school curriculum | Check the inclusion of biodiversity in formal education | Consultation to the Municipal Education Plan of the municipality | 0 points: biodiversity or its elements are not covered in the school curriculum |   |
|           |               |                    |                          | 1 point: biodiversity and nature are included in the school curriculum being considered as part of the routine process |   |
|           |               |                    |                          | 2 points: biodiversity and nature are included in the school curriculum being planned as part of the routine process |   |
|           |               |                    |                          | 3 points: biodiversity and nature are included in the school curriculum in the implementation process as part of the routine process |   |
|           |               |                    |                          | 4 points: biodiversity and nature are included in the school curriculum |   |
| 23. Number of outreach or public awareness events held in the city per year | Number of biodiversity-related events held publicly in the city per year | General bibliographic search mediated by keywords (events, environment, Sorocaba 2019) | 0 points: 0 events per year |   |
|           |               |                    |                          | 1 point: 1–59 events per year |   |
|           |               |                    |                          | 2 points: 60–149 events per year |   |
|           |               |                    |                          | 3 points: 150–300 events per year |   |
|           |               |                    |                          | 4 points: >300 events per year |   |

**Maximum score of 92**
was assigned a value of 0 to 4 points, totaling 92, considering that, as higher the score obtained, the better the level of urban biodiversity in the municipality (Cabral et al. 2012; Machado et al. 2014). The indicators were studied in order to evaluate if alterations would be necessary to suit the reality of the city, choosing to modify only one of them (20). CBI helps cities to manage biodiversity and provide useful information (Reyhanian and Porshokouh 2016).

**Semi-structured interviews**

Semi-structured interviews aim to promote freedom of expression to interviewees, while allowing a more direct chat about a specific topic (Fraser and Gondim 2004). In the work in question, a roadmap composed of four questions related to the conservation of biodiversity and ecosystems in the municipality of Sorocaba was prepared, namely:

Q1. How do you evaluate biodiversity management in the municipality of Sorocaba?
Q2. Do you know the City Biodiversity Index? Do you think it should be applied successively in the municipality? If so, why?
Q3. What strategies for the conservation of ecosystems do you think are essential to be adopted?
Q4. In the municipality of Sorocaba, what is missing in order to achieve a good performance in relation to the conservation of biodiversity and ecosystems?

To accomplish this stage, 14 technicians from the environmental sphere of the city were contacted via e-mail, telephone and personally approached, transforming the above-mentioned questions into interesting conversations. Some answers were recorded and transposed in full. Others, already written. For the analysis of the obtained data the following process was followed: i) descriptive analysis of the responses, aiming at segregating the information to be evaluated individually; ii) critical analysis in order to identify whether or not they have achieved a consensus and iii) discussion to understand certain divergences, if any, exist.

**Results**

**Biodiversity**

The results showed that Sorocaba obtained a good performance in six indicators inserted in “Biodiversity”. About the indicator 1, the city has exact 45,000,0 ha and 1,654,17 ha of green areas, 90% occupied by 23 municipal parks. For the calculation of the indicator 1 were considered all the parks, squares and public gardens, obtaining a proportion of 0.036 (3.7%). Besides that, has about 9.890 ha of remaining forestry (661 fragments), fact that enables the existence of green corridors (described on indicator 2). However, geo-processing works carried out in the municipality point in their results that the city original landscape presents many anthropic barriers, like the presence of highways and private properties, making it extremely fragmented and, consequently, making connectivity difficult.

About your biological diversity addressed on indicators numbered 3 to 8 and 10, Sorocaba has a total of 310 bird species, 632 angiosperms, 65 amphibians and 28 mammals. In the 2014 inventory, these numbers corresponded respectively to 280, 441, 48 and 23. The butterfly group, otherwise, was not sampled on the first inventory, which influenced the score obtained in indicator 6, considering that there was not species increase or decrease (43 inventoried in the current edition) (Fig. 2).

