Geodesign Brazil: Trees for the Metropolitan Area of São Paulo

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Abstract. Trees are central in the Nature-based Solutions for promoting simultaneously quality of life and biodiversity while providing mitigation and adaptive ecosystem services in the cities. Based on the Geodesign framework using the GIS-Colab Platform, the impact of decision-making scenarios on tree-cover changes, as well as the consequences it will have for carbon sequestration, was evaluated for 2020, 2035 and 2050 in the Metropolitan Area of São Paulo (MASP). This metropolitan area is one of the largest urban conglomerates in the world with more than 22 million people. It lies on the Atlantic Rainforest Biome, a tropical moist

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broadleaf forest regarded as a world hotspot of biodiversity. First, a diagnostic of the current conditions was elaborated using available layers of geospatial data from the MASP. Then the future tree cover was discussed according to three scenarios: i) the non-adopters that represent the business as usual; ii) the late-adopters that develop innovative actions from 2035; and iii) early-adopters that undertake innovative interventions of urban greening from 2020. The vegetation cover was estimated to be reduced by 4% considering the current non-adopter scenario by 2050. On the other hand, vegetation cover has the potential to increase 30% in 2050, once there is an early adoption of innovative interventions, promoting various ecosystem services and co-benefits that support the quality of life and the biodiversity in the MASP, while fostering the carbon credit in the city through vegetation carbon sink. This article points to possible pathways required to attain desired afforestation goals in the MASP following the Geodesign framework. This framework proved to be effective even though it was based only on remote meetings, imposed by the social distancing during the pandemic of COVID-19.

Keywords: Urban trees · Carbon credit · Geodesign framework · Early-adopter

1 Introduction

Cities are renowned for their direct and indirect negative impacts on the global biogeochemical cycles and on the resilience of the world's natural environments. As major drivers of global environmental changes, cities are now seen as the main source of solutions, helping to support mitigation and adaptation plans to climate change based on global agreements like The Paris Agreement [1], and strategies for a sustainable world such as the Sustainable Development Goals [2]. Urban forests can be defined in its broad sense as the set of all forest fragments, parks, gardens and street trees [3]. The role of urban forests on CO2 sequestration largely depends on the protection of the natural capital of cities and the availability of open spaces for afforestation. As in many cities worldwide, transport is the main source of carbon dioxide in the metropolitan areas of Brazil. The infrastructure that supports urban mobility, together with housing, also competes for the available open spaces for greening in the urban fabric. Therefore, integrated multi-sectorial approaches are essential for any actions promoting the protection of the urban forest and the afforestation of the available spaces to promote urban carbon sink.

Integrating mobility, housing and green infrastructure in urban planning to mitigate atmospheric carbon dioxide, especially in the large metropolitan areas, will inevitably lead to other positive impacts of urban forests. Ecosystem services, such as: reduction of air pollution, shading and stabilization of temperature and noise reduction [4–6] would foster the quality of life in the cities by improving mental and physical health. In addition, the improvement of the urban environment by planting trees also reflects on the way people live and move, increasing the efficiency of the urban activities. Both urban afforestation and high efficiency of the urban activities may reduce the environmental impacts and massive carbon footprint of the cities.

The balance between urban CO_2 sources and sinks depends on the historical processes of land-use change and occupation of the cities that are based on the dynamics and impacts of decision making. The Metropolitan Area of São Paulo (MASP) is an

example of one of the largest urban conglomerates in the world that face problems created by unplanned growth during the last decades. This area hosts more than 22 million inhabitants distributed along 39 municipalities. Out of the total 8051 km^2 [8] of the MASP, almost 56% is covered by trees [9]. Tree cover, however, is rather unequal and it is mostly concentrated on two main protection areas in the continuous green belt across the north (Serra da Cantareira), and south (Serra do Mar) of the MASP borders that provide many ecosystem services to the cities including water supply.

This study presents the results of a co-design process, based on Steinitz's Geodesign Framework [10], conducted by a multidisciplinary group of experts. The main objective was to evaluate the deforestation and afforestation trends on the MASP´s urban forests by 2050 under three different decision-making scenarios, I) non-adopters, II) late-adopters, III) early adopters. These scenarios are then discussed in the light of carbon sink and credits of carbon. The research presented here is part of the "Geodesign Brazil: Trees for Metropolitan Regions", a study that is being conducted in nine different metropolitan areas of the country.

