Beyond food: urban agriculture's contribution to the well-being of the metropolis of São Paulo

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Introduction

The most recent demographic forecasts suggest the world population will reach 9 billion by 2050 (UN, 2018), of which 68% will reside in urban areas. Cities are currently responsible for consuming 80% of global energy production and about the same amount in greenhouse gas emissions (WORLD BANK, 2010). In order to reduce the environmental impact of cities, approaches not often associated with modern conceptions of urbanization, such as agricultural production, are emerging as viable alternatives to strengthen the resilience of urban areas, as well as mitigate the negative impacts of climate change and biodiversity loss (ALIER, 2005). In this context, urban and periurban agriculture (UPA) have raised increasing interest from governments, civil society, academia, and multilateral organizations. The UPA agenda has gained space in political discourse thanks to a range of stakeholders, including insurgent movements in cities, government initiatives, regional and international collaboration networks, and new programs dedicated to the topic in universities and research institutes,[1] although actual implementation is still very linked to local experiences, and lacks proper systematization and documentation. That said, the theme of agriculture in cities is now firmly on the agenda, bringing to light new paradigms for urban-rural territorial planning and for food and environmental issues.

New approaches, such as the notion of urban-regional food systems (FAO, 2018) and eco-agri-food systems (TEEB, 2018), have given rise to studies and analyses that recognize the limits of addressing new and persistent food-related problems through sectoral approaches and policies. In this sense, agriculture, and its forms of distribution, commercialization, and food consumption are becoming a strategic component of urban planning, no longer relegated to entities dealing exclusively with supply and agricultural and agrarian issues. In the current pandemic context, the reshape of food systems gains even greater prominence, with 53% of households in the Southeast region of Brazil experiencing some degree of food insecurity,[2] a situation that worsens in areas where rural and urban[3] areas intersect (70%) and in rural areas (75%). Another aspect to consider is the reduction in the consumption of fresh food, which exceeds 85% in food insecure households (GALINDO *et al*., 2021).

In the Metropolitan Region of São Paulo (MRSP), the object of analysis of this research, a recent study launched by the Instituto Escolhas, in partnership with URBEM, demonstrated the potential of UPA to contribute to feeding the population of 21 million inhabitants of the metropolis.[4]

The study analyzed the economic viability of different types of UPA, issuing recommendations to the institutions and policies dealing with different issues addressed. There are many opportunities for UPA in the context of the metropolis: the compiled data indicate that 14% of the average household budget of the MRSP population is allocated to food, and that 40% of the average family food expenditure is on food away from home. In addition, 13% of the employed population works in activities directly related to food. The importance of the agricultural sector in one of Latin America's largest human settlements is also reflected in its participation in the national market: the MRSP accounts for 52% of

[1] Examples in Brazil include the MUDA - *Movimento Urbano de Agroecologia* [Urban Agroecology Movement] in the municipality of São Paulo, the CAU - *Rede Carioca de Agricultura Urbana* [Carioca Network of Urban Agriculture] and the AMAU - *Articulação Metropolitana de Agricultura Urbana* [Metropolitan Articulation of Urban Agriculture] in the Metropolitan Region of Belo Horizonte. The institutionalization of the subject of urban agriculture in universities appears in disciplines such as those taught at the Federal University of Goiás (UFG) and the Postgraduate Program in Social Sciences in Development, Agriculture and Society (CPDA/UFRRJ). Other relevant organizations are detailed in the following chapter.

[2] Food and nutritional security refers to the right to regular and permanent access to quality food, in sufficient quantity, without compromising people's other essential needs. The National System of Food and Nutritional Security (Law nº 10.346/2006) also highlights the importance of this access being linked to "health-promoting food practices that respect cultural diversity and that are environmentally, culturally, economically, and socially sustainable" (Art. 3).

[3] The study "*Efeitos da pandemia na alimentação e na situação de segurança alimentária no Brasil"* used the category "lives in rural and urban areas" as a resource to register the varied arrangements of how the territory is occupied according to the perception of the interviewees, enabling an analysis of the relations between rural and urban areas beyond legal frameworks. More information on the results and methodology of the study is available (in Portuguese) in Galindo et al., 2021.

[4] The last Demographic Census conducted by the Brazilian Institute of Geography and Statistics (IBGE - acronym in Portuguese, which stands for *Instituto Brasileiro de Geografia e Estatística*) dates back to 2010, with the sum of 19,683,975 inhabitants recorded for the MRSP. As a decennial survey, the next census should be conducted in 2021 (since it was suspended in 2020 due to the pandemic). In parallel, the IBGE prepares annual population estimates. The 2020 population estimate released by the Institute for the MRSP is 21,893,842, which represents a little more than 10% of the Brazilian population.

mushrooms, 52% of spinach, 16% of collard greens, 10% of cabbage, and 9% of lettuce produced in the country. These are some of the indicators that exemplify the importance and magnitude of the food system in the metropolis of São Paulo, alongside detailed data about agriculture in the region. It is important to mention that the supply projection (INSTITUTO ESCOLHAS; URBEM, 2020) was driven by the objective of making this food system more sustainable, complementing protected areas and other forms of native vegetation that still make up the landscape of the MRSP. Thus, the analyses advocated agricultural techniques committed to environmental restoration, models of production farms adapted to family labor and to quality food that does not depend on external inputs or agrochemicals, in addition to market access routes that remunerate farmers fairly, without penalizing consumers.

In view of the estimated productive potential, the heterogeneity of the expressions of UPA, and its different objectives in the metropolis' territories, other relevant questions have arisen, such as: how do these different forms of UPA relate to urban and periurban spaces? Beyond the socio-economic factors discussed in the previous study, to what extent can UPA play other, notably socio-environmental, roles in the context of the metropolis? International literature indicates the promotion of habitat for local fauna and flora (ZHAO; SANDER; HENDRIX, 2019), and in some cases, UPA can sustain greater biodiversity than green areas in cities (LIN; PHILPOTT; JHA, 2015); soil protection through increasing water infiltration capacity, which reduces flood risk and improves water quality and availability (AYAMBIRE *et al*, 2019); the reduction of the "metabolic fracturing"[5] of cities by incorporating organic solid waste and effluents (FOSTER, 1999; MCCLINTOCK, 2010); and the reduction of CO_2 emissions along the production chain because of short production and consumption circuits (CLEVELAND *et al*., 2017).[6]

In the metropolitan territory, urban and periurban agriculture can fulfill many different functions where vast urbanized areas with a persistent urban sprawl end up pressuring areas of native vegetation and endangering the protection of water springs (BORELLI, 2006; SANCHÉZ, 2003; SEPE; PEREIRA, 2015). Such areas are responsible for protecting the remnants of the Atlantic Forest, ensuring the recharge of aquifers and acting as refuges for local fauna and flora, as well as allowing recreational and educational activities. Moreover, the equivalent of 46% of the administrative unit of the MRSP is still composed of forest formations - 362,300 hectares of a total 796,500. The urbanized area is equivalent to 26%, while agricultural areas, or those that demonstrate a potential for cultivation, occupy 22% of the region (ESCOLHAS; URBEM, 2020).

According to data from the 2017 Agricultural Census, the agricultural areas are partially occupied by productive activities.[7] There are 5,083 agricultural establishments covering around 15.5% of the total area of the MRSP. It is worth mentioning that 86.4% are small farms (up to 20 hectares) responsible for approximately 60% of the value of food produced. Moreover, 65% of the total number of establishments are dedicated to family farming (ESCOLHAS; URBEM, 2020). If, on the one hand, the metropolis hosts a significant diversity and wealth of socio-ecological interaction, on the other hand, great challenges are faced in rendering urban development compatible with nature conservation and the provision of ecosystem services (ES). Moreover, the growth of the urban fabric, in conjunction with climate change, can contribute to the intensification of extreme weather events, such as the occurrence of intense rainfall capable of causing severe flooding (NOBRE *et al*., 2011, p. 242). This has been increasingly recurrent in metropolitan municipalities. Moreover, soil sealing favors the increase of local

[5] This term is used to point out the growing imbalance in the metabolic interaction between humanity and nature, which stems from capitalist production and the growing division between the city and the countryside.

[6] Short commercialization circuits are characterized by the geographical proximity between producer and consumer through the reduction of intermediaries in the commercial chainlink (TRAVERSAC, 2010). Some examples of short circuits are producer fairs, some modalities of organic fairs, responsible consumption groups, Communities Sustaining Agriculture (CSA), public procurement, and other forms of direct sales.

[7] The Agricultural Census, conducted periodically, applies the term *"estabelecimento agropecuário*" [agricultural or cattle-raising establishment], only to units that are fully or partially dedicated to agricultural, cattle-raising, forestry, and aquaculture activities. Census units, regardless of their size, legal form, or location, are considered to be those with the objective of production, whether for sale or for self-consumption (IBGE, 2018a). The Agricultural Census covers all active producers located by the census takers, regardless of whether they own land or not (DELGROSSI, 2019).

temperatures, which can create a heat island effect. As a result, water crises tend to be more frequent, like the one experienced between 2013 and 2015, which impacted the supply of the MRSP and the regions from which it imports water.

In view of the complex mosaic of land use characterizing the MRSP (TRAVASSOS; PORTES, 2018) and the multifunctionality approach of agriculture in landscapes and territories, the present study evaluates UPA's potential ecosystem service provision by simulating future scenarios. With this projection, the study aims to analyze how UPA can contribute to the conservation of natural resources, all while providing healthy local food. Given the breadth of the ecosystem service approach, five ecosystem services were selected as priorities for evaluation: food supply, flood mitigation, heat mitigation, erosion regulation, and water yield. For this, spatially explicit biophysical modeling[8] was applied, in addition to an analysis of the four case studies already addressed in the aforementioned study (ESCOLHAS; URBEM, 2020).

This report is structured in four chapters. The first, a literature review, presents: (i) a discussion on UPA from a territorial approach; (ii) the notion of multifunctionality of agriculture in urban spaces; and, finally, (iii) the definition of the concept of ecosystem services adopted in the research. The second chapter, on methodology, describes the methodological path undertaken, based on the assessment framework of the TEEBAgriFood initiative. The analytical results and the discussions they have engendered comprise the third chapter, based on comparative analyses between the aforementioned case studies and between different future scenarios of UPA expansion in the MRSP, at different scales. The fourth and final chapter presents the study's main conclusions.

[8] Spatially explicit biophysical modeling estimates quantitatively different types of land features and land uses and the ecosystem services that result from them, which generate benefits to society (e.g., erosion regulation, water provision) (TEEB, 2018).

Conceptual framework

Urban and periurban agriculture and ecosystem services: possible links between approaches

This first chapter is devoted to exploring the conceptual and practical interfaces between the multifunctionality of urban and periurban agriculture and ecosystem services. We start from the premise that the very notion of urban agriculture challenges both the imaginary and a well-established tradition in agricultural and agrarian development policy-making, which circumscribes agricultural practice to the rural domain, entailing consequences for land use planning.[9] The concept of multifunctionality simultaneously expands the vocation of agriculture itself as of urban and periurban spaces. From the territorial point of view, agriculture starts to play multiple roles, being able to combine the production of food and raw materials with the preservation of the environment, among others. In the context of this study, the multifunctionality approach to agriculture proves essential, serving as a gateway for evaluating ecosystem services related to the practice in its different instances in the metropolis of São Paulo.

The following three approaches at the interface of the study will be presented: urban and periurban agriculture in its territorial context; the multifunctionality of agriculture and ecosystem services; and the theoretical and methodological framework of the TEEBAgriFood initiative, whose analytical foundation is based, among others, on the notion of multifunctionality of agriculture through the assessment of ecosystem services.

Urban and periurban agriculture and territories

The practice of agriculture in and around cities is historically documented in the formation of urban centers (CORRÊA *et al*., 2020; BIAZOTI, 2020 p. 34; ALMEIDA, 2016; CALDAS; JAYO, 2019). More recently, in the push for more sustainable urban environments, the objectives, meanings and multiple manifestations of the practice of agriculture have been evoked, and more specifically their interplay with the economic, social, and environmental dimensions of urban space. When reviewing the literature on urban and periurban agriculture (UPA), the modernization model for urban and rural spaces (CALDAS; JAYO, 2019) arises as a factor implicated both in the *remnant* character of certain activities linked to agriculture in urban spaces, and in the *emerging* status of a practice hitherto "displaced" in the imaginary of what constitutes the city. Whether as an activity that *still resists* in urban spaces, or as a *recent* practice in modern urbanization, urban agriculture challenges peremptory associations of rural and agricultural, as well as of urban and industrial, commercial, or service work, grounded in opposing dualities typical of modern thought (CARNEIRO, 2008.

Current discussions and understandings of the concepts of urban and periurban agriculture present new and different contours in relation to former phenomena, in which productive gardens were constituent elements of ancient urban civilizations. Despite representing "remnant materialities" linked to cities' need for food supply (MCCLINTOCK, 2013 NAGIB, 2020, p. 24), current debates around urban agriculture point to the allocation of functions and meanings that are traditionally associated with the rural in urban spaces, even if they are not portrayed as mere reproductions of habits and ways of life (ALMEIDA *et al*., 2012; COSTA; MARINELO, 2019; SCHOOLS; URBEM, 2020). Besides the supply of primary products for urban inhabitants, neighborhood relations grounded in the autonomy of local communities (NAGIB, 2020, p. 482 and 484; BIAZOTI, 2020, p. 182) and proximity to the cycles of nature (NAGIB, 2019 PESSOA *et al*., 2006) are taken into account in the claim for a reorganization of

[9] To cite a few examples at the federal level that react to the gap in public policy mechanisms aligned with the practice of UPA, there are currently three legislative proposals (Projeto de Lei – PL, in Portugues) in progress aimed at greater efficiency of use and functionality of urban spaces through urban agriculture: PL no. 9025/2017 (access link); PL no. 303/2019 (access link) and PL no. 182/2017 (access link).

urban-rural territories (ALMEIDA *et al.,* 2012; CURAN, 2020, p. 23). Similar to what is referred to as the "new rurality" (FAVARETO, 2007; CARNEIRO, 2008), recent approaches to so-called "urban" agriculture make explicit the limits in treating countryside and city as opposing and rigidly delineated universes (CARNEIRO, 2008). This demonstrates a certain insufficiency in taking agricultural activity as a reference to define the rural, and vice-versa.

Thus the dynamics and functions of UPA (MOUGEOT, 2000) are placed at the center of the analysis, as well as their implications on livelihoods. Beyond the spatiality of an economic activity and the paradigms linked to it, the meanings, challenges and potentialities of different agricultures in territorial contexts are discussed, pointing to the heterogeneity of their manifestations and territories. This is what Favareto (2007) identifies as a "shift from a sectorial approach to a territorial approach", demanding a combination of ecological, social and economic criteria. From an analytical point of view, other roles played by agriculture and its agents within the territory and the landscape are taken into consideration. From an institutional point of view, new perspectives are opened for public policies dedicated to agriculture and land use planning.

With regard to the production element, the traditional functions of agriculture are imbued with new values, which incorporate the central component of food consumption by the inhabitants of cities and their surroundings (ZASADA, 2011), emphasizing the adoption of sustainable agricultural practices. In light of this, food and nutritional security configures one of the most discussed aspects of urban agriculture, alongside the sustainability of cities and urban planning (CORRÊA *et al*., 2020; PESSOA *et al*., 2006; CABANNES; MARCCHINO, 2018).

Public policies and UPA initiatives in the world

During times of food scarcity, or in the advent of crises and conditions that destabilize the food supply (ZEEUW *et al*., 2011), it is not uncommon for urban agriculture experiences to gain greater prominence, visibility and motivation, including through public programs. Some commonly cited examples of this type of promotion are the "Liberty and Victory Gardens*"* present in several countries and the British "Dig for Victory" campaign hosted during the two World Wars. The Cuban experience of agroecological urban agriculture, institutionalized in the National Council of Urban Agriculture (NCUA), configures another governmental effort to mitigate supply problems arising from the commercial rupture at the end of the Cold War, aggravated by the economic embargo promoted by the USA (CORRÊA *et al*., 2020; NAGIB, 2020, p. 60; MEES, 2020).

More recently, the COVID-19 pandemic, caused by the SARS-CoV-2 virus, has also sparked debate about the important role of urban agriculture in food supply. Whether as part of a proposed transition to more resilient food systems in the post-COVID era (ALTIERI; NICHOLLS, 2020; PULIGHE, 2020; KIHARA; NZUKI, 2020; LIMA, 2020; EVANS; DAVIES, 2020; LAL, 2020), as an active agent in the design of urban food system adaptation strategies during the pandemic (FRIEDMANN, 2020) or as an important link in the local supply of large cities (FERREIRA *et al*, 2020; INSTITUTO ESCOLHAS; URBEM, 2020; DAVIS; MCCARTHY, 2020), urban agriculture has been widely discussed in the context of how the pandemic impacts upon food availability.

In addition to the emphasis on UPA's contribution in situations of contingent shortages, the contribution of UPA to food and nutritional security in cities has been documented as an important component in providing quality food, including for self-consumption, especially in regions of social vulnerability, where fresh food is commonly scarce (MOUGEOT, 2005, p. 3; MCCLINTOCK, 2013).

In this regard, the World Food Summit in Rome (1996), dedicated to discussing strategies to eradicate world hunger within the framework of the Food and Agriculture Organization (FAO), included urban agriculture as a strategic part of mitigating situations of extreme poverty and food insecurity. Although strongly directed at the productive perspective, which resulted in debates led by social movements and academia (CURAN, 2020), resulted on an important document, which amplifies and sheds light on the practice, along with other international forums, such as FAO's 15th Committee on Agriculture (COAG) (1999) and the World Commission on the Environment (1987, also known as Brundtland Report, "Our Common Future") (CABANNES; MARCCHINO, 2018, p. 21; ALMEIDA, 2016, p.159).

As a result of efforts by organized civil society, academics and multilateral organizations, initiatives to support UPA have taken shape in several countries. Starting in the 1980s, important support organizations were created as a result of a movement for institutional recognition linked to the theme of food and job creation, forming an international network of support and visibility for the practice (ALMEIDA, 2016).[10]

More recently, the New Urban Agenda (2016), at the United Nations Conference on Housing and Sustainable Urban Development (Habitat III), firmed up urban planning's commitment to the promotion of sustainable agriculture policies in urban, periurban and rural areas to promote food security (UN-HABITAT, 2016). The Milan Urban Food Policy Pact (2015) recognizes the strategic role of cities in promoting sustainable food systems and food and nutritional security. Going further, it points to urban and periurban agriculture as a central element in biodiversity conservation, "thereby contributing to synergies across food and nutrition security, ecosystem services and human well-being" (MUFPP, 2015; ESCOLHAS; URBEM, 2020, p. 10).

The content of the forum debates and the reference reports (derived directly from the former) reinforce the move away from a perspective of agriculture as an economic activity dedicated only to the production of raw materials towards a broader view. In this vision, elements such as the quality of food produced - highlighting the health of both consumers and producers -, the forms of distribution and commercialization, the welfare provided by food production in localities, and its links with the landscape are taken into consideration (ALMEIDA, 2016).

Another aspect to highlight in relation to urban and periurban agriculture concerns the differences between the global North and South. A recent bibliometric study applied the four Human Development Index (HDI) bands — low, medium, high and very high — of the 2016 UN Human Development Report to identify and compare qualifying elements of UPA (CORRÊA *et al*., 2020). In countries whose HDI is high or very high, much of the publication content refers to community gardens, where the participation of the local municipality is associated with the management of the spaces. Gardens are cited for the benefits generated in the urban environment, such as recreation, reduction of obesity and depression, and food and environmental education when inside schools (Idem; ALMEIDA, 2016, p. 63). There are also studies dedicated to the evaluation of food contamination from urban pollution, with a range of recommendations, highlighting the history of each locality (CORRÊA *et al*., 2020). Another axis of debate in these countries surrounds the activist expression of urban agriculture as a criticism of the current economic system, combining environmental aspects and the right to the city (MCCLINTOCK, 2013; NAGIB, 2020). Finally, the perspective of urban and periurban agriculture through the ecosystem services approach appears specifically in the two very high and high HDI groups. This approach will be further detailed at the end of this chapter.

In medium and low HDI countries, the focus of discussions around UPA centers mainly on agricultural production, with an emphasis on the recommendation of low environmental impact

[10] As an example, ALMEIDA (2016) cites the creation of the International Development Research Centre (IDRC), in Canada, in 1984, as a pioneering institution in supporting agriculture and urban food systems, and the Support Group on Urban Agriculture (SGUA) through the Urban Agriculture Advisory, *of* the United Nations Development Programme (UNDP), since 1996, as an important link in the coordination of international organizations. The Support Group created the Resource Center on Urban Agriculture and Food Security (RUAF), initially as a network and today as an institution of action and dissemination on the subject. The World Food Summit (2002) and the UN High Level Task Force on the Global Food Security Crisis (2008) recognize urban agriculture as a strategy to reduce food insecurity. In Latin America, the author highlights the IPES - *Promoción del Desarrollo Sostenible* [Promotion of Sustainable Development] and the meetings and declarations held in Lima (Peru), Quito (Ecuador) and Rosario (Argentina) for the promotion of urban agriculture through the support of local authorities (Idem), forming the RUAL - *Red Urbana de Agricultura Latinoamericana* [Urban Network of Latin American Agriculture].

techniques, linked to the notion of sustainability. The discussions point to the social, economic, and environmental benefits of UPA and the need for institutional support, which is still scarce, for its maintenance. Another aspect addressed refers to the proximity of food production to consumption centers, implying less dependence on long supply chains. More specifically in countries with low HDI, the central issue concerns the contribution of UPA to food and nutritional security in cities, marked by intense rural exodus and high urban poverty rates (CORRÊA *et al*., 2020). In this sense, the participation of UPA is highlighted as an economic activity and a means of access to food in cities, differently to what is discussed in HDI countries, where large retail chains predominate in the organization of supply (ALMEIDA, 2016, p. 65).[11]

Panorama of UPA in Brazil

In Brazil, there are several UPA initiatives present in cities and their surroundings, some of which have institutional programs dating back to more than a decade, as seen in Belo Horizonte (MG) (ALMEIDA, 2016), and more recently, Maringá (PR) (ALBERTIN *et al*., 2016) and Teresina (PI) (MONTEIRO; MONTEIRO, 2006). The survey "Panorama of urban and periurban agriculture in Brazil and policy guidelines for its promotion"[12], conducted in eleven Brazilian metropolitan regions (SANTANDREU; LOVO, 2007), shows that the practice was a reality in all regions of Brazil, especially in the capital cities. The study also points out that the methodology focused on the central municipalities of each metropolitan region — a choice made due to the time required for the research — suggests that in smaller municipalities, examples do exist but yet poorly documented.

The work of Santandreu and Lovo (2007) also pointed out the lack of large-scale public policies; the low level of integration with the production chain, marked by informality; the capacity of urban and periurban agriculture to expand and consolidate itself as a multifunctional activity; and the diversity of institutions involved in its promotion, from government programs and universities to non-governmental organizations (NGOs) and organized civil society. The "Panorama" is one of the results of the food and nutritional security policies created in the early 2000s under the Brazilian Ministry of Social Development (MSD) and the *Fome Zero* [Zero Hunger] Program (ALMEIDA, 2016, p. 95), which is much referenced as a conceptual basis for urban and periurban agriculture in Brazil. More recently, a survey of municipal initiatives supporting agroecology compiled 36 programs and projects specifically dedicated to urban and periurban agriculture in Brazil. In the Southeast region, this is one of the five most cited project themes in the surveyed initiatives (LONDRES *et al*., 2021).

Besides the particularities associated with human development indices, UPA is present in a range of configurations in urban and periurban spaces. Its heterogeneity is the subject of academic debates, which also address the difficulty in stipulating policies able to cover the specificities of land use, access to resources, licensing of activities, use of urban inputs (e.g., pruning waste), and public policy mechanisms, among others.

An issue worth highlighting are the categories used for agricultural censuses, which are not always well adapted to the urban and periurban contexts. One example is the very concept of rural property and the imprecise definitions of rural and urban census sectors. Considering the heterogeneity and the mosaic aspect of urban, and especially periurban land features, the limitations also manifest themselves in the spatial analyses of land use, whereby agricultural areas are sometimes overestimated or underestimated. The impasse goes back to the lag in criteria to define the real conditions of

[11] In Brazil, the modernization of the food supply system began in the 1960s, combatting the famine crises that were common at that time and with important State interventions. The São Paulo wholesale produce market ETSP - *Entreposto Terminal São Paulo,* located in CEAGESP, in the West Zone of the city of São Paulo, was the first such warehouse to be created through the program, followed by 47 other warehouses and more than a hundred retail facilities, as well as retail stores and "*sacolões"* [large grocery stores] run by the states and municipalities throughout the 1970s and 1980s. More information about the food system in the Metropolitan Region of São Paulo can be found in "Closer than you think: the challenges of food production in the metropolis of São Paulo".

[12] TN - Translation of the original title "*Panorama da agricultura urbana e periurbana no Brasil e diretrizes políticas para sua promoçã*o", study available only in Portuguese.

urbanization and rurality in the Brazilian territory (PEREIRA *et al*., 2017), for the most part leaving it up to the fiscal interests of municipalities to maintain urban perimeters (IBGE, 2017).[13] Travassos and Ferreira (2016) also point out the invisibility to which hybrid areas common to metropolises — that is, at the intersection between rural and urban — are relegated by public authorities, fulfilling functions sometimes of a strictly environmental nature, sometimes as land banks at the service of cities.

In this sense, it is worth emphasizing the ambiguity to which the terms rural and urban are subject. Besides serving both academic research and common sense in the construction of cultural and symbolic values, they are also used in statistical and public policy-making agencies (CARNEIRO, 2008). There is a vast range of literature dedicated to the ways of classifying territories into urban or rural categories (CARNEIRO, 2008; TRAVASSOS; FERREIRA, 2016; IBGE, 2017), much associated with the difficulty of delimiting such spaces. Despite the critics addressed to these categories which account for only part of the reality, in the context of public policies, such delimitation is important for the planning and management of territories (IBGE, 2017). The recent reinsertion of the rural area in the municipality of São Paulo[14] resulted from the need for institutional recognition of activities performed in the region, but especially of the proposal to develop other agendas based on the multiple functions of such localities, in which the provision of environmental and ecosystem services is taken into account (TRAVASSOS; FERREIRA, 2016).

As a result of this diversity, typologies of urban and periurban agriculture have been developed and presented in academic literature. This is in an attempt to align with efforts made to understand how the scope and meaning of urban and periurban agriculture materializes in different contexts, as well as how the demand for categorization emerges in the light of programs and public policies. Thus, irrespective of the location being inside or on the fringes of the urban fabric, the functional relations established with the economic and ecological system — or urban ecosystem, according to Mougeot (2000) — are at the center of the analysis of UPA. This results in a notion of heterogeneity and multifunctionality that is intrinsic to the concept and practice of urban and periurban agriculture, with distinct characteristics predominating for each type and their links to territory[15], which reinforces the need to overcome strictly sectoral approaches.

The multifunctionality of agriculture

One of the most highlighted characteristics of UPA is its multifunctionality (GOMES *et al*., 2019). This attribute has guided the development of public policies on agriculture and rural issues since the 1990s, especially in European countries, and gained prominence in the sustainable development debate in the Agenda 21 documents, resulting from the United Nations Conference on Environment and Development (UNCED, known as Rio-92) (HUANG *et al*., 2015). The multifunctionality approach is in line with the notion of territory (BONNAL *et al*., 2008). As Carneiro (2008) points out, it is about recognizing the dimensions beyond economy that are involved in productive processes linked to agriculture. Originally based on three pillars (economic, social and productive), multifunctionality emerged as a way to recognize and value family-based agriculture (BONNAL *et al*., 2008). Thus, the unit of analysis is no longer agriculture *stricto sensu,* but rather the rural family as a social unit, linked to a territory with specific socioeconomic, cultural and environmental characteristics. The incorporation of the territorial scale implies the examination of "functions", that is, the provision of public goods by farmers, and the "corresponding role of actors and social networks in the social construction of the

[13] In Brazil, the urban perimeters are determined by the municipalities (Decree-Law No. 311 of 2 March 1938), which are responsible for collecting the Urban Land Tax (ULT). The Rural Land Tax (RLT) is levied on properties located in rural areas - or urban areas, in cases where the agricultural activity is intended for commercialization. The RLT, whose rates are lower, is collected by the Federal Revenue.

[14] The rural zoning of the municipality of São Paulo has been extinct since 2002, and was delimited again in 2014, as part of the Strategic Master Plan, Law No. 16,050, of 31 July 2014.

[15] For more information about the construction of the typologies of urban and periurban agriculture in the Metropolitan Region of São Paulo and in other cities and regions, see the survey and typology carried out in "Closer than you think: the challenges for food production in the metropolis of São Paulo".

respective territories” (Idem).

In Brazil, the multifunctionality of agriculture has appeared in political and academic debates, especially since the early 2000s. With specific contours carved by its socioeconomic context and marked by the heterogeneity of expressions of agriculture in the territories (BONNAL *et al*., 2008), four main ***functions*** stand out, as outlined below. In addition to the agri-food focus, the composition of other activities performed by productive families is incorporated as a strategy for permanence in the agricultural activity. In this sense, the guarantee for Brazilian families' ***socioeconomic reproduction*** through an essentially agricultural occupation is contingent upon secure access to land, combined with better conditions for market insertion via agricultural product prices (Idem). Another highlighted function concerns the ***food and nutritional security*** of families engaged with agriculture and society, given that in the Brazilian scenario, self-consumption gains prominence, being linked to food quality and the mitigation of social vulnerability.

The ***maintenance of the social fabric***, whereby agricultural activity is a component of the family economy, highlights other elements beyond the essentially agricultural economic aspect, such as ways of life, the relationship with the local environment, the proximity relations between families and neighborhoods, as well as food autonomy. This identifies, in an ambivalent way, the importance of agricultural activity for the sociocultural maintenance of local communities as a condition for citizenship, while at the same time attenuating the identification of rural areas exclusively with agriculture, highlighting other possibilities for the economic occupation of rural areas, based on environmental purposes and ideals.

The multifunctionality of agriculture also combines aspects related to the conservation of biodiversity and habitats. Thus, the ***preservation of natural resources and the rural landscape*** evokes two practical directions for Brazil: (i) the need to align proposals for sustainable rural development, such as policies that strengthen productive and economic components for farming families, to the multifunctionality goal of agriculture (BONNAL *et al*., 2008); and (ii) the promotion of another approach by environmental enforcement agencies, in order to combine the preservation of native vegetation with agriculture at the level of the production unit (Idem), entailing consequences that go beyond its limits, involving functions within the landscape. The latter can be observed in more recent policies, such as the National Environmental Registry of Rural Properties and certain modalities of Payments for Environmental Services (PES). In any case, although the notion of multifunctionality has gained prominence in academic debates and in the promotion of family farming in Brazil, there are few public policies designed and oriented towards the multifunctional approach. Some examples, still mainly directed towards the productive dimension, are the food and nutritional security programs under the *Fome Zero* [Zero Hunger] program, which have been institutionalized such as the Food Acquisition Program (FAP); certain credit lines of the National Program for Strengthening Family Agriculture; and the Program for Sustainable Development of Rural Territories (MORUZZZI; CHIODI, 2018; BONNAL; MALUF, 2009).

These are the key conceptual goals underpinning the debate on the multifunctionality of agriculture in Brazil (BONNAL *et al*., 2008). The interface between urban and periurban agriculture and the notion of multifunctionality also highlights other functions that are particularly relevant in the context of cities. In addition to food and nutritional security, other important functions include the empowerment of women, the promotion of health and public safety, the (re)connection with nature, job creation and the generation of income, the reconnection between production and consumption (stimulating new forms of distribution and commercialization), resource and nutrient cycling, the promotion of green spaces in the city (CURAN, 2020, p. 41) and the political engagement of citizens (BIAZOTI, 2020).

Although it is increasingly relevant, the multifunctionality of urban agriculture is still little explored when new public policies for urban and periurban contexts are designed (ALMEIDA *et al*., 2012). In addition to the limited visibility and institutional support received in Brazil — especially in comparison to the European Community, where the degree of multifunctionality of the production system affects the level of state support received —, the weak influence in public policies may also be related to the wide scope of the approach, in face of agriculture's particularities in urban and periurban spaces. That is to say, in the context of setting public policy agendas, it is important to ask what focus is necessary, given how agriculture's functions in local contexts might be better supported. Or, on the other hand, it is worth elucidating the conditions required for producing better framing agriculture's functions, since certain risks — especially of systemic impacts on the health of the local population due to the use of agrochemicals or those concerning the quality of soil, air, and water in the urban environment — result in the practice being restrained by governments (CURAN, 2020, p. 27). As Almeida (2016) argues:

> From the perspective of multifunctionality, it is argued that certain types of urban agriculture are more closely related to each of the dimensions commonly associated with this practice — social, economic and environmental. It also considers the importance of assessing these relationships when defining policy approaches and designs to support this activity, so that these measures can contribute to a wide variety of urban issues and serve as tools that diversify and strengthen strategies for urban management and the sustainable development of cities (p. 69)[16].

Notably in relation to the preservation of natural resources and the landscape, the ecosystem services approach comprises a useful tool for qualifying and valuing this function, which will be further detailed in the following item.

Ecosystem services

The multifunctionality approach is key to understanding the interface between agricultural practices, territory, and the function of preserving natural resources. In this sense, it highlights the importance of environmentally-conserved landscapes for the maintenance of the well-being of humanity. Anthropic activities, such as urbanization, industrialization, and the homogenization of crops, accompanied by increasing dependence on chemical inputs, have accelerated the processes of degradation and alteration of natural ecosystems. Thus, the unsustainable use of natural resources and the fragmentation of native vegetation, with the consequent reduction of biodiversity, have directly affected the quality of life, since they negatively impact the maintenance of those goods and services derived from nature that are essential to human health. Examples of these services include drinking water supply, climate regulation, soil fertility, and natural pest and disease control (BRAAT; BRINK, 2008; IPBES, 2019; MEA, 2005; SILVA, 2018).

In general, ecosystem services are defined as the conditions and processes by which natural ecosystems support human life (DAILY, 1997; FISHER; TURNER, 2008; FISHER, TURNER; MORLING, 2009). However, this concept still presents divergences, with two main lines of thought. The first argues that ecosystem services are more closely related to ecosystem processes, such as pollination (DAILY, 1997; DE GROOT *et al*., 2010), while the second line of thought argues that the services are related to the benefits generated by ecosystem functions and processes, i.e. the fruits generated from pollination (WALLACE, 2007; FISHER; TURNER, 2008; FISHER, TURNER; MORLING, 2009). Although the concept itself is disputed, a common thread between the two visions deserves to be highlighted: human demand. Thus, for a given ecosystem service to exist, there must be a beneficiary, that is, an individual or a group of people who benefit through the provision of that good or service (FISHER; TURNER, 2008; DE GROOT *et al*., 2010; SILVA, 2018).