The application of indicator 10 is important due to the relevance of knowing and distinguishing the invasive alien species that will cause some damage to the ecosystem where they are inserted. After literature review has been confirmed 42 invasive alien species of a total of 1.376 species (proportion of 3.05%), 24 of these presents some degree of threat. Compared to the year of the first inventory there is a small difference in the proportion, the native species being equal to 1.182 and the exotics, 36 (2.95%).

Sorocaba is composed of five protected areas (CUs) registered in National Register of Conservation Units (CNUC), ensuring biodiversity conservation and allowing only indirect use of its resources. Besides that, has nine areas of environmental interest and 19 public spaces of social interest. For the calculation of indicator 9 was considered only CUs, making a total of 181,17 ha of protected areas and obtaining a proportion of 0.40%.

**Ecosystem services**

The Sorocaba Urban Afforestation Diagnosis showed the existence of 74,638 trees in central flowerbeds and sidewalks and 30,000 in gardens and backyards, adding the fragments areas, and riparian forests obtained by aerial photographic surveys, totaling 6,014,05 ha of permeable areas (proportion of 13.36% to indicator 11) and 25.6% canopy projection in the urban environment, which corresponds to about 11,520 (indicator 12). As already mentioned, Sorocaba is composed of 1,654,17 ha of green areas and it its estimated a total of 679,378 inhabitants, obtaining a proportion of 2.435 ha to the indicator 13, although the acceptable value for a green infrastructure is 40 m² per inhabitant.

Concerning indicator 14, more than 500 annual formal and educational visits in municipal parks were made in 2019, like the Parque da Biquinha (with 81 participants) and the Água Vermelha (440). For the calculation it was
considered that each child under the age of 16 made at least three (3) visits throughout the year.

**Governance and management**

The general budget of Sorocaba in 2019 was R$ 1,783,756,790, the part spent on natural resources, ecosystems regeneration and biodiversity equal to R$ 20,087,475,06, equivalent to a proportion of 1.13% to indicator 15. Part of this amount corresponds to parks, squares and gardens maintenance (R$ 9,689,077,24), environmental control (R$ 101,429,91), environment support fund (R$ 241,837,64), Zoo (R$ 4,635,450,39), Environmental Education (R$ 5,766,88) and other expenses.

The indicator 16 evidenced the existence of 13 improvements of environmental quality projects and actions by government institutions in 2019, predominantly by ecological parks through SEMA. Some of them involve monitored visits to the green areas, donations seedling plantations, vacation projects and socio-environmental awareness activities with birdwatching practices. Besides that, indicator 17 showed the existence of strategies and action plans for biodiversity conservation in the municipality, like the creation of Municipal Environmental Education Program (ProMEA), a political-legal instrument which aims to guide Environmental Education projects with strategies plans and guidelines, having as basic principle its institutionalization and capitalization in the formal and non-formal spheres, and others.

About the infrastructures related to the environment and biodiversity covered in indicator 18, Sorocaba has eight (8) installations that involve services aimed at fostering research, environmental education and awareness, discussion induction and strategies for the great city management. In addition, the municipality participates in numerous measures concerning biodiversity, management and environmental sustainability in cooperation with other secretariats and agencies. The installations identified in indicator 18 that carried out partnerships in campaigns, actions and projects were: CETESB together with SEMA, in the evaluation of black smoke emissions in the city; “Irmãos Villas-Bôas” Botanical Garden in association with Legado das Águas in the donation of native orchids from the garden to the private reserve; Zoo Park “Quinzinho de Barros” in partnership with SEMA and Secretary of Education (SEDU) in the elaboration of the contest “Zoo and the city”, and Autonomous Water and Sewer Service (SAAE) in association with SEMA in the creation of the Rio Sorocaba Environmental Education Center, totaling five (5) installations involved in inter-agency partnerships.