2 Material and Methods

With the aim to increase the vegetation cover and carbon sink in at the MASP, a group of 13 researchers of various fields, worked remotely during synchronous workshop sessions using the GISColab platform.[1] This platform was developed by the Geoprocessing Laboratory of the School of Architecture of the Federal University of Minas Gerais. It uses the Geodesign framework but in a flexible approach that is adapted to the Brazilian context. The combination of Geodesign framework and GISColab platform allows the co-design of ideas and plans for large regions and are specially suitable for remote work during the pandemic.

The co-design workshops took place in four thematic meetings (Fig. 1), namely: (i) reading enrichment, which consists of obtaining and evaluating georeferenced data to characterize the current scenario of vegetation cover; (ii) development of non-adopter scenarios (2035–2050) according to the business as usual; (iii) development of late-adopter scenarios (2050) built upon the non-adopter scenario up to 2035, and the late adoption of innovations; and finally, (iv) development of early-adopter scenarios (2035–2050) that adopt innovative actions right from the beginning.

Initially, the available database on the GISColab platform was analyzed by the participants, who identified the most relevant data layers to the MASP and then estimated and established goals for the changes in the number of street trees; water reservoirs; detention ponds; green detention reservoirs; informal settlements; urban sprawl; natural and planted forest areas; and urban Heat Islands for the three scenarios (Table 1).

For all scenarios, the values of increasing or decreasing percentage of green cover related to 2020/21 were estimated to 2035 and 2050. Linear trends from historical

[1] The Brazilian Geodesign platform - GISColab has the premise of supporting and connecting Spatial Data Infrastructure (SDI), WebGis, and Geodesign in order to provide integrated and georeferenced information on the territory, enabling a wide availability of data to support the discussions and negotiations on the adopted spatial profile [11]. Available at: http://www.giscolab.com/geodesign/#/.

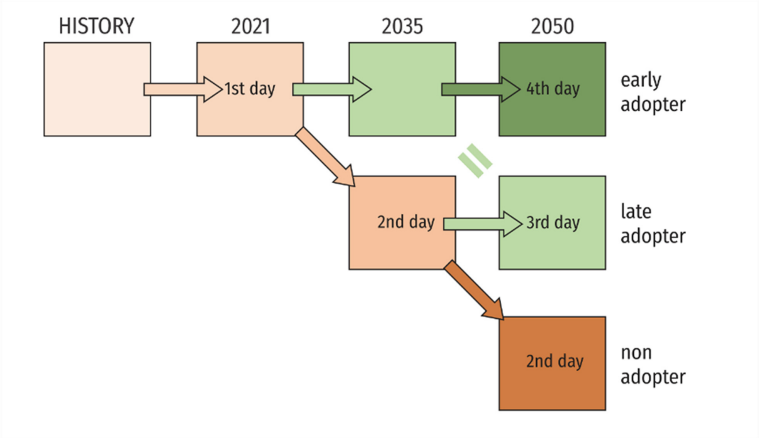

Fig. 1. Geodesign workshops workflow. Source: Authors. Adapted from IGC, 2021.

datasets starting in 1985 up to the present were used for the extrapolations. The number of detention ponds proposed by the Master Plan for the Macrodrainage of the Alto Tietê Basin [12] was evaluated, considering not only the construction rate and the typology, but whether they would be made by concrete or integrate the Green Infrastructure. In addition, future urban sprawl was extrapolated by analyzing the census datasets [13] that also includes the distribution and growth of slums and urban settlement areas, and changes in natural and planted forests available on MapBiomas (MapBiomas/IBGE)[2]. For street trees, data from the Municipal Plan for Urban Trees [14] were used, including data on tree fall, replacement of senescent individuals, and planting. Finally, the goals for the afforestation of the MASP were discussed and defined by the present group of researchers during the workshop.

2.1 Reading Enrichment

The workshop took place remotely to cope with the social distancing protocols of the COVID-19 pandemic, which allowed the participation of researchers from various institutions with different backgrounds. This early step was essential to promote an appropriate collaboration, following the Geodesign framework [10]. The team first discussed national and international reference cases, in different contexts and scales, and then proposed guidelines, general strategies and public policies to guide the development of the workshop. Overall, they aimed at conserving the protected areas and existing vegetation, increasing the vegetation cover in urban, peri-urban and rural areas, and restoring mainly riparian forests. Two examples of these strategies can be mentioned: I) the support to plant trees through public policies and environmental compensation plans mainly for the construction industry, and II) the creation and implementation of an afforestation plan

[2] The Expressive Vegetation Map in GISColab was based on Vegetable Cover Maps of Brazilian Biomes developed by GeoPrea Laboratory (EAU/UFMG). Available at: http://mapas.mma.gov.br/mapas/aplic/probio/datadownload.htm?/mosaicos_vegetacao/.

for streets and highways, with recommendations of appropriate techniques and species for each context.