In the context of the IPBES - Intergovernmental Platform on Biodiversity and Ecosystem Services, which is an important panel dedicated to developing scientific evidence for sustainable development decision-making, ecosystem services have been redefined as nature's contributions to people (NCP). The notion of NCP aims for a more inclusive and diverse approach to the relations between the environment and society, considering the possibility of contrasting perceptions about what

[16] TN - Translation of an excerpt from the original study, available only in Portuguese.

defines nature itself according to different existing forms of interaction with the environment (SAO PAULO, 2020b, p. 19; PASCUAL *et al*., 2017). In this IPBES approach, nature is assigned: "intrinsic values", which are the inherent values of nature, regardless of human judgment; "instrumental values", in which nature is valued as a means to satisfy human needs/preferences; and, finally, "relational values", in which the central role of nature in cultural and social processes is considered, and in which a sense of belonging, cultural identity, sociability, and social cohesion are generated.

Ecosystem services are usually divided into four categories: provisioning (such as food and drinking water); regulating (regarding the natural regulation of water and climate, for example); cultural (promoting recreation and spiritual activities); and supporting (responsible for the functioning of all other services, such as soil formation, nutrient cycling, etc.) (MEA, 2005). While this classification has been widely disseminated, it is not unanimous, much like the concept of ecosystem services itself. Other proposed and accepted classifications exist, including the one that was selected for this study: the Common International Classification of Ecosystem Services - CICES (HAINES-YOUNG; POTSCHIN, 2013). CICES does not take into account the category of supporting services, since it considers them "ecosystem functions", which do not evidence an immediate link between the service and its beneficiary. This classification provides a hierarchical structure of ecosystem services, in which each level provides a more detailed description of the service to be considered. CICES' general framework was developed with the intention of fostering a relationship between ecosystem services and different classes of land uses, characterizing it as a flexible, adaptable, and refined tool applicable to different situations and locations around the world (HAINES-YOUNG; POTSCHIN, 2013).

The CICES methodology presents an interesting aspect when considering different classes of land use, given that different ecosystem services are provided in each of these classes in different magnitudes. Thus, better conserved natural areas have greater potential to provide a variety of ecosystem services (BURKHARD *et al*., 2009; FERRAZ et *al*., 2014; SILVA *et al.,* 2016). Regulating services, for example, show an increase in better conserved forested environments (BRAAT; BRINK, 2008). This rule does not apply to all types of services due to the fact that some services require human intervention in order to convert a resource or ecological function into an ecosystem service, as is the case for agricultural fields with provisioning services (food) (BRAAT; BRINK, 2008; DE GROOT *et al*., 2010). Cultural services can also require a minimum of infrastructure to generate demand and be accessed by people, but may lose their value or cease to exist in degraded ecosystems (BRAAT; BRINK, 2008; DE GROOT et *al*., 2010), and a third possibility is the generation of disservices that affect human well-being (VAZ *et al*., 2017).

The areas occupied by UPA are examples of managed environments that provide ecosystem services, the most obvious of which is food production. Additionally, depending on the type of management adopted, the location, and the extent of cultivated areas, UPA can promote other services, such as climate regulation, flood control, and the promotion of urban biodiversity by acting as an ecological corridors for avifauna and a habitat for pollinators, among others (LIN; PHILPOTT; JHA, 2015; ZHAO; SANDER; HENDRIX, 2019). More specifically, in urban environments idle land is often occupied for waste dumping, favoring the spread of disease vectors. Many examples of UPA, such as the areas under power lines in the MRSP, are the result of the conversion of degraded areas, generating benefits to the surroundings.

More practical approaches to ecosystem services allow the latter to be incorporated into the decision-making of key actors such as governments and farmers, who have a direct influence on the dynamics of land use in a region or locality over time. The decisions of such actors are based mainly on economic, cultural, or political aspects, directly affecting the provision of ecosystem services, since they alter the characteristics, processes, and components of ecosystems (LAMBIN *et al*., 2001; STICKLER et *al.,* 2013; DEFRIES et *al.,* 2010; SILVA, 2018). In this sense, there is an increase in the number of studies that relate the quantification and valuation of ecosystem services to changes in land use and land cover in different landscapes (KREMEN; OSTFELD, 2005; BENNETT; PETERSON;

GORDON, 2009). In the context of public policies, ecosystem services have been incorporated mainly through programs that involve Payments for Environmental Services (PES).

Because of this, the terms “ecosystem services" and “environmental services” are commonly used synonymously. Although there is a line of research which does in fact use them synonymously, in practical terms, this research recognizes a distinction. While ecosystem services could exist independently of human action, environmental services are defined as benefits arising from anthropogenic initiatives operating in favor of ecological systems for the maintenance or recovery of ecosystem services. Because environmental services occur at a local scale, they are able to be separated into measurable components, and there is generally a market value to be negotiated. For example, forest restoration actions in a given area are considered environmental services, given that over time they can recover the climate regulating ecosystem services provided by the vegetation. Another example would be the implementation of contour lines and terracing in agricultural fields, comprising environmental services aimed at improving the ecosystem service of soil quality and erosion control.

PES programs and policies emerged with the aim of encouraging improved natural resource management in order to guarantee ecosystem services (SANTOS *et al*., 2012). They are economic incentive instruments, which assist and complement command and control policies (such as the Native Vegetation Protection Law, Law No. 12.651/2012) in environmental conservation (SANTOS *et al*., 2012; ARAÚJO, 2015; SILVA *et al*., 2016). These incentive mechanisms aim to compensate, monetarily or otherwise, those who protect the environment and provide environmental services, stimulating biodiversity conservation behaviors in society (ARAÚJO, 2015). In general, a PES program can be defined as the transfer of resources between social actors, which aim to create incentives to align individual or collective decisions about land use with the social interest in the management of natural resources (MURADIAN *et al*., 2010).

It is worth mentioning that in early 2021, Brazil approved the National Policy for Payments for Environmental Services (Law No. 14,119), which defines objectives, guidelines, actions, and criteria for implementing PES in the country. This policy framework is of relevance, since it increases the legal security of the programs implemented and, at the same time, brings more clarity regarding other key aspects, such as the areas and ecosystem and environmental services that are considered to be of priority.

Even in the face of the multifunctional character of UPA – which includes the provision of ecosystem services –, incorporating agriculture into urban planning and management and the design of effective incentive mechanisms is challenging for several reasons. Among these reasons is the lack of indicators available to measure the positive and negative impacts of various typologies of UPA, as well as continual inquiry into their economic viability and scalability, creating obstacles to their wider dissemination. While the Escolhas; URBEM study (2020) further investigated the conditions under which the different typologies of UPA become economically viable in the MRSP, other studies conducted in the state of São Paulo point to the need for ecosystem services provided by nature to be made more visible in order that they be considered in decision making (DIB *et al*, 2020; LATAWIEC et *al*., 2018; SÃO PAULO, 2020b; SAAD; ROCHA; SILVA, 2016; OZMENT *et al*., 2018), particularly given that in the latter, the contribution of agriculture remains unknown and little problematized in the urban context. The theoretical-methodological framework of TEEBAgriFood, briefly presented below, configures a timely avenue of analysis, capable of generating evidence about the other benefits of agriculture, as well as its environmental costs. The application of the TEEBAgriFood framework in the urban context is a new phenomenon and is therefore used in an experimental fashion in this study.

TEEBAgriFood: multifunctionality of agriculture and ecosystem services

As previously mentioned, the TEEBAgriFood initiative subscribes to the efforts for developing new approaches in response to the limits of addressing food-related problems through studies and sectoral policies. This approach aims to identify the so-called externalities on the production and distribution, commercialization, consumption and disposal systems, as well as to address the potential trade-offs between the various aspects of human welfare and the guarantee of an ecologically-balanced environment. In this sense, the initiative aims to analyze the eco-agri-food system, integrating all the spheres that compose it (human, environmental, economic and social), thereby allowing a systemic view of production, distribution, consumption and disposal. To this end, it categorizes the resources used along the value chain into different types of capitals (natural, human, social and produced) and flows (agricultural production, ecosystem services, waste), considering in detail the multifunctional character of agriculture and its relationship with the territory.

Produced capital refers to all manufactured assets, such as buildings, machinery, and physical infrastructure, as well as financial assets. *Natural capital refers to* the limited stocks of physical and biological resources and ecosystems' ability to provide ecosystem services. *Human capital refers to* the knowledge, skill, competencies and attributes of individuals that are linked to human well-being. Finally, *social capital* encompasses the shared networks, values, norms, and understandings that drive cooperation, and can manifest in formal and informal arrangements. Natural capital is understood as underpinning all production and the allocation of the other forms of capital (TEEB, 2018).

The initiative is based on the premise that agriculture depends on natural capital (soil, water) to be viable and to generate flows (food) that benefit the actors involved in the process in different ways. However, depending on how natural capital is managed, depletions (loss of fertility, less water availability) can be generated, with consequences for ecosystem services, which in turn impacts human welfare. Agricultural production around the metropolis, for example, is fundamental to generate flows of fresh food to supply its inhabitants. However, the indiscriminate use of agrochemicals can impact the water quality of the springs on which its inhabitants depend. These flows of food and water production, which include the ecosystem services of food supply and water yield, are immersed in complex relationships and respond to different interests, requiring further analysis in order to reconcile the demands of the territory.

On the basis of the types of capital identified, the flows generated from their employment are mapped. These can include inputs purchased, agricultural and food products produced, associated ecosystem services and waste generated. These flows in turn impact resource stocks (capitals) as well as the well-being of society. Impacts are considered from different perspectives: environmental, economic, social, and human health (*Figure 1*). Once the TEEBAgriFood methodology has been used to map and identify the characteristics of the different types of capital, as well as their flows, by quantitative and qualitative indicators, this information becomes an important tool for adapting or developing public policies, as well as guiding private and third sector initiatives, aimed at achieving social and environmental well-being. Thus, TEEBAgriFood goes beyond the role of systematizing and measuring flows and impacts, proposing itself an instrument of social transformation towards sustainable development.

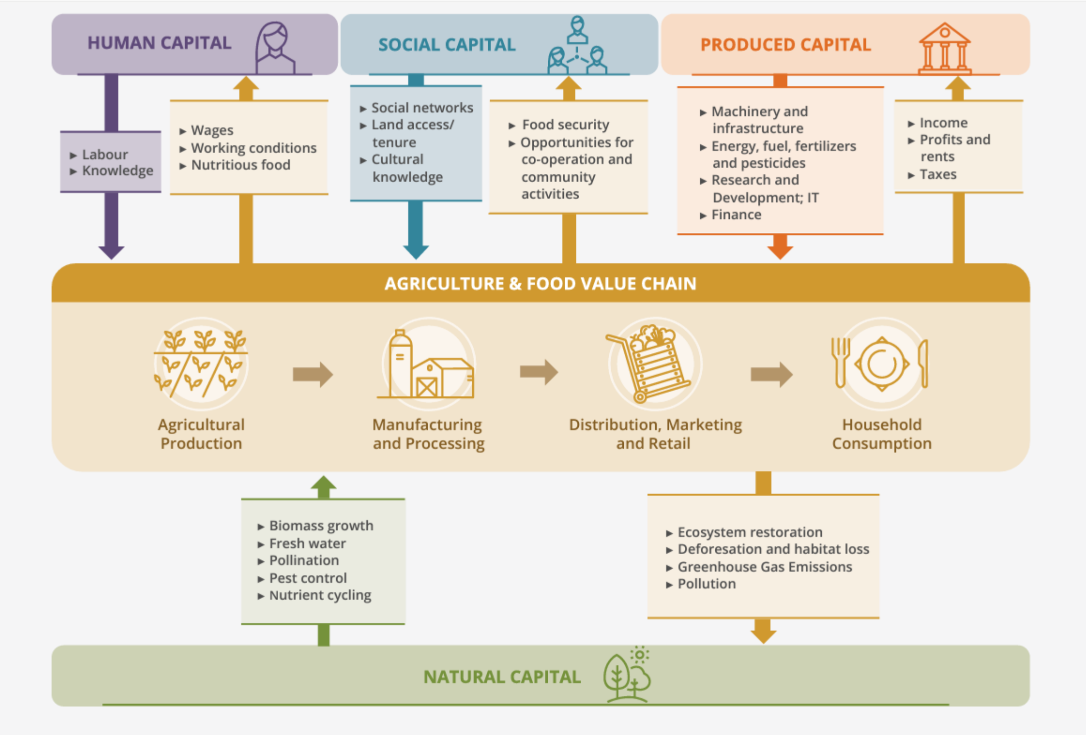

Figure 1 - Capitals and flows involved in eco-agri-food systems (TEEB, 2018).

Finally, through the elaboration of qualitative and quantitative evidence that demonstrates the connections and interdependencies that exist in the eco-agri-food system and in the territory, the initiative aims to pave the way for decision-making, including actors all along the value chain (TEEB, 2018, pp. 23-6). In a practical sense, the framework is based on the construction of intervention scenarios in a complex context, with a view to guaranteeing food production committed to maintaining ecosystems (Idem), that is, considering agriculture’s multiple functions in the territory. Adapting this methodological-conceptual instrument to the case of UPA implies adjusting the scope of the flows investigated, since the ecosystem services generated are spatially delimited in a context of multiple land use, in which diverse pressures act upon the capitals under investigation.

Materials and Methods

The methodology is inspired by the six steps of the TEEB framework (2010) adapted for TEEBAgriFood studies (TEEB, 2018), which are described in Figure 2. The research methodology described in this chapter comprises a mixed-methods approach, encompassing qualitative and quantitative analyses, as well as dialogue with key social actors.

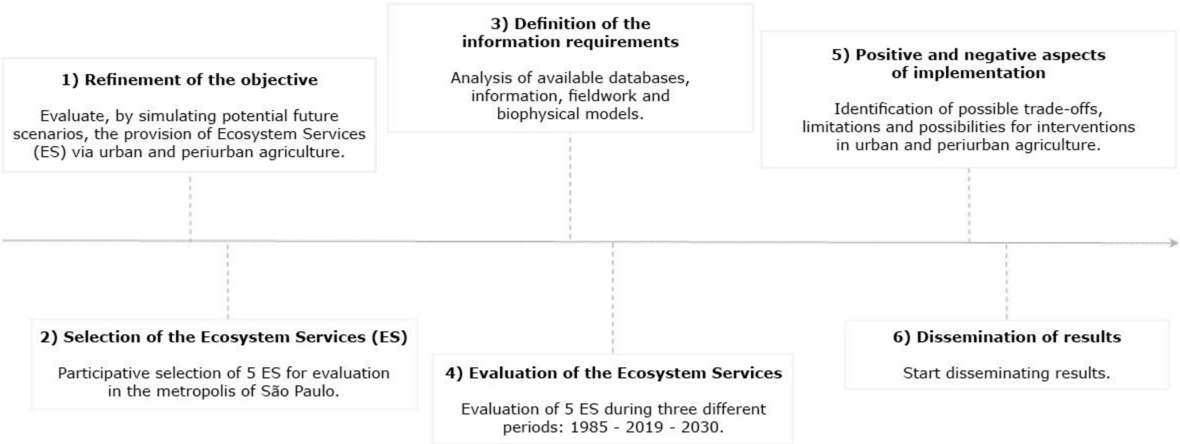

Figure 2 - Steps of the TEEBAgrifood assessment framework adapted to the study.[17]

The research objective was refined through preliminary interaction with social actors engaged in both the field of UPA and ecosystem services (*Step 1 of the framework*). As a result of this participatory process and according to a feasible analytical scope, the ecosystem services were identified (*Step 2*), based on their relevance to the context of the MRSP, as well as the methods and data required for their assessment (*Step 3*), which in this research also includes case study data collected from farmers in the territory.

Once the methods and data were set, the assessment of the ecosystem services were held, considering three periods: past (1985), present (2019), and the projection of future scenarios (2030). The participation of key actors was important for incorporating desirable agricultural productive systems and for prioritizing interventions strategies in the territory (*Step 4*). The formulation of alternative scenarios allowed the evaluation of possible results generated by the activation *vs* absence of an UPA incentive policy (*Step 5*). Finally, the publication of the study comprises one of the strategies for communicating the impact of possible policy formulations to stakeholders (*Step 6*).[18]

The elements of each step are detailed in the following items:

Step 1 - Refine the research objective and scope

The first step of the TEEBAgriFood studies is dedicated to defining the scope of analysis and refining the research objectives with the key social actors of the eco-agri-food system. This participatory strategy aims to broaden the possibilities of incorporating issues related to the research scope by engaging with government agencies, farmers and their institutions, private enterprise, and civil society.

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[17] Authors' elaboration on the basis of TEEB (2018).
[18] A discussion about public policy can be found in the last chapter of this study.

In addition, this step effectively develops the role the research will play in supporting the decision-making process.

The path laid out in this study differs from the first step in procedural terms. Instead of first engaging with the actors, there was a concomitant process of refining the objective and scope throughout the research, and of building the necessary institutional links to make it feasible. Initially, the possibility of technical collaboration was forged between the researchers of the study "Closer than you think: the challenges for food production in the metropolis of São Paulo" (ESCOLHAS; URBEM 2020) and the consultants of the TEEBAgriFood Program (UNEP). In this initial collaboration, the focus on ecosystem services was envisioned as a way to complement the financial viability analysis that was being conducted for UPA. At this point, the dialogue was initiated with different actors, such as state and municipal managers, university researchers, and representatives of social movements. Later on, in view of the issue's potential to inform public policies, which could promote both UPA and PES, it was decided that an exclusive study would be conducted into this issue. Given the fact that the study themes are little explored in academic literature, and that a TEEBAgriFood study focused on urban agriculture is unprecedented, the research scope since the beginning assumed an exploratory character, taking into consideration the need to broaden and deepen the debate.

In order to expand the pre-existing participatory component and adapt it to the TEEBAgriFood studies, a working group (WG) was created in order to critically discuss central aspects of the research, notably the objectives, the limits of the methodologies applied and the preliminary results. Two meetings of the WG were organized[19], structured as workshops and mediated by facilitators. This allowed the preliminary research results to be monitored, as well as enabling the recording of the different perceptions and issues raised during the debates. In addition, the WG meetings unfolded in later individual focal meetings with specific actors and experts.

Preliminarily, institutions and local actors engaged in the two WG were mapped out, and participants were contacted in advance to take part in the working group meetings. Firstly, the mapping process identified public management and research institutions that address the issues of water resources, forest preservation and conservation, and agriculture in the MRSP. Subsequently, private institutions that work directly with one or more of these themes were identified. It is worth mentioning how useful the study "Ecosystem Services and Well-Being in the Green Belt Biosphere Reserve"[20] was for the mapping process. Coordinated and recently released by the Instituto Florestal,[21] the aforementioned study brings together numerous researchers and experts on the subject in a scope circumscribing the MRSP territory.

As a result of the mapping and engagement processes conducted, WG participants include representatives from academia, social movements and organized civil society, as well as public and private managers and local urban and periurban farmers.[22] It is worth mentioning that, although the case studies were conducted prior to the mapping of key social actors, their contribution in establishing local production parameters was crucial for the delineation of future scenarios, which is detailed later in this chapter.

In the first meeting of the WG, the research components were presented: the objectives, the methodological strategies, and the development of a preliminary future scenario considering the five ecosystem services evaluated in this study. This initial meeting included small breakout discussion groups around three sets of key questions. Participants were encouraged to identify the most relevant ecosystem services to be analyzed in the context of the MRSP, as well as reflecting on the t UPA police

[19] The first WG was held on 16 December 2020, and the second, on 2 March 2021. In all, the WGs involved the participation of more than forty actors, in addition to the study's management and research team.

[20] TN - Translation of the original title *"Serviços ecossistêmicos e bem-estar na Reserva da Biosfera do Cinturão Verde",* study available only in Portuguese.

[21] São Paulo State Secretary of Infrastructure and Environment (SIMA/SP).

[22] The list of participating entities can be seen in Annex 1.

options in the MRSP and what their possible impacts might be. Finally, participants were asked to determine which analyses still needed to be conducted in order to stimulate policymaking capable of strengthening agricultural systems with potential to provide ecosystem service.

The second meeting of the WG presented and debated the theoretical interfaces of the study and the alternatives for future scenarios, as well as an analysis of existing public policies dedicated to the valuation of ecosystem services and the promotion of the different aspects of UPA. The aspects related to water production in the MRSP, such as the adoption of water-saving agricultural techniques, were central to the debate, and were incorporated into the research. Another in-depth discussion around crossing the heterogeneous socioeconomic and territorial characteristics of the metropolis, which make explicit the overlapping layers of social and environmental vulnerabilities, reinforced the relationship between ecosystem services, human welfare, and the functions of UPA in localities, especially on promoting food and nutritional security. This last point was considered in the elaboration of the **Alternative Scenarios** proposed by the study.

Briefly, the participation of key social actors allowed the refinement of: (i) the specific research objective, from real demands experienced by public and private managers and other actors; (ii) the most appropriate databases for MRSP; (iii) the selection of the most relevant ecosystem services in the context of MRSP; (iv) the identification of the main agricultural systems with the potential to provide ecosystem services; and, finally, (v) the central elements to compose the future scenarios, such as the priority areas for the expansion of sustainable UPA.

Step 2 - Identify ecosystem services and analyze impact and capital dependencies

Selection of Ecosystem Services

The identification of the most potentially relevant ecosystem services started with the team of researchers and collaborators of the study “Closer than you think: the challenges for food production in the metropolis of São Paulo” (ESCOLHAS; URBEM 2020). And, as already mentioned, during the first meeting of the WG, a collective discussion was held concerning which were the most important ecosystem services to be evaluated in the MRSP. The discussion took place after the presentation of the preliminary results, which reinforced the importance of the five pre-selected ecosystem services, as well as including a more detailed analysis of the case studies conducted in the context of the previous study. Table 1 identifies the ecosystem services mentioned at the time.

Table 1 - List of ecosystem services mentioned by the participants during first WG.[23]

Ecosystem Service	# of Mentions	Ecosystem Service	# of Mentions
Water Yield	7	Erosion regulation	2
Food supply	5	Flooding	2
Cultural Services	5	Mental Health	1
Climate regulation	4	Waste Incorporation (composting)	1
Microclimate regulation	4	Carbon Sequestration	1
Biodiversity	2		

[23] Authors’ elaboration.

Based on the notes made at the first WG meeting, as well as the availability of data and methodologies, the ecosystem services selected for evaluation in this research followed the criteria of being related to strategic urban issues linked to the sustainable development of the MRSP and, at the same time, to strengthening of the local supply of healthy food. The urban issues prioritized were the availability and quality of water, flood control, and the expansion of green spaces for improving the climatic comfort. Finally, the five ecosystem services preliminarily selected for biophysical modeling were maintained, namely: water yield, erosion regulation, flood mitigation, heat mitigation, and food supply. In addition, based on qualitative data deriving from the case studies, descriptive analyses about cultural services and relational values were integrated, including the service of waste incorporation (composting).

The **water yield** service refers to surface water bodies that provide drinking water. In the MRSP, this service becomes relevant due to the scarcity (supply for different activities) experienced in recent periods (the 2013-14 drought).

The **erosion regulation** service refers to the reduction in soil loss due to the retention effects of natural vegetation, which mitigates human use (or prevents potential damage) to the environment and human health. In the case of the latter, erosion regulation is also related to the containment of slope areas that, in the case of irregular anthropic intervention, may cause mass movements and landslides. This service also impacts water resources, to the extent that the sediments resulting from the processes of soil erosion are transported by rain, reaching water bodies and negatively influencing their quality. Other aspects related to erosion are soil fertility and agronomic productivity, which are directly linked to the soil management options.

Flood mitigation is a service related to the regulation of water flows provided by green areas. The increasing rate of soil sealing in urban environments accelerates rainwater runoff and increases the probability of overloading the drainage system. Green areas (or natural infrastructures) tend to attenuate runoff by infiltrating into the soil and thus strengthening cities' resilience against extreme weather events, such as heavy rainfalls.

Heat mitigation service can be defined as the mediation of atmospheric environmental conditions (including micro and meso-scale climates) due to the presence of vegetation. Densely-urbanized areas such as in the MRSP are usually affected by the rise in surface temperature, which can impact local temperatures, with consequences for the human health, the productivity of workers and energy consumption for air conditioning. In this sense, green areas have the ability to provide shade, to modify the thermal properties of the urban areas and to increase cooling and humidity through evapotranspiration processes.

Finally, the **food supply** service comprises the ecological contribution of ecosystems to the growth of cultivated agricultural crops, which can be harvested and used directly for food, or as raw material for food production. Access to fresh and helthy food is a growing demand, and particularly relevant among vulnerable populations, a situation that is aggravated in the current context of increased food insecurity rates due to the COVID-19 pandemic (GALINDO *et al*., 2021).

For most of these services, spatially explicit biophysical modeling is available to allow assessments at the metropolitan scale, as detailed in Step 4. A more refined analysis of different urban and periurban farming systems in the MRSP was carried out through the four case studies gathered in Escolhas; URBEM (2020). This allowed to identify other impacts at local scale that could not be captured via spatial analysis.[24]

[24] A modeling of *waste incorporation* was done using data gathered from the case studies and based on extrapolations.

The methodological procedures regarding field data collection, as well as the TEEBAgriFood framework used in the examination of the case studies, are described below.

UPA - the impacts and dependency on capitals: case studies

As mentioned in the first chapter, TEBAgriFood comprises an approach dedicated to analyzing the eco-agri-food system, integrating all its relevant dimensions (human, environmental, economic and social). To this end, the initiative has developed a comprehensive Assessment Framework (described in Table 2), with an emphasis on identifying significant visible and invisible dependencies and impacts of eco-agri-food systems in human, social, natural, and produced capitals (TEEB, 2018, p. 43). With the support of the Assessment Framework, the four case studies (CSs) described in Escolhas; URBEM (2020) were analyzed. The Framework is grounded in three guiding principles, briefly noted below.

The first principle, concerning *universality,* proposes that the Framework may be used in any geographic, ecological, or social context, no matter what is the entry point or application. The second, *comprehensiveness*, aims to consider the entire value chain and all significant impacts in an agri-food system. The Framework's comprehensiveness implies that systems are evaluated in terms of economic, environmental and social flows — such as production, consumption, ecosystem services, pollution, social benefits — and in terms of the *capital base (or stock)* that sustains them, which may be impacted by the activities. The capital base is equally comprehensive, considering the produced, natural, human, and social capitals mentioned in the first chapter of this study. The third and final guiding principle of the Assessment Framework refers to *inclusion*, which means supporting diverse forms of assessment. The TEEBAgriFood recognizes that it is neither feasible nor appropriate to analyses all aspects of human well-being in monetary terms. Thus, other forms of valuation in qualitative terms are encouraged. Following this premise that this research seeks to identify "relational values", in which nature and agriculture play a central role in cultural and social processes, such as: sense of belonging, cultural identity, sociability, and social cohesion (PASCUAL, 2017).

It is important to stress that this analytical effort was designed to compare and contrast each case study's performance in the light of the TEEBAgriFood Framework, identifying their standout aspects. However, given the focus of the research on urban and periurban agriculture, the analysis did not cover all the aspects that define an eco-agri-food system, focusing on the value chains links related to agricultural production and commercialization. That is, the analysis did not go into more detail as regards the links of distribution, consumption and waste. The structure of the Assessment Framework adapted for this research is detailed below (*Table 2*), highlighting the elements analyzed i in the scope (blue) and not included (gray).

Table 2 - TEEBAgrifood Assessment Framework applied on study cases. [25]

			Value Chain			
			Agricultural production	Processing	Distribution and commercialization	Household Consumption
STOCKS/ OUTCOMES (change in capital stock)	Natural capital	Water				
		Soil				
		Air				
		Vegetation cover and habitat quality				
		Agrobiodiversity				
	Produced capital	Buildings				
		Machinery and equipment				
		Infrastructure				
		Research and Development				
		Financing				
	Human capital	Education/skills				
		Health				
		Working conditions				
	Social capital	Land access/tenure				
		Food security				
		Opportunity for empowerment				
		Social Cooperation				
		Institutional strength				
		Laws and regulations				
Flows	Agricultural and food outputs	Agricultural and food products				
		Income: value added, operating surplus				
		Subsidies, taxes and interest				
	Purchased Inputs	Labour inputs				
		Intermediate consumption (produced inputs such as water, energy, fertilizers, pesticides, animal health and veterinary inputs)				
	Ecosystem Services	Provisioning				
		Regulation				
		Cultural				
	Residuals	Agricultural and food waste				
		Greenhouse gas emissions				
		Other emissions to air, soil and water				
		Wastewater				
		Solid waste and other residuals				

[25] Adapted from TEEB (2018).

In addition, the CSs correspond to four different types of urban and periurban agriculture in the metropolis of São Paulo, as proposed by Escolhas; URBEM (2020), enabling the aspects of the different agriculture typologies present in the MRSP to be related to ecosystem services provisioning. The authors suggest a typology of UPA designed to capture elements of the heterogeneity of practices their links to the food market in the territory, with some previously selected criteria. The typology of UPA in the MRSP was elaborated from a set of quantitative (Brazilian Census of Agriculture) and qualitative data, from specialized literature on the subject, and from the mapping of 90 cases throughout the metropolitan area. These cases were categorized according to ten criteria, which were previously selected based on the literature reviewed, according to FAO's *World Agriculture Watch*.[26] The variables for each criterion were adapted according to the concepts and institutional parameters of Brazilian public policies, such as the concepts of "fiscal module", in the case of the scale of the establishments, "organic agriculture", and "family agriculture".

The survey was conducted via bibliographic databases (the CAPES Publication Portal; Scielo; FGV Digital Library; the "Brazilian Horticultural Association Magazine" and the "Bota na Mesa" [Put it on the table] project from FGVCes)[27]; in the city halls of the MRSP municipalities where the agricultural and livestock sector is more prominent (Salesópolis, Mogi das Cruzes, Suzano, Biritiba-Mirim and Cotia); in collaborative maps prepared and disseminated by organized civil society (MUDA Map; the Southeast and South Map of Community Gardens and of Organic Producers; and the Map of Urban Gardens of ABC Paulista)[28]; and in the database of the *Projeto Ligue os Pontos* [Connect the Dots Project] from São Paulo City Hall. Websites consulted included those of the Organic Agriculture Association (AAO - acronym in Portuguese), the Campinas Association of Natural Agriculture (ANC - acronym in Portuguese), the Association of Producers and Distributors of Horticultural Products of the State of São Paulo (APHORTESP - acronym in Portuguese), the Brazilian Association of Producers and Exporters of Fruit and Derivatives (ABRAFRUTAS - acronym in Portuguese) and the Brazilian Institute of Horticulture (IBRAHORT - acronym in Portuguese), as well as the National Register of Organic Producers (NROP, June 2020) from the Ministry of Agriculture, Livestock and Supply (MALS).[29] Finally, the research also used the Google search tool with the following keywords: cooperative plus the municipality name; producer/farmer association plus the municipality name; community/urban garden plus the municipality name (ESCOLHAS; URBEM, 2020). Table 3 presents the variables used to construct the typological framework, as well as the resulting types of agriculture. It is worth noting that the nine designated types should be interpreted as approximations that synthesize categories related to complex social and economic processes, that do not represent closed categories.

[26] Nine articles were consulted that propose typologies for urban and periurban agriculture, of which three are dedicated to analyzing experiences in the municipality of São Paulo. For consultation, the referenced articles and the considerations of the World Agriculture Watch used in the construction of the proposed typology are systematized in Table 2 of Escolhas; URBEM (2020), along with more details about the development of the typology.

[27] The original names in Portuguese of the bibliographic databases consulted are: Portal de Periódicos da CAPES; Scielo; Biblioteca Digital da FGV; Revista da Associação Brasileira de Horticultura

[28] The original names in Portuguese of the organized civil society entities who produced collaborative maps are: Mapa Sudeste e Sul de Hortas Comunitárias e de Produtores Orgânicos; Mapa de Hortas Urbanas do ABC Paulista.

[29] The original names in Portuguese of the associations whose websites were consulted are: Associação da Agricultura Orgânica (AAO), Associação de Agricultura Natural de Campinas (ANC), Associação dos Produtores e Distribuidores de Hortifrúti do Estado de São Paulo (Aphortesp), Associação Brasileira dos Produtores e Exportadores de Frutas e Derivados (Abrafrutas), Instituto Brasileiro de Horticultura (Ibrahort), Cadastro Nacional de Produtores Orgânicos (CNPO, junho de 2020) do Ministério da Agricultura Pecuária e Abastecimento (MAPA).

Table 3 - Typology of urban and periurban agriculture in MRSP proposed by ESCOLHAS; URBEM (2020).[30]

Location	Main function	Market engagement and commercialization	Employment of Technologies	Associativism	Establishment scale	Main production	Main labour	Typology
On the fringes or outside the urban area	Predominantly commercial	High, mostly long circuits	High	Higher degree - associations, unions and cooperatives	Average and large property	Livestock, forestry, horticulture	Contracted > Family	Medium and large-scale commercial agriculture
					Small landholding or property	Horticulture	Contracted > Family	Small-scale Commercial Agriculture
							Family > Contracted	Commercial family farming
	Commercial and private consumption	Medium, short circuits	Low	Lowest degree	Small landholding or property	Horticulture, Livestock	Family > Contracted	Multifunctional agriculture
Within the urban area	Commercial and private consumption	Medium, short circuits	Low	Higher degree - Associations, NGOs	Urban plot	Horticulture, Small-scale livestock	Family > Contracted	Multifunctional Urban Agriculture
	Commercial	High, short circuits	Highest	Not applicable	Urban plot	Horticulture	Contracted	Vertical Urban Farm
	Private consumption, educational, community activities and activism	Not in the market	Low	Highest Degree - Collectives	Gardens and flowerbeds, public and private areas	Horticulture	Community, institutional, contracted and voluntary	Institutional gardens
								Productive Farms
								Community gardens

Of the 90 experiences surveyed, 44 are located within the urban area and 46 are outside it.[31] Of the initiatives located within the urban fabric, 13 were characterized as *institutional gardens,* 15 as *community gardens*, 15 as *multifunctional urban agriculture,* and one as a *productive backyard*. Of the 46 initiatives located outside the urban fabric, 10 are *medium and large-scale commercial farming* specializing in conventional horticulture, 13 *multifunctional farming* initiatives, and 23 *small-scale commercial farming* or *commercial family farming*, since it was not possible to distinguish between the categories of family or employer for all the small-scale cases surveyed.

The four CS analyzed were selected through the survey described above. 36 establishments were contacted that had either provided access information (e-mail and/or telephone) or were accessed through referrals from researchers and professionals working in the region. Of these, ten farmers (predominant activity in the MRSP) were available to participate in semi-structured interviews, comprising the following types of agriculture: (i) medium and large-scale commercial farming; (ii) small-scale commercial farming; (iii) commercial family farming; (iv) multifunctional farming; (v) multifunctional urban farming.[32] All interviewed farmers were then invited to participate in the second round of data collection for the development of economic-financial models, the object of analysis in the previous study (ESCOLHAS; URBEM, 2020).[33] Four CS were modeled, which are also analyzed in this study.