Regarding indicator 20, it was found that the municipality has several environmental policies, such as the Municipal Environmental Education Policy (n. 7,854/2006), enacted to direct institutions in the process of activities aimed at environmental awareness; the Sorocaba Municipal Environmental Policy (n. 10,060/2012) that comes into full agreement and compliance with international agreements, including the Convention on Biological Diversity based on this study; the Municipal Policy of Biodiversity Refuges Protection (n. 12,059/2019), which aims to protect green areas of the region that provide shelter and food for the resident species, and others.

![Fig. 2 Richness of species belonging to the taxons referenced in the surveys carried out in 2014 and 2020](image-url)
In addition to inter-agency cooperations, the Sorocaba City Hall also entered partnerships with four (4) higher education institutions to achieve projects and actions related to environmental awareness and increased researches, and events with the objective of preparing inventories and reports. Other sectors, also in collaboration with City Hall, involve an Environmental Education center and other departments, making a total of seven (7) installations involved in partnerships.

About the formal education, in Sorocaba the basic education is divided into three cycles: basic, elementary and secondary education, jointly encompassing integral teaching based on Law 11.133/2015. Throughout the second cycle (subdivided into Elementary School I and II) issues such as the relationships and interactions between living beings and sustainable development are addressed, aiming to understand the universe and environment in which the human being is inserted through the combination of subjects such as Physics, Chemistry and Biology (forming the knowledge area of Natural Sciences). In this way, biodiversity is part of the scope of promoting science on the part of students about the way scientists build new knowledge, and of developing a critical eye in the search for solutions inherent to anthropic impacts.

Finally, the survey carried out in indicator 23 indicates a total of eight (8) events inherent to biodiversity and the environment, including universities, associations and other installations, with a good part of these (workshops and forums) having the institutions inserted in the higher education network as the main headquarters and directors, being one of the indicators with the lowest score in governance.

The application of 23 CBI indicators resulted in 57 points out of a total of 92 (61.9%) for the studied city. Taking into account the extensive urban area analyzed in Sorocaba and the suppression of remain forests triggered by the city's infrastructure, the indicators 1, 2, 6, 9, 11, 15, 16 and 23 contributed to lower performance on the index, being four of Biodiversity, one of Ecosystem Services and three of Governance and Management (Table 2).

The polls and the chats pointed out that 50% of the interviewees do not know the Index and 33.3% know it, but not in depth. Of the knowledgeable portion of the CBI, all consent that the same should be applied successively in the municipality so that we can monitor the progress of the city and promote faster effective responses. The answers reached a consensus that the index can be a useful tool for detecting changes, both positive and negative. If negative, it will be possible to implement actions that previously avoid harmful impacts on biodiversity.

Also, 33.3% estimate that biodiversity management in the municipality of Sorocaba is not very effective, i.e., the issue has been more on the agenda in previous administrations. On the other hand, Environmental Education was pointed out as a promising strategy in biodiversity conservation in 50% of the responses; as well as the implementation of Public Environmental Policies, since many of them do not necessarily include the conservation of Conservation Units and parks, important refuges for biodiversity and subsidize in the promotion of Environmental Education activities.

## Discussion

The CBI indicators allow an integrated analysis of the environmental management of cities. Although Sorocaba presents a reasonable number of public spaces that aim to concatenate the needs of local demand and conserve biodiversity in all its interfaces (Macedo et al. 2012), many of these are under mismanagement and abandoned. Furthermore, has a significant urban portion that, even in detriment of the rural area, could not be avoided due to its degree of urbanization and growth (approximately 98,98%) (Seade – Fundação Sistema Estadual de Análise de Dados 2019). According to Ofori et al. (2018), due to forest fragmentation, habitat loss, decrease of local biodiversity and disturbance-tolerant species are relatively frequent phenomena. The result obtained for indicator 1 reflected the aforementioned reality, being evident the urban area advance on the open spaces (parks, squares and other places related to recreation) and the ineffectiveness of many action plans aimed at restoring areas damaged by human intervention (Lança 2007).