The metropolitan structuring axes were identified, which serve as the basis for planning the MASP urban area growth, with special attention to the green areas. Areas for conservation were identified, such as the natural forests from the São Paulo Green Belt Biosphere Reserve (UNESCO) that includes remnants of the Atlantic Rainforest such as Cantareira State Park and the Capivari Monos Permanent Protection Area. The Green Belt is currently threatened by the urban sprawl of the MASP with a high pressure on the native forests and water resources. In summary, the reading enrichment allowed filling the gaps in the database, while evaluating the past trends and understanding the current dynamics of the city for the landscape prognosis in future scenarios.

2.2 Non-adopter (2035 and 2050)

The non-adopter scenarios for 2035 and 2050 were discussed based on four pillars, (i) the current legal instruments concerning the cities' master plans, urban forests, green areas, protected areas and open spaces; (ii) the current trends in tree planting and survival rates; (iii) the pressure for land development from the construction industry and real estate market; and (iv) the illegal activities that take place especially in the Green Belt at the borders of the MASP.

Most cities in the MASP updated their master plans recently or are in the process of establishing new plans. These plans regulate the land use across the city, defining the maximum verticalization, economic activities and minimum percentage of green and open spaces in the cities' districts, to name a few. Therefore, such mechanisms have the potential to protect some of the cities' green spaces, but not all of them, according to the percentages of development area allowed in each district. In addition, laws and regulations already define extensive protected areas in the MASP including remnants of the Atlantic Rainforest, such as State and Municipal Parks, Ecological Stations, which are unlikely to change soon.

Some of the mentioned plans also established goals for tree planting in the cities, so that thousands of trees are being planted yearly in the MASP. There are also groups of activists regularly planting trees in the city [15]. However, there is still a huge backlog of poorly managed trees that are prone to fail especially during the summer, or the wet season. More than 2,000 mature trees fall only in the city of São Paulo every year [16]. In addition, there is a high mortality rate in the new plantation programs in the cities. Although the number of individuals is likely to increase in 2035 and 2050, the ecosystem services balance such as carbon sink is likely to be negative with the significant reduction of the mature tree cover over the cities.

Tree cover may also be threatened by the current pressures from the construction industry and real estate market [17]. Especially for the largest cities of the MASP, the available space for construction of new buildings is becoming increasingly rare, threatening the few non-protected green areas in the city, some of them still baring significant native fauna and flora. The current laws and regulations are not sufficient to keep these areas under protection as many compensatory mechanisms are available allowing the development of these private lands.

Finally, public areas in the green belt are currently endangered by the activities of organized crime. Extensive areas of native vegetation around the main water reservoirs of the MASP are being converted into informal settlements [17, 18]. Although they are considered Permanent Protected Areas, the expansion of forest conversion is at a rate far superior to that of State oversight. The municipalities of the MASP have adopted the strategy of promoting the urbanization of the informal settlements and not the reallocation of these vulnerable families that is usually adopted in many other cities worldwide [19]. As a result, large areas of Native Atlantic Rainforest will be permanently lost affecting the water security of more than 20 million people [20, 21].

The water supply system is already threatened by the combination of recurrent unfavorable climate conditions and increasing water demand in the MASP. The increasingly frequent climate extremes such as the drought caused by an unusual mid-troposphere blocking during the summer of 2014 [22] potentially affects the water supply in the cities of the MASP. For instance, by the end of 2014, the Cantareira system, the main potable water reservoir of MASP, had a negative 2% total volume compared to normal levels. Such unfavorable climate conditions observed in the last years are consistently decreasing the volume of water in the main reservoirs [23], which is likely to continue to decrease in the upcoming years [24].