[30] Escolhas; URBEM, 2020.

[31] The municipalities included were: Arujá, Biritiba-Mirim, Cajamar, Cotia, Diadema, Embu das Artes, Embu-Guaçu, Franco da Rocha, Guararema, Guarulhos, Juquitiba, Mogi das Cruzes, Salesópolis, Santo André, Santa Isabel, São Bernardo do Campo, São Lourenço da Serra, São Paulo, and Suzano.

[32] It is important to emphasize that, both in this research and in the typology reference in question (Escolhas; URBEM, 2020), the notion of multifunctionality of urban agriculture is not restricted to the two types "multifunctional agriculture" and "multifunctional urban agriculture". The choice of the term "multifunctional" to designate them aims, in the context of an economic analysis, to make explicit other elements that constitute these experiences beyond their relation to commercialization.

[33] More detail about the semi-structured interviews and the economic-financial models is found in Chapter 5 and Appendices 2 and 3 of Escolhas; URBEM (2020).

Similar to the typology earlier described, the case studies are not intended to exhaust the heterogeneity of UPA in the Greater São Paulo Metropolitan Area, but rather to promote a deeper examination of how natural, human, produced, and social capital are mobilized in each productive system, generating impacts (positive and negative) on the provision of ecosystem services. In addition to complementing the quantitative analysis carried out through the biophysical assessment of ecosystem services, the assessment of the CS subsidized the inclusion of cultural services and the service of waste incorporation in the study.

The interview script briefly covered the farmer's history and daily life, the crops produced, farm management and administration processes, the characteristics of the establishment, natural resources, and also the impacts of the pandemic on the farmer's activity. The elements identified in the case studies used for the selection of biophysical parameters for the ecosystem services assessment are detailed in the last topic of Step 4.

Table 4 systematizes the collection of information from farmers within the scope of the study conducted by Escolhas; URBEM (2020).

Table 4 - Profile of farmers interviewed as presented in ESCOLHAS; URBEM (2020).[34]

Case Study	1	2	3	4
Date of interview	16/7/2020	13/7/2020	16/7/2020	1/7/2020
Type	Medium and large-scale commercial agriculture	Commercial family farming	Multifunctional agriculture	Urban multifunctional agriculture
Municipality	Embu-Guaçu	Itapecerica da Serra	Mogi das Cruzes	São Paulo
Location	Urban fringe	Urban fringe	Urban fringe	Intraurban
Establishment scale	Medium property	Small property	Small landholding	Urban plot
Main production	Horticulture	Horticulture	Horticulture	Horticulture
Main labour power	Contractor	Family	Family	Family

It is important to mention that, with the exception of one case, all cases are practitioners of organic agriculture, making up the largest representation in the study. In any case, although proportionally corresponding to the smallest fraction of establishments in the MRSP (7.5% of the total MRSP, alongside 44% of establishments that declare the use of pesticides), it is the production system best suited to environmental regulations in the MRSP (ESCOLHAS; URBEM, 2020), as well as the model that presents the best environmental performance in the construction of sustainable food systems (FRANCIS *et al*, 2008; ALTIERI, 2009; CHAPPELL; LAVALLE, 2009; ALTIERI *et al*., 2012).

Step 3 - Information demands and methods

In this section, the data and methods for assessing ecosystem services are presented, including their biophysical modeling and proxy. With the exception of the food supply service, where an indicator of production per area is proposed, all other services are assessed using biophysical modeling from the *Integrated Valuation of Ecosystem Services and Tradeoffs* (InVEST). InVEST is a set of models used to map and evaluate ecosystem services, allowing one to explore how changes in ecosystems can lead

[34] Authors' elaboration.

to changes in the flows of different benefits to people (NATURAL CAPITAL, 2021).[35] This platform features various biophysical modeling options designed to facilitate the incorporation of nature´s value by decision makers, civil society, and private enterprise. The models reliability is attested in different publications (TEEB, 2018; LATAWIEC, 2018; OZMENT, 2018) and also from a comparative perspective with other methods (LEHMANN, 2015; BAGSTAD, 2013; POLASKY, 2011).

Spatially explicit biophysical modeling helps to assess how the characteristics of land use, and changes made to these, can impact ecosystems and society at large. Such models can serve as key inputs for the assessment of natural capital and ecosystem services related to agriculture, enabling their inclusion in decision making. Spatial data allow visualization through maps, graphs, diagrams, and tables, composing a perspective on ecosystem functions and services within a specific territory (TEEB, 2018, p. 277). It is important to clarify that this quantification exercise is restricted to an instrumental view of nature, in which it is seen as a means to satisfy human needs and preferences (PASCUAL, 2017).

It is noteworthy that, among the biophysical models adopted, there is a difference both in the period of their refinement and in the number of applications already carried out. For the water yield and erosion regulation models, there is a large amount of information, with research that partially includes the MRSP (DIB *et al*., 2020; OZMENT *et al*., 2018). The specifically urban ecosystem services modeling (flood and heat mitigation), on the other hand, are more recent, with fewer publications and applications (SHARP, 2020). Thus, in addition to the inherent limitations of each biophysical model, indicated by the developers themselves, there are also restrictions regarding the data availability, due to the heterogeneity of the UPA and its territory, which will be identified throughout the research.

The modeling adopted in this research complies with the criteria of allowing open access, requesting available data, and presenting reliability in the results (BAGSTAD *et al*., 2013), as well as being suitable to the scope and timeline of the study. Thus, feasible tools were explored that enable nature's different values to be incorporated into decision making (HAMEL *et al*., 2019; LEVREL *et al.,* 2017; CABRAL *et al.,* 2016). The emerging evidence on the contribution of UPA to ecosystem services provisioning can serve as input when analyzing the impact of programs to promote this practice, establish priority lines of actions and, more broadly, contribute to strengthening the dialogue with environmental and urban development policies.

Table 5 lists these services, according to the system adopted by the Common International Classification of Ecosystem Services (CICES, 2019),[36] presenting the indicators used and the biophysical modeling employed. The modeling´s limitations are based on the information provided by the developers themselves (SHARP, 2020) or on studies that have made use of the same proxy for food provision (HAMEL *et al.,* 2019; LEVREL et *al.,* 2017; CABRAL *et al*., 2016).

[35] For more information on InVEST with other ecosystem services that can potentially be modeled: https://naturalcapitalproject.stanford.edu/software/invest. Accessed on: 27 April 2021.

[36] As mentioned in the previous chapter, CICES aims to present a classification of ecosystem services designed to facilitate an understanding of how to measure, analyze, and compare them. The main categories of ecosystem services are provisioning, regulating, and cultural. For more information: https://cices.eu/. Accessed on: 23 October 2020.

Table 5 - Ecosystem services considered in this research and the methods used for their assessment.[37]

Ecosystem Service	CICES (5.1)	Indicator (unit)	Evaluation method	Description	Limitations	Data Request
Erosion regulation	2.2.1.1 Control of erosion rates	Sediment retention, ton/year	Sediment Retention Model - InVEST	It maps the location and amount of erosion produced in a watershed and the amount of sediment reaching waterways.	Based on annual soil loss, it considers only rill/inter-rill erosion processes	Land use map; digital elevation model; rainfall erosivity index; soil erodibility; watershed boundaries; drainage network map; threshold flow accumulation; calibration parameters; P and C factors for each land use class.
Water Yield	4.2.1.1 Surface water for drinking	Realized water supply, m^3/year	Annual Water Yield - InVEST	It calculates the average annual amount of water produced in a drainage basin and assesses fresh water production.	It is based on the average annual precipitation, and does not consider seasonality, groundwater recharge, or the water cycle (after the export of moisture to the atmosphere).	Land use map; root restriction layer depth; average annual precipitation map; plant available water content; potential annual evapotranspiration; Z parameter; watersheds boundaries; average annual reference evapotranspiration; maximum root depth and Plant evapotranspiration coefficient (Kc) for each land use class.
Heat Mitigation	2.2.6.2 Regulation of temperature and humidity, including ventilation and transpiration	Urban heat mitigation index, no unit	Urban Cooling Model - InVEST	It estimates the heat reduction provided by green areas in cities.	There are not yet enough applications to ensure that standard climate parameters used are applicable to tropical conditions.	Land use map; reference evapotranspiration; green area maximum cooling distance; baseline air temperature; magnitude of the urban heat island effect; air temperature maximum blending distance; coefficient of the shade, albedo and evapotranspiration for each land use class.
Flood Mitigation	2.2.1.3 Hydrological cycle and water flow regulation (Including flood control, and coastal protection)	Runoff retention, m^3	Urban Flood Risk Mitigation Model - InVEST	It calculates the reduction in stormwater runoff provided by green areas.	Based on specific precipitation events that are higher in intensity. It does not reflect a possible prior accumulation of water caused by a sequence of rains.	Land use map; watersheds boundaries; depth of rainfall (mm); map of the hydrological group of soils;; runoff coefficient for each land use class and soil hydrological groups.
Food supply	1.1.1.1 Cultivated terrestrial plants grown for nutritional purposes	Total area of agricultural and livestock production, ha	Area Count Available for agriculture and pasture	The total area of agricultural and pasture is used as a proxy for the area of food production.	This proxy does not reflect the true area devoted to agricultural and livestock production, having limitations to capture the heterogeneity of land use near cities.	Land use map - agricultural and livestock land use classes (pasture, mosaic of agriculture and pasture, sugarcane, soy, perennial crops, other temporary crops, organic agriculture, agroforestry system).

[37] Authors' elaboration.

For each model described in the following section, a literature review was conducted in order to search for accurate local data, including consultations of the databases of research institutions and official agencies (National Institute of Meteorology, National Water Agency, Brazilian Institute of Geography and Statistics, Brazilian Agricultural Research Corporation)[38].

Step 4 - Evaluation of selected ecosystem services

This section presents in detail how the selected modeling operates and how the data was used to evaluate the five ecosystem services foreseen in the research scope.

Erosion regulation

InVEST's Sediment Delivery Ratio model evaluates the capacity of the landscape to retain sediments in a basin or watershed. The Universal Soil Loss Equation (USLE) is used for this calculation, thus quantifying the potential soil loss:

$$USLE = R * K * LS * C * P$$

in which USLE is the amount of annual soil loss per pixel, R is the rainfall erosivity factor, K is the soil erodibility factor, LS is the slope length-gradient factor, C is the cover-management factor for each land use, and P is a factor that varies according to the type of soil conservation practices employed.

Sediment retention, an indicator describing the ecosystem service, thus corresponds to the difference between the potential soil loss (USLE) of the landscape and the maximum potential soil loss, assuming the bare soil (SHARP *et al*., 2020).

Rainfall erosivity was obtained by the equation proposed by Wishmeier and Smith (1978),

$$R = 67.355 \left(\frac{r^2}{p}\right)^{0.85}$$

where R is the rainfall erosivity, r is the average monthly precipitation (mm) and p is the average annual precipitation (mm). The annual R is given by the sum of the values obtained for each month of the year.[39]

Table 6 describes the variables in the erosion regulation model, as well as the data sources used in the research.

[38] The original names in Portuguese of the databases consulted are: Instituto Nacional de Meteorologia, Agência Nacional das Águas, Instituto Brasileiro de Geografia e Estatística, Empresa Brasileira de Pesquisa Agropecuária.
[39] More information on how the model works can be found at http://releases.naturalcapitalproject.org/invest-userguide/latest/sdr.html. Accessed on: 27 April 2021.

Table 6 - Description of the edaphoclimatic variables and of the land use and land cover variables employed to model the ecosystem service of erosion regulation.[40]

Required data	Description	Source
Digital elevation model	Raster dataset with an elevation value for each cell. [unit: meters].	Obtained from the Geomorphometric Database of Brazil (TOPODATA - http://www.dsr.inpe.br/topodata/), with 30 meters of resolution.
Rainfall erosivity index	This variable depends on the intensity and duration of rainfall in the area of interest. The greater the intensity and duration of the rain storm, the higher the erosion potential. [unit: MJ·mm·(ha·h·year)$^{-1}$]	Data from five meteorological stations in MRSP, registered in the Climatological Normal 1961-1990 (INMET, 1992), were used to perform an interpolation of the erosivity values for MRSP. These calculated values are corroborated in systematic reviews on erosivity for the Southeast Brazil (OLIVEIRA; WENDLAND; NEARING, 2013).
Soil Erodibility	Soil erodibility, K, is a measure of the susceptibility of soil particles to be detached and transported by rainfall and runoff. [unit: tons·ha·h·(ha·MJ·mm)$^{-1}$]	Review of studies in the same hydrographic region (DIB *et al*., 2020; SAAD; ROCHA; SILVA, 2016; SAAD, 2018a)
Land Use Map	Raster data set, with an integer code for each cell.	MapBiomas collection 5 (2020)
Watersheds	Watershed that contribute to the area of interest	Boundaries of the drainage sub-basins in the state of São Paulo (SÃO PAULO, 2013)
Drainage Network Map	Drainage obtained by contour lines from 1:50,000 map.	The state drainage network map was used because it covers the metropolitan region (SÃO PAULO, 2013b).
Threshold flow accumulation	Number of upstream cells that must flow into a cell before it is considered part of a flow.	The value 500 was assumed because it presented greatest similarity to the state drainage network map.
Calibration parameters	Two calibration parameters that determine the shape of the relationship between hydrologic connectivity and sediment delivery rate.	Default values provided by the developers.
C and P factors	Cover management factor [floating point between 0 and 1]; P Factor - support practices factor [floating point between 0 and 1].	For each land use class, the C and P factors were obtained by reviewing the literature (LATAWIEC *et al*., 2018; ROSÁRIO; GUIMARÃES; VIANI, 2019; SAAD *et al.,* 2018; OZMENT et al., 2018; DIB *et al.,* 2020).

In the case studies conducted in this research, the practice of maintaining mulch with tree pruning materials was discovered; as such, the C factor (soil cover management) recommended for this condition (DA SILVA; EDMAR SCHULZ, 2001) was adopted for the land use class "Organic farming". This same factor for the "Agroforestry systems" class was based on specific values (MOSTER, 2018). For the "Mosaic of agriculture and pasture" class, a simple average between values of the other agriculture and pasture classes was adopted.

Water Yield

The InVEST Annual Water Yield Model that was employed simulates the amount of water produced annually within a given hydrographic unit, identifying the contribution of each landscape component and the impacts of eventual changes in land use. This modeling is a relatively simple water balance, as it does not consider interactions with groundwater or water seasonality (SHARP, *et. al*., 2020).

The estimate is made by calculating the difference between the (annual) precipitation and the actual evapotranspiration (Budyko curve), using the following equation:

$$Y(x) = \left(1 - \frac{AET(x)}{P(x)}\right) . P(x)$$

[40] Authors' elaboration.

where Y is water yield for each pixel (x), AET(*x*) is the annual actual evapotranspiration for pixel *x* and P(*x)* is the annual precipitation on pixel *x.*[41]

Table 7 presents the description of the variables in the water yield model, as well as the sources used in the research.

Table 7 - Description of climate variables and land use and land cover variables employed to model the ecosystem service of water yield.[42]

Required Data	Description	Source
Map of the root restriction layer depth	Depth at which root penetration is inhibited due to a physical barrier. Soil depth can be used as a proxy. [unit: millimeters]	Average values were found in the literature reviewed (LATAWIEC, 2018; EMBRAPA, 2006; SAAD; ROCHA; SILVA, 2016).
Average annual precipitation map	A raster dataset with a value other than zero for the average annual precipitation of each cell. [unit: millimeters]	Historical rainfall series 1977-2006 (ANA, 2011).
Map of the Plant Available Water Content	Value of available water content for each cell. The fraction of plant available water content (PAWC) is the fraction of water that can be stored in the soil and which is available for plant use. PAWC ranges from 0 to 1.	For the soil types in the region, these specific parameters were found in the soil sample database (OTTONI, 2018).
Map of the Average Annual Reference Evapotranspiration	It is the potential loss of water from soil by both evaporation and transpiration by a crop (alfalfa) if enough water is available. [unit: millimeters].	Global Reference Evapo-Transpiration (Global-ET0) (TRABUCCO; ZOMER, 2018).
Z Parameter	Consists on the average number of rainy days per year.	It was calculated based on the Climatological Normal 1961-1990 (INMET, 1992), resulting in the value 21.
Watersheds	Watersheds contributing to an area of interest	Boundaries of the sub-watersheds in the state of São Paulo (SÃO PAULO, 2013).
Biophysical parameters for each land use class	Plant evapotranspiration coefficient (Kc): based on the physiological characteristics of the plant to modify the evapotranspiration reference (based on alfalfa). [range 0 to 1.5] Maximum root depth: depth to which 95% of the roots of a given vegetation type are located. [unit: millimeters].	The values of plant evapotranspiration coefficient (Kc) and root depth relative to each land use class were obtained through a literature review of studies conducted in the state of São Paulo (LATAWIEC *et al*., 2018; SAAD; ROCHA; SILVA, 2016; SAAD *et al*., 2018a).

The value of 85.4 m^3/s (FABHAT, 2016) was used for the elaboration of the water consumption thresholds, in which the demand is broken down into 88% domestic, 8% industrial, and 3.7% from agriculture. Based on this proportion, the corresponding volume of water consumed for each pixel *(*m^3/year/pixel) of land use classes in question was assigned: mosaic of agriculture and pasture (64), temporary tillage (64), urban infrastructure (1,014) and organic farming (42). Regarding this last value, a 19% reduction in water consumption was applied, due to the differential in water retention stemming from higher soil organic matter contents in organic agriculture, as compared to conventional agriculture (TEOFILO *et al*., 2012; MAROUELLI, 2010, 2010b, 2006; STONE, MOREIRA, 2000).

Heat Mitigation

The urban heat island phenomenon, i.e. the high difference between rural and urban temperatures, is caused by a change in the energy balance in cities due to two main factors: the thermal properties of materials used in urban areas (e.g. concrete, asphalt), which store more heat, and the reduced cooling effect of vegetation (through shade and evapotranspiration). The InVEST urban cooling model estimates the cooling effect of vegetation based on available climate and land use data (SHARP, 2020).

[41] For more information on how this model works: http://releases.naturalcapitalproject.org/invest-userguide/latest/reservoirhydropowerproduction.html. Accessed on: 27 April 2021.
[42] Adapted from Latawiec et al (2018).

The Urban Cooling Model enables the calculation of a heat mitigation index based on shade, evapotranspiration, albedo (reflection coefficient) and distance from green areas. This equation is as follows:

$$CC = 0.6 * shade + 0.2 * albedo + 0.2 * ETI$$

where CC is the cooling capacity and ETI is the evapotranspiration index. The standard values (0.6; 0.2; 0.2) are based on empirical data that prove the greater impact of shade as compared to evapotranspiration (SHARP, 2020). For green areas above 2 hectares, there is an additional cooling effect on the surroundings, calculated by the distance of the CC values of the green area and the pixel of interest.[43]

To estimate the city-wide heat reduction, the model uses the urban heat island (UHI) magnitude (city scale), UHI_max. This UHI magnitude is defined for a specific period (e.g., current or future climate) and time (e.g., nighttime or daytime temperatures).

The air temperature without air mixing $T_{airnomix}$ is calculated for each pixel as:

$$T_{airnomix,i} = T_{air,ref} + (1 - HM_i) \cdot UHI_{max}$$

where $T_{air,\ ref}$ is the rural reference temperature and UHI_{max} is the magnitude of the UHI effect for the city. Due to air mixing, these temperatures vary spatially. The actual air temperature (with mixing), T_{air}, is derived from $T_{airnomix}$ using a Gaussian function with user-defined *Kernel* radius r.

Table 8 describes the variables in the heat mitigation model, as well as the data sources used.

[43] More information on how this model works can be found at http://releases.naturalcapitalproject.org/invest-userguide/latest/urban_cooling_model.html#. Accessed on: 27 April 2021.

Table 8 - Description of climate variables and land use and land cover variables employed to model the heat mitigation ecosystem service.[44]

Required data	Description	Source
Reference evapotranspiration	It is the potential loss of soil water by both evaporation and transpiration considering a crop (alfalfa) with enough water available. [unit: millimeters].	Global Reference Evapo-Transpiration (Global-ET0) (TRABUCCO; ZOMER, 2018).
Green Area maximum cooling distance	Distance over which urban parks (> 2 ha) will have a cooling effect. [unit: meters]	Standard values provided by the developers (SHARP, 2020).
Baseline air temperature	Rural temperature reference (where the urban heat island effect is not observed) for the period of interest. [unit: degrees Celsius]	For the base temperature in rural areas outside of heat islands, the value of 17ºC was used, a measurement taken in September 2011, daytime (BARROS & LOMBARDO, 2016).
Magnitude of the urban heat island effect	The difference between the rural temperature reference and the maximum observed temperature in the municipality. [unit: degrees Celsius]	Stipulated at 10.1ºC (BARROS & LOMBARDO, 2016).
Air Temperature Maximum Blending Distance	Search radius used to account for the air mixing. [unit: meters]	Standard values provided by the developers (SHARP, 2020).
Biophysical parameters for each land use class	Plant evapotranspiration coefficient (Kc): potential evapotranspiration due to physiological characteristics of the plant [range 0 to 1.5]; Shade: a value between 0 and 1, representing the proportion of tree cover (0 for no trees; 1 for full cover); Albedo: a value between 0 and 1, representing the proportion of solar radiation directly reflected by the land use class.	A literature review was conducted for Kc and Albedo values (ABREU-HARBICH; LABAKI; MATZARAKIS, 2015; ALBUQUERQUE, 2012; BARTESAGHI *et al*., 2018; BÖHMER *et al*., 2005; DEILAMI, 2018; STEWART, 2012), while Shade values were calculated based on the percentage of vegetation canopy cover (SEXTON *et al.,* 2013).

Flood Mitigation

Flooding can originate from different sources, including: riverine, coastal, and stormwater (urban) flooding. Green areas can play a role in mitigating each of these flood types. With respect to those deriving from stormwater, the focus of this InVEST model, green areas operate primarily by reducing runoff production, decreasing surface flows, and creating space for water (in floodplains or basins).

The Urban Flood Risk Mitigation model calculates the reduction in runoff, i.e. the amount of runoff retained per pixel compared to the volume of precipitation. For each land use class and hydrologic soil type, runoff Q (mm) is calculated by the Curve Number method (Soil Conservation Service)[45], by the following equation:

$$Q_{p,i} = \begin{Bmatrix} \frac{(P-\lambda Smax_i)^2}{P+(1-\lambda)Smax_i} if P > \lambda . Smax_i \\ 0 otherwise \end{Bmatrix}$$

where P is the design storm depth (mm), $S_{max,i}$ is the potential retention (mm), and λ . S_{max} is the rainfall depth required to initiate runoff (calculated as a function of curve number) (SHARP et. al., 2020).[46]

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[44] Authors' elaboration.

[45] The Curve Number, developed by the SCS (Soil Conservation Service, 1957), is a simple, widespread, and efficient method for determining the approximate runoff volume of a rainfall event in a region. Although it is designed for a particular rainfall event, the method can be scaled to arrive at annual runoff values. The input data for using this method are few: rainfall amount and curve number (CN). The CN is based on the hydrologic soil class and the land use and land cover of the basin. (ANA, 2018, p. 1).

[46] For more information on the model used, access http://releases.naturalcapitalproject.org/invest-userguide/latest/urban_flood_mitigation.html. Accessed on: April 27, 2021.

S_{max} (calculated in mm) is a function of the curve number,CN, which corresponds to an empirical parameter that depends on land use and soil characteristics:

$$Smax,i = \frac{25400}{CNi} - 254$$

The model then calculates the runoff retention per Ri pixel as:

$$Ri = 1 - \frac{Qp,i}{P}$$

And the runoff retention volume per pixel R_m3i as:

$$R\_m3i = Ri \cdot P \cdot pixel.area \cdot 10^{-3}$$

Table 9 describes the variables in the flood mitigation model, as well as the data sources used in the research.

Table 9 - Description of climate variables and land use and land cover variables employed to model the flood mitigation ecosystem service.[47]

Required data	Description	Source
Watersheds	Watersheds contributing to a research area of interest	Boundaries of the -watersheds of the state of São Paulo (SÃO PAULO, 2013).
Depth of Rainfall	Rainfall volume for which runoff is to be calculated. [units: rain millimeters].	A standard precipitation of 50 mm was adopted, considering this as an increasingly frequent critical event as described for the MRSP, both because of climate change and urban expansion (NOBRE *et al*., 2011; RAIMUNDO; SANSIGOLO; MOLION, 2014; MARENGO, 2020).
Map of the hydrological group of soils	It corresponds to the hydrological type of the soil (A, B, C or D).	Map of the hydrological soil groups of Brazil (ANA, 2018).
Biophysical parameters for each land use class	Runoff coefficient for each hydrological soil group.	Values identified in the literature review on hydrologic soil types and their correspondences with land use classes (TUCCI, 2004, p. 406; MOSTER, 2015).

Food supply

The total area devoted to agriculture provided by MapBiomas (2020) is used as a proxy for the food supply service for both 1985 and 2019. Other research adopts this proxy due to the need to use spatially explicit data (HAMEL *et al*., 2019; LEVREL et *al*., 2017; CABRAL *et al*., 2016). Data from the Survey of Agricultural Production Units of the State of São Paulo (LUPA – acronym in Portuguese, which stands for *Levantamento de Unidades de Produção Agropecuária do Estado de São Paulo*) present greater accuracy in terms of production volume and gross value of production; however, this data does not allow a spatial reading of the landscape due to the fact that it is aggregated by municipalities, a factor that limits the correlation this agricultural production with the adopted categories of agricultural area in the land use map. In order to maintain the spatial-temporal analysis, we chose to adopt the categories related to agricultural and livestock activity from MapBiomas (2020), considering that this indicator is limited to the area available for agricultural and livestock activities designed to supply food, without reflecting the volume or value of production.

[47] Authors' elaboration.

In order to compose this proxy, the following land use classes were considered: pasture, sugarcane, mosaic of agriculture and pasture, perennial crops, soybeans, other temporary crops, organic agriculture, and agroforestry systems.

For the food supply potential of the organic farming land use class, the production (including losses in the distribution system) and consumption thresholds described in Escolhas; URBEM (2020) are used. These thresholds were established by combining different sources: (i) agricultural production census data circumscribed to the MRSP and (ii) data from localized case studies. Subsequently, based on this data, a refinement of production potential was performed for the financial and production modeling of two hypothetical cases of organic agriculture, being a *peri-urban model* and an *urban model*. The food consumption parameter adopted refers to the nutritional portioning of adult meals for the Youth and Adult Education of the National Fund for Education Development. Two portions of vegetables and greens per meal and two meals per day over a year were considered to calculate the number of people supplied (ESCOLHAS; URBEM, 2020). The information is described in Table 10.[48]

Since spatial information on the location of organic farming areas in the MRSP is not available, this qualification of the supply potential is only made in the future scenarios, as will be detailed below.

Table 10 - Productive thresholds and supply potential of urban and periurban agriculture.[49]

Features	Unit	Periurban Model	Urban Model
Total Area	ha	4.55	0.2
Area of forest vegetation	ha	2.55	0
Area with agricultural production	ha	2	0.14
Labour power	people	6	1
Meals/year		483,245	58,844
Persons/year		662	81
Potential supply per unit area	(people/ha/year)	331	576

The spatial and census analyses are based on categories that do not satisfactorily address the specificities of the UPA. The census categorization, which is divided into rural and urban, implies limitations already pointed out in Chapter 1. In order to qualify the food supply potential of organic agriculture, it was necessary to adopt a spatially explicit definition that differentiates the productive activity in urban or periurban areas. Thus, we adopted the Brazilian Institute of Geography and Statistics (IBGE - acronym in Portuguese, which stands for *Instituto Brasileiro de Geografia e Estatística*) Urbanized Areas (2015) spatial criterion, as presented in Figure 3. The agriculture within the urbanized areas (dense or not very dense) were considered as the *urban model*, and the remaining areas were assumed as *peri-urban model* (Table 10). The idea was to translate the organic farming class, either in its urban or peri-urban variants, into a number of productive units with defined supply potential (people/ha/year).

[48] More details can be found in Chapter 2 of the research "Closer than you think: the challenges for food production in the metropolis of São Paulo".
[49] Based on Escolhas; URBEM (2020).

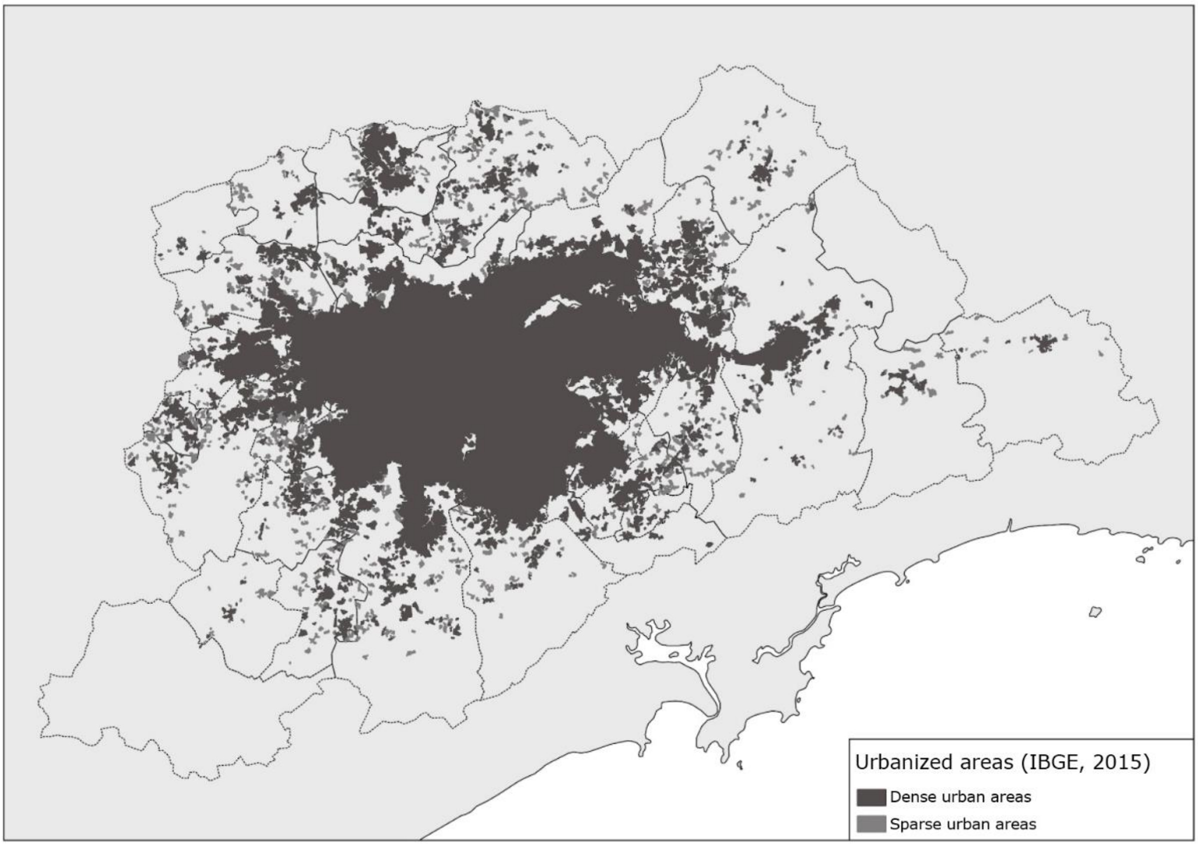

Figure 3 - Urbanized areas in MRSP. [50]

Biophysical parameters related to land use classes

Table 11 presents the biophysical parameters used in the modeling for each land use. These values are the result of a literature review in the InVEST publications database, in which the following criteria were applied to select the studies: 1) explicitly identification of the biophysical parameters, 2) justification of the choice of these parameters, whether by field measurement or by referencing in other publications, and 3) area of interest inside the state of São Paulo, preferably in the metropolitan region.

For the classes of forest formations, urban infrastructure and the mosaic of agriculture and pasture, the parameters found in the literature review were chosen according to the fulfillment of the criteria presented. The InVEST models applied in the research suggest to choose parameters that reflect the reality verified in the field, especially in matter of management options related to agriculture, such as the C and P factors. In these cases, tillage and the absence of mulching and other conservationists’ practices were verified through satellite images for the agriculture classes.

It is important to mention that the parameters used for the erosion regulation and water yield models were reviewed by specialists who applied this type of analysis. In conjunction with the literature review and the verification through satellite images, the four case studies analyzed served as a base for the choice of parameters referring to organic agriculture. The practices and management processes identified in the case studies guided the literature review, in order to obtain the information required to biophysical parameters for organic agriculture land use classes. In comparison with other types of agriculture, organic agriculture differs in having: (i) greater resistance to erosive processes (C factor), due to the maintenance of soil mulch and conservationist practices (P factor), such as terracing and vegetated strips around crops; (ii) lower water consumption, due to better water retention caused by

[50] Adapted based on IBGE (2015).

higher organic matter rate in the soil; and (iii) higher water infiltration rate in the soil, mitigating the surface runoff related to floods (CN).

Although there is no representative for the class of agroforestry systems (AFS) among the case studies — which prevents characterizing its productive potential more precisely —, we chose to include AFS nonetheless because it appears in the Municipal Plan of Conservation and Recovery of Areas Providing Environmental Services (SÃO PAULO, 2020) and it was mentioned by certain stakeholders in the working group. The biophysical parameters of AFS found in the literature presented better soil cover rates (C factor) and shade, which puts them at an advantage over other types of agriculture regarding the provision of erosion regulation and temperature cooling services. Regarding water infiltration, AFS also perform better, followed by organic farming and other temporary crops.