The indicator 3, based on a group that responds to urbanization in different ways and looks for urban parks to meet their needs (Franchin and Júnior 2004) presented satisfactory results, since the 320 birds species sampled in the municipality corroborate the idea of calling Sorocaba as the “City of Biodiversity”. From the same perspective, the difference in the number of species in the groups covered in indicators 4, 5, 6, 7 and 8 reflects the importance of conducting studies and surveys about the municipality floristic and fauna diversity over the years, since there is a great potential for increasing the list.

Following the definition proposed by Mota et al. (2016), “protected areas” could be defined as: Conservation Unit for indirect use, aimed at preserving biodiversity without external anthropic interference, according to the National System of Conservation Units (SNUC), and Conservation Unit for sustainable use (or direct), which also promote the conservation of species and others components, allowing recreation and leisure upon the population demand. Sorocaba obtained a lower score on indicator 9, since it consists of only five (5) Conservation Units. In compensation, these are part of about 47% of the forest coverage of all parks, with only one of them closed for visitation (Natural Park Dr. Bráulio Guedes da Silva, with 71.55% of coverage).
Table 2  Results of calculations for the 23 CBI indicators

| Indicators                                      | Calculation                                                                 | Score obtained                                      |
|------------------------------------------------|-----------------------------------------------------------------------------|-----------------------------------------------------|
| **Biodiversity**                               |                                                                             |                                                     |
| 1                                              | Total area of green areas: 1,654,17 ha                                      | 1 point: 1,0%–6,9%                                   |
|                                                | Total area of the municipality: 45,000,0 ha                                 |                                                     |
|                                                | $\frac{1,654,17}{45,000,0} \times 100 = 0.036$ (3,7%)                     |                                                     |
| 2                                              | IND2 = $\frac{1}{A_{\text{total}}} (A^1 + A^2 + A^3 + ... + A^n)$           | 0 points: < 200 ha                                   |
| Absence of green corridors                     |                                                                             |                                                     |
| 3                                              | Number of bird species in built up areas 310 species                        | 4 points: > 240 species                              |
| 4                                              | Difference in the number of vascular plants species between 2014 and 2020   | 4 points: increase in 4 species or more              |
|                                                | 2014: 441; 2020: 632 = increase in 191                                     |                                                     |
| 5                                              | Difference in the number of bird species between 2014 and 2020              | 4 points: increase in 4 species or more              |
|                                                | 2014: 280; 2020: 310 = increase in 30                                       |                                                     |
| 6                                              | Difference in the number of butterfly species between 2014 and 2020         | 0 points: the number of species remains the same or  |
|                                                | 2014: no datasets; 2020: 43 = no increase or decrease                       | decreases                                           |
| 7                                              | Difference in the number of amphibian species between 2014 and 2020         | 4 points: increase in 4 species or more              |
|                                                | 2014: 48; 2020: 65 = increase in 17                                        |                                                     |
| 8                                              | Difference in the number of mammal species between 2014 and 2020            | 4 points: increase in 4 species or more              |
|                                                | 2014: 23; 2020: 28 = increase in 5                                          |                                                     |
| 9                                              | Total area of protected areas: 181,17 ha                                    | 0 points: < 1,4%                                    |
|                                                | Total area of the municipality: 45,000,0 ha                                 |                                                     |
|                                                | $\frac{181,17}{45,000,0} \times 100 = 0.40\%$                            |                                                     |
| 10                                             | Number of invasive alien species: 42                                        | 3 points: 1,0%-11,0%                                 |
|                                                | Number of native species: 1.376                                            |                                                     |
|                                                | $\frac{42}{1.376} \times 100 = 3.05\%$                                   |                                                     |
| **Ecosystems services**                        |                                                                             |                                                     |
| 11                                             | Total area of permeable areas: 6,014,05 ha                                  | 0 points: < 33,1%                                    |
|                                                | Total area of the municipality: 45,000,0 ha                                 |                                                     |
|                                                | $\frac{6,014,05}{45,000,0} \times 100 = 13.36\%$                         |                                                     |
| 12                                             | City canopy cover: 11,520 ha                                               | 2 points: 19,2–29,0% of tree cover                  |
|                                                | Total area of the municipality: 45,000,0 ha                                 |                                                     |
|                                                | $\frac{11,520}{45,000,0} \times 100 = 25.6\%$                            |                                                     |
| 13                                             | Total area of green areas: 1,654,17 ha                                     | 4 points: > 0.9 ha / 1000 persons                    |
|                                                | Total number of inhabitants: 679,378                                       |                                                     |
|                                                | $\frac{1,654,17}{679,378} \times 100 = 0.243 ha/1000 persons$             |                                                     |
| 14                                             | Number of educational visits in 2019: 521                                   | 3 points: 3 formal education visits per year         |
|                                                | Number of visits each child made per year: at least 3                      |                                                     |
| **Governance and management**                  |                                                                             |                                                     |
| 15                                             | Environment-related budget in 2019: R$20,087,475,06                         | 1 point: 0,4%–2,2%                                   |
|                                                | Total budget in 2019: R$1,783,756.790                                       |                                                     |
|                                                | $\frac{20,087,475,06}{1,783,756.790} \times 100 = 1,13\%$                 |                                                     |
| 16                                             | Number of biodiversity projects implemented by the city annually: 13        | 1 point: 12–21 programs/projects                     |
| 17                                             | Existence of local biodiversity strategy and action plan: yes               | 4 points: existence of action plans and local strategies related to biodiversity |
| 18                                             | Number of facilities relating to biodiversity: 8                           | 4 points: > 3 functions                              |
| 19                                             | Number of city or local government agencies involved in inter-agency cooperation pertaining to biodiversity matters: 5 | 3 points: cooperation of 5 agencies |
The problem involving invasive alien organisms is often overlooked and camouflaged in nature, triggering a certain concern due to the impacts inherent to biological invasions that happen slowly and, for the most part, irreversible (Ziller 2010). This fact attributed a certain advantage to indicator 10, which aims to measure the impact that these species have on the city, since the discrepancy between the number of exotic and native species found in Sorocaba is relatively large.