Following the trend described before, street afforestation is expected to increase by 18% in 2050, which is not sufficient to replace the ecosystem services lost by the senescence, removal and fall of mature trees. A 5% increase in informal settlements is also projected together with an increase of 34% in urban sprawl and a consequently reduction of natural forest areas by 4%. Planted forests are expected to increase by 78% (Eucalyptus, Pine) negatively impacting the urban and peri-urban biodiversity. Regarding the impacts on the recharge of water reservoirs due to the expansion of impervious cover, a drastic reduction in reservoirs of 76% is expected in the MASP. The construction of detention ponds on urban areas, must increase by 146%, competing for available open space which could be partially or totally used for planting trees. Green detention reservoirs and recovery wetlands to be built, would show a decrease of 1%. Regarding the Urban Heat Island, it is predicted an average of 22 °C of surface temperature in the central area of São Paulo city (the warmest area in the MASP), related to its surrounded rural and natural areas.

2.3 Late-Adopter (2035 and 2050)

Similar trends to the non-adopter scenario described above are expected up to 2035 in the late adopters scenario. It is only after 2035 that a significant change is expected in the actions from policy makers and society regarding the main environmental, social, and economic issues in the city. These issues are then tackled by the implementation of innovative solutions that must account for the possible negative impacts of the non-adopter approach on the urban green infrastructure.

Thus, the measures necessary for the qualification of the urban environment by 2050 start upon an already vulnerable environment and may be less effective compared to the current needs of the MASP. Three approaches guided the innovative action to start in 2035, namely: I) protecting, II) expanding and III) creating a green infrastructure. These

approaches relied on the control of urban sprawl, qualification of the existing land cover, promotion of green and blue infrastructure.

To achieve the objective to increase the tree cover in the MASP, these actions should be considered simultaneously to offer a real change in the development of the city from 2035 until 2050. We identified the main points to control the reduction of pre-existing green areas and promote the afforestation of new areas. First, there is a need of controlling the urban sprawl of the metropolitan area of São Paulo, including the optimization of the existing urban land occupation. Central areas that have a large accumulation of vacant buildings offer most opportunities for change.

The requalification of the existing occupation of the urban landscape must rely on the implementation, monitoring, continuous revision and sectorial articulation of different public policies, such as: (i) public policies, with focus on encouraging the protection of green areas with financial incentives, based on the payment for ecosystem services, while including innovative solutions such as: green roof, cisterns, green wall with climbing plants; and (ii) elaboration of new housing policies that consider the synergy between conservation of green buffer zones and the sustainability of local economic activities, by a green-economy concept.

These policies should provide structure for urban redevelopment projects through urban design with Green Infrastructure principles, in a wide participatory and inclusive manner, by maintaining the population in the site, but within a secure and eco-friendly condition.

In addition, one must also consider the relationship between trees and urban water that lead to a gradual change from a conventional "gray" monofunctional infrastructure, into a system of multifunctional green infrastructure. The following actions were considered: (i) the transformation of the existing edges of the Flood Storage Reservoirs System. These areas present the potential to be reforestated, while planning areas of permanence and social interaction. (ii) development of plans focused on the water quality of the reservoirs, considering the concept of regeneration in urban design of the respective water basins; (iii) environmental program for reforestation of existing urban watersheds, altogether with related public housing policies; and (iv) restoration of the riparian forests of the Pinheiros and Tietê River.

Finally, the reconfiguration of the urban forest was also discussed. This concept considers the complete system of open spaces in the metropolitan area, the protected and natural reservoirs, public parks, squares, streets, and private free spaces.

The main condition to protect the existing green assets, besides the topics already discussed here, focused on better management practices of urban trees and vegetation: (i) improving the urban aerial electrical distribution system, that currently present serious conflicts with the existing street-trees; (ii) elaboration of a specific master plan for trees management, introducing processes of optimization, such as the concept of reverse logistics to consider the pruning tree residues applications in civil construction, urban furniture, fertilization, etc.; and (iii) development of a master plan for planting new trees, considering the different existing biomes and innovative solutions.

To increase tree-coverage within the urban built area, different actions were brought to discussion considering the 2050 scenario, that were based on previous experiences, such as the Sacramento "Green City", in the U.S.A., examples from Singapore, and

the revision of local experiences in Brazil such as Maringá city. They include: (i) public policies that encourage urban planting and afforestation, considering its ecosystem services; (ii) redesign of existing streets with based on Green Infrastructure principles associated with the creation of sustainable and safe urban mobility; and (iii) optimization of parking spots as the main strategy for making additional space feasible for permeable areas, afforestation, and the implementation of green-blue infrastructural components and urban farming infrastructures.