Table 11 - Parameters used in biophysical modeling for land use class.[51]

Land use class	C Facto	P factor	Root depth (mm)	Kc	Shade	Albedo	Green area	CN_A	CN_B	CN_C	CN_D
Forest formation	0,0001	1	4.000	1,1	0,66	0,15	1	30	55	70	77
Forest plantation	0,0080	1	5.000	0,82	0,69	0,15	1	36	60	73	79
Pastoral formation	0,0024	1	2.000	0,9	0,16	0,2	1	30	58	71	78
Other non forest natural formation	0,0024	1	2.000	0,9	0,16	0,2	1	30	58	71	78
Pasture	0,0520	1	5.00	0,75	0,16	0,2	1	30	58	71	78
Annual Farming	0,3500	1	317	0,90	0,17	0,2	1	49	69	79	84
Sugar cane	0,2342	1	1.600	1,02	0,27	0,2	1	49	69	79	84
Mosaic of agriculture and pasture	0,2121	1	875	0,82	0,23	0,2	1	49	69	79	84
Urban Infrastructure	0,1	1	-1	0,45	0,07	0,2	0	83	89	92	93
Other non vegetated area	1	1	-1	0,50	0,09	0,28	0	83	89	92	93
Rocky outcrop	1	1	-1	0,50	0,32	0,25	0	99	99	99	99
Mining	0,9000	1	-1	0,50	0,07	0,28	0	99	99	99	99
River, lake and ocean	0	0	-1	0,90	0,09	0,06	1	99	99	99	99
Perennial crop	0,1300	1	700	0,92	0,69	0,2	1	60	76	85	90
Soybean	0,2158	1	950	0,90	0,41	0,2	1	49	69	79	84
Other temporary crops	0,3500	1	300	1,21	0,17	0,2	1	49	69	79	84
Agroforestry system	0,0250	0.25	500	1,21	0,69	0,2	1	25	55	70	77
Organic farming	0,0750	0.45	2.364	0,92	0,23	0,12	1	36	60	73	79
BIOPHYSICAL MODELS	Erosion regulation										
			Water yield								
				Heat Mitigation							
								Flood Mitigation			

C Factor: soil cover management factor (floating point between 0 and 1); P Factor: soil conservation practices (floating point between 0 and 1); Root depth (mm): depth to which 95% of the roots of a given vegetation type are located; Plant evapotranspiration coefficient (Kc): potential evapotranspiration due to physiological characteristics of the crop (range 0 to 1.5); Shade: a value between 0 and 1, representing the proportion of tree cover (0 for no trees; 1 for full cover); Albedo: a value between 0 and 1, representing the proportion of solar radiation directly reflected by the land use class; Green area: a value of 0 or 1 (1 means that the land use class is considered a green area); The columns CN_A, CN_B, CN_C, CN_D, whose letter suffix corresponds to the hydrological soil group, correspond to the runoff coefficient.

[51] Authors' elaboration.

Step 5 - Delineation of future scenarios: positive and negative aspects of public policy alternatives

Scenarios are representations of possible futures for one or more system components, particularly for drivers of changes in nature and their entailing benefits for people, including policy alternatives and management options (IPBES, 2016). The TEEBAgriFood framework generally focuses on intervention scenarios, i.e., public policy alternatives that have the potential to promote sustainability in eco-agri-food systems (TEEB, 2018) — in this research, a possible expansion of UPA providing ecosystem services.

The development of the future scenarios was an ongoing process throughout all the steps of the study. From the initial stages (Steps 1, 2 and 3 of the TEEBAgriFood framework), different approaches to the scenarios were tested, establishing narratives that expressed different plausible futures. As the research progressed, bringing preliminary results (Step 4), different maps were developed that reflected policy contexts of expansion or retraction of agriculture in the metropolis (Step 5), allowing the identification of marginal changes over time. This resulted in the establishment of comparative analyses pertaining to the potential for ecosystem service provision in each scenario. In this way, scenarios were constantly refined and reshaped during all stages of the research, based on the interaction with WG participants, specialists, and managers.

The scenario parameters were therefore defined based on the research objective, and on the interaction with the social actors involved. Parameters included: selected public policies, drivers and their magnitude in the land use transition, types of agricultural systems to be considered, timeline of the proposed changes, and priority areas for UPA allocation.

The comparison between the gains and losses of environmental services related to UPA was conducted between three temporal horizons: 1985, representing the past, 2019, the present, and 2030, projecting future trends for service provision. This past horizon was adopted due to the availability of LandSat satellite images, used by MapBiomas for the development of land use maps. As for future representations, three future possibilities were considered: (i) the Business as Usual (BAU), considered the baseline in which the patterns of land use and urban development discovered in the last decade are maintained; and (ii) the alternative Scenarios 1 and 2, in which the objective is to evaluate the contribution of an eventual expansion of agriculture in the metropolis, according to different priority areas. In these last two scenarios, two classes of sustainable agriculture were incorporated — organic agriculture and agroforestry systems (AFS). The differences in the evaluation of the ecosystem services in question correspond to the different biophysical performances of each type of agriculture considered. Obviously, other types could compose mosaics of different types of agriculture in Scenarios 1 and 2, but it was necessary to focus on a feasible scope, considering to the two types indicated by key actors and which are also catered for in existing public policies.

The differences among the scenarios (1985, 2019, BAU, Scenarios 1 and 2) are expressed in their respective land use maps, considering the MRSP boundary. Their characteristics and limitations will be detailed below.

Land use maps

There is a difference in the availability of land use maps among the municipalities of the MRSP, which the capital is the area with the most mappings of vegetation and urban areas. It was found that the data covering the entire metropolitan region was either outdated, or had insufficient resolution to distinguish smaller-scale agriculture — as is the case of the land use map produced by IBGE, whose grid is 1 km^2. In the face of such a finding, MapBiomas collection 5 (2020) was adopted, which provides land use maps with 30 m resolution, in addition to temporal coverage from 1985 to 2019. Thus, the spatial analysis in this research capture only agricultural areas exceeding 900 m^2, with limitations for lower agricultural areas, mostly located within the urban fabric.

Even though the MapBiomas land use map benefits from a rigorous supervised automatic classification and from cross-referencing with other reliable bases for creating and validating the final products, there are still some limitations regarding the differentiation between agriculture and pasture classes. This is because Mapbiomas presents a land use classification named “mosaic of agriculture and pasture”, which does not differentiate between the two uses. Therefore, the land use map was corrected by identifying the agriculture areas through satellite images (Google Satellite), until the class “other temporary crops” in the land use map corresponded to the 12,000 hectares of temporary crops declared in the 2016/17 LUPA[52]. Thus, temporary crop areas that had been classified as a “mosaic of agriculture and pasture” and “pasture” could be properly reclassified.

In these spatial databases, there is a limitation to specify the agricultural production systems, which hinders a proper analysis of the crop´s management and its influence in the ecosystem services provisioning. If, on the one hand, the 2019 horizon presents a limitation in indicating whether an agricultural area is organic or conventional, on the other hand, in the land use maps used in the future scenarios, it is possible to work with such distinctions, allocating a certain area to each productive system according to the criteria adopted.

Future land use projections for MRSP

The land use map of 2030 is used as the basis for all future scenarios (BAU, Scenarios 1 and 2). The prediction of future changes in land use was carried using the Land Change Modeler program (TerrSet© 18.31) from the transition patterns observed in the period between 2008 and 2018. This timeline was adopted because it portrays a period of greater stability in population growth (0.97% per year), after the acceleration experienced until the 1980s (4% per year) (BORIN, 2013, based on 1940-2010 Census data). The main vector of change in land use in this period is urbanization, as supported by the literature and sectorial plans (SÃO PAULO, 2020b). It has already been discussed that, in a broader perspective, other vectors have impacted the provision of ecosystem services and biodiversity, as in the case of the expansion of industrial agriculture itself, influenced by changes in consumption patterns and diets. However, in the last thirty years, we have noticed a decrease in agricultural areas around the metropolis, due to the incorporation of areas by urbanization processes (ESCOLHAS; URBEM, 2020). Thus, urbanization was considered as the main vector of land use change, principally occupying areas intended for agricultural activity.

The urbanization vector is composed of different variables, such as: (1) a digital elevation model, (2) a road network (municipal, state and federal) and (3) the distance from urbanization cores. Based on this vector and its variables, a transition sub-model was developed to simulate land use changes based on trends observed in the period (2008-2018). Restrictions to urban growth in Environmental Conservation Unit areas of the three administrative spheres were considered.

The algorithm of this transition sub-model calculates the probability and magnitude of land use transitions and their relationships with these enumerated variables (1, 2 and 3), performing a sequence of tests to increase the accuracy of the results (machine learning). Half the transition samples are reserved for testing and the other half for gauging, according to the adopted algorithm. It is possible to validate the algorithm by comparing the future land use map with an already existing land use map (2019), which enables the detection of possible errors and feeds the iteration process.

[52] As previously stated, LUPA refers to *Levantamento de Unidades de Produção Agropecuária do Estado de São Paulo* [Survey of Agricultural Production Units of the State of São Paulo].

Business as Usual Scenario: Baseline

The final product of the future land use projections is the Business as Usual (or baseline) scenario, where there is no effective policy for strengthening urban and periurban agriculture and where urban growth occurs at the rate observed in areas of agricultural activity. More than pointing out exactly where land use change will occur, the objective of this future land use map is to identify trends, in order to enable reflection on the possible consequences for ecosystem services provisioning. Table 12 details the assumptions adopted for the construction of the BAU scenario.

Table 12 - Business As Usual (BAU) Scenario assumptions.[53]

Scenario	BAU
Assumptions	It follows the trends identified in the 2008-2018 period, with urbanization as the main vector.
Priority Areas	None, it follows the trends identified in the 2008-2018 period, with urbanization as the main vector, except for expansion in environmental protection areas.

Alternative Scenarios 1 and 2: Priority areas for expansion of sustainable urban and periurban agriculture

Using the land use map generated for 2030, Scenarios 1 and 2 represent distinct strategies for strengthening UPA for ecosystem services provisioning. Unlike the BAU, in the alternative scenarios, the priority areas define in which locations of the MRSP the expansion of UPA will occur. UPA was allocated to areas where there are specific socioeconomic and environmental demands, disregarding the Full Protection Environmental Conservation Units (CU)[54]. Other categories of Conservation Units, such as the Environmental Preservation Areas, include in their Management Plans how agriculture zoning can be restricted. Many of these units still do not have such plans, or such zoning is unavailable, which prevents the refinement of this specificity in these scenarios. However, the expansion of UPA occurs only in consolidated agricultural and livestock areas, and not in forested areas, which greatly reduces the probability of violating these environmental restrictions. This same logic applies to other restricted areas, such as any Indigenous Lands existing in the territory.

Figure 4 contains the spatial socioeconomic and environmental indicators used to generate the priority areas for UPA allocation. According to data prepared by Escolhas; URBEM (2020), it was possible to point out the areas where there is lower density of establishments that sell fresh food (butchers, fishmongers, vegetable retailers) and of a mixed nature (supermarket, bakery, restaurant, mini-market, canteen), and that are outside the radius of 1 km of public supply facilities (such as street fairs and open-air markets). The study used the classification of private food establishments from the Mapping of Food Deserts identified in the Annual Social Information Report (2018) in the Metropolitan Region of São Paulo. The density of establishments was calculated based on a hexagonal grid, representing their distribution according to demographic data from the 2010 Demographic Census.[55] By overlapping the location of public supply equipment and food commercialization establishments (Maps A and B in Figure 4), areas of low density of commercial establishments for fresh and mixed products were identified.

By including data on social vulnerability (SEADE, 2013)[56] (Map C in Figure 4), it was possible

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[53] Authors' elaboration.

[54] TN - In Brazilian legislation the environmental protected areas can be of different types, which reflects different restrictions for their uses. The Full Protection Environmental Conservations Units are the most restrictive type, as they aim to fully preserve existing natural resources within their boundaries, without direct human interference or environmental changes.

[55] The data used follow the methodology of the Mapping of Food Deserts in Brazil (CAISAN, 2018) with adjustment for greater granularity. More information is available in Chapter 3 of Escolhas; URBEM, (2020).

[56] The Paulista Index of Social Vulnerability is "a typology that classifies the municipalities of the State of São Paulo

to select areas in which the expansion or strengthening of urban and periurban agriculture could play a distributive role in ensuring food and nutrition security. This adjustment in priority areas aims to reinforce both the food and nutritional security function of urban and periurban agriculture (presented in Chapter 1) and the inclusion principle advocated in TEEB (2018).

Complementarily, other priority areas were considered only in Scenario 2. These include: “mosaic of agriculture and pasture” areas within heat islands with intensity above 4ºC (Map D in Figure 4) (CHAKRABORTY; LEE, 2019); and areas that are morphologically more susceptible to flooding (Map E in Figure 4) (SIURB, 2020). The inclusion of these two other priority areas is designed to address the urban management issues, considering that UPA could provide ecosystem services that contribute to water and microclimate regulation. In sum, these priority areas are where the greatest socio-environmental impact is expected and that can be prioritized by public managers.

Table 13 details the assumptions adopted for the construction of the proposed alternative scenarios.

Table 13 - Assumptions of the alternative scenarios.[57]

Scenario	Scenario 1	Scenario 2
Assumptions	Explore the potential for food supply and ecosystem service provision in areas with a shortage of fresh food supply and high social vulnerability.	Explore urban and periurban agriculture’s potential for food supply and ecosystem service provision based on goals presented in existing public policies for agroecological transition (SÃO PAULO, 2020).
Priority Areas	Areas with low density of fresh food commercialization establishments and with high social vulnerability, distinguishing areas around waterbodies. (Maps A and B in Figure 4)	1) areas with low density of fresh food commercial establishments and high social vulnerability; 2) flood-prone areas; 3) heat islands areas; 4) agroecological transition in existing horticulture areas. (Figure 4)

into social vulnerability groups based on a combination between the demographic and socioeconomic dimensions. Considering a set of variables, this indicator allows for a better identification of the specific factors that produce the deterioration of living conditions in a community, helping to define priorities for assisting the most vulnerable populations”. In total, there are seven categories of vulnerability, ranging from low to high, differentiating areas into urban, rural, and subnormal settlements (Fundação SEADE, 2013, p. 4).

[57] Authors’ elaboration.

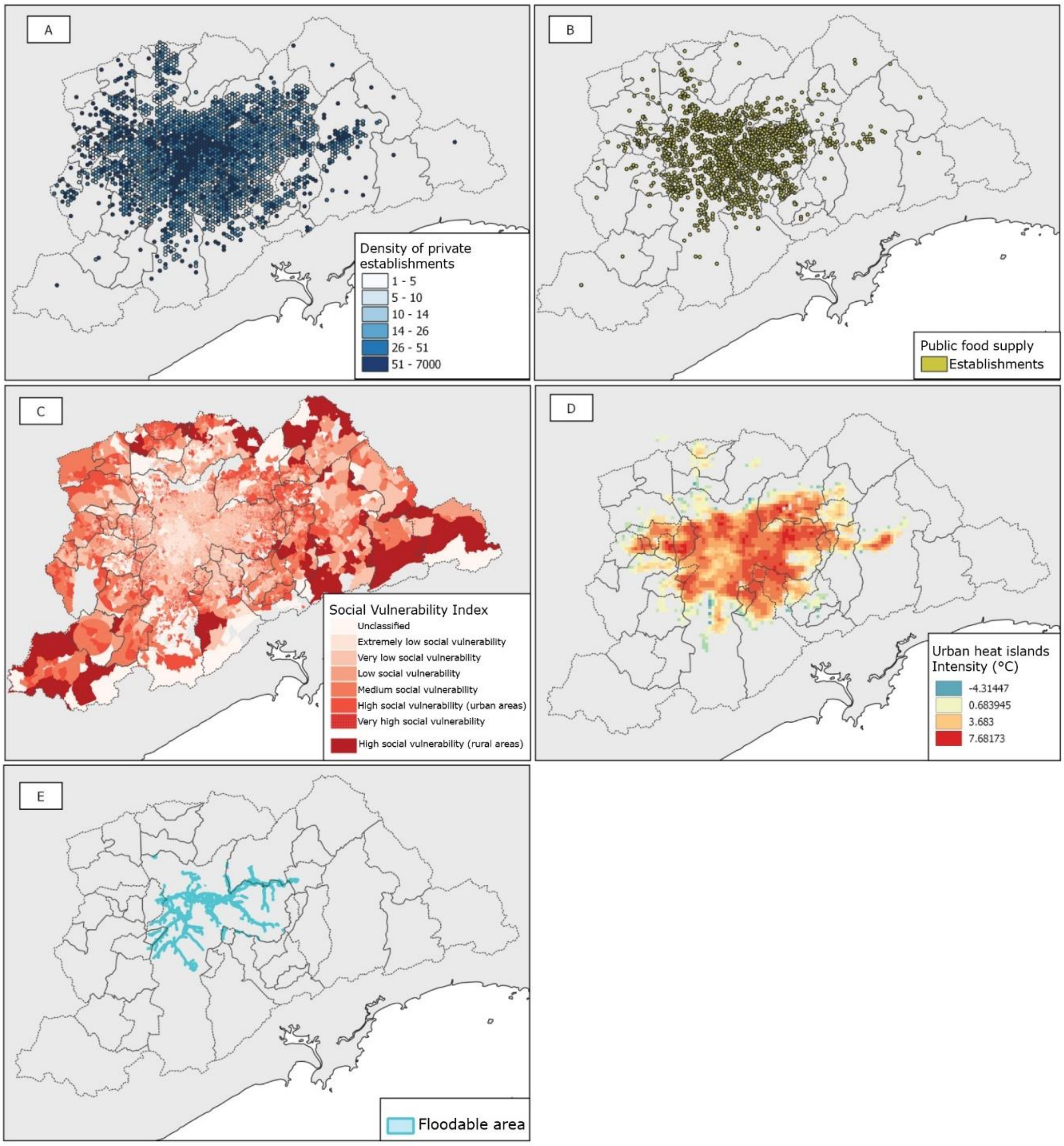

Figure 4 - Definition of priority areas for alternative scenarios. Authors' elaboration. A) map of the density of commercialization establishments of fresh and mixed products per 10,000 inhabitants; B) map of the public equipment for food supply; C) map of the social vulnerability index; D) map of the urban heat islands; E) maps of the areas susceptible to flooding.

Step 6 - Engaging with stakeholders to implement change and generate impact

Step 6 of the TEEBAgriFood framework is to disseminate the results of the research in order to engage decision makers and society more broadly in possible interventions that are favorable to the sustainability of eco-agri-food systems. The research was presented on 21 April 2021 at the TEEBAgriFood Initiative Regional Symposium in Latin America, entitled "Valuing nature for the transformation of food systems".[58] In addition, as mentioned at the beginning of this section, the methodology and preliminary results of the study were presented on different occasions to managers and decision makers. This presentation was also held in working groups and specific meetings, as well as during the discussion about the research in internal events of the TEEBAgrifood Brazil Program, promoted by the UN Environment Programme (UNEP). The publication of the study seeks to instigate reflection on the different interfaces between public policies in which UPA can respond to the demands for food and nutritional security, social inclusion and provision of ecosystem services in the MRSP. The publication of the study also includes an Executive Summary prepared to facilitate its broad dissemination among different audiences.

Limitations of the materials and methods used

The research was based on the adoption of accessible and replicable methods, aiming to assess a comprehensive range of ecosystem services relevant to the urban context. This scope implied choices related to the feasibility and degree of precision of the results.

It is essential to advise that the study did not calibrate the biophysical modeling used, and therefore the results achieved are more demonstrative of trends than absolute values. As such, the research is considered to be of an exploratory nature. Calibration is performed based on specific parameters measured in the field, allowing the results to be gauged according to what is observed in the locality. Even if the parameters used are not measured locally, it is understood that the results between the different types of land use are reliable, allowing a relative (rather than absolute) assessment of the provision of ecosystem services (SHARP, 2020). In this sense, the comparative analysis of the results in relative values (percentage) will be prioritized, and it is important to remember that the values obtained should not be considered absolute, as they may differ from those observed in the field.

To run the erosion regulation and water yield models, the choice of biophysical parameters and all the necessary inputs for modeling were reviewed by specialists, guaranteeing that the information used corresponded to the geographical scope of the research. Regarding the urban models (heat and flood mitigation), which have fewer applications in Brazil, their developers (Natural Capital Project) were consulted to clarify doubts about the application.

Regarding the data used in the model, the main limitation that impacts all results is the resolution of the land use map (MAPBIOMAS, 2020), in which certain areas of UPA (less than 900 m²) are not detected, leaving many community gardens, productive backyards, and orchards out of the ecosystem services assessment.

For the erosion regulation model, important erosive processes are not captured, such as gully erosion and landslide events (SHARP, 2020). In the water supply model, the literature reviewed points out a series of limitations regarding the water cycle. Results of this model frame vegetation as a consumer of available water, a simplification refuted by Brazilian authors, who in turn present evidences

[58] In the original study, the Portuguese title is listed as: "*Proporcionando a valoração da natures para a transformação dos sistemas alimentares*". For more information about the event and the content debated, access: http://teebweb.org/news-and-training/events/teebagrifood-regional-symposia-2021/.

on the dynamics between vegetation and the atmosphere that promote the increase of rainfall in the medium and long term, as well as its importance for water cycle regulation (LATAWIEC *et al.,* 2018; CARDINAEL, 2020; ANDERSON, 2008).

As for the flood mitigation model, the result refers to only one rainfall event, which is an important limitation. The option adopted in this case was the selection of critical events (50 mm rainfall) related to climate change, and which therefore do not reflect the more everyday dimension of floods that is promoted by the accumulation of water caused by sequences of lesser precipitation.

As regards the models that accumulate the most applications in relevant literature (erosion regulation and water yield), information was easily located in public databases. For the urban models, due to their recent development, fewer applications and data are available. Regarding the heat mitigation model, the values for albedo were found within the Southeast region, in relatively few studies and which did not necessarily correlate the values to the land use classes used in this research. This made it necessary to incorporate values found on international literature, as indicated by developers. For the shade parameters, given that no specific literature was available, spatial data on the canopy cover of trees above 5 meters were used (SEXTON *et al*., 2013). Since the model considers trees above 2 meters, there is probably an underestimation of the shade values. For the flood mitigation model, on the other hand, data collection was facilitated by the work conducted by the National Water Agency (NWA), which systematized the hydrological soil groups on a map and correlated them with land use classes (ANA, 2018).

The limitation regarding the proxy used to define the food provisioning service is relevant, since this indicator is circumscribed to land use classes framed as agricultural activities, without reflecting volume or value of production, an effort that was carried out in Escolhas; URBEM (2020) from census data.

Regarding case studies, it is important to highlight the limitations inherent in qualitative approaches, notably their restricted generalization capacity. However, as in Escolhas; URBEM (2020), the choice of cases was based on the set of 90 establishments identified and categorized in the MRSP, understood as typical cases of this context, even though they lack a more comprehensive quantitative analysis. The cases studied exacerbate certain attributes of the typology, such as the greater participation of organic establishments, resulting from organic producers' willingness to participate in interviews. This is in addition to the fact that the case studies do not cover urban agriculture types that do not engage in some form of commercialization. Thus, generalizations are limited and the results of the case studies cannot be extrapolated to the set of agriculture in the metropolis (Idem). The detailing of the case studies should be considered in the time frame in which the information was collected, especially taking into account the impact of the COVID-19 pandemic, always highlighted in the text.

Finally, the relevance of identifying such limitations is reinforced, demonstrating how they condition the results achieved. In this way, the challenges in the interface between UPA and ecosystem services are evidenced in the evaluation methods themselves, allowing for their improvement in future studies considering the specificities of this land use.

Results and discussions

To begin with, the results of the impact and capital dependency analysis will be presented via the four case studies located in the Metropolitan Region of São Paulo. As per the methodology, the interaction with key actors and the case studies analyzed were designed to anchor the ecosystem service assessment to the specificities of UPA in the MRSP. Practices and productive systems identified in the case studies informed the search for specific parameters, which in turn were instrumental in running the biophysical modeling. Finally, the perceptions of key actors were incorporated into the framing of future scenarios.

After the case study section, the assessment of ecosystem services is detailed, focusing on the main land use changes between the years 1985 and 2019. This same assessment is made for future scenarios in 2030. The BAU scenario indicates what the future trends for the same services would be, in the case of an absence of interventions linked to UPA. The last topic presents the results of the alternative scenarios (1 and 2), in which policies to strengthen sustainable UPA, at the metropolitan scale and at the municipal level, are envisaged.

Capital Impacts and Dependence of the UPA: Case Studies

The case studies (CS) were analyzed based on the eco-agri-food systems assessment framework proposed by the TEEBAgriFood initiative and detailed in the methodology chapter of this research. The Framework's three guiding principles inspires the study analysis directly in context and are worth resuming here. In relation to *universality*, as already mentioned, the application of the Framework was specifically directed towards evaluating the production systems of the four CS in the MRSP, without seeking to deepen the analysis of the spheres of distribution, commercialization, and consumption. Thus, regarding *comprehensiveness*, the economic, environmental, and social flows addressed, as well as the analysis of impact and dependency on capitals, are both focused on the production sphere, with some more comprehensive notes about the agri-food chain, such as the use of urban organic waste to prepare inputs and the different forms of commercialization. As for *inclusion*, the valuations elaborated have a mixed character, as they are economic and non-economic.

The following section will contextualize the four CS and then detail the results in terms of the impacts and dependencies of human, social, natural, and produced capital, as well as their influence on ecosystem services flows.

Contextualization of the Case Studies

Following the UPA typology proposed by Escolhas; URBEM (2020) and described in the previous section, the case studies analyzed cover examples of medium and large-scale commercial agriculture (C1), commercial family farming (C2), multifunctional agriculture (C3) and urban multifunctional agriculture (C4). The satellite images of each case study aim to make explicit the territorial context in which each experience is embedded; however, their explicit location is not indicated, avoiding identification of interviewees.

<u>Case Study C1</u>

The first case study comprises two properties located in the periurban area of the municipality of Embu-Guaçu (Figure 5). Together, the two areas total 40 hectares, with 10.8 hectares dedicated to horticultural production and approximately half of the total area occupied by forest cover, described as an environmental protected area ("Legal Reserve" in Brazilian legislation) by the interlocutor. Access to the land was obtained through family succession, in addition to the gradual purchase of a portion of the area. The owner, who manages the activity with his family, also conducts the commercialization, principally involving other businesses.. Besides his family, around fifty employees work in the area.

The production is specialized in horticulture and six specific types of leafy greens. In the early 2000s, the production system was divided into hydroponics and open field cultivation. The management employed is conventional, with increasing use of different agrochemicals, reaching more than 10,000 plants produced per day. The open field is irrigated via sprinklers, while the hydroponics structure has 4,800 m² (0.48 hectare) of greenhouses. The water sources include a stream on the property and a tube well used for hydroponics. The production structure also has tractors, agricultural implements, trucks, and cold storage.

The production flow is conducted through long commercialization circuits, supplying a range of different customers. The owner is a licensee of the São Paulo wholesale produce market (CEAGESP - acronym in Portuguese, which stands for *Companhia de Entrepostos e Armazéns Gerais de São Paulo*). Since a significant portion of customers are restaurants and other businesses, the COVID-19 pandemic has negatively impacted production, which has also suffered from the increase in agricultural inputs prices. Finally, it is worth mentioning that most recommendations for fertilization and pest control are made via the companies that sell the agrochemicals. In terms of social organization, the producer is part of an association of rural producers in the municipality.

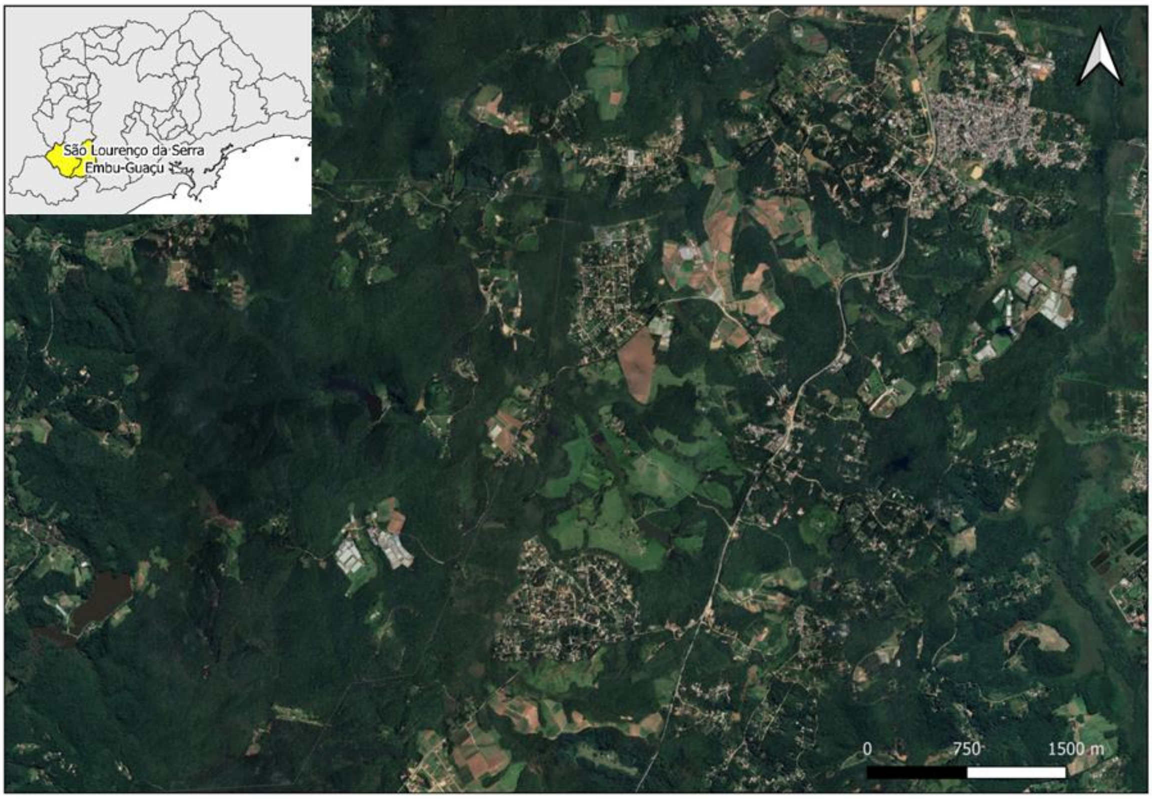

Figure 5 - Satellite image of the surroundings of case study c1. Scale 1:30000.[59]

Case Study C2

The second case study constitutes a farming couple who recently ventured into agricultural production. They are located in a periurban area of the municipality of Itapecerica da Serra, cultivating around 2,500 m² (0.25 hectare) (*Figure 6*). The property has a total area of 8 hectares, with approximately 3 hectares of forested area occupied by RL and Permanent Preservation Area (PPA). The farm, which the couple live on and which they rent, has had no agricultural use for the past thirty years. Farming activities are performed full-time by the farmer and part-time by his wife, who also works

[59] Google Earth, 2021.

in the public sector.

The production is mostly dedicated to horticulture and includes 17 different products. Unlike most producers in the region, who are specialized in hydroponics, the farmer and his wife adopted organic system, despite not being certified or formally recognized. As a consequence of the trust relationships they established with consumers at the produce market where they retail their products, they have managed to set their prices as equivalent to organic produce prices. Besides the organic composting and green manure production performed onsite, the main agricultural inputs purchased are phosphate fertilizers, potassium sulfate and neem oil. The irrigation system is aspersion with water sourced from the spring of the water course that crosses the property. The structure also has a tractor, agricultural implements, a backpack brush cutter, and a cold chamber.

Commercialization is conducted via the municipal farmers' market, and approximately 15% of the production is reserved for the family's private consumption. Seeing as the produce market was not cancelled during the COVID-19 pandemic, there was an increased consumer demand for products. The couple has also participated in organic gardening courses offered by the National Service for Rural Learning and, in addition, they are union members and maintain contact with the Organic Agriculture Association (AAO - acronym in Portuguese).

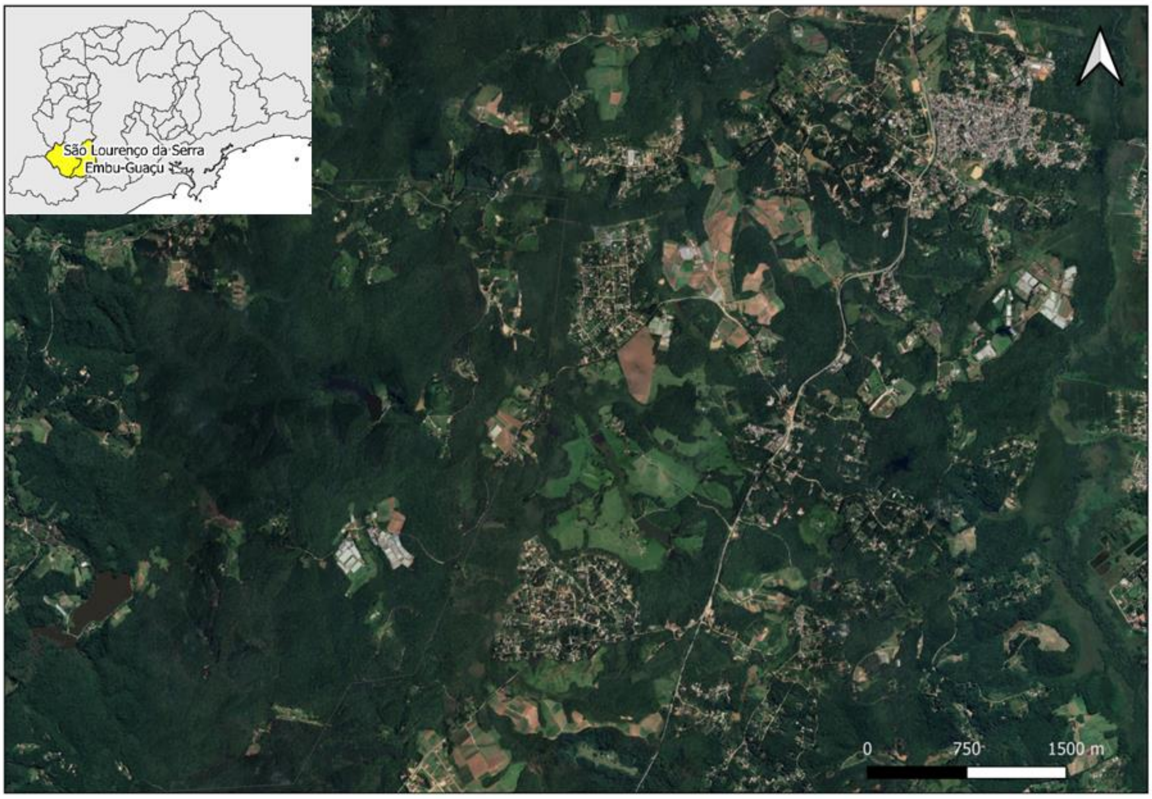

Figure 6 - Satellite image of the surroundings of case study c2. Scale 1:30000.[60]

Case Study C3

The third case study focuses on another couple of farmers, located on the edge of the urbanized sprawl of the Jundiapeba district, in the municipality of Mogi das Cruzes (*Figure 7*). The area totaling 7,500 m² (0.75 hectare) is located in a settlement composed by approximately 320 other families. The couple has lived there since 2000 and cultivates 4,080 m² (0.4 hectare). Both are exclusively dedicated

[60] Google Earth, 2021.

to the activity, and the farmer has recently begun receiving rural retirement benefits. Access to the land was obtained through an agrarian reform program, which is still in the process of land regularization. It is important to mention that being a floodplain area, some plots have watercourses on them, as well as APPs, which is not the case in C3. No information was found about a RL common to the settlement (ANTONACCI, 2018).

Production is mostly devoted to horticulture, although the farmers have an orchard, raise chickens and perform crop rotation in an area where they produce corn for domestic consumption. In all, there are 26 garden beds, with 80% of the seedlings produced on the plot and 20% purchased. The plot also has a natural physical barrier around it to avoid possible contamination of production by the agrochemicals used in neighboring plots. The main input is organic compost made in the production area itself. The plot has a sprinkler irrigation system, with water sourced from a common well and a cistern capable of storing 25,000 liters of water, with the possibility of harvesting rainwater. Located in an alluvial plain, periods of water scarcity are thus faced with a certain tranquility. Regarding the structure, the couple has a small greenhouse for seedling production and a power tiller tractor. The system adopted is organic, recognized via the Social Control Organization (SCO),[61] unlike their neighbors, who specialize in conventional horticulture.