The indicators that most favored a low performance of the “Ecosystem Services” axis belong to the themes “Climate regulation” (11) and “Proportion of tree cover” (12). Regarding this first, although permeability through vegetation contributes to the infiltration of water in the soil, it is known that this element is appeased by deforestation and the paving of large areas (Hülsmeyer and Souza 2007). The municipality of the study has mostly waterproofed areas, although it has 25.6% of tree cover in relation to the total area (de Mello et al. 2016).

It can be said that biodiversity protection is intrinsic to man, since he aims to maintain a connection with nature and its services. The Conservation Units for indirect use and municipal natural parks are intended for the conservation of biological diversity, Environmental Education (EE), scientific research, recreation and leisure (Assad 2000). In this context, the value given to indicator 13 was one of the highest in the category. The city has more than 30 parks (closed and open) that are part of the union of protective measures aimed at the conservation of certain places and presents a reasonable performance when developing measures to reconcile EE with conservation actions (Rodrigues et al. 2019). The activities not only cover students from the formal school environment, but are also aimed at training professionals, be they teachers, managers or employees, and for socio-environmental awareness.

About half of the indicators included in “Governance and Management” reached maximum scores, except for those referring to the city’s budget for biodiversity (15), number of projects (16), government agencies (19), institutions involved in partnerships (21) and annual events (23). Regarding this first, it is clear that the obstacles found for the conservation of areas, resources and species are, in part, linked to political and budgetary neglect (Milano 2001). The value attributed to the fifteenth indicator corroborates this statement, since the city budget spent on biodiversity is considerably low, taking into account all the amount spent in other departments.