Regarding commercialization, 70% of production is sold through local cooperatives that access the public procurement systems of the PAA - *Programa de Aquisição de Alimentos* [Food Purchase Program] and the PNAE - *Programa Nacional de Alimentação Escolar* [National School Meals Program], and the other 30% through produce markets. Institutional sales are made through one of the two local cooperatives. During the COVID-19 pandemic, there was an impact mainly on deliveries through the PNAE, later compensated by public grant opportunities to secure food for donation. Regarding the weekly produce market in which the couple participates, in the context of the pandemic, consumers began to seek basket of organic products delivery systems directly from the farmers' lots. The couple has family and personal history in agriculture, having improved the techniques of organic production and commercialization via courses provided by the S System.[62]

[61] Law No. 10,831/2003 defines an organic production system and its forms of conformity assessment, comprised of three modalities: third-party certification, via a private entity; participatory certification, via an PCAB (Participatory Conformity Assessment Body); and recognition via an SCO (Social Control Organization), in which organized farmers duly registered in Ministry of Agriculture systemcarry out their verification processes with monitoring by an inspector (LEÃO, 2019).

[62] This is the set of Brazilian corporate entity organizations of focused on professional training, social assistance, consulting, research and technical assistance. The S system comprises the National Service of Industrial Learning (SENAI – acronym in Portuguese, which stands for *Serviço Nacional de Aprendizagem Industrial*); the Trade Social Service (SESC - acronym in Portuguese, which stands for *Serviço Social do Comércio*); the Industry Social Service (SESI - acronym in Portuguese, which stands for *Serviço Nacional da Indústria*); and the National Trade Apprenticeship Service (SENAC - acronym in Portuguese, which stands for *Serviço Nacional de Aprendizagem Comercial*). There is also the National Rural Learning Service (SENAR - acronym in Portuguese, which stands for *Serviço Nacional Aprendizagem Rural*); the National Cooperativism Learning Service (SESCOOP - acronym in Portuguese, which stands for *Serviço Nacional de Aprendizagem do Cooperativismo*), and the Social Transport Service (SEST - acronym in Portuguese, which stands for *Serviço Social do Transporte*). More information at: https://www12.senado.leg.br/noticias/glossario-legislativo/sistema-s.

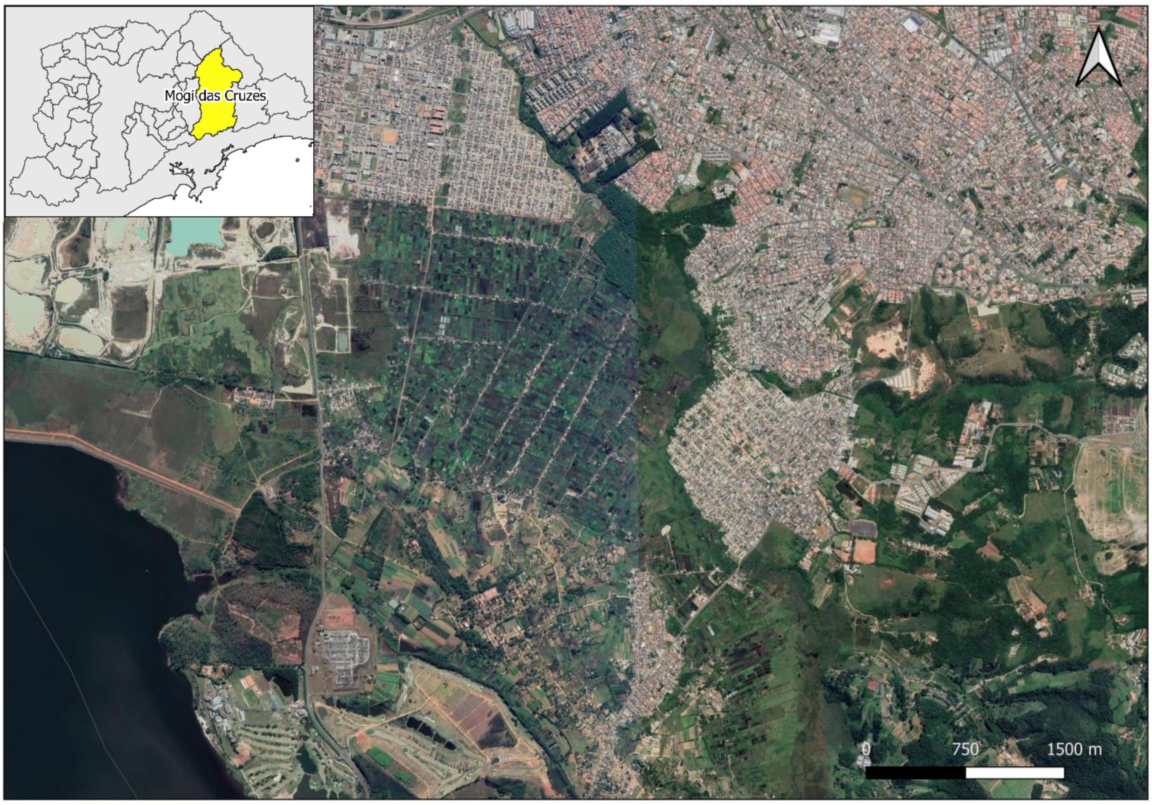

***Figure 7** - Satellite image of the surroundings of case study C3. Scale 1:30000.*[63]

Case Study C4

The fourth and final case study analyzes a farming couple that cultivates an area of 6,000 m² (0.6 hectare) in the corridor under electric power lines in the São Mateus neighborhood, in the São Paulo municipality (*Figure 8*). The production area is located within the urban area and is not the couple's residence. Their involvement in urban agriculture dates back to 2010, and currently the farmers are exclusively dedicated to the activity and to the commercialization of their products and those of other producers in the region. It is important to note the occasional support of a day laborer for the activities of the plot. According to the research interlocutor, it is difficult to find labor in the region willing to perform agricultural production activities on a regular basis at the level of remuneration farmers can afford. Access to the land on which they currently work came about through a local producers' association. To this end, they established a loan agreement with the energy concessionaire responsible for maintaining the area, which currently needs to be updated.

Production specializes in horticulture and includes more than fifty items, including wild edible plants and bananas. The production is organically managed and recognized through an SCO. The main input used is organic compost, made locally from urban, market and household pruning waste, as well as ash collected from bakery ovens. Manure and phosphate fertilizers are periodically purchased. Irrigation is conducted manually and partially by sprinkling, relying on two water sources: the public supply system and, more recently, a semi-artesian well. However, water cost and availability are identified as limiting factors for the expansion, diversification and improvement of the vegetable garden. The 2014 water crisis was a problematic milestone in production, including for the farmers' neighbors, especially due to the increased cost of water via the São Paulo State Basic Sanitation Company

[63] Google Earth, 2021.

(SABESP). As regards the structure, the couple has a greenhouse for seedlings.

Before the COVID-19 pandemic, commercialization was conducted weekly in two local organic produce markets, one in a ceded private commercial area and the other in a public park. Once a month, the couple also participated in a market organized by the Itaquera unit of the Commerce Social Service (SESC - acronym in Portuguese, which stands for *Serviço Social do Comércio*). With the social distancing measures, the farmers' only maintained sales in the store they opened in their place of residence, which required adaptations to delivery systems, besides the participation in donation programs organized by civil society. In addition to the couple, other family members are also consumers of their products.

Although the couple has a background in agriculture, they sought to improve their horticulture techniques via several courses provided by the House of Ecological Agriculture (HEA) at the local city hall, in addition to other courses linked to the municipality of São Paulo and Learning Services provided by the S System.

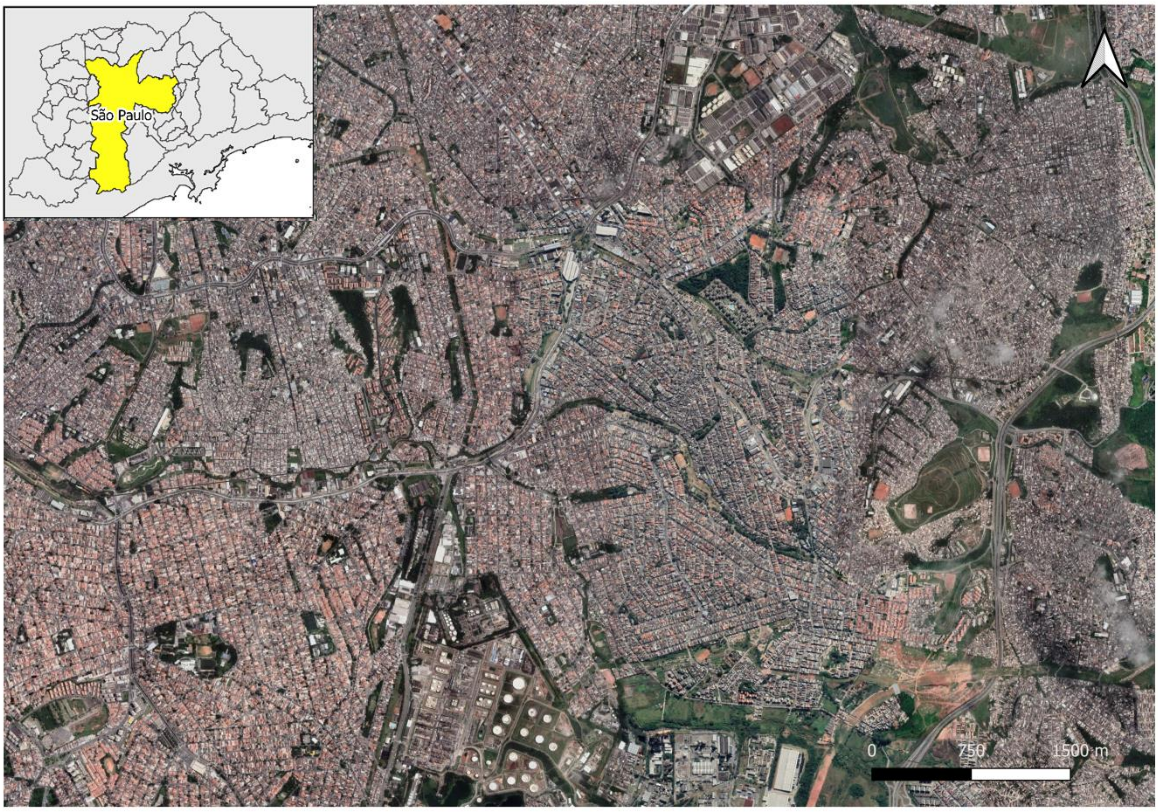

***Figure 8** - Satellite image of the surroundings of case study C4. Scale 1:30000.* [64]

[64] Google Earth, 2021.

Overview table

Table 14 summarizes the profile of each case study, in terms of location, total area, productive area, productive management, farmer experience, market access and land tenure.

Table 14 - Summary of the information collected in the case studies.[65]

Case Study	C1	C2	C3	C4
Location	Periurban	Periurban	Periurban	Urban
Total area	40 ha	8 ha	0.75 ha	0,6 ha
Productive area	10.8 ha	0,25 ha	0,4 ha	0,6 ha
Type of agriculture according to Escolhas; URBEM (2020)	Medium and large-scale commercial agriculture	Commercial family farming	Multifunctional agriculture	Multifunctional urban agriculture

Stocks and flows: analyses of dependencies and impacts of agriculture

As presented in Chapter 1, the TEEBAgriFood approach enables the analysis of visible and invisible dependencies and impacts in terms of human, social, natural and produced capital in eco-agri-food systems. This perspective makes it possible to analyze costs and benefits of certain production and distribution models in social, environmental and economic terms. In this study, the Framework focuses mainly on the agricultural production link and describes: (i) the natural, social and human capitals, as well as inputs and technologies involved in the four CS and (ii) the resulting flows, in which ecosystem services are situated.

Table 15 features a comparative assessment of the capitals and flows involved in the agricultural production process, which can be of a qualitative nature (in green), quantitative (in yellow) or already monetized (in blue).

[65] Authors' elaboration.

Table 15 - Framework for the analysis of capital dependencies, resulting flows and impacts generated for capitals.

EVALUATION OF ECO-AGRI-FOOD SYSTEMS			Agricultural production			
			Case Study 1 (C1)	Case Study 2 (C2)	Case Study 3 (C3)	Case Study 4 (C4)
STOCKS (changes in capitals)	Natural Capital	Water	Stream and tube well (with permit for use)	Water from springs located within the area (with permit for use)	Semi-artisan well and rainwater harvesting (with permit for use)	Common well and treated water
		Soil	Decreased fertility	Fertility is gradually being restored	Soil with high fertility (Escolhas; URBEM, 2020)	Fertility is gradually being restored
		Vegetation cover and habitat quality	50% of the property occupied by native vegetation	37% of the property occupied by native vegetation	17% of the plot occupied by an orchard	No tree cover allowed
		Agrobiodiversity	11 cultures	17 crops	47 crops	50 crops
	Produced capital	Buildings	Shed for machinery	Residence	Residence	-
		Machinery and equipment	Tractors, tractor implements and logistics fleet	Tractor, tractor implements, backpack brush cutter, sprayer	Power Tiller	Manual hose, greenhouse for seedlings
		Infrastructure	4,800 m^2 of greenhouses; sprinkler irrigation structure	Cold room, sprinkler irrigation structure, greenhouse	Sprinkler irrigation structure, greenhouse	Manual irrigation, greenhouse for seedlings
		Subtotal (R$)	564.537	69.900	50.300	38.000
	Human capital	Health	Use of agrochemicals	Use of low toxicity products	Use of low toxicity products	Use of low toxicity products
	Social capital	Land access/tenure	Private	Rent: R$ 1.000/month	Rural settlement	Area granted under high voltage power lines
		Food security (distribution and commercialization)	Sales to intermediaries	Self-consumption; direct sale to consumer	Self-consumption; direct sale to consumers; public procurement	Self-consumption; direct sale to consumer
		Social cooperation (networks/associations)	Association of farmers of the region in the municipality	Rural Syndicate	Cooperative of rural producers in the settlement; SCO	Association of farmers of the region in the municipality; SCO
		Laws and regulations	Rural credit policies	-	Pronaf Aptitude Declaration; PAA; PNAE; Organic Policy	Pronaf Aptitude Declaration; Organic Policy.
FLOWS	Agricultural production	Agricultural products (units/ha/year)	540.740	67.200	88.553	76.000
		Gross income (R$/ha/year)	402.082	354.300	189.000	235.200
	Purchased inputs	Labor inputs (R$/ha/year)	-166,756 (cost)	Family	Family	Family + temporary
		Intermediate consumption (R$/ha/year)	-79.848	-94.560	-6.250	-41.197
	Ecosystem services	Provision, regulation and cultural	Food supply; regulation of climate and the hydrological cycle; erosion control and maintenance of biodiversity	Food supply; maintenance of soil fertility and biodiversity; regulation of climate and the hydrological cycle; erosion control	Food supply; maintenance of soil fertility and biodiversity; regulation of the hydrological cycle; interaction with the natural environment; development of research	Food supply; maintenance of soil fertility and agrobiodiversity; interaction with the natural environment; development of research; environmental education actions

Firstly, in relation to soil management, case study C1 reports a constant decrease in natural fertility due to the continuous use of agrochemicals (ESCOLHAS; URBEM, 2020), requiring greater expenditure on fertilizers for the replacement of nutrients. In the case of hydroponics, the soil (natural capital) is completely replaced by an entire infrastructure of cultivation (produced capital), which tends to artificialize the production process. If, on the one hand, this allows greater productive intensification per unit area, on the other hand, the artificialization implies the waterproofing of the soil through the greenhouse structures. It is important to mention that conventional agriculture management also includes dependence on long chains of mineral fertilizers. Since these fertilizers are water soluble, they represent a potential source of groundwater and drainage basin contamination. In contrast, organic management (C2, C3 and C4) includes practices such as green manuring, mulching, composting and application of slow-release fertilizers,[66] which favor the maintenance of soil fertility and water quality.

Concern about the quality and quantity of water available for agriculture has become more relevant in the MRSP since the water crisis of 2013 and 2014, stimulating the adoption of different strategies to reduce water consumed by irrigation. Among the case studies, two general strategies can be noted: in hydroponics (C1), this reduction results from the adoption of a closed system (with water recirculation), increasing also the efficiency in the application of fertilizers and agrochemicals; for the cases of organic multifunctional agriculture (C3 and C4), the reduction in water consumption occurs by increasing the organic matter content in the soil, by applying mulching, and by stimulating the growth of the root system, by controlling the time between waterings . Both C3 and C4 were impacted by the drought period in question, but they answered in different ways, due to the stocks they have in terms of natural and produced capital. In the case of C3, the water crisis was overcome by relying on the local soil characteristics (located in wetlands), without major impacts on production. For C4, in addition to the increased cost of using water acquired via the public supply system, the shortening of irrigation periods impacted productivity.

Beyond the moments of water stress, hydroponics proves to be more efficient when considering the volume of production per liter of water consumed. The capture and storage of rainwater present in C3 are relevant, since they expand and diversify the sources of supply of this natural capital. In the case of agriculture within the urban fabric (C4), the use of treated water for irrigation proved to be unsustainable due to its entailing costs. Still in relation to water provision, the preservation of springs and watercourses is remarkable in the first two cases (C1 and C2), in which an important portion of the area is covered by native vegetation.[67] This type of vegetation provides support and regulation services of productive processes, which includes the maintenance of biodiversity and the protection of water sources. This vegetation can form ecological corridors and stepping stones,[68] favoring native species. Despite the small size of the C3 and C4 plots, the low-impact organic management, together with the high diversity of cultivated species, makes such systems favorable for biodiversity. Agro-biodiversity is a fundamental part of ecosystem services, and processes such as pollination, biological control of pests and diseases and the nutrients cycling in the soil depend on it, in addition to the preservation of local cultural food habits.

Although C1 has a considerable hydroponic area, where demand for agrochemicals is low, the field horticulture area requires greater application of these products, while in the other three CS, low toxicity inputs are used or obtained internally in the production area. The intensive use of high toxicity agrochemicals incurs indirect impacts on the health of those eating the food produced and, more directly, on the health of farmers and their employees (BURALLI, 2020). In the context of conventional

[66] Both compost (humus) and phosphate fertilizers used by organic farmers only become soluble when humic acids from the soil and roots are in contact, so that nutrients are made available according to plant needs, avoiding leaching processes and eutrophication of groundwater.

[67] This characteristic follows the pattern in MRSP: according to data from the 2017 LUPA, the average production unit has 56% native vegetation (area of natural vegetation, floodplain or reforestation). See Escolhas; URBEM, (2020), p. 73.

[68] The native vegetation in Legal Reserve Areas constitute ecological corridors being defined as strips of vegetation intended to connect forest areas, while the ecological stepping stones configure small islands of natural habitat that, in a set of fragments, make up points of ecological connection (METZGER, 2019).

agriculture, the exacerbated use of agrochemicals, or without respect for safety protocols, affects one of the fundamental stocks of the operation, which is human capital, and can also impact the quality of water and biodiversity, the natural capital. On this issue, data made available by the Brazilian Unified Health System indicate 1,856 notifications of acute intoxication by pesticides in the MRSP between 2007 and 2020,[69] with 119 in 2019, the reference year of the research. The World Health Organization suggests that for each case reported, fifty unreported cases should be calculated (CARNEIRO *et al*., 2012), resulting in an estimate of 5,950 poisonings in 2019 or 29,800 between 2007 and 2020 in the Metropolitan Region of São Paulo. It is also estimated that for every US$ 1 spent on the purchase of agrochemicals, US$ 1.28 are generated with external costs in the health system (SOARES, 2012).

Social capital is decisive in the productive arrangements in cases C3 and C4. In both cases, access to land is the result of a long process of mobilization. Regarding C3, the collective articulations were made with the agrarian reform programs, which involved more than a decade of negotiations. For C4, the mobilizations were geared towards occupying idle land in the city through agriculture, requiring dialogue between public and private sectors, and more specifically with the electricity utility company, although such agreements are outdated. At the production level, the C4 model also provides access to fresh quality food for the surrounding populations, which is recognized as a region of social vulnerability (HDI 0.732),[70] as well as self-consumption by the farmers and their families. With regard to commercialization, the creation of local markets via producer markets or other modalities of short commercialization circuits also occurs through social coordination, involving municipal authorities and organized civil society. In the case of C4, both the concession of the area and the initiative of a local shopping center to provide space for an organic food market also indicate the engagement of the private sector.

The participatory processes of organic conformity assessment also highlight the importance of social capital for the three CS engaged in organic management. In the case of C2, the trust relationships built with consumers in local produce fairs allow the sale of products at a price equivalent to that of organic products, even though the area is still in a process of agroecological transition, and does not yet have access to any of the mechanisms of official recognition of organic production. In the cases of C3 and C4, the social control processes (SCO) on the part of farmers, which are also sanctioned through the trust relationships established between producer and consumer, allow their products to be sold as organic, obtaining advantages in public grant applications. As for the latter, the link with cooperatives and other forms of associativism is fundamental for participation in larger public food purchase programs, such as PNAE and PAA. In contrast, the long commercialization chains show a premium below the viable level in the medium and long term, as exemplified in C1 (ESCOLHAS; URBEM, 2020).

It is worth mentioning that social capital is also expressed via "*mutirões*"[71], sociabilities and the construction of knowledge around agricultural activities. The cultural ecosystem services arising from these agricultural areas feed back into both social capital and human capital through the social benefits generated via these processes. With regard to social capital, school visits, the creation of neighborhood links and the hosting of applied research projects all tend to increase the number of people engaged in short commercialization circuits or other collective forms of support for the practice. Regarding human capital, cases C3 and C4 provide spaces for environmental and food education that are used in formal educational circuits, through school and researcher visits, and informal visits, organized via contact with the local community. Regarding this last issue, the Casas de Agricultura, the S System and the

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[69] Data is available for the years 1978, 1991 and, as of 2006, annually. For more information access: http://tabnet.datasus.gov.br/cgi/tabcgi.exe?sinannet/cnv/Intoxbr.def

[70] At: https://www.prefeitura.sp.gov.br/cidade/secretarias/upload/Informes_Urbanos/29_Dimensoes_IDH-M.pdf. Accessed on: 2 May 2021.

[71] [TN] The term *mutirão* (plural "*mutirões*") stands for different forms of collective mobilization based on mutual aid and joint action that bring people together in order to perform a specific operation in a task-force manner. It originally referred to the reunion of neighbors in rural areas with the objective of carrying out heavier tasks that exceeded an extended family's work possibilities (such as land clearing, harvesting and construction of communal spaces) and now is applied more broadly.

associations that support agriculture play an important role in providing technical assistance and enhancing the value of agricultural activity, strengthening the human capital on which agriculture depends.

Finally, if on the one hand C1 has a greater negative impact on various capitals, on the other, when considering food production, its provisioning capacity is markedly high. Considering the number of units produced per hectare per year, C1's productivity represents almost six times that of those practicing organic agriculture (C2, C3 and C4). It is worth noting that the diversity of food harvested differs between the cases presented, with diversification and self-consumption being strategies for the multifunctional agriculture models (C3 and C4). On the other hand, in terms of gross revenue (R$/ha/year), the same proportion found in units produced per hectare is not perceived. The biggest difference is expressed in the production cost, which, for C1, represents around 75% of its revenue, while for the other cases, it remains around 50%. This higher production cost is justified by the constant increase in the price of external inputs, together with the low prices received for the products, resulting in a critical situation in which the operational profit is negative for the conventional hydroponic producer (ESCOLHAS; URBEM, 2020, p. 119).

Typology of urban and periurban agriculture and ecosystem services

By analyzing the four case studies, it is possible to highlight the main ecosystem services provided by the types of agriculture that the Escolhas; URBEM (2020) study proposed for the metropolis of São Paulo. The resource elaboration of a typological framework for UPA, although contingent upon actual proximity to real experiences, enables the case study data to be extrapolated to other similar experiences. In order to stick to the types of agriculture that correspond to the CS, the elements used in the construction of the typology that generate positive and negative impacts on ecosystem services have thus been applied in a more general sense.

The following elements are highlighted as a result of the analysis of impacts and capital dependence in direct interface with ecosystem services: location, scale, management, use of technologies, and the main labour force. In the following section, the main ecosystem services impacted or favored by the different types of urban and periurban agriculture analyzed in the research are briefly outlined in relation to the landscape and the production system adopted.

Landscape

The location and scale of farms are directly related to the landscape in which they are located and are therefore key components in determining the positive and negative impacts that different types of agriculture can have on ecosystem services. While farming initiatives located in periurban areas have more extensive production areas and must include a portion of vegetation within the establishment, farming experiences within the urban fabric allow greater proximity to the consumer, as well as creating green areas in cities.

In the cases of *medium and large-scale commercial agriculture* and *commercial family farming*, the presence of a Legal Reserve is associated with several ecosystem services. Although this factor is not one of the variables in the construction of the typology proposed by Escolhas; URBEM (2020), it is implicit to the size and presence of watercourses in the establishment, as stipulated in the Forest Code (Law No. 12.651/2012). Native vegetation is able to provide several ecosystem services, such as climate regulation, erosion control, regulation of the hydrological cycle and maintenance of biodiversity. In relation to *multifunctional agriculture*, the cultural service of interaction with the natural environment is mentioned, in the construction of identities and symbologies of the "rural world" and its customs, capable of valuing agricultural activity in its multiple forms. The presence of orchards, common to this type of agriculture, favors climate regulation, regulation of the water cycle and pollination.

For the *urban multifunctional agriculture* experience, its positioning within the urbanized area highlights the services of maintaining biodiversity, even if on a local and small scale, regulating the microclimate and maintaining the water cycle, as well as the incorporation of organic waste. The cultural service of interaction with the natural environment is also satisfied through sociability with the neighborhood, students and researchers who frequent the production area, strengthening social ties, the education of citizens in relation to the environmental agenda and other food-related issues. The development of research, such as this study, is also favored through this type of initiative. In addition, due to its location, it has a strategic position in the food supply.

Production systems

Agricultural management, access to technologies and the type of labor power employed in production are also crucial factors that impact ecosystem services. Due to its technological size, *medium and large-scale commercial agriculture* has a high capacity for food supply. Water consumption tends to be high, while efficient irrigation structures make it possible to save the resource per unit of production. In the case of hydroponics, in relation to other horticultural production systems, the water supply service is positively impacted from the point of view of its availability, due to the reduction in water consumption per unit produced. However, the dependence on the use of agrochemicals negatively impacts this service through the infiltration of highly toxic components that can reach groundwater sources. The same occurs with the soil regulation service, either by the action of pesticides on the organisms that compose it, or by the increasing loss of fertility observed, by the constant tilling of soil.

The type of *commercial family farming* analyzed in this study adopts organic management. Thus, the water supply service is less impacted by the application of low-toxicity inputs, besides being associated with more efficient irrigation technologies. Similarly, the services of maintaining soil fertility and pollination are also favored by organic management. With regard to food supply, the direct route to the consumer provided more stability during disruptions due to the COVID-19 pandemic than in the conventional supply chain. In the cases of *multifunctional agriculture*, urban or otherwise, organic management is associated with the provision of quality food. The services of maintaining agro-biodiversity and soil fertility are linked to product diversity and agroecological pest and disease management. More specifically in relation to the urban experience, the ecosystem service that stands out for its scarcity is water supply. This is due to the restricted access to alternative water sources and water-efficient irrigation structures in the urban environment. Finally, as mentioned in the methodology of the study, this typology-based exercise is not intended to represent the totality of the heterogeneity of urban and periurban agriculture in the metropolis, but rather to emphasize particularities of the experience that are related to the multifunctionality of agriculture.

Evaluation of ecosystem services of urban and periurban agriculture in the MRSP

Based on the practices and management observed in the case studies, it was possible to find biophysical parameters from the literature reviewed that were better adjusted to the local reality, and thus, based on the modeling adopted, evaluate the potential for providing the five ecosystem services (food supply, flood mitigation, heat mitigation, water yield, and erosion regulation) in the metropolis of São Paulo. The results of this assessment are presented through a comparative analysis between different time horizons (1985, 2019, and 2030), and summarized in Figure 9. These variations in provisions will be analyzed in detail in the following sections.

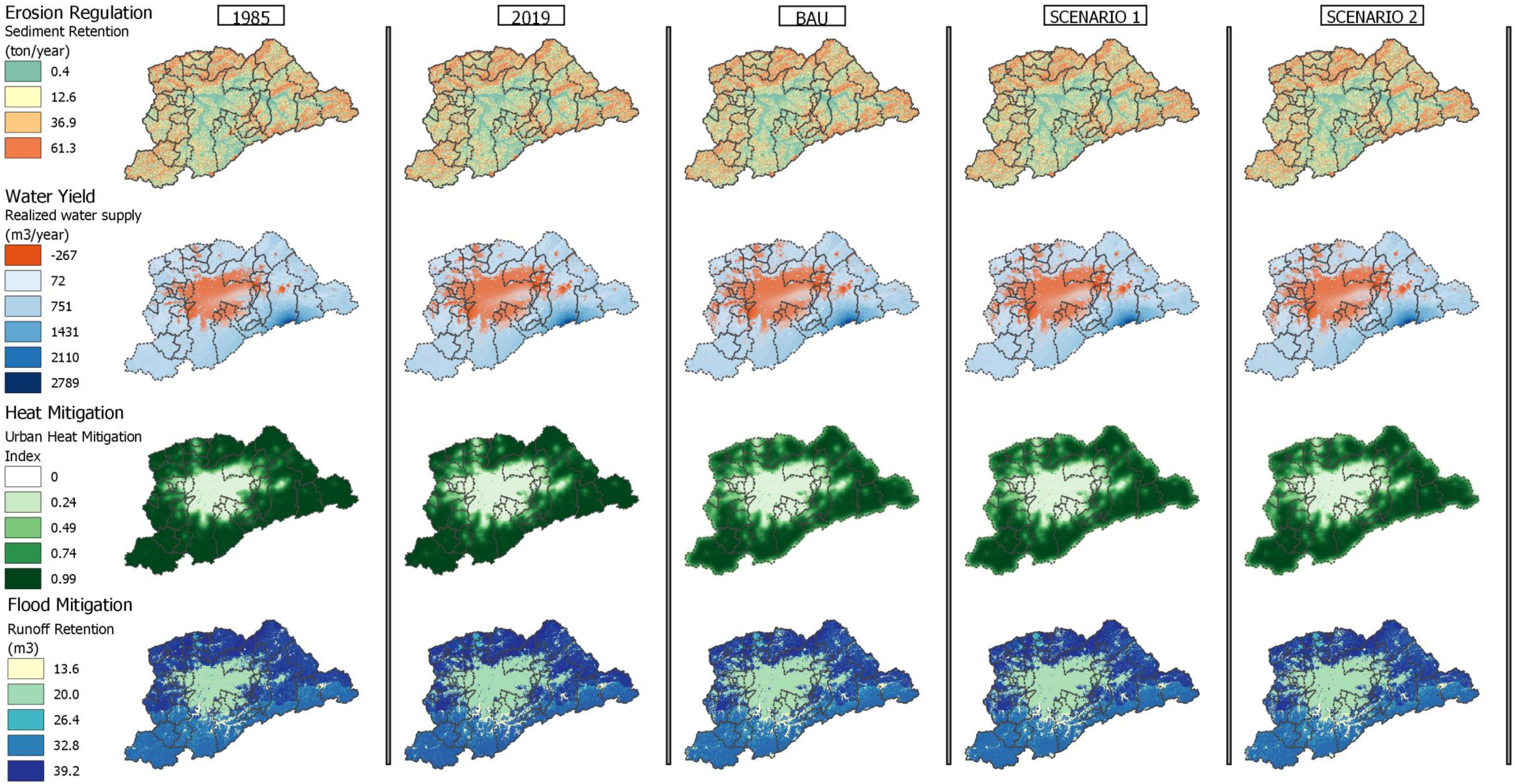


Figure 9 - Map of ecosystem services provision (erosion regulation, water yield, heat mitigation and flood mitigation) in MRSP for scenarios 1985, 2019, and 2030 (BAU, scenarios 1 and 2). Authors' elaboration.

Changes in land use for the Metropolitan Region of São Paulo

The main variable between these different time periods and their respective scenarios is the land use land cover maps. The maps for 1985 and 2019 (*Figures 10 and 11*) are based on MapBiomas (2020). The changes in land use in the period between 1985 and 2019 reflect in changes in ecosystem service provision, in which the dynamics related to the areas of agriculture and pasture are relevant to the present study.

When considering the net change in land use change between 1985 and 2019, the “mosaic of agriculture and pasture” class lost the most area, the equivalent to 31,000 ha, followed by “forest formation” and “pasture”, which lost 13,000 and 10,000 ha respectively, while the “urban infrastructure” class grew by 52,000 ha (*Table 16*). It is possible to track such changes between land use classes, that is, the change from one type of class to another. In Table 16 the vertical axis represents the year 2019, while the horizontal axis represents 1985, and the intersections between the axes represent the magnitude of hectares changed between the classes in question.

In Figure 12, the main land use classes that contributed to the urban expansion (52,000 ha) are distinguished (forest formation, forest plantation, mosaic of agriculture and pasture, pasture), which points to a growth pattern concentrated on the fringes of the metropolis. This data indicates an urban expansion in the municipalities around the São Paulo capital at expense of agriculture and pasture, totaling a reduction of 22% in agricultural areas between the years 1985 and 2019, (ESCOLHAS; URBEM, 2020 p. 34).

Table 16 - Changes in land use between the years 1985 and 2019.

		1985										
	Land use land cover classes	Forest formation	Forest plantation	Pasture	Mosaic Agriculture and pasture	Urban Infrastructure	Other non vegetated areas	Rocky outcrop	Mining	River, lake and ocean	Other temporary crops	**TOTAL (ha)**
2019	Forest formation	324143	532	8182	28618	106	216	3	19	245	132	362363
	Forest plantation	10198	4451	3713	7609	0	1	0	0	1	145	26141
	Pasture	4326	53	22303	7548	14	91	1	46	4	369	34768
	Sugar cane	11	1	1	8	0	0	0	0	0	0	22
	Mosaic Agriculture and pasture	34002	180	27962	75110	132	772	9	221	211	892	139538
	Urban Infrastructure	13303	20	10435	31400	148727	1656	2	257	365	255	206423
	Other non vegetated areas	292	0	176	406	2	170	0	60	21	9	1136
	Rocky outcrop	37	0	1	58	0	3	11	0	0	0	110
	Mining	97	0	44	61	7	7	0	755	6	3	980
	River, lake and ocean	2588	1	82	1294	22	244	4	28	17896	14	22176
	Perennial crop	1	0	0	0	0	0	0	0	0	0	1
	Soybean	9	2	0	26	0	0	0	0	0	14	51
	Other temporary crops	382	3	1351	860	1	8	0	11	2	191	2811
	TOTAL (ha)	389389	5243	74251	152996	149010	3167	30	1399	18751	2026	796519

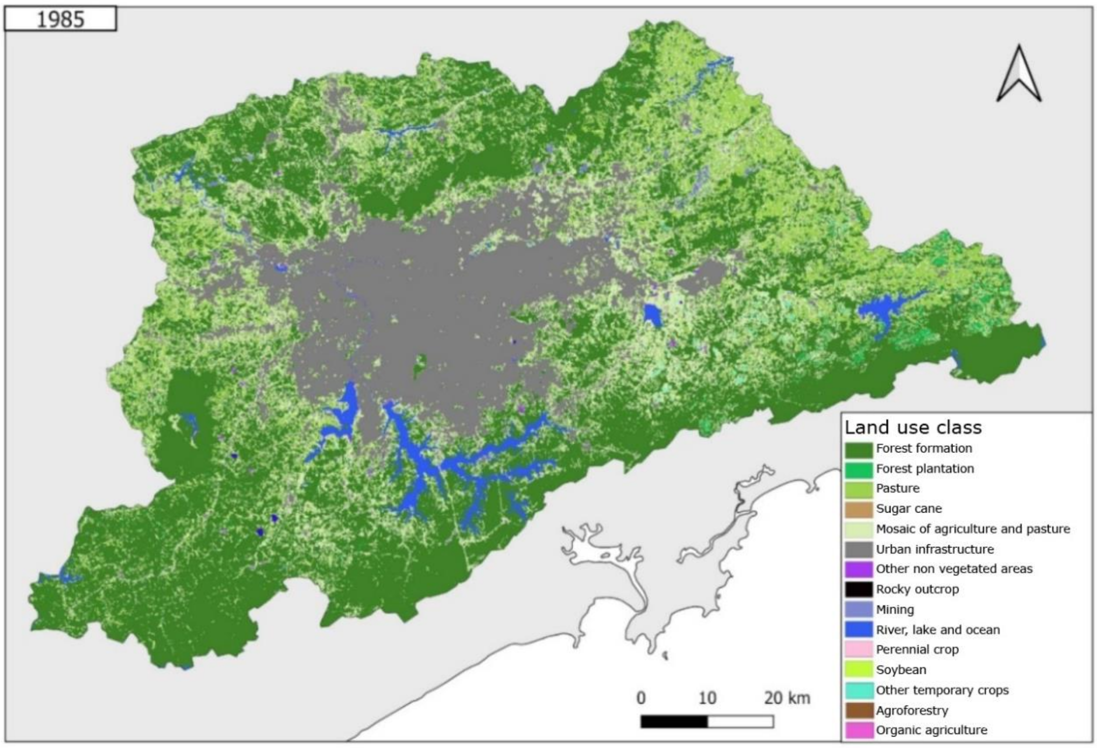


Figure 10 - Land use map of MRSP in 1985. [72]

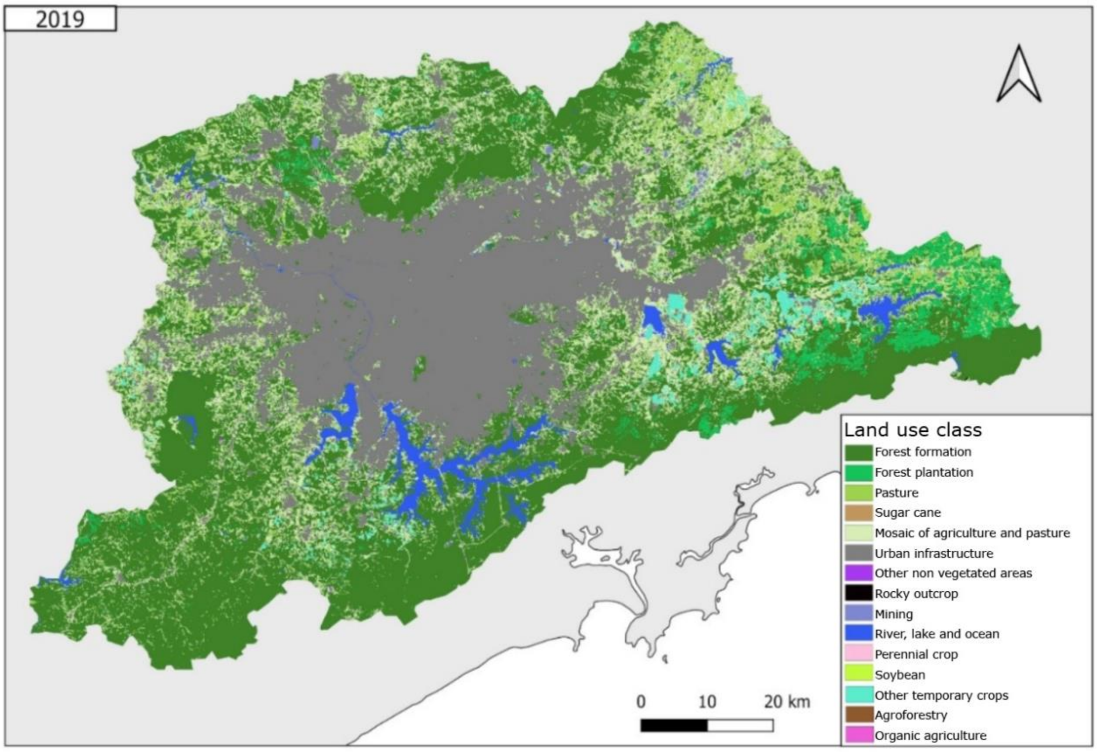


Figure 11 - Land use map of MRSP in 2019. [73]

[72] Adapted based on MapBiomas (2020).
[73] Adapted based on MapBiomas (2020).

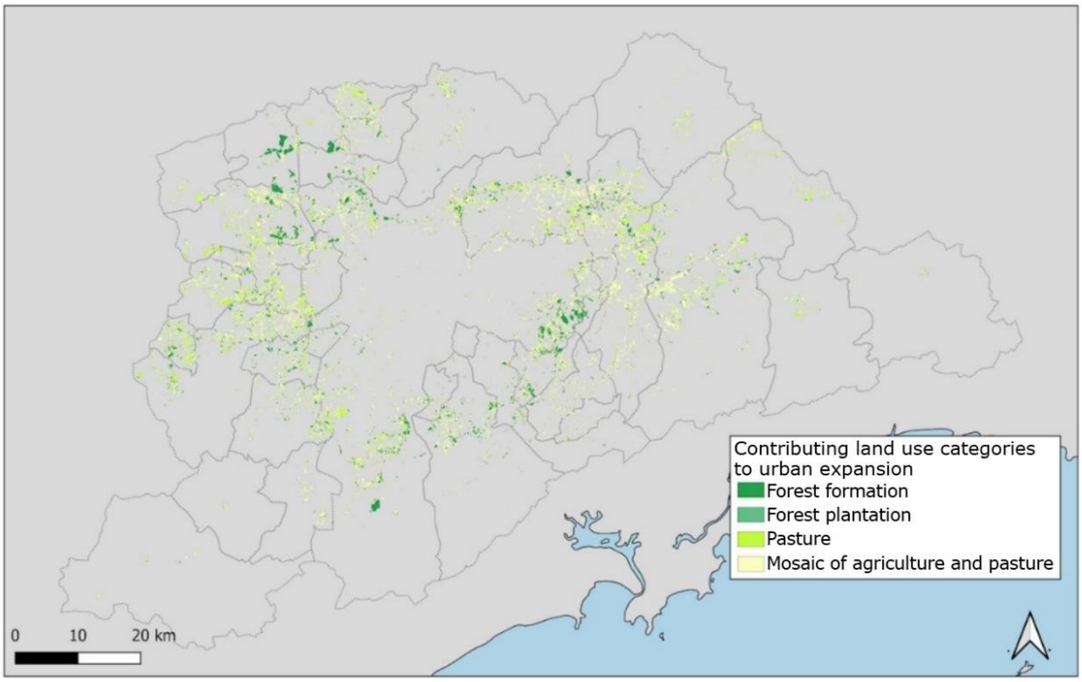


Figure 12 - 1985 land use categories that contributed to urban infrastructure class expansion during the 2019 time period.

The provision of ecosystem services in MRSP between 1985 and 2019

Based on these changes in land use between 1985 and 2019, the results of spatially explicit biophysical modeling point to a decline in the provision of the five ecosystem services evaluated (food mitigation, water yield, flood mitigation, heat mitigation and erosion regulation). Detecting the variations in each ecosystem service provisioning will be fundamental to subsequently identifying the contribution that sustainable agriculture can make (Scenarios 1 and 2).

Between 1985 and 2019, heat and flood mitigation services decreased by approximately 5% (*Figure 13* and *Table 17*), which corroborates the aggravation, during this time interval, of the heat island phenomena and recurring floods, as pointed out by Marengo *et al*. (2020). In this period, there was a growth from 1,490 to 2,064 km² of urban area, which represents an increase from 18% to 26% in the total territory of the MRSP. In these urban areas, non-vegetated surfaces predominate, such as roads, streets and buildings, with low water permeability, which hampers infiltration and, at the same time, favors the increase of temperature in the soil and environment. According to the results, for the municipalities of the MRSP, an increase of 1ºC was recorded in the average temperature.[74] The literature reviewed shows that in São Paulo the increase of 1ºC in the average temperature corresponds to an increase of 3.46% in general mortality and 3.26% in cardiovascular and respiratory mortality (MCMICHAEL *et al*., 2008; BARROS; LOMBARDO, 2016). As for the loss in flood mitigation service, it means that, considering a heavy rainfall of 50 mm[75] there are 14 million m³ of water-surface runoff with the potential to cause floods.

[74] For the period studied.
[75] In Nobre et al. (2011, p. 242), an increase in rainfall totals above 50 mm/day was recorded, something practically non-existent in the 1950s, with a recurrence of two to five times per year in the city of São Paulo.

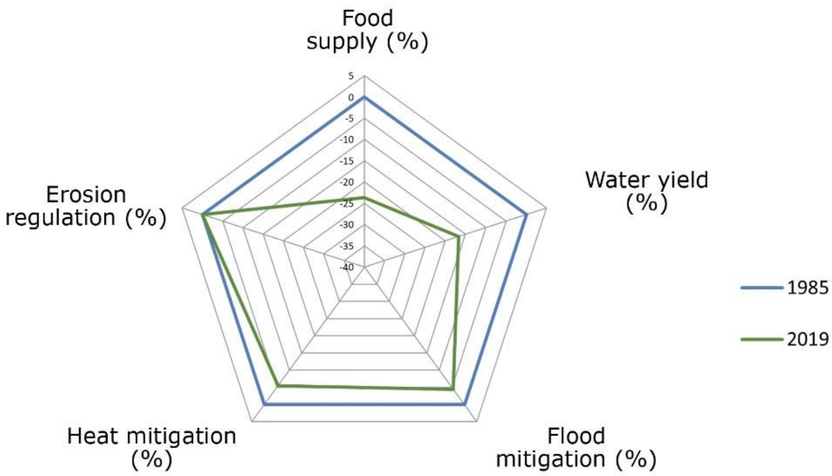


Figure 13 - Provisioning of ecosystem services in the MRSP: a comparison between 1985 and 2019. The blue line represents the reference year 1985, while the green line represents 2019. The axes express the variation in percentage of ecosystem services.

Table 17 - Quantitative results for the provision of the five ecosystem services in the years 1985 and 2019.

Ecosystem service	1985	2019	Difference (%)
Food supply (thousand ha)	229,2	177,1	-22,70
Water yield (m^3/s)	67,4	50,7	-24,7
Flood mitigation (million m^3)	325,3	310,9	-4,41
Heat mitigation (heat mitigation index)	0,395	0,373	-5,49
Erosion regulation (million ton/year)	313,7	313,6	-0,03

Another service impacted is erosion regulation. This indicator is calculated by measuring the landscape’s capacity to retain sediments. The results show only a slight loss between 1985 and 2019, below 1%. Although this particular result does not indicate such a significant loss as was experienced in other services, the variation in other indicators reveals a different situation.

The quality of the water can be compromised by the export of soil reaching water bodies, which results in additional treatment and dredging expenses. Therefore, the model used provides complementary indicators allowing the estimation of sediments exported. A potential soil loss between 70 and 80 ton/ha/year is estimated,[76] which in the literature reviewed is considered a high rate (PEREIRA, 2014; VALENTE *et al.,* 2001). With the natural rate of soil loss registered at around 2.4 ton/ha/year, equivalent to the annual rate of soil formation (SILVA, DA; ALCARDE; HITOMI, 2011), the levels estimated were unsustainable. It is important to consider that part of this soil loss is retained in the terrestrial environment (sediment retention service), while the export of sediments to water bodies is what directly impacts water quality. Compared to 1985, the export of sediments to watercourses in 2019 is 1.5% greater. This greater amount of sediments in water leads to an increase in turbidity, and also promotes siltation processes on rivers and large dams, generating costs to society. According to

[76] These values should be considered with caution since the model was not calibrated with data collected in the field. However, other studies in São Paulo state used the same biophysical modeling and performed the calibration, reaching values close to those presented in this study: 70.4 ton/ha/year for soil loss (LATAWIEC, 2018).

Costa et. al. (2013), in the two main waterways of the MRSP alone, the Tietê and Pinheiros rivers, R$ 160 million are spent annually with silt removal.

The results for the water yield service are for watersheds, rather than the municipal boundaries. Thus, only the results of the Alto Tietê River Basin are presented, considering that it covers more than 70% of MRSP territory, where 20 million inhabitants reside (FABHAT, 2019). The indicator of this service, realized water supply (m^3/s), entails the water production minus consumption, having registered a drop of 24.7% between 1985 and 2019. This is explained by the increase in water consumption which follows urban growth. The situation can be observed clearly on the urban fringes, where urban expansion has encroached on formerly agricultural areas. The watersheds that previously had a positive balance in water production became deficient, such as sub-basin 191 (SÃO PAULO STATE, 2013), highlighted in Figure 14. This hydrographic unit partially covers the municipalities of Osasco, Carapicuíba and Cotia, precisely where the urban area grew from 50% to 85% within the sub-basin. It should be noted that the results of the water yield model cover only the Alto Tietê River Basin (BHAT), while the supply system of the MRSP captures water at specific points, making use of a series of transpositions that import water from other basins (BICUDO *et al*., 2020).

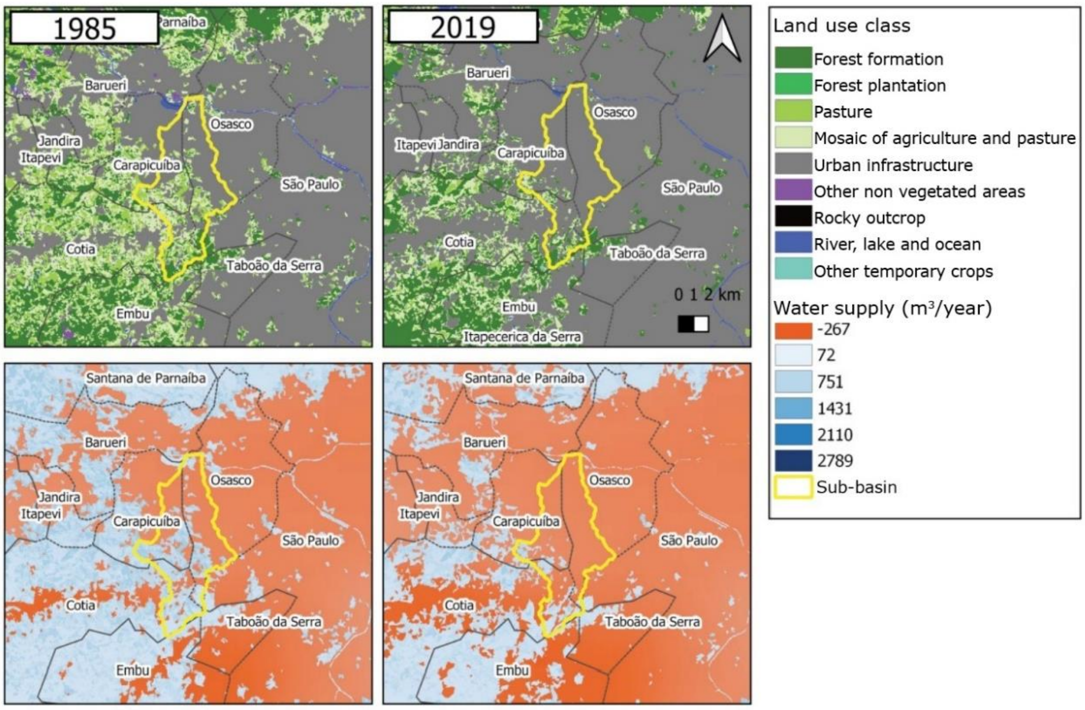


Figure 14 - Changes in land use in the 191 sub-basin and water yield service between 1985 and 2019. In this period, the urban area grew from 50% to 85% in the sub-basin, which increased water consumption above its own availability.

The results point to an annual water yield of 141 m^3/s (without discounting consumption) in 2019 in the BHAT, which would be able to supply the current demand of 85 m^3/s , and even the projections for 2050, in which there is a projected leap to 97 m^3/s (FABHAT, 2016). However, the quality of the water produced within the urban area is compromised by the lack of basic sanitation, while water infiltration is limited due to soil sealing, which hampers the recharge of water sources and the regulation of the water cycle. Because of these factors, among others, the possibility of using the water yield in this basin is greatly reduced. At the same time, the water that is not available for consumption, but is occasionally present in the drainage system, causes problems for urban management in periods of maximum flow, often taking form of flooding. Another important point is related to the seasonality of precipitation, something that the biophysical modeling used has limitations in capturing, since it is an annual analysis. As pointed out by Bicudo *et al*. (2020), the total demand is twice the minimum flow rate found in the BHAT (39 m^3/s), which triggers a highly critical situation, whereby the water availability per inhabitant per year is less than in areas of the Northeastern semi-arid region in Brazil that face long droughts, for example. With such a tight margin between the production and consumption of water, prolonged drought conditions may incur a dearth in supply, and also in regular situations when there is less precipitation, such as in winter time (July up to August).

When analyzing the changes between 1985 and 2019 in the provision of ecosystem services, it is possible to verify that some municipalities accumulate more losses than others. The balance between positive or negative changes is translated in a gradient that expresses the accumulation of losses and gains in ecosystem services (*Figure 15*)[77]. To complement the analysis, Table 18 details which services declined, using red and green arrows. These indicate whether there was, respectively, a decrease or increase in a specific service, while the yellow line shows that there was no change.

The greatest accumulation of losses in ecosystem services occurred on the urban fringe, in eleven municipalities around the capital, and is related to the conversion of agricultural and forest areas into urban areas. In the cases of Osasco, Poá, Diadema, São Caetano do Sul, Taboão da Serra and Carapicuíba, the losses are not as high, because since the 1980s, they have already consolidated their urban areas.

The municipality of Salesópolis is the only one in which more gains have been accumulated than losses. This can be explained by low urban growth, coupled with the conversion of pasture into forest plantation (eucalyptus). This reforestation is therefore the main factor responsible for the improvement in heat and flood mitigation services. Also in the watersheds that comprise Salesópolis and Biritiba-Mirim, the substitution of agriculture for forestry decreased the need for irrigation, creating a virtual positive balance in water yield in relation to 1985.

[77] The urban cooling/flooding and erosion regulation models allow for results to be interpreted based on pixel (or raster cell) values, and to perform their aggregation by administrative units. However, the result of water production is mandatorily expressed through drainage basin boundaries. In order to make this last service compatible with an analysis by administrative unit, a detailed reading of the sub-basins that intersect the municipalities was carried out in order to verify the trend for an increase or decrease in water production.

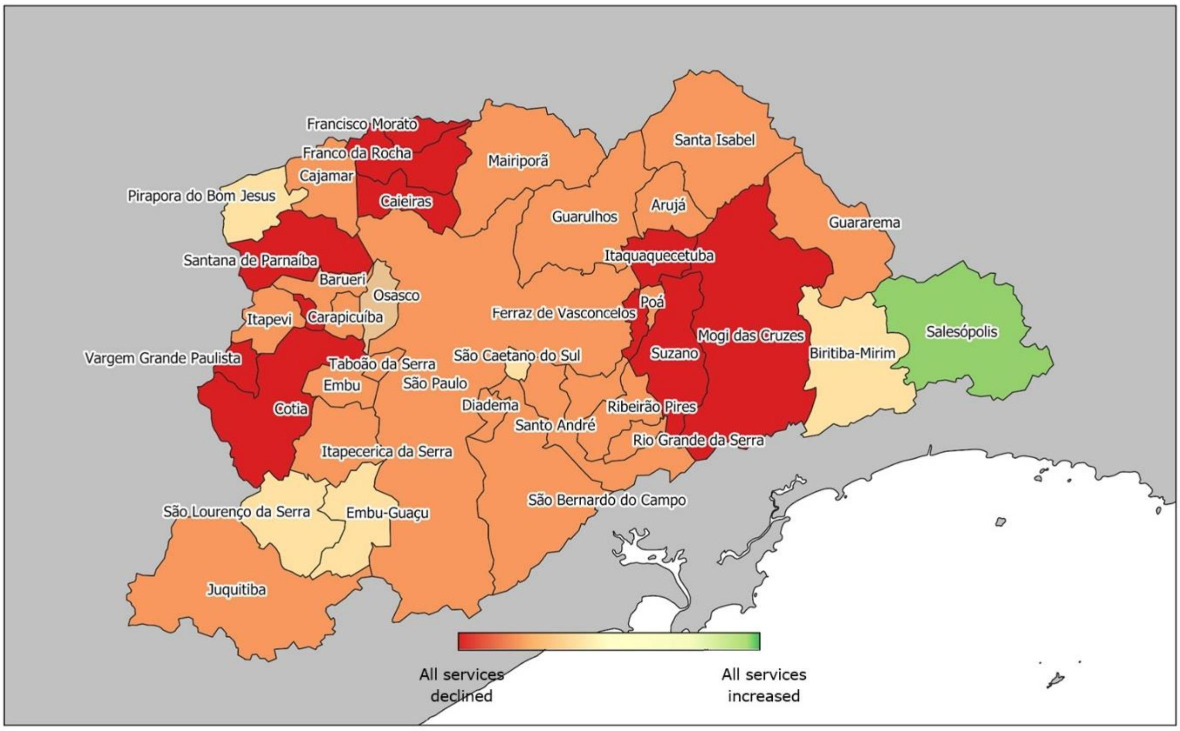


***Figure 15** - Changes in the supply of ecosystem services per municipality in the metropolitan region of São Paulo, comparing the years 1985 and 2019.*

Table 18 - Losses and gains in ecosystem services between the years 1985 and 2019 by municipalities.

Municipality	Water Yield (trend*)	Erosion regulation (%)	Heat mitigation	Flood mitigation	Food supply
Arujá	-1	0,35	-6,48	-7,06	-23,00
Barueri	-1	1,41	-12,50	-14,38	-67,57
Biritiba-Mirim	1	-0,22	1,11	-2,01	-18,36
Caieiras	-1	-0,40	-2,23	-4,86	-42,64
Cajamar	-1	-0,84	-13,38	-5,53	24,64
Carapicuiba	-1	0,44	-16,68	-16,25	-71,34
Cotia	-1	-0,47	-3,53	-5,68	-22,32
Diadema	-1	0,34	-4,81	-4,50	-65,35
Embu	-1	0,54	-8,19	-8,80	-36,08
Embu-Guaçu	-1	0,00	-3,04	-2,27	0,02
Ferraz de Vasconcelos	-1	-0,74	-16,99	-10,65	-22,52
Francisco Morato	-1	-0,61	-12,33	-6,89	-30,66
Franco da Rocha	-1	-0,75	-5,32	-3,29	-8,58
Guararema	-1	-0,04	5,51	-2,02	-18,72
Guarulhos	-1	0,14	-6,87	-7,66	-57,04
Itapecerica da Serra	-1	0,19	-1,63	-4,56	-23,15
Itapevi	-1	0,09	-1,85	-8,14	-36,91
Itaquaquecetuba	-1	-0,82	-23,31	-18,56	-48,05
Jandira	-1	-0,08	-24,27	-20,11	-73,32
Juquitiba	-1	0,02	-0,09	-0,24	-4,73
Mairiporã	-1	0,04	-0,05	-1,39	-9,76
Mauá	-1	0,21	-13,61	-10,15	-51,84
Mogi das Cruzes	-1	-0,02	-3,64	-5,37	-15,47
Osasco	0	0,41	-12,98	-10,20	-85,00
Pirapora do Bom Jesus	-1	0,06	1,41	-1,35	-13,39
Poá	-1	0,45	-13,94	-11,47	-62,31
Ribeirão Pires	-1	0,34	-4,55	-4,98	-30,26
Rio Grande da Serra	-1	0,04	-3,72	-3,32	-16,96
Salesópolis	1	0,39	6,76	-1,18	-42,44
Santa Isabel	-1	-0,50	0,46	-1,33	-3,19
Santana de Parnaíba	-1	-0,08	-7,05	-8,85	-31,61
Santo André	-1	0,15	-1,58	-2,25	-51,41
São Bernardo do Campo	-1	0,23	-2,21	-3,75	-45,03
São Caetano do Sul	-1	0,00	0,00	-0,13	0,00
São Lourenço da Serra	-1	0,00	0,09	-0,31	-7,18
São Paulo	-1	0,10	-5,35	-5,41	-41,89
Suzano	-1	-0,31	-9,11	-8,19	-18,55
Taboão da Serra	-1	0,22	-9,48	-6,69	-66,96
Vargem Grande Paulista	-1	-1,61	-15,41	-14,43	-27,62

Business as Usual Scenario for 2030

The Business as Usual (BAU) scenario was simulated for 2030, based on the land use transitions observed over the last decade (*Figure 16*), as described in item 2.5 of Chapter 2. In this scenario, urban growth occurs in 12,000 hectares, mainly over mosaic areas of agriculture and pasture (7,300 ha) and forested areas (4,700 ha) (*Table 19*). This expansion is corroborated in international projections that indicate a population growth of 2 million by 2030, reaching close to 24 million for the MRSP (UN-DESA, 2018). In addition to urban growth, BAU also considers 5% deforestation in relation to 2019, which occurs mainly outside protected areas.

Table 19 - Changes in land use between 2019 and BAU. [78]

	Land use land cover classes	2019: Forest formation	Forest plantation	Pasture	Sugar cane	Mosaic Agriculture and pasture	Urban Infrastructure	Other non vegetated areas	Rocky outcrop	Mining	River, lake and ocean	Perennial crop	Soybean	Other temporary crops	TOTAL (ha)
	No data	573	17	22	0	111	8	0	1	0	9	0	0	0	838
BAU	Forest formation	312539	3811	1436	0	23895	2134	54	20	14	894	1	0	151	344953
BAU	Forest plantation	3116	20996	145	1	1087	11	0	0	0	2	0	17	21	25398
BAU	Pasture	1678	55	23575	0	6786	270	13	3	13	72	0	0	160	32629
BAU	Sugar cane	0	1	0	3	0	0	0	0	0	0	0	0	0	4
BAU	Mosaic Agriculture and pasture	34680	902	7311	11	87565	4992	352	23	108	1269	0	3	805	138029
BAU	Urban Infrastructure	6824	225	853	2	11226	197860	111	4	245	311	0	0	586	218251
BAU	Other non vegetated areas	102	1	7	0	351	86	534	0	13	16	0	0	3	1113
BAU	Rocky outcrop	30	0	4	0	53	0	1	51	0	1	0	0	15	155
BAU	Mining	23	0	17	0	119	104	40	0	752	8	0	0	5	1067
BAU	River, lake and ocean	1501	4	8	0	758	253	20	0	9	19562	0	0	29	22143
BAU	Perennial crop	0	0	0	0	0	0	0	0	0	0	0	0	0	0
BAU	Soybean	2	3	0	0	1	0	0	0	0	0	0	19	1	25
BAU	Other temporary crops	384	44	356	2	1516	105	10	0	7	5	0	10	9495	11935
	TOTAL (ha)	361450	26058	33734	20	133469	205825	1135	103	1161	22149	1	50	11272	796540

Compared to 1985, the BAU scenario follows the downward trend in ecosystem service provision, mainly regarding water yield (-28%) (*Figure 17*). Urban growth of 12,000 hectares will increase water consumption by 2,500 l/s, which corresponds to the volume needed to supply 600,000 normal households annually.[79] This increase in consumption alone represents 6% of the total water available in drier seasons (39,000 l/s) (BICUDO *et al*., 2020), favoring the growing tendency for the Alto-Tietê River Basin to become an importer of water.

As for the decrease in heat mitigation (-7.4%) (*Table 20*), other complementary indicators point to the increase of 1.6ºC in average temperature in the municipalities of the MRSP, in relation to 1985. As for erosion regulation, the complementary indicators point out that soil loss and sediments export are, respectively, 9% and 22% greater than in 1985. The difference between the sediments exported to the watercourses between 1985 and BAU is 1.3 million tons, which corresponds to 100,000 more dump trucks of soil.[80] In relation to dredging, a procedure that is part of the silt removal strategies, R$ 28.60 per ton removed from the water is calculated.[81]

[78] Authors' elaboration.
[79] According to Sabesp (2016), a normal residence consumes 10,000 liters per month.
[80] It was considered that each dump truck holds 13 tons of sediments.
[81] The reference value was obtained in GAEA; Latawiec (2018) and updated according to the National Consumer Price Index (INPC) for March 2021.

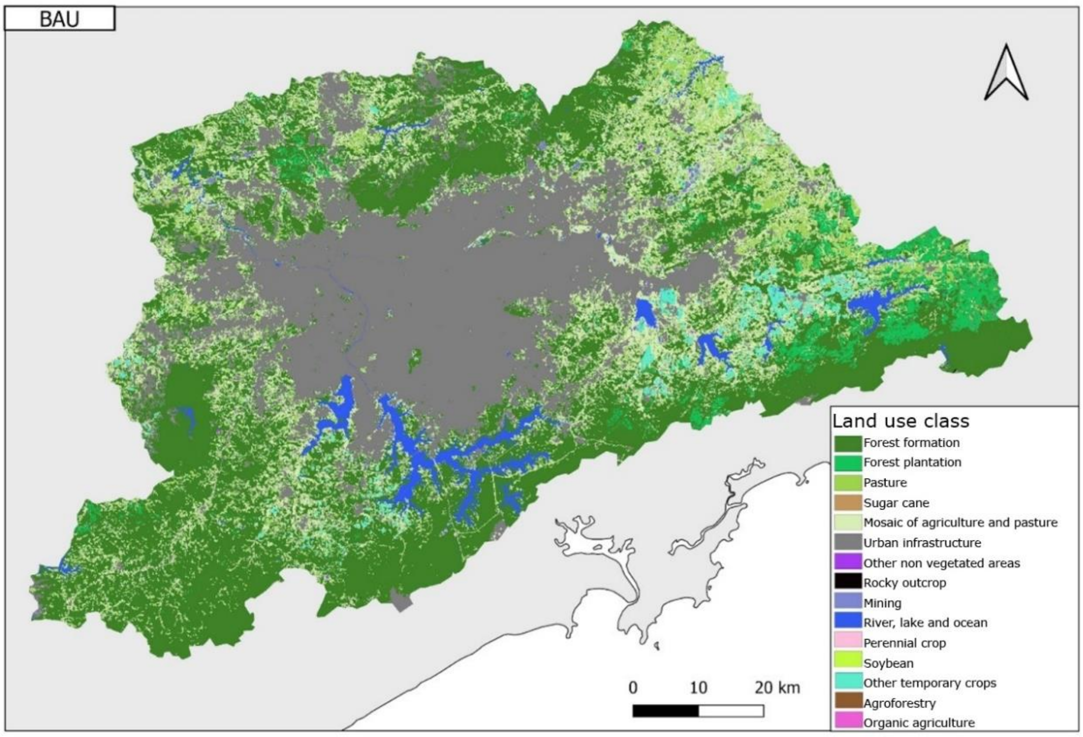


Figure 16 - Land use maps of MRSP for the BAU scenario for the year 2030.[82]

Between 1985 and BAU, the resulting increase in soil sealing will reduce water infiltration by 5.5%, corresponding, in case of heavy rains (50 mm), to 17 million m^3 more water in drainage paths, a volume equivalent to 21 flood-control reservoirs such as Guamiranga.[83] In São Paulo, rainfall with lower volumes causes flooding points in the city, and in the last decade, two to five days per year with volumes above 50 mm were recorded in the MRSP (MARENGO *et al*., 2020). The phenomenon is related to climate change, the expansion of the urban sprawl, and the urbanization model, as well as natural climate variability. Finally, the damages in constructions and urban infrastructure caused by floods also incur costs for the population.

The area of agriculture in BAU grows due to the deforestation rate, positively altering the food supply service. However, it is worth reinforcing that the proxy used does not allow us to infer that this necessarily means an increase in the volume of food produced.

[82] Authors' elaboration.

[83] The Guamiranga "*piscinão*" [Portuguese for "large pool"] was inaugurated in 2017, with a volume for 850,000 m^3, being the largest flood control reservoir in the municipality of São Paulo and costing R$160 million. http://www.capital.sp.gov.br/noticia/maior-piscinao-da-cidade-de-sao-paulo-e-inaugurado-na-zona-leste-1.

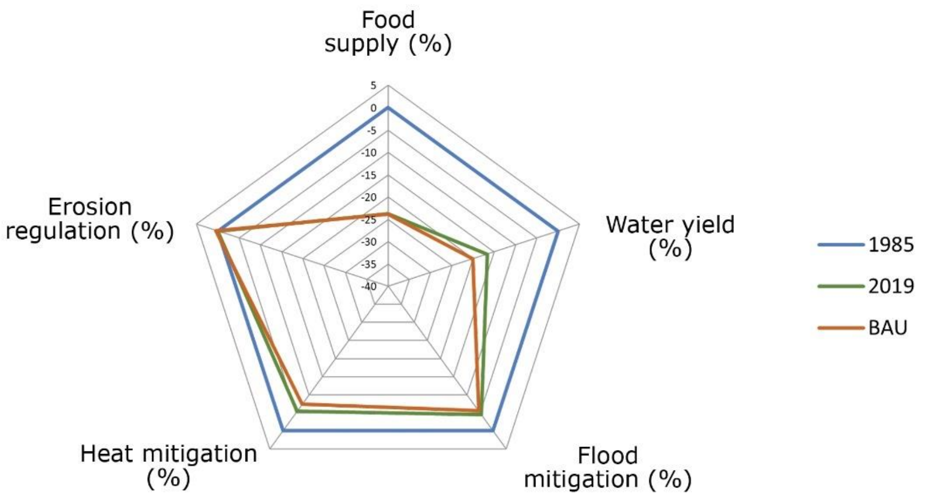


Figure 17 - Ecosystem services provisioning in the MRSP: a comparison between 1985, 2019, and BAU. The blue line represents the reference year 1985, while the green, 2019, and the orange, BAU. The axes express the variation in percentage of ecosystem services.