Given the entire environmental infrastructure of the municipality, mobilization by the municipal spheres could be greater in the increment of annual projects. On the other hand, it has institutions of socio-environmental interests and facilities related to the environment, mostly aimed at promoting Environmental Education activities, which attributed a certain advantage to indicator 18.

The median score attributed to indicators 19 and 21 was possibly due to the methodology used to consult data referring to agencies that work in partnerships (electronic databases provided by the City Hall and other electronic addresses associated with the City Council). The city of Lisbon achieved a considerably satisfactory valuation (102), a fact that may have been triggered by the effective contact method carried out by Cardoso (2011), where each institution identified in indicator 18 was contacted via e-mail to survey which of them worked together with other entities in programs and projects.

Given the opportunity to reduce the impact of development, comprehensive policies can strengthen the protection of biodiversity (Soto-Montes-de-Oca et al. 2020). Urban land conservation results in adverse effects on natural ecosystems and biodiversity (Tóth et al. 2021). Results from CBI contribute to biodiversity management, policymaking can favor conservation at the local level and the officers play an important role in activities implementation (Uchiyama and Kohsaka 2019). Effective knowledge can be obtained by using CBI, and this feasible indicator is helpful for the formulation of environmental policies (Uchiyama and Kohsaka 2017).

Table 2 (continued)

| Indicators                                                                 | Calculation                                                                                               | Score obtained                                                                                   |
|---------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------|
| 20  Existence of public environmental policies: yes 4 points: existence of  | 4 points: existence of public environmental policies related to biodiversity                            |
| 21  Number of agencies/ private companies/ NGOs/ academic institutions /   | 2 points: partnership with 7–12 agencies / private companies / NGOs / academic institutions / international organizations |
| 22  Inclusion of biodiversity in formal education: yes 4 points: biodiversity and nature are included in the | 4 points: biodiversity and nature are included in the school curriculum                           |
| 23  Number of biodiversity-related events held publicly in the city per   | 1 point: 1–59 events per year                                                                         |
| year: 8                                                                    |                                                                                                           |

Total of 57
The policy level requires resources and planning to reduce risks and damage in urban areas, and minimizing land cover changes is necessary to provide biodiversity and ecosystem services (Soto-Montes-de-Oca et al. 2020). In addition, we need to remember that biodiversity conservation involves different sectors (e.g., industry, construction), and decision-makers can use CBI to formulate management strategies (Uchiyama and Kojsaka 2019). CBI enhances the establishment of adequate management of biodiversity in a city, a situation directly linked to sustainability (Uchiyama et al. 2015).

The government must consider the complex interactions between sectors (social, environmental, economic) and biodiversity management plans to obtain the best solution (Chen et al. 2020). Therefore, CBI is a tool to assess progress related to the increase in biodiversity due to conservation and preservation efforts (Reyhanian and Porshokohou 2016). In the Sorocaba case, CDI showed that the municipality has positive evaluations in many indicators over the years, although there is a need for the local administration to improve aspects as connectivity and proportion of protected areas. These aspects can promote the attendance of international and national policies, resulting in positive aspects for society and biodiversity. In addition, the CBI assesses the activities and destined efforts, which can eventually make up for the shortcomings.

There are signs that by 2030, 290,000 km² of natural habitat will be converted to urban lads (McDonald et al. 2020). Front to this, policy play an important role in the cities. In Sorocaba, the increase in soil sealing was obvious to support the increase in population and human activities in the past few years (Silva et al. 2021), the CDI application brings scientific information to support biodiversity maintenance. In addition, corrective actions or efforts may be doomed to such landscape changes and loss of natural habitat. The built environment leads to the loss of biodiversity, and practices must be implemented to achieve Sustainable Development Goals (Opoku 2019), the CDI is an opportunity for Sorocaba City address new politics and strategies to protect biodiversity.