Table 20 - Quantitative results for the provision of the five ecosystem services in the years 1985,2019 and BAU.

Ecosystem service	1985	2019	BAU
Food supply (thousand ha)	229,2	177,1	181,3
Variation (%)*	0,0	-22,7	-20,8
Water yield (m^3/s)	67,4	50,7	48,2
Variation (%)*	0,0	-24,7	-28,5
Flood mitigation (million m^3)	325,3	310,9	307,3
Variation (%)*	0,0	-4,4	-5,5
Heat mitigation (heat mitigation index)	0,395	0,373	0,365
Variation (%)*	0,0	-5,5	-7,4
Erosion regulation (million ton/year)	313,7	313,6	315,0
Variation (%)*	0,0	-0,03	0,4

Alternative Scenarios for 2030

The sample portion identified in areas with low density of fresh healthy food commercialization establishments (ESCOLHAS, 2020; CAISAN, 2018) and with high social vulnerability (SEADE FOUNDATION, 2013), excluding Environmental Protection Conservation Units, points to an area of 167,000 hectares in the MRSP, distributed among all land use classes (60% forest formations, 4% urban infrastructure, 31% agricultural areas, 4% rivers and lakes). Of this total, 52,000 hectares in consolidated agricultural areas (mostly pastures and mosaics of agriculture and pasture) were identified as being suitable for transition to sustainable agriculture (organic agriculture and agroforestry systems). This priority area and its land uses are indicated in Figure 18.

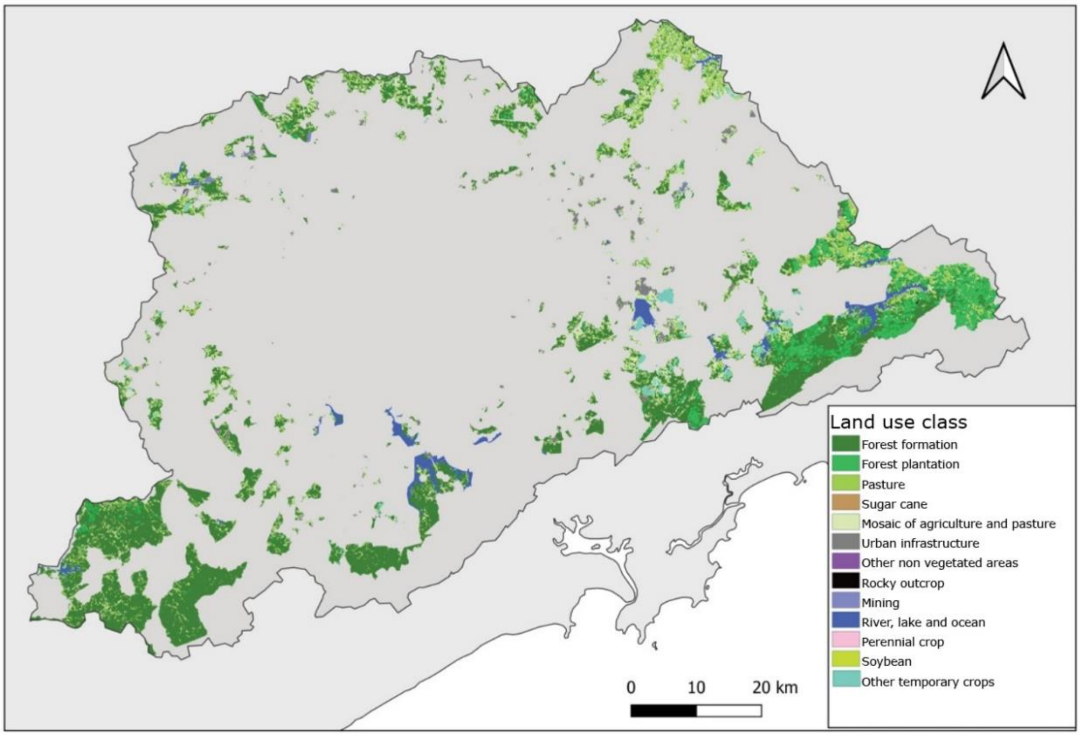


Figure 18 - Land use of the priority area with low supply of fresh and healthy food and high social vulnerability in the MRSP used in scenarios 1 and 2. The total area is 167,000 hectares, and the area available for transition to sustainable UPA is 52,000 hectares, as it only includes the agricultural classes: pasture, sugarcane, mosaic of agriculture and pasture, perennial crops, soybean, other temporary crops. [84]

As mentioned in the methodology, the Paulista Vulnerability Index (FUNDAÇÃO SEADE, 2013) is based on data from the Demographic Census (IBGE, 2010), enabling a deeper understanding of the social vulnerability condition. In the areas indicated in Figure 18, it is estimated that: 363,000 inhabitants, of which approximately 51,000 residents are located in subnormal settlements;[85] 7% of households have no per capita income; R$ 470 is the average income for women responsible for households; 10% of this population are children. In order to explore the potential of agriculture for provisioning ecosystem services in these areas that present a lack of fresh food and high social vulnerability, two alternative scenarios were considered: in the first, Scenario 1, the maximum potential of transition to sustainable agriculture is explored, considering the 52,000 hectares available; in the second, Scenario 2, a smaller transition is established, from a proportion suggested in public policies (GOVERNMENT OF SÃO PAULO, 2020), of 5,400 hectares, adding other priority areas such as those susceptible to flooding and heat waves.

Table 21 details these differences between BAU, Scenarios 1 and 2, specifying the differences between the magnitudes of transition in land use and priority areas.

[84] Authors' elaboration.

[85] According to the IBGE (2010b, p. 8), a subnormal agglomeration consists of at least 51 housing units (shacks, houses etc.) mostly lacking essential public services, occupying or having occupied, until a recent period, land owned by others (public or private) and being arranged, in general, in a disorderly and/or dense manner.

Table 21 - Characterization of future scenarios: assumptions, priority areas, and soil transition magnitude.

Scenario elements	BAU	Scenario 1	Scenario 2
Assumptions	It follows trends identified in the period from 2008-2018, with urbanization as the main driver to land use change.	Explore the maximum potential for the provisioning of food and ecosystem services in areas with no fresh food supply and high social vulnerability.	Explore urban and peri-urban agriculture's food and environmental service provisioning potentials based on targets presented in existing public policies.
Land use	43% forest formations, 28% urban infrastructure, 22% agricultural areas	43% forest formations, 27% urban infrastructure, 23% agricultural areas	43% forest formations, 28% urban infrastructure, 22% agricultural areas
Priority areas	Urbanization occurs mainly under agricultural areas, near already urbanized areas, public roads and on low slopes. There are restrictions on urban growth in environmental protected areas.	Agricultural areas around areas of low density of fresh food commercialization establishments and with high social vulnerability (52,000 ha), including 12,500 ha of agroforestry systems and 39,500 ha of organic agriculture.	1) Areas with low density of fresh food commercialization establishments and with high social vulnerability (683 ha) transitioned to organic agriculture; 2) Agroforestry systems in flood-prone areas (511 ha); 3) Agroforestry systems in heat islands areas with intensity above 4ºC (722 ha); 4) transition in existing horticulture areas (3,600 ha) to organic agriculture
Sustainable AUP	0	52,000 ha	5,400 ha
Urban Expansion	Total: 12,000 hectares	Urban expansion: 9,000 hectares	Total: 12,000 hectares (same as BAU)

In terms of land use, Scenarios 1 and 2 present similarities with the BAU scenario, except for the transitions to sustainable UPA in the priority areas described. This difference is marked in Scenario 1, where the transition occurs, preventing urban growth in these areas as predicted in BAU. In the BAU scenario, the change in land use maintains the patterns observed in the last decade, resulting in an advance of 12,000 hectares of the urbanized area, which means 2% of the total area of MRSP. In Scenario 1, due to the allocation of 52,000 hectares of urban and periurban agriculture, urbanization is reduced by 3,000 hectares.

This capacity to contain the expansion of the urban sprawl is assumed by the fact that the *urban* and *periurban agriculture models* used in this research, which have been detailed through financial modeling, considerate the productive and commercialization characteristics necessary for the activity to be more profitable than the land price (ESCOLHAS; URBEM, 2020). That is, the implementation of urban and periurban agriculture models in the 52,000 hectares of available area (mostly mosaic of conventional agriculture and pasture land use classes) in Scenario 1 implies a modification of urbanization rates found in the last decade, representing a 25% decrease in urban growth projected for 2030. In Scenario 2, due to the smaller magnitude of transition to sustainable UPA, urban growth equals that of BAU.

Scenarios 1 and 2 are based on the premise of prioritizing the food supply to vulnerable populations in areas with no fresh and healthy food establishments. The difference between the two scenarios is that the first considers the total available area (52,000 ha of agriculture and pasture areas), to outline the maximum potential of local supply, while the second starts from a smaller magnitude (5,400 ha), in which agriculture is also allocate in areas with urban management issues related to ecosystem services selected in the research.

Scenario 1 considers a priority area (*Figures 18* and *19*), identifying the Permanent

Preservation Areas (PPA) within,[86] to which biodiverse agroforestry systems (12,500 ha)[87] are allocated, while the rest of the available area is assumed as organic farming (39,500 ha) in its *urban and periurban agriculture model*s variations.

For Scenario 2, we consider the allocation of sustainable agriculture to three priority areas: 683 hectares in areas with a lack of fresh and healthy food supply and with high social vulnerability; 511 hectares in flood-prone areas (SIURB, 2020), in which agroforestry systems (AFS) are a reinforcement for infiltration and water retention; and 722 hectares to areas intensely afflicted by the heat island phenomenon (CHAKRABORTY; LEE, 2019; LOMBARDO, 2016), in which the effect of AFS on microclimate intend to mitigate high temperatures. The latter two priority areas are entirely within the urbanized area, with approximately 60 hectares of overlap between heat islands and floodplains. In this last scenario, the agroecological transition is also considered to be 30% of the already existing horticulture areas, extrapolating one of the goals of the Municipal Plan of Conservation and Recovery of Areas Providing Environmental Services (GOVERNMENT OF SÃO PAULO, 2020) of the municipality of São Paulo for the whole metropolis region. According to LUPA (2016/2017), there are 12,000 hectares with temporary crops in MRSP; and considering the agroecological transition at 30%, it adds 3,600 ha of organic agriculture (Figure 20).

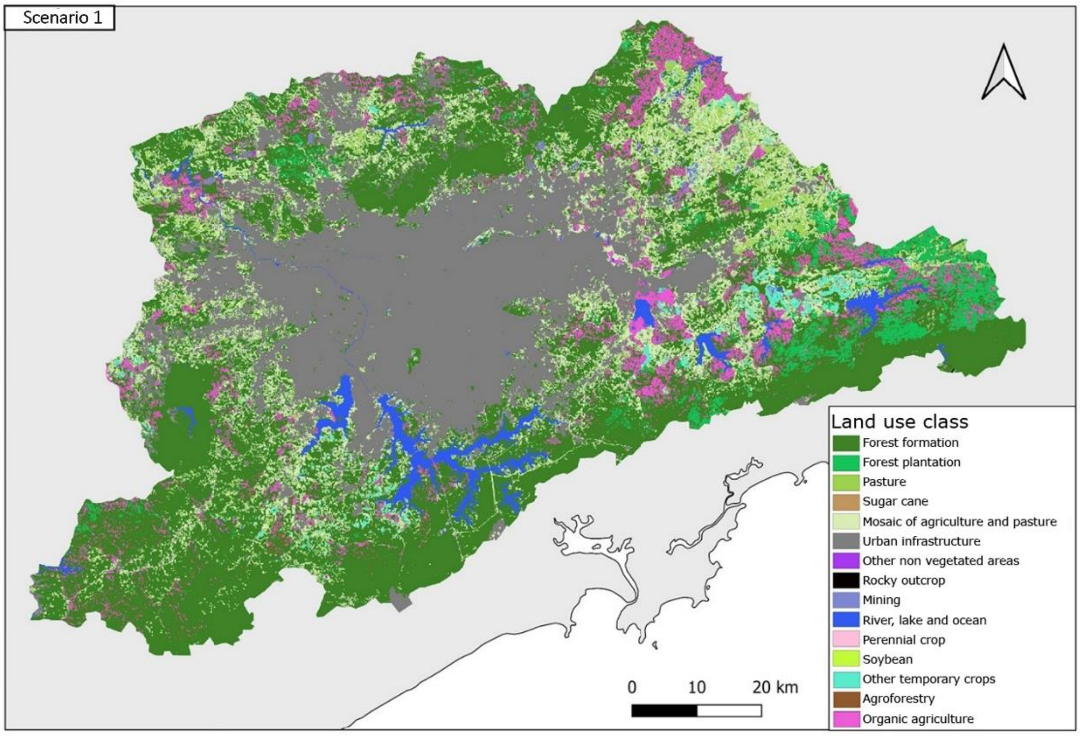


Figure 19 - Land use maps of the MRSP for scenario 1 for the year 2030.[88]

[86] Only the Permanent Preservation Areas (PPAs) with anthropic use were considered, from the mapping of FBDS (2013) with pixel at 5x5 m, rendering necessary a resampling that excludes such areas below 30x30 m. This limitation is due to the compatibility of resolution with the land use map, being a prerogative of the biophysical models used.

[87] Agroforestry systems with 50% native trees are allowed in PPAs with consolidated use on small properties (up to four fiscal modules), see Article 66 of Federal Law 12.651 from 2012. Given that 84% of rural establishments in the MRSP are small properties, this possibility is assumed, although it requires further refinement when considering rural property boundaries.

[88] Authors' elaboration.

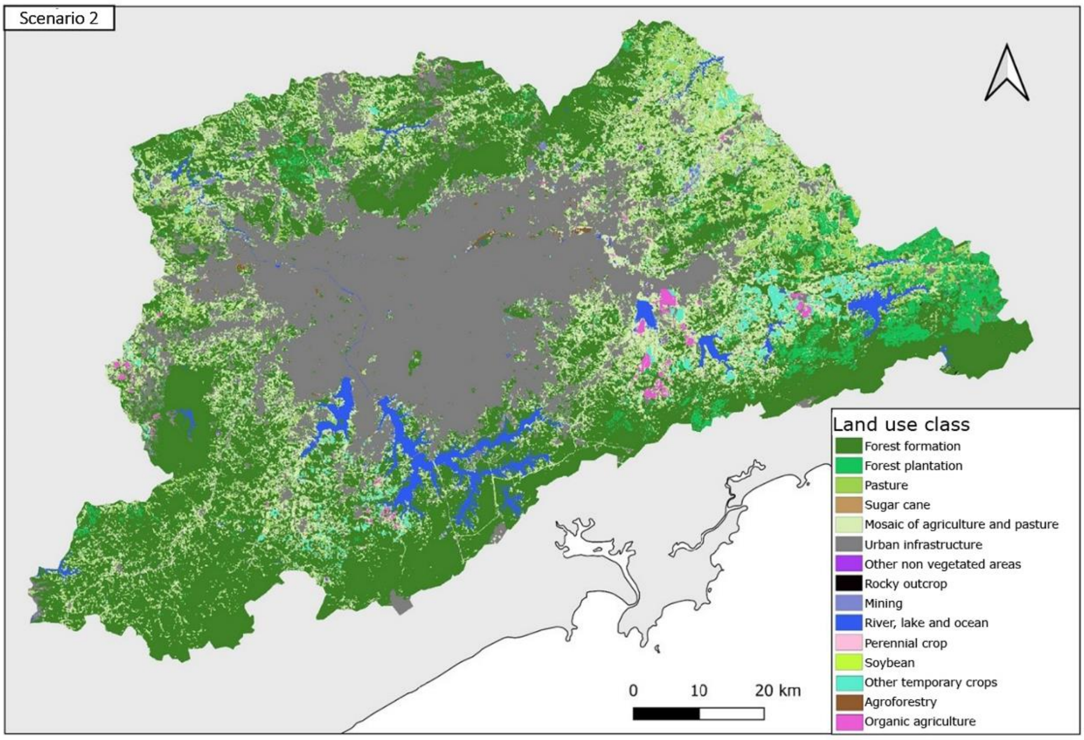


Figure 20 - Land use maps of scenario 2.[89]

Based on the hypothetical *models for urban and peri-urban* agriculture at the production levels modeled in previous research (ESCOLHAS; URBEM, 2020), and identifying the transitioned organic agriculture areas in relation to the urbanized area pointed out by IBGE (2015), it was possible to estimate the potential food supply. For organic agriculture within the urbanized area, the potential supply of the *urban agriculture model* (576 people/ha/year) was adopted, while the rest was computed as *peri-urban agriculture model* (331 people/ha/year). As a result, the numbers of production units of each model in the alternative scenarios were estimated. Only the "area with agricultural production" was considered in this calculation (*Table 10*), assuming that the area of native vegetation in the periurban model would be represented by forested areas within the 167,000 hectares with a shortage of fresh food supply and high social vulnerability, as these amount to 60% in this particular selection.

In Scenario 1 (52,000 hectares), it would potentially be possible to supply 13.7 million inhabitants, improving also socioeconomic indicators. This would require 17,000 productive units according to the *urban agriculture model* (on 2,300 ha) and 18,000 units of the *periurban agriculture model* (on 37,400 ha). With Scenario 2, on the other hand, it is possible to supply 1.4 million people: 562 ha with 2,811 productive units of the *urban agriculture model*, and 121 ha with 60 productive units of the *periurban agriculture model* (Table 22).

[89] Authors' elaboration.

Table 22 - *Potential food supply by organic agriculture in scenarios 1 and 2.* [90]

	Scenario 1 (52,000 hectares)			Scenario 2 (5,400 hectares)		
Agriculture Model	Organic farming area (ha)	Number of production units	Food supply (people)	Organic farming area (ha)	Number of production units	Food supply (people)
Urban model	2.390	17.075	1.376.374	263	1.877	151.261
Periurban model	37.418	18.709	12.384.833	3.988	1.994	1.320.083
Total	**39.808**	**35.784**	**13.761.207**	**4.251**	**3.871**	**1.471.344**

The comparison between the scenarios presented in Figure 21 and Table 23 allows us to see how the increase in the area of sustainable agriculture influences the other four ecosystem services evaluated, but also entails some trade-offs — for example, in Scenario 1 there is a better performance in four services to the detriment of the water yield service.

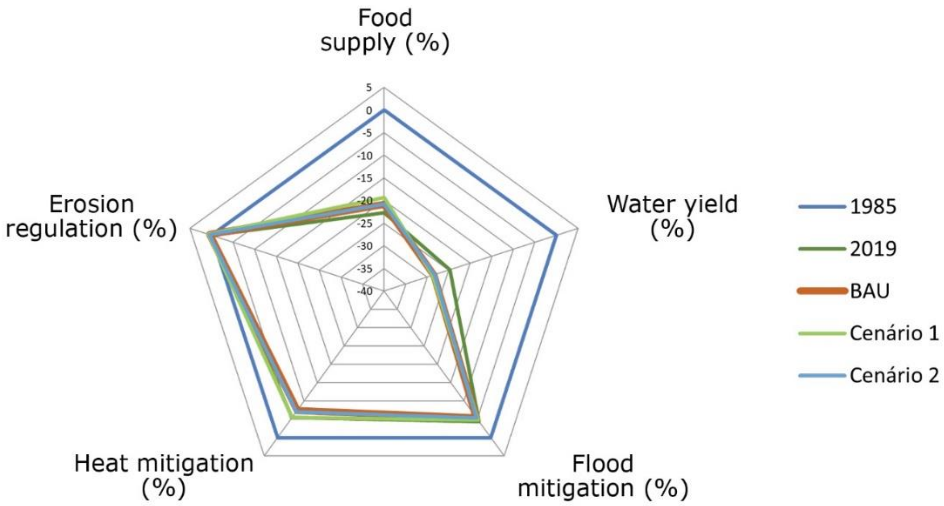


Figure 21 - Variation in the provision of ecosystem services between 1985, 2019, BAU, scenarios 1 and 2.

[90] Authors' elaboration.

Table 23 - Quantitative results for the provision of the five ecosystem services for 1985, 2019, BAU and scenarios 1 and 2.

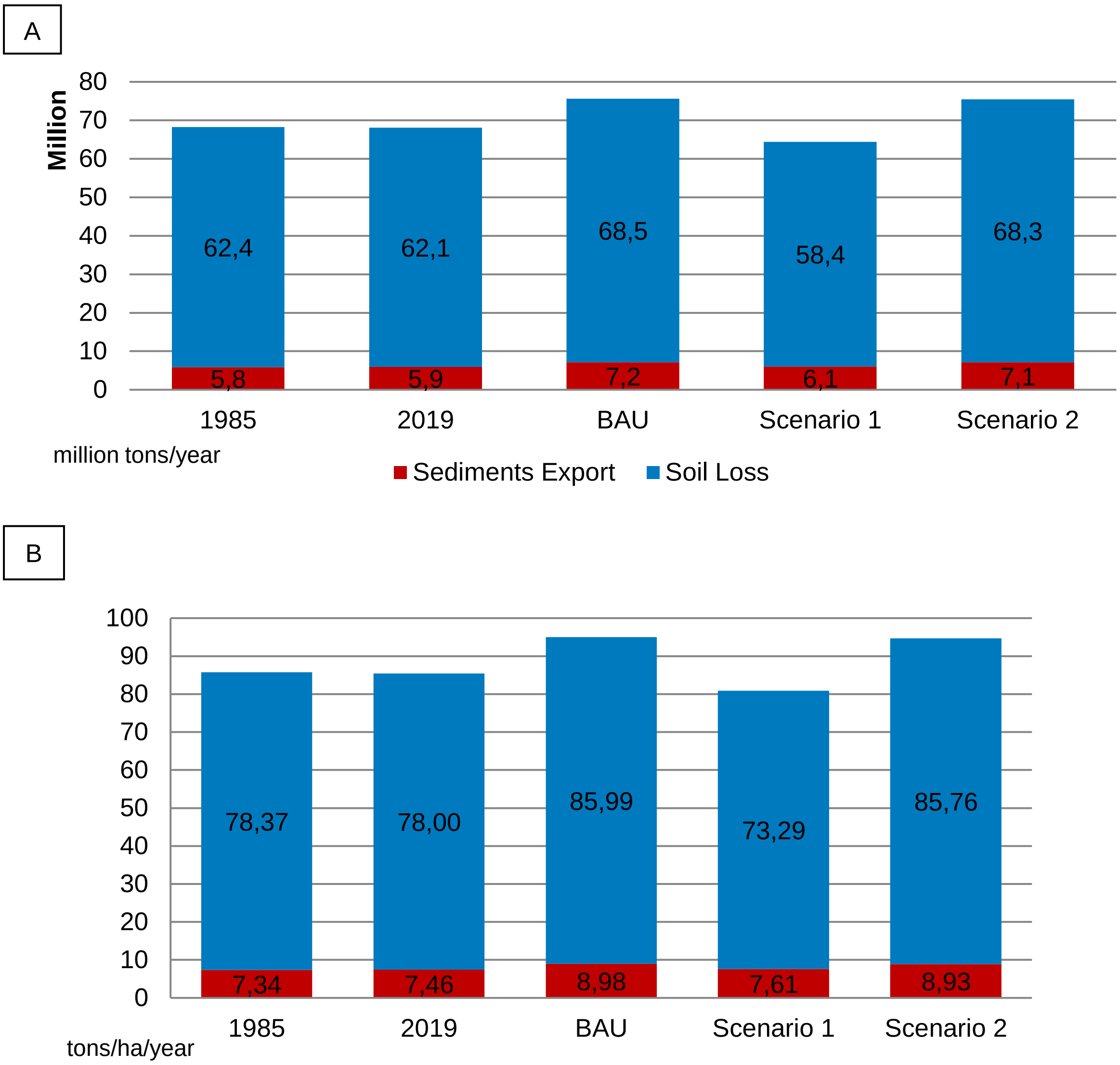
Ecosystem service	1985	2019	BAU	Scenario 1	Scenario 2
Food provision (thousand ha)	229,2	177,1	181,3	184,7	181,3
Variation (%)*	0,0	-22,7	-20,8	-19,3	-20,8
Water yield (m^3/s)	67,4	50,7	48,2	48,0	48,4
Variation (%)*	0,0	-24,7	-28,5	-28,7	-28,2
Flood mitigation (million m^3)	325,3	310,9	307,3	309,7	307,6
Variation (%)*	0,0	-4,4	-5,5	-4,8	-5,4
Heat mitigation (heat mitigation index)	0,395	0,373	0,365	0,373	0,367
Variation (%)*	0,0	-5,5	-7,4	-5,5	-7,1
Erosion regulation (million ton/year)	313,7	313,6	315,0	316,1	315,1
Variation (%)*	0,0	-0,03	0,4	0,77	0,45

*The variation is in relation to 1985

Scenarios 1 and 2 generally fail to perform better than 2019 scenario, being of an incremental nature in relation to BAU. This is because in all future scenarios, the urban sprawl still occurs, which continues to negatively impact the ecosystem service provision. It can be observed that the transition to sustainable UPA cannot improve the provision of services relative to the present, but it can contribute to buffering the likely impacts of future urban growth.

In general, erosion regulation presents an increase across all scenarios, above the 2019 levels. From the complementary indicators presented in Figure 22, it can be observed that, even though BAU presents a positive performance in terms of sediment retention, the amount of sediments generated is much greater than in the other scenarios, reaching a soil loss of 68 tons per year in the MRSP. Also in BAU, the sediments reaching watercourses are 22% greater than in the year 1985, while in Scenario 1, this ratio is only around 3% greater. It is valid to point out that in Scenario 1, there is a smaller soil loss than in 1985 — there are almost 5 million tons less per year in the MRSP. In relation to BAU, in Scenario 1 there is 1 million tons less, which corresponds to 83,000 fewer dump trucks of sediments reaching watercourses annually.

This performance is directly linked to the ecological management of the soil (mulching) and the conservationist practices in the production systems, as well as the strategic positioning of AFS in PPAs, as sediment retention barriers around springs and watercourses. In Scenario 2, both sediments retention and soil loss are marginal, due to the small incremental area in which conservationist practices are assumed (5,400 hectares of sustainable UPA).



ton/ha/year

Figure 22 - Comparison between soil loss and sediment export for the different scenarios. Soil loss in blue, and sediment exportation in red. A) total values for the MRSP and b) result in ton/ha/year.

Less expressive, but still very close to the 2019 levels, is the balance for heat mitigation in Scenario 1. On average, the seven top-performing municipalities presented an average reduction of 0.1ºC in temperature in Scenario 1, as compared to BAU.

For flood mitigation, once again the increase in the area of sustainable agriculture observed was still unable to surpass 2019 levels; however, Scenarios 1 and 2 performed better than BAU. Although showing better results (0.77%) than the future scenario without agricultural expansion, the UPA allocated in Scenario 1 would be responsible for an increase in water infiltration, corresponding to the volume of almost three flood-control reservoirs such as Guamiranga.

Even though these last two services are correlated to the green areas, a higher elasticity is perceived in mitigating heat than in mitigating floods. This may be related to the increase in cooling caused by AFS (and other green areas) larger than 2 hectares, since the model considers air mixing, thus creating a cooling zone around green areas. The modeling of flood mitigation considers only the retention of surface runoff at individual pixel level, without taking into account the possible cumulative flows along the landscape (SHARP, 2020).

Finally, a possible trade-off in relation to water yield is observed with the lowest level in Scenario 1 (-28.7%, in relation to 1985, and -0.2% in relation to BAU), due to the extra consumption necessary for irrigating the new agricultural areas (*Figure 23*). This is part of a relevant discussion about water availability in the MRSP reported by key actors and the demand for new water sources.

Water consumption in organic systems is lower than in conventional systems. The water retention in organic farming is 19% higher than that of conventional agriculture because of the higher rate of organic matter in the soil (TEOFILO *et al*, 2012; MAROUELLI, 2010, 2010b, 2006; STONE, MOREIRA, 2000). Even so, the magnitude of expansion of 52,000 hectares of sustainable agriculture implies a higher water consumption than that verified in 2019 and in BAU. When considering more efficient systems such as drip-irrigation (ANA, 2019), there is the added benefit of a 15% reduction in water consumption by crops. Assuming a hypothetical 34% reduction in water consumption for organic agriculture would be enough to reverse this trade-off, and would result in Scenario 1 performing better than BAU (Scenario 1 (B) in Figure 23).

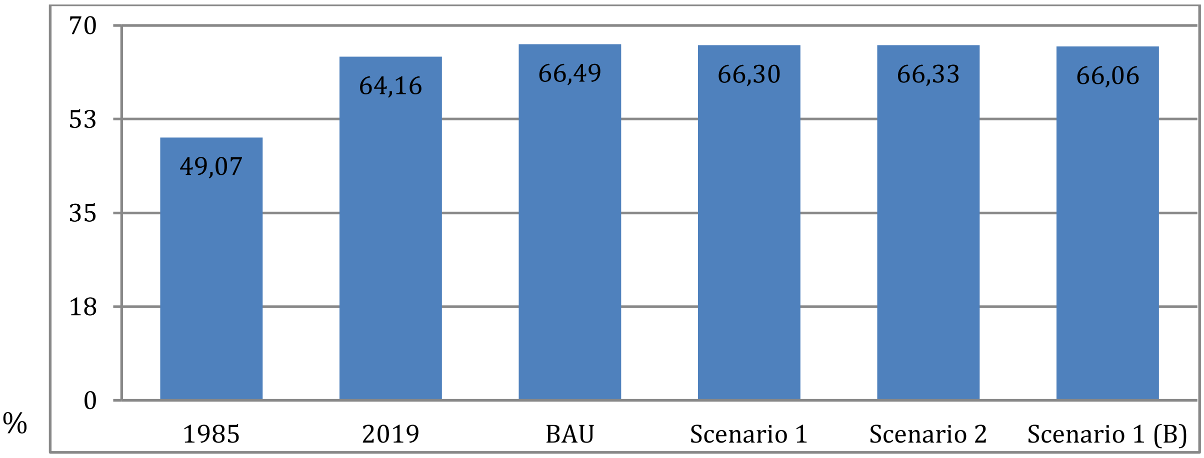


Figure 23 - ***Comparison of realized water supply (Water Yield) between the different scenarios for the Alto-Tietê River Basin. Scenario 1 (B) considers the greatest efficiency in water consumption (34% reduction) by adopting drip irrigation systems.***

However, agriculture's negative impact on water supply must be put into perspective given the limitations of the modeling used, since it does not consider the dynamics related to groundwater. It is important to highlight that 70% of agricultural establishments in the MRSP use groundwater sources for food production and therefore do not compete with domestic consumption (ESCOLHAS; URBEM, 2020, p. 82).

It is important to emphasize that in these results, the contribution of AFS and organic agriculture is underestimated because the water modeling covers an incomplete subsection of the hydrological cycle, and does not take into consideration the dynamics between vegetation, atmosphere and groundwater. The literature reviewed demonstrates that in the medium and long term, AFS have a positive effect on water regulation, making water production more stable and less susceptible to extreme events, such as floods and droughts (CARDINAEL, 2020; ANDERSON, 2008).

Table 24 compares, by municipality, the conditions of ecosystem service provision between BAU, Scenarios 1 and 2. Based on the results, it can be seen that Scenario 1 has a more robust performance due to the magnitude of the transition to sustainable agriculture (52,000 ha), and can provide services that would fulfill an important role in the metropolitan scale, with possible cumulative effects that go beyond municipal boundaries. An example of this is the cooling buffer promoted by green areas, or the retention of sediments along watershed. In the municipalities with the greatest historical loss of agricultural and vegetation areas, as presented in Figure 15, promoting UPA in areas with no fresh food supply and high social vulnerability has the potential to promote a positive impact on ecosystem service provision, capable of buffering the impacts caused by the urban growth projected for 2030.

The more discrete results in Scenario 2 show that even with transitions of lower magnitude, there are results at the municipal or at -watershed scale. For example, in Scenario 2, the municipality of Barueri received 120 hectares more of AFS in heat island areas, consequently presenting a better result than in Scenario 1. For other municipalities that did not have land availability inside areas with no fresh food supply and social vulnerability— such as Jandira — and which were therefore not considered in Scenario 1, the addition of 34 hectares in Scenario 2, in areas with heat islands and floods, resulted in positive results for erosion regulation (0.27%) and for the mitigation of heat (2.43%) and floods (0.46%). When considering other priority areas, Scenario 2 had a more extensive distribution character than Scenario 1, with significant benefits for heat mitigation in urbanized municipalities that still have area for UPA expansion.

Finally, the results demonstrate that AFS play an important role in mitigating flooding, heat islands and soil loss. Although data on habitat availability and quality was not generated in the case studies, according to the literature reviewed, organic crops can present associated biodiversity, and AFS can reach levels of equivalence to natural ecosystems (PERFECTO; VANDERMEER, 2010).

Table 24 - Municipalities with gains and losses (%) in ecosystem services when comparing scenarios 1 and 2 with BAU.

	Scenario 1 X BAU				Scenario 2 X BAU			
Municipality	Agriculture (ha)	Erosion Regulation	Heat Mitigation	Flood Mitigation	Agriculture (ha)	Erosion Regulation	Heat Mitigation	Flood Mitigation
Arujá	965.1	1.23	3.28	0.94	31.9	0.03	0.07	0.02
Barueri	34.3	0.07	0.41	0.21	152.6	0.15	2.92	0.51
Biritiba-Mirim	2000.5	0.25	1.74	0.82	389.0	0.00	0.26	0.14
Caieiras	17.3	-0.01	0.06	-0.06	6.2	-0.01	0.01	0.01
Cajamar	626.3	0.30	1.35	0.34	38.7	-0.02	-0.09	-0.03
Carapicuíba	0.2	0.00	0.54	0.02	22.0	0.02	0.65	0.21
Cotia	1789.6	0.28	1.65	1.27	212.4	0.06	0.33	0.22
Diadema	21.2	0.07	0.29	-0.09	2.8	-0.03	-0.18	-0.03
Embu	52.5	0.02	0.44	0.11	13.7	0.02	0.09	0.04
Embu-Guaçu	1577.2	0.51	2.46	1.24	65.2	0.01	0.00	-0.04
Ferraz de Vasconcelos	181.2	1.03	3.39	0.86	33.8	0.06	1.36	0.38
Francisco Morato	852.5	1.16	7.07	1.17	34.2	0.13	0.31	0.03
Franco da Rocha	1587.4	0.10	2.75	-0.29	59.9	0.00	0.10	0.01
Guararema	2850.9	0.45	4.06	0.69	156.9	0.00	0.08	0.03
Guarulhos	393.5	0.17	0.51	0.14	265.1	0.02	0.73	0.21
Itapecerica da Serra	860.4	0.31	1.25	0.67	27.5	0.03	0.09	0.06
Itapevi	446.5	0.35	2.20	0.84	62.2	0.06	0.72	0.19
Itaquaquecetuba	543.6	0.99	4.09	1.23	230.4	0.27	2.91	0.61
Jandira	0.0	0.02	0.07	-0.07	34.3	0.27	2.43	0.46
Juquitiba	4299.1	0.34	2.74	1.13	26.2	0.00	0.12	0.01
Mairiporã	2422.6	0.23	1.98	1.23	98.8	0.02	0.10	0.04
Mauá	140.9	0.24	1.23	0.41	16.7	0.03	0.25	0.13
Mogi das Cruzes	7104.5	0.45	3.43	1.42	792.4	0.05	0.36	0.32
Osasco	-0.2	0.02	-0.13	-0.04	29.9	0.04	0.83	0.12
Pirapora do Bom Jesus	637.2	0.35	1.70	0.45	30.1	-0.03	0.22	0.01
Poá	4.2	-0.12	-0.16	0.00	31.8	0.25	2.60	0.63
Ribeirão Pires	113.7	0.14	0.34	0.30	2.2	0.01	0.00	-0.02
Rio Grande da Serra	238.1	0.44	1.99	1.20	12.2	0.04	0.01	0.06
Salesópolis	4917.7	0.22	3.52	1.19	141.4	0.00	0.09	-0.02
Santa Isabel	7733.1	1.06	8.15	1.18	221.3	-0.02	0.17	-0.03
Santana de Parnaíba	1712.3	0.44	3.11	1.13	58.3	0.01	0.21	0.01
Santo André	116.3	0.06	0.34	0.24	6.4	0.00	0.10	0.04
São Bernardo do Campo	916.3	0.07	0.97	0.65	33.9	0.00	0.02	-0.02
São Caetano do Sul	0.0	0.00	0.00	0.01	0.0	0.00	0.00	0.00
São Lourenço da Serra	525.0	0.17	0.93	0.41	14.6	0.00	0.04	0.00
São Paulo	1323.9	0.08	0.41	0.17	1342.6	-0.03	0.27	0.04
Suzano	2693.4	1.10	4.27	1.59	151.3	0.20	0.42	0.39
Taboão da Serra	1.1	-0.02	0.50	0.27	8.5	-0.06	0.30	0.23
Vargem Grande Paulista	210.8	0.50	1.91	1.25	56.4	-0.01	0.69	0.30

Projection of waste incorporation by urban agriculture in Scenario 2

<u>Evidence from case study C4</u>

The practice of composting highlights another ecosystem service related to agriculture, the incorporation of waste, which enables the reduction of "metabolic fracture": with the advent of mineral fertilizers, the return of urban waste to fertilize the field was dismissed, squandering its nutrients and causing an impact on ecosystems where it is dumped (MCCLINTOCK, 2010; FOSTER, 1999).

The evaluation of the CS revealed the practice of composting to produce organic fertilizer in cases C3 and C4. Specifically in relation to the urban experience (C4), this practice is made possible through the articulation between the farming couple, the electricity utility company and the neighborhood. By means of an informal agreement, the couple receives tree pruning material from other areas under the power lines, which are under the responsibility of the utility company. Other organic waste is obtained from other neighborhood households and from informal agreements with local traders.

The generation of compost therefore depends on the social capital mobilized among residents, market traders and bakeries in the surrounding area, who contribute selected organic waste and ashes. The waste is gradually collected, forming two compost piles of 2 m x 1.5 m that alternate in providing organic fertilizer for agricultural production. The piles are composed of layers of materials that are rich in carbon (tree pruning) and nitrogen (household and market waste), and are turned weekly so that their temperature and humidity remain controlled. It takes approximately two to three months for the decomposition process of organic matter to be completed. The proportion of materials that make up the two piles is described in Table 25 below.

Table 25 - Materials and proportions used in the C4 compost piles.

	Material	Quantity (kg)	Proportion (%)
Composition of 1 battery	Pruning of trees in the power grid	2.000	63,0
	Waste from open-air produce markets	500	15,7
	Ash	400	12,6
	Household organic waste	235,6	7,4
	Poultry manure	40	1,3
	Subtotal urban waste (excluding manure):	3.135,6	100,0
	Compost production	1.000	~ 3 months

Thus, considering the two piles, there are 6.27 tons of urban organic waste incorporated by C4 every three months. According to our interlocutor, the amount generated by the two compost heaps is not yet sufficient to cover the demand for fertilization of the plantations, which would be possible only with ten heaps. Making such an extrapolation, there would potentially be 31.35 tons incorporated every three months, approximately.

The intra-urban organic input production strategy described (C4) opens up the possibility of proposing decentralized waste incorporation systems based on community mobilization, as is the case of the Composta Santos program[91] or the so-called "*Revolução dos Baldinhos"* [Bucket Revolution] (ABREU, 2013). This type of action is less dependent on robust collection and treatment infrastructures that demand high control, as is the case of composting plants (SILVA *et al*., 2005), and can result in cost savings for both the municipality and urban and periurban farmers. It is worth mentioning that the municipality of São Paulo has already had two composting plants deactivated in the early 2000s due to problems reported in the processing and quality of the material generated (VASCONCELOS, 2003; MARRA, 2004)[92].

According to the Integrated Solid Waste Management Plan of the Municipality of São Paulo, the cost per ton of waste collection, transportation and disposal in landfills is estimated between R$ 150 and R$ 500 (SÃO PAULO, 2014). Assuming the most conservative value of R$ 150 per ton, the cost currently avoided by the composting of unit C4 is calculated at R$ 3,762 per year (25.08 tons of organic urban waste incorporated per year). This number could hit R$ 18,810 if C4 reaches the ten piles it requires every three months. This last value corresponds to 3.7 times the credit limit granted to each

[91] This is the Santos City Hall's program to encourage the recycling of organic solid waste. More information at https://www.santos.sp.gov.br/?q=hotsite/composta-santos.

[92] Currently, the São Paulo City Hall has five composting yards that use waste from open-air produce markets and generate organic inputs destined to public squares and gardens. Each unit can receive 3,000 tons of waste and process 600 tons of compost over a one-year period (São Paulo, 2020).

PRONAF B beneficiary for the 2020/2021 Plano Safra.[93] For the service they provide, the C4 farming couple could be hired by the municipality or the public cleaning company, a situation already outlined by law (Article 36 of Law No. 12.305/2010).

Extrapolation to alternative Scenario 2

An extrapolation for the purpose of understanding the potential of waste incorporation by UPA can be made. For this purpose, Scenario 2 as the scenario with the smallest magnitude of transition in agriculture (5,400 hectares) is chosen. Considering the 1,877 productive units of the *urban agriculture model*[94] in Scenario 2, it is possible to extrapolate the amount of waste potentially incorporated by these areas. Based on the proportions mentioned, around 588,000 tons of organic urban waste could be incorporated every three months by urban agriculture. The extrapolation is detailed in Table 26.

Table 26 - Values for waste incorporation extrapolation

	Material	Current qty (kg)	%
Scenario 2	Pruning of trees in the electrical and municipal network	375.400.000	63.0
	Waste from open-air produce markets	93.850.000	15.7
	Ash	75.080.000	12.6
	Household organic waste	44.225.874	7.4
	Poultry manure	7.508.000	1.3
	Subtotal organic waste (excluding manure):	588.555.874	100.0
	Compost production	**1.877.012**	Every ~ 3 months
	Composting area (m²)	**56.310**	

This arrangement would have the maximum potential of incorporating around 2.35 million (2,354,223.50) tons of organic waste per year throughout the MRSP, a value that surpasses the compostable organic household waste of the municipality of São Paulo, equivalent to 1.87 million tons (1,876,822.95).[95] In relation to pruning waste, 49,000 tons of material were generated in São Paulo in 2019, which could be destined to a decentralized composting system, without accounting for the pruning values of the electric power utility company, which are not made available. Needless to say, there are over 600,000 trees interacting with the power grid in the 24 municipalities covered by the company in MRSP. Annually, the cost avoided would equal R$ 353,133,525, generating savings to the public coffers and providing a source of raw material to urban farmers. This amount represents 2.8 times the budget of the municipality of São Paulo with the National School Meals Program - PNAE (R$125,954,044) in 2019, or 9.3 times the amount available for the same amount in the purchase of food from family farming for school meals.[96]

[93] To consult, access: https://www.bnb.gov.br/documents/165130/228956/PRONAF_PLANO_SAFRA_2019-2020_QuadroResumo_TABELA_GruposPRONAF_grupos_e_Linhas_GERADO_em07_07_2020.pdf/bfa7cc05-a7e7-d8e9-0228-94f7cf4dbd49.

[94] To calculate the extrapolation in the *urban agriculture model* production units, the same organic compost requirements found in the C4 model were adopted.

[95] In the municipality of São Paulo alone, 3,680,045 tons of common household wastes were collected in 2019, of which 51% is suitable for composting (São Paulo, 2014). For more information on solid waste quantities in the MRSP, access: https://www.prefeitura.sp.gov.br/cidade/secretarias/subprefeituras/amlurb/index.php?p=185375#:~:text=Compared%20the%20%20C3%BAltimos%20four%20years,more%20than%20the%20 previous%20year...

[96] Law No. 11,947 of 16 June 2009, determines that at least 30% of the amount passed on to states, municipalities and the Federal District by the National Fund for Education Development (FNDE - acronym in Portuguese, which stands for *Fundo Nacional de Desenvolvimento da Educação*) for the National School Meals Program (PNAE - acronym in Portuguese, which stands for *Programa Nacional de Alimentação Escolar*) must be used to purchase foodstuffs directly from family farms. For more information about Education revenue for the municipality of São Paulo in 2019, access: http://diariooficial.imprensaoficial.com.br/doflash/prototipo/2020/Julho/11/cidade/pdf/pg_0141.pdf.

Decentralized composting systems also present some challenges, among them: minimum infrastructure for safe composting, avoiding any possibility of contamination; capacity-building for urban farmers to be able to safely and effectively perform the composting technique (human capital); capacity-building for the local community to separate organic waste suitable for composting (human capital); development of trust relationships between the parties involved (social capital); and formal agreements with energy and urban cleaning utilities to deliver pruning materials with an agreed regularity.

Conclusions

This study sought to estimate urban and periurban agriculture's future potential for ecosystem service provision in the context of advancing urbanization in the MRSP. As presented in Chapter 1, a interface between UPA and ecosystem service is recent, especially in emerging countries, challenging traditional approaches to the conceptions of territory and agriculture. UPA calls into question the sectoral vision of urban and rural spaces as being restricted to the economic activities with which they are conventionally associated (FAVARETTO, 2007). Similarly, an assessment of ecosystem service provision can expand the functional relations of agricultural activity to encompass human welfare. In this sense, the notion of multifunctionality of agriculture, essential to TEEBAgriFood studies, operates at the interface between agricultural practices, territory and its function of conserving natural resources. In addition to producing raw materials and food, agriculture has a strategic contribution as an important source of ecosystem services in the management of territories and landscapes.

While the multifunctional approach identifies agricultural activity as an articulating agent of functions at the level of territory, where the social and productive family unit is the essential actor (CAZELLA, BONNAL, MALUF, 2009), the ecosystem services approach recognizes ecosystem functions as agents that generate essential benefits for human welfare. Both perspectives have the landscape as the foundation of their analysis and, in the context of agriculture, this study highlights how ecosystem functions are impacted by agricultural activity and inform intervention strategies in the structuring of urban agendas for metropolitan land management.

As such, it is important to situate the exploratory character of the research, both in the articulation between the three approaches mobilized in the study, as well as in the use of the methodologies in urban and periurban contexts. The ecosystem services approach is demonstrated to be a resource capable of qualitatively and quantitatively measuring the contributions and impacts of urban and periurban agriculture in the Metropolitan Region of São Paulo. In a heterogeneous context, it was possible to present evidence regarding how best to position this approach in a space where urban use still predominates and continues to expand. The analysis of the case studies, using the tools proposed by the TEEBAgriFood Framework, suggests some prospects for strengthening the multifunctionality approach to agriculture in view of the various types existing in the metropolis. Within the case studies, incorporating sustainable practices into alternative future scenarios made it possible to assess how agriculture can be strengthened in the wider metropolitan context, in a way that is compatible with the provision of essential ecosystem services to territories. The scenario whereby current conditions are maintained in the territory demonstrates the negative effects of urbanization compromising the areas intended for agriculture, encouraging the occupation of forested areas.

This exploratory exercise gave rise to an inter- and transdisciplinary research design. On the one hand, the interdisciplinary challenge is expressed in the evaluation of a range of ecosystem services and their respective biophysical models within each specific field (hydrology, climatology and pedology), and crossing with the economic and social dimensions of agricultural activity, as seen in the case studies. On the other hand, the transdisciplinary character is manifested in the interactions promoted with key stakeholders, whose interlocution contributed to positioning the premises, methods and results of the research in light of actual experiences lived in the MRSP territory.

The use of open access models, which facilitate future replication by different technical bodies, seemed to be a viable tool for incorporating the values of nature and agriculture into urban planning and policies. Although research results present more trends rather than absolute values, due to the lack of calibration of the models, the research contribution is also manifested in how it connects recently-developed tools in the field of ecosystem services and studies in urban and periurban agriculture. In this way, these trends should be the target of future research, through comparison with more sophisticated modeling, including calibration and validation of the results. In relation to the case studies analyzed in this research, future studies could focus, using the same TEEBAgriFood Framework, on other types of non-commercial agriculture, such as community gardens, institutional gardens, productive backyards and other experiences.

Contributions to the research agenda and evidence generation

Due to the exploratory component mentioned above, it is important to situate some conclusive notes from the research that can contribute to this emerging field of analysis. The spatially explicit biophysical modeling proved to be sensitive to the differences in management between conventional agriculture, organic agriculture and agroforestry systems (AFS). In this sense, prior analysis of capital impacts and dependencies throught case studies and literature review was fundamental. The results show that, although the contribution of organic farming areas and AFS does not reach the same levels of forest areas in the provision of ecosystem services, their values are higher than those of urbanized areas. Agricultural landscapes make up important transition zones between urban land use and forests, providing ecosystem services that translate into benefits for human and social well-being.

In the intra-urban environment, although the degradation of ecosystem functions and competition for land and water resources are more intense, the ecosystem services provided by agriculture stand out because of the proximity of the people who benefit from them (WANG *et al*., 2019). While agriculture can provide such services, it is also dependent on a minimum quality of the ecosystem, which can be restricted under contaminated water, soil and air conditions. In addition, different types of urban agriculture, such as *institutional gardens*, *productive backyards* and *community gardens,* can promote mental and physical health, socialization and networking.

This dimension of the relational values of urban agriculture, as well as framing it in the context of urban environmental quality, should be further explored in future studies. The importance of overcoming existing barriers in public management and the limits of approaches and methodologies that hinder the production of evidence and initiatives to support the practice should be emphasized, as presented in Chapter 1. In this sense, we highlight the need for the elaboration of census data collection categories and the production of spatial analyses adapted to the urban context which can be sensitive to non-urban features. It is evident that the recognition of the different types of agricultural activities in the urban space should identify their specificities, incorporating other types of agriculture other than those analyzed in this study. In this sense, the access to reliable quantitative data can favor the understanding of the magnitude of the effect of possible public and private interventions. The lack of information on the availability of alternative water sources, the production and disposal of organic waste, the land tenure situation and the identification of idle land for urban agriculture are all noteworthy.

Impacts on the territorial development of the metropolis

Urban growth has led to the loss of ecosystem services relevant to the well-being of the inhabitants of the metropolis. Projections indicate that, in the event that there is no intervention, by 2030 there will be 12,000 more hectares of consolidated urban area, generating several negative impacts compared to 1985.

The heat mitigation service is reduced 7.4%, which corresponds to an increase of 1.6ºC in the average temperature in the hottest periods; the decrease of 28% (19 m^3/s) in the realized water supply in the Alto-Tietê Basin, mainly due to domestic consumption; and the increase in 22% (7.2 million tons) in the amount of sediments reaching the watercourses, with the potential to cause siltation and decrease water quality. The resulting increase in soil sealing will reduce water infiltration by 5.5%, corresponding, in case of heavy rains (50 mm),[97] to 17 million m^3 more water in drainage systems.

[97] In São Paulo, rainfall with lower volumes causes flooding points in the city, and in the last decade, two to five days per year with volumes above 50 mm were recorded in the MRSP (MARENGO et al., 2020). This fact is related to climate change, expansion of the urban sprawl, and the urbanization model, as well as natural climate variability.

The literature points out that the increase of 1ºC in average temperature corresponds to an increase of 3.46% of general mortality and 3.26% of cardiovascular and respiratory mortality (MCMICHAEL *et al*., 2008; BARROS, LOMBARDO, 2016). For each degree higher in temperature, there is an increase of 1.7% in energy consumption due to air conditioning, considering hot climates (SANTAMOURIS, 2014).

From 1985 to BAU (Business as Usual, 2030), the decrease in realized water supply (19 m^3/s) corresponds to the volume necessary to supply 5 million normal households annually.[98] This increase in consumption alone represents 48% of the total water available in drier seasons (39 m^3/s) (BICUDO *et al*., 2020), favoring the tendency for the Alto-Tietê Basin to import water.

The difference between sediments exported to watercourses between 1985 and BAU is 1.3 million tons, which is the equivalent of 100,000 soil dump trucks[99] unloading into watercourses over the period of a year. The increase in the amount of sediments suspended in the water results in expenses for its treatment and in the de-silting of rivers and other watercourses, as well as in the replacement of nutrients from eroded agricultural soil. In the Tietê and Pinheiros rivers alone, 40,000 dump trucks with sediments were removed, costing the public coffers R$ 45 million in 2019.[100] In relation to dredging, a procedure that is part of the silt removal strategies, R$ 28.60 per ton removed from the riverbeds is calculated.[101]

Comparing BAU again with the 1985 situation, the soil sealing will increase, in case of heavy rainfall (50 mm), by 17 million m^3 of water with the potential to cause flooding, a volume corresponding to 21 flood-control reservoirs similar to Guamiranga.[102] Extreme climatic events, such as intense rainfall and prolonged dry seasons, have been increasingly frequent in recent decades. Flooding in parts of the metropolis put vulnerable populations especially at risk, and also cause damage to urban infrastructure.

Agriculture's incorporation of sustainable farming practices

The case studies indicate two ways of incorporating sustainability into production systems. On the one hand, there is the sustainable intensification on production systems, mainly oriented towards long distribution circuits and marked by efficiency in the consumption of materials and energy through the intensive use of technology. This strategy of production intensification can reduce the need for land, as it has the potential to free up more space for conservation and environmental preservation areas. The hydroponic system reported in the case studies (C1) follows these premises by being highly efficient in terms of production volume and optimization in the use of conventional agriculture inputs. However, in order to obtain these high levels of production, large investments are required, such as infrastructure for cultivation without soil, performing the replacement of certain stocks of natural capital by produced capital. This path increases dependence on external input flows, causing a potential impact on natural ecosystems and human health.

The other strategy forsustainability is composed by models of *multifunctional agriculture*, combining different functions such as family income production, self-consumption, food quality, commercialization in short circuits, conservation of natural resources, cultural demands and the production of a more inclusive urban space. Such models advocate for maintaining ecosystem cycles through strategies that preserve and regenerate their capacity to provide ecosystem services,

[98] According to SABESP (2016), a normal residence consumes 10,000 liters per month.
[99] It was considered that each dump truck holds 13 tons.
[100] Source: https://www.infraestruturameioambiente.sp.gov.br/2020/02/recorde-de-desassoreamento-do-pinheiros-evitou-que-efeitos-da-chuva-fossem-mais-graves/ .
[101] The reference value was obtained from Gaea; Latawiec (2017).
[102] The Guamiranga "*piscinão*" [Portuguese for "large pool"] was inaugurated in 2017, with a volume for 850,000 m^3, and is the largest flood control reservoir in the municipality of São Paulo: http://www.capital.sp.gov.br/noticia/maior-piscinao-da-cidade-de-sao-paulo-e-inaugurado-na-zona-leste-1.

generating visible results mainly in the medium and long term. As a result, this particular type of agriculture is liable to face barriers to its incorporation into priority policy agendas, despite the multiple available opportunities to strengthen it, such as those found in the case studies, whereby techniques aligned with environmental conservation are adopted. Access to alternative water sources, more efficient production structures and urban resources that can be used in the production system are all ways to complement the recommendations elaborated by Escolhas; URBEM (2020), which focus on the economic and managerial capacity-building potential of urban and periurban agriculture.

These two ways of responding to the demands for sustainability present their limits. In the case of *medium and large-scale commercial agriculture* analyzed in this study, for commercialization purposes, it is necessary to devise another strategy to complement crops produced only in ground soil. In field production, natural capital is depleted through soil management and by the use of agrochemicals, causing a cascading effect of increasing demand for external inputs that restore lost fertility and protect monocultures from pests and diseases. For *multifunctional agriculture*, even if the cost of external inputs is lower, access to land is a limiting factor. The two cases analyzed (C3 and C4) do not include the cost of land, but rather the cost of mobilizing social capital through a series of political articulations and specific trajectories linked to demands for land access near the city and countryside.

With regard to food supply, while the *medium and large-scale commercial agriculture* analyzed in this study favors access to food at more competitive prices, *multifunctional agriculture* aims to promote food and nutritional security through production for self-consumption and commercialization as income generation.

UPA's contribution to ecosystem service provision in the MRSP

The alternative scenarios proposed were intended to evaluate how a possible policy of strengthening and expanding urban and periurban agriculture could contribute to improving ecosystem service provision. The projections were based on the premise of priority allocation of sustainable agriculture in areas with shortages of fresh food supply and high social vulnerability, in order to reconcile the demand for food, income and environmental services. These demands are even more urgent in the context of the COVID-19 pandemic, in which 29.9% of the population of the Southeast region of Brazil presents mild food insecurity and 23.5%, moderate and mild food insecurity (GALINDO *et al*, 2021).

Considering this priority area in Scenario 1 (52,000 ha of transition to UPA), the first contribution of UPA to the provision of ecosystem services includes a distributional aspect: there is an important performance in *food supply*, with the capacity to provide 13 million people locally with vegetables and leafy greens. For the 363,000 inhabitants who today do not have access to fresh food and live in conditions of high social vulnerability, this would be a strategy to strengthen food and nutritional security, besides being an alternative source of income for 129,000 people.

For other services, in general, levels do not present an improvement compared to 1985, and not even to those from 2019, which are of an incremental nature in relation to the no intervention scenario projected for 2030 (BAU). This is because in all future scenarios, urban expansion continues to occur, which continues to negatively impact on the provision of ecosystem services; however, UPA contributes in different ways to buffering the impacts of this urban growth. When analyzing the maximum magnitude of UPA expansion (52,000 ha), in relation to BAU, gains are verified in all services (0.77% in flood mitigation, 2% in heat mitigation and 0.33% in erosion regulation), except on water yield service. An important trade-off was detected in relation to the increase in the agricultural area and the consequent increase in the consumption of water available for irrigation.

Gains in relation to maintaining current conditions until 2030

When comparing Scenario 1 with BAU, there are 83,000 fewer dump trucks of soil being carried to watercourses. This difference occurs mainly due to the ecological soil management considered in Organic Farming and AFS in Scenario 1. For the heat mitigation service, the reduction in average temperature is mainly related to the allocation of AFS in contiguous areas above 2 hectares, and precisely because of this, the effects of this service tend to be more visible in local scale. In some municipalities there is a cooling effect of around 0.1ºC (Salesópolis, Francisco Morato, Mairiporã and Vargem Grande Paulista).

For flood mitigation, the expansion of UPA cannot overcome the impacts of the impermeable area expansion within the urban area, although it shows better results (0.77%) than the future scenario without agricultural expansion. The allocated UPA would be responsible for an increase in water infiltration corresponding to the volume of almost three flood-control reservoirs, such as the Piscinão Guamiranga.

And finally, in terms of water yield, there is an important trade-off, in which this expansion causes an increase in water demand (1.8 m^3/s) for agriculture, which represents a volume necessary to supply 400,000 homes annually. However, assuming greater water retention in the soil and more efficient irrigation techniques, it is possible to reach an efficiency of 34% in water use by agriculture, which would eliminate the increase in this demand and perform better than the no intervention scenario (BAU).

The expansion in smaller magnitude (Scenario 2, of 5,400 ha of UPA expansion), within the targets established in public policies and extrapolated for MRSP (GOVERNMENT OF SÃO PAULO, 2020), points to more discrete results when considering the metropolitan scale, but that are still relevant at the municipal scale. Especially in municipalities located on the urban fringe (Jandira and Poá), and that still have areas of agriculture and pasture, increases close to 3% in heat mitigation are possible, with the allocation of approximately 30 hectares of sustainable agriculture. This higher efficiency was achieved at local level by also considering other priority areas for agriculture allocation, such as heat islands and areas susceptible to flooding, where the AFS had a relevant contribution. Even if the results in Scenario 2 are more discrete, the proposed model of waste incorporation shows that it is possible to reach relevant numbers for the MRSP, with the potential to absorb 2.35 million tons of organic waste per year.

The assessment of the five ecosystem services through the development of future scenarios of transition to sustainable UPA outlined the potential of agriculture in the face of other vectors of land use change, such as urban growth. In order to project horizons that are further away (2050), it would be necessary to incorporate other vectors, such as climate change. Thus, the approach of simulating future scenarios aims to identify the robustness of gains and also possible trade-offs between the ecosystem services evaluated, configuring a more systemic reading that can contribute to future decision making within complex contexts.

Improving metropolitan urban management

Based on the results, it is possible to identify that depending on the sustainability assumptions mentioned above, UPA is able to compose a range of alternatives that can inform the debates on the metropolitan development process. However, the strengthening of urban and periurban agriculture needs to be combined with a broader set of solutions in both urban and periurban environments. The research highlights the following actions: reducing losses in the water distribution system; creating permeable soil areas within the urban fabric; encouraging green infrastructure (roofs, walls and rooftop slabs); recovering degraded areas and protected areas (public and private) through forest restoration. Although such possibilities exist, the challenge remains in the creation and integration of programs, incentives, mechanisms and policies that promote the regulation of urban and periurban land use, and that effectively address issues of land access, both for pressing urban issues (such as social housing) and for agriculture.

The research results indicate that the incorporation of sustainable agricultural practices favors the provision of a set of ecosystem services that can form a broad strategy to mitigate the impacts of urban growth. The regulation of the water cycle and erosion, and the mitigation of heat and flooding are examples covered in the research. There is even greater potential for the incorporation of waste to generate benefits in terms of savings for the public budget and the restoration of soil fertility in small areas. Other services could be related to sustainable agriculture, such as air purification; the reduction of emissions by carbon sequestration (HAMEL *et al*., 2019); the maintenance of habitats (LIN; PHILPOTT; JHA, 2015); in addition to the potential to contain the urban sprawl (UN-FAO, 2014), contributing to the protection of springs, which, among other functions, are essential to the metropolitan supply.

Articulating public policies

It is important to mention that in order to develop large-scale policies dedicated to urban and periurban agriculture, a regulatory framework in the metropolitan context is still necessary to define the practice. This definition, which would require effective state and municipal participation, could guide priority areas of intervention, as suggested by the study, through zoning, strengthening the agenda and its benefits among the municipalities that make up the MRSP. In this sense, the combination of census and spatial data, which allow greater accuracy in the development of evidence, can contribute to the proposition of criteria capable of defining urban agriculture, particularly in view of its multifunctional character in the territory. In the case of periurban agriculture, an interesting criterion to be added concerns economic data that shows land processes of incorporation of agricultural areas for urban use.

As a result of the participatory strategy of the research, it is possible to diagnose the emergence of the two agendas of urban and periurban agriculture and ecosystem services in the context of public management, with emphasis on the performance of the municipality of São Paulo,[103] as well as the need for a greater rapprochement between municipal authorities linked to urban management, environmental protected areas, and agricultural agencies. More specifically, with regard to urban and periurban agriculture, its particularities are still scarcely represented in public policies in the MRSP, with the exception of a few municipalities, such as Osasco, Diadema, São Bernardo do Campo and São Paulo.[104]

Although there are policies dedicated to both urban agriculture and ecosystem and environmental services, the dialogue between the two areas is still scarce. In the context of Payments for Environmental Services (PES) programs,[105] a possible way to strengthen UPA, whereby its functions

[103] The Strategic Master Plan of the Municipality of São Paulo establishes four Green Plans dedicated to the Recovery of the Atlantic Forest, Afforestation, Solidarity and Sustainable Rural Development, in addition to the Municipal Policy for Environmental Services.

[104] The Operation Work Program (Law No. 13.178, 17/9/2001) aims to stimulate the search for occupation of unemployed workers. The calls for proposals include community garden projects. Besides this, the PROAURP (Urban and Peri-urban Agriculture Program of the Municipality of São Paulo - Law nº 13.727/04 and Decree nº 51.801/10), created in 2004, aims to support and encourage local production, helping in the implementation of vegetable garden projects (community, educational, medicinal, private consumption and income generation). The participants accompanied by PROAURP have access to technical and agroecological guidance, tools, seeds and other inputs. It is also worth mentioning the first Municipal Plan for Food Security and Nutrition (2016 to 2020) and the Municipal Plan for Agroecology and Sustainable Rural Development, both of the municipality of São Paulo, whose actions include urban agriculture.

[105] At the national level, Law No. 14.119 of January 13, 2021 was recently sanctioned, defining concepts, objectives, guidelines, actions and criteria for the implementation of the National Policy for Payment for Environmental Services (NPPES).

are strategic in urban and territorial management, is to create public tenders that can cover a cluster of environmental services, rather than focusing on a single service or product. However, cultural ecosystem services, notably educational activities linked to UPA experiences and the maintenance of localized food knowledge and habits, still have limits in their recognition within this type of public policy, pointing to the need for creating other mechanisms. Organic and agroecological production policies (Law No. 10,831/2003 and Law No. 16,684 of 19 March 2018)[106] are also ways of valuing and strengthening UPA, as they are linked to the creation of local markets. Another possibility is the territorial taxation policy, which could incorporate compensation mechanisms in different modalities of green taxation.

Two bills linked to UPA are worth mentioning. The first, under the National Policy on Social Housing (PL No. 9,025/2017), creates incentives for local production of agroecological food among the guidelines of the National Social Housing System, created by Law No. 11,124/05. The second, the National Urban Agriculture Policy, aims to strengthen UPA by taking advantage of idle areas of unoccupied or underutilized urban real estate. Finally, we highlight the participation of collectives and civil society organizations in policy design processes at local and metropolitan levels. The Integrated Urban Development Plan proves to be a fruitful space for prioritizing shared agendas among the municipalities of the metropolis, since agriculture implies two prominent functions of common interest in the MRSP: water and land use. As final statement, this research reinforces the importance of conducting analyses at the metropolitan level, combining efforts of a common agenda while according the necessary attention to regionalized particularities, since the results express important local impact to be further explored.

At the state level, since 2010 there is the State Policy on Climate Change (State Decree No. 55.947/2010), which stipulates the Ecological Economic Zoning as a management and land-use planning instrument focused on guiding public and private investments that make socioeconomic and environmental aspects compatible.

[106] The Organic Production and Certification Policy (Law No. 10,831/2003) determines what an organic production system is, as well as the different forms of conformity assessment, including participatory systems. The State Agroecology and Organic Production Policy was instituted in 2018 (Law No. 16,684 of 19 March 2018) with the objective of promoting and encouraging the development of agroecology and organic production in the state.

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ANNEX

Institutions participating in the working group:

ENGLISH	PORTUGUESE
TEEBAgriFood Initiative (UNEP)	Iniciativa TEEBAgriFood (PNUMA)
Agronomic Institute of Campinas	Instituto Agronômico de Campinas (IAC)
Alto Tietê Watershed Committee	Comitê de Bacia Hidrográfica do Alto Tietê (CBH-AT)
Urban Agroecology Movement	Movimento Urbano de Agroecologia (MUDA)
Federal University of ABC	Universidade Federal do ABC (UFABC)
Institute of Economics at the University of Campinas	Instituto de Economia da Universidade de Campinas (Unicamp)
URBEM Institute	Instituto URBEM
Faculty of Medicine, University of São Paulo	Faculdade de Medicina da Universidade de São Paulo (USP)
Activist Bench - Collective Mandate Legislative Assembly of the State of São Paulo	Bancada Ativista - Mandato Coletivo Assembleia Legislativa do Estado de São Paulo
Forestry Institute	Instituto Florestal
Peripheral Paulistanas Agroecological Farmers Network	Rede de Agricultoras Paulistanas Periféricas Agroecológicas (RAPPA)
Luiz de Queiroz" College of Agriculture	Escola Superior de Agricultura “Luiz de Queiroz” (Esalq/USP)
Mackenzie Presbyterian University	Universidade Presbiteriana Mackenzie
Brazilian Institute for Development and Sustainability	Instituto Brasileiro para o Desenvolvimento e Sustentabilidade (IABDA)
Foundation for the Upper Tietê River Basin Agency	Fundação Agência da Bacia Hidrográfica do Alto Tietê (FABHAT)
LivUp	LivUp
Federal Rural University of Rio de Janeiro	Universidade Federal Rural do Rio de Janeiro (UFRRJ)
Office of Councilwoman Cris Monteiro	Gabinete Vereadora Cris Monteiro (NOVO)
Center for Sustainability Studies of the Getulio Vargas Foundation	Centro de Estudos em Sustentabilidade da Fundação Getulio Vargas (GVCes)
Connect the Dots Project	Projeto Ligue os Pontos (PMSP)
Center for Groundwater Research	Centro de Pesquisas de Águas Subterrâneas (Cepas/USP)
Brazilian Business Council for Sustainable Development	Conselho Empresarial Brasileiro para o Desenvolvimento Sustentável (CEBDS)
Secretariat of Green and Environment / Municipal Government of São Paulo	Secretaria do Verde e do Meio Ambiente/Prefeitura Municipal de São Paulo (SVMA/PMSP)
Municipal Secretariat of Urbanism and Licensing	Secretaria Municipal de Urbanismo e Licenciamento (SMUL/PMSP)
National Council of Environment Biosphere Reserve	Conselho Nacional da Reserva da Biosfera do Meio Ambiente
Green Belt Biosphere Reserve	Reserva da Biosfera do Cinturão Verde
Secretariat of Infrastructure and Environment/São Paulo State Government	Secretaria de Infraestrutura e Meio Ambiente/Governo do Estado de São Paulo (SIMA)
Kairós Institute	Instituto Kairós
Agriculture and Supply Secretariat/São Paulo State Government	Secretaria de Agricultura e Abastecimento/Governo do Estado de São Paulo (SAA)
SubPrefeitura de São Mateus	SubPrefeitura de São Mateus (PMSP)
Cooperative of Work and Technical Advice, Rural Extension and Environment	Cooperativa de Trabalho e Assessoria Técnica, Extensão Rural e Meio Ambiente (Amater)
Institute of Agricultural Economics/Paulista Agency of Agribusiness Technology	Instituto de Economia Agrícola/Agência Paulista de Tecnologia dos Agronegócios (IEA/APTA)