The search for evaluation (be it diagnostic, procedural or global) of the existence and effectiveness of policies that involve the mitigation of predatory actions on the environment, as well as the conservation of biodiversity, is extremely important for a municipality, since it can subsidize improving environmental quality and promoting the development of new projects (Assis et al. 2012). Sorocaba is very precursor in this sense, given the existence of public policies that aim to integrate public power and civil society and concatenate its needs with the preservation of nature, also counting on the establishment of strategic areas for the conservation of species and natural resources (Mota Junior et al. 2020), giving a good score for indicator 20.

Based on the assumption that the interactive approach to themes inherent not only to the conservation of biodiversity, but also to the adoption of measures and solutions for environmental issues, contributes a lot to the change of values and behaviors, resulting in what we call “ecological subject” (i.e. the one that proposes to adopt sustainable practices for the benefit of nature and the well-being of the population) (Loureiro 2004), the evaluation carried out by indicator 22 is so important as the others, since the ethics of safeguarding all the natural system surrounding the planet must apply at the individual, community, national and global levels.

In this segment, many institutions have adopted progressive views so that the environmental issue does not become something banal and a simple requirement in legal areas, but an essential factor in reconciling economic development and conservation of species, natural resources and ecosystems, whether through projects, programs or events (Lins and Silva 2009). However, the low score obtained in the last indicator shows a lack of significant mobilization on the part of the municipal authorities and indicates a need for reassessment by them in the increase of events on the agenda. The semi-structured interviews conducted among the city’s environmental technicians confirmed the results obtained in the aforementioned indicators. It showed that, although Sorocaba has a relevant biodiversity, there is still much to be done. In addition, the interviewees agreed that the strongest point of the city in relation to biodiversity conservation is Environmental Education, as shown in indicator 14. An important fact obtained through the chats is the consensus that the CBI should be applied successively in the municipality. Although a portion of the interviewees are not aware of this, it was agreed that a metric of this proportion is essential in monitoring biodiversity and promoting conservation strategies. These data reveal the real importance of this study, since, as already mentioned, it is the first employment of the CBI in the city.

**Conclusion**

The CBI aims to improve the biological diversity maintenance in the cities, given that the methodology makes it possible to identify species and ecosystems and recognize the importance of conservation. This work allowed the creation of a database capable of providing information for future works and applications of CBI, to compare the city’s progress over the years. The index application showed that the city was well evaluated in most of the indicators, ten of which with maximum score (4) and four with minimum (0). Therefore, to ensure the progression of city sustainable development – and particularly in obtaining higher values – it is recommended to adopt a new environmental ethics that reconciles developmentalism ad sustainability. This way
the city can develop economically, socially and environmentally, in order to meet the growing demand of the population without causing major damage to ecosystems. The successive application of CBI can support the expansion of conservation and environmental management of the agenda in the city. The data provided by the index may indicate a good or bad administration of environmental issues, and may suggest proposals for interventions and improvements, so that the city reaches a good level of sustainability.

In this case it is necessary to think about the urban environment as a factor intrinsically linked to the defense of the environment. The mobilization by governmental segments to regulate laws and policies that aim the sustainable development, as well as of the citizens in the adoption of “green measures” in their daily lives, are progressive attitudes capable of taking the city to a new level. The interviews showed that the governmental spheres of the municipality were once much more focused on promoting actions aimed at conserving biodiversity and ecosystems, and that today this management is not so fortified.

At last, society needs to participate in decision-making so that it can go hand in hand with the Public Authorities in establishing of effective public policies, a strategy also mentioned by a number of respondents, along with the promotion of “citizen science”, which consists in the participation of society not only in decision-making, but in the collaboration of important research in the segment of biodiversity and its conservation.

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Data availability Due to the sensitive nature of the species locations the datasets from the current study are not publicly available but are available from the corresponding author on reasonable request.

Declarations

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Conflict of interest The authors declare that they have no conflict of interest.

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