Thus, the 2035 late-adopter scenario most of the items analyzed (see Table 1) considered 50% less changes related to the 2050 non-adopter scenario. For example, the impact on drinking water reservoirs in the late-adopter 2035 scenario corresponds to a reduction of 38% in relation to 2020. By 2050, the late-adopter scenario is expected to lead to positive changes. This was reflected in almost all the items evaluated, like increasing the number of street trees by 30%, reducing water availability by only 10%, decreasing the number of detention ponds on forests to 83%, while increasing green detention reservoirs by 10%. A drastic reduction of 0.5% of informal settlements is also predicted, and a limited increase of urban sprawl of 9%, while increasing afforestation by 45%. There is still an expected increase in the Urban Heat Island - UHI but limited to 10 °C.

2.4 Early Adopters (2035 and 2050)

The proposed measures in the early-adopter scenario relied on the most innovative public policies, many not yet developed or practiced in the city of São Paulo. The scenarios considered the application of green infrastructure technology to promote the conservation and expansion of forest fragments and green areas. In addition, a great effort for creating new urban forests is fostered by different activities.

These activities include planting street trees, planting trees in the parking spots, in at least 2 parking spaces every 100m. In each parking spot, there is room for planting up to 16 trees, which would be associated with bio-retention structures. According to these plans, the scenarios developed showed a significant increase in the vegetation cover of the MASP compared to the levels of 2020, and consequently reaching the established goal of 30% increase in vegetation cover, resulting in a more sustainable urban development under the aspects analyzed, as described in Table 1.

The early-adopters scenario of 2035 considered similar rates that the late-adopter 2050 for issues such as, number of trees on the roads, urban sprawl evolution and urban heat islands, while more significant positive changes were predicted for the other items. By 2035, it is expected a 10% increase in water reservoir volume, a 4% reduction in detention ponds built on forests, and an increase of 35% in green detention reservoirs. It is also expected a total control of the growth in informal settlements, a 15% increase in natural forests and a 10% increase in planted forests, and a 10 °C increase in surface temperature due to UHI. By 2050 the scenario is rather optimistic, with 50% more street trees, 25% more water availability, 8% less detention ponds built on forests and 70% more green detention reservoirs.

It is also expected a significant reduction in informal settlements, a controlled urban sprawl around 4% increase, 30% more natural forests and 15% more planted forests, and only a 5 °C rise in surface temperature due to UHI (see Table 11 for the complete

data). The predicted lower impact of UHI in early-adopter scenario by 2050 assumes of a greener city [25]. Urban environmental planning actions outlined within green infrastructure strategies would leverage the preservation of forests, planting of trees, and construction of green detention reservoirs (Fig. 2).

Table 1. Predicted changes of the Metropolitan Region of São Paulo (total area 7 946,84 km^2) according to the early, late and non-adopters' approach. The increased percentage is related to the 2020/21 and the references for Early adopters are based on goals for the Design decisions. The year 2035 is similar for late and non-adopter.

	CURRENT	EARLY		LATE		NON	REFERENCES
	2020	**2035**	**2050**	**2035**	**2050**	**2050**	
Number of street trees based on the balance between planted and fallen plus removed trees.	652,146	30%	50%	9%	30%	18%	[16, 26]
Impacts on the recharge of water reservoirs due to expansion of impervious cover	1.132. 610.000m³	10%	25%	-38%	-10%	-76%	[23, 27]
Detention ponds over urban forests to be built.	48 un.	-4%	-8%	73%	83%	146%	[26, 12]
Green detention reservoirs and recovery wetlands to be built.	0 un.	35%	70%	1%	10%	1%	[26, 11]
Increase/Reduction in informal settlements	88,34 km²	0%	-5%	2,5%	0,5%	5%	[13, 24, 28]
Urban sprawl evolution	2.038,69 km²	8%	4%	17%	9%	34%	MapBiomas platform Growth compared with 1985-2019 period
Increase/Reduction in Natural forest areas due to urban sprawl/reduction	3.581,85km²	15%	30%	-2%	-2,5%	-4%	
Increase in Planted Forest (Eucalyptus, Pinus and Araucaria) areas due to urban sprawl/reduction	260,92 km²	10%	15%	40%	45%	78%	
Increase in the Urban Heat Islands: average of the surface temperature of central area of SP less rural areas	15°C	10 °C	5 °C	18 °C	10 °C	22°C	[29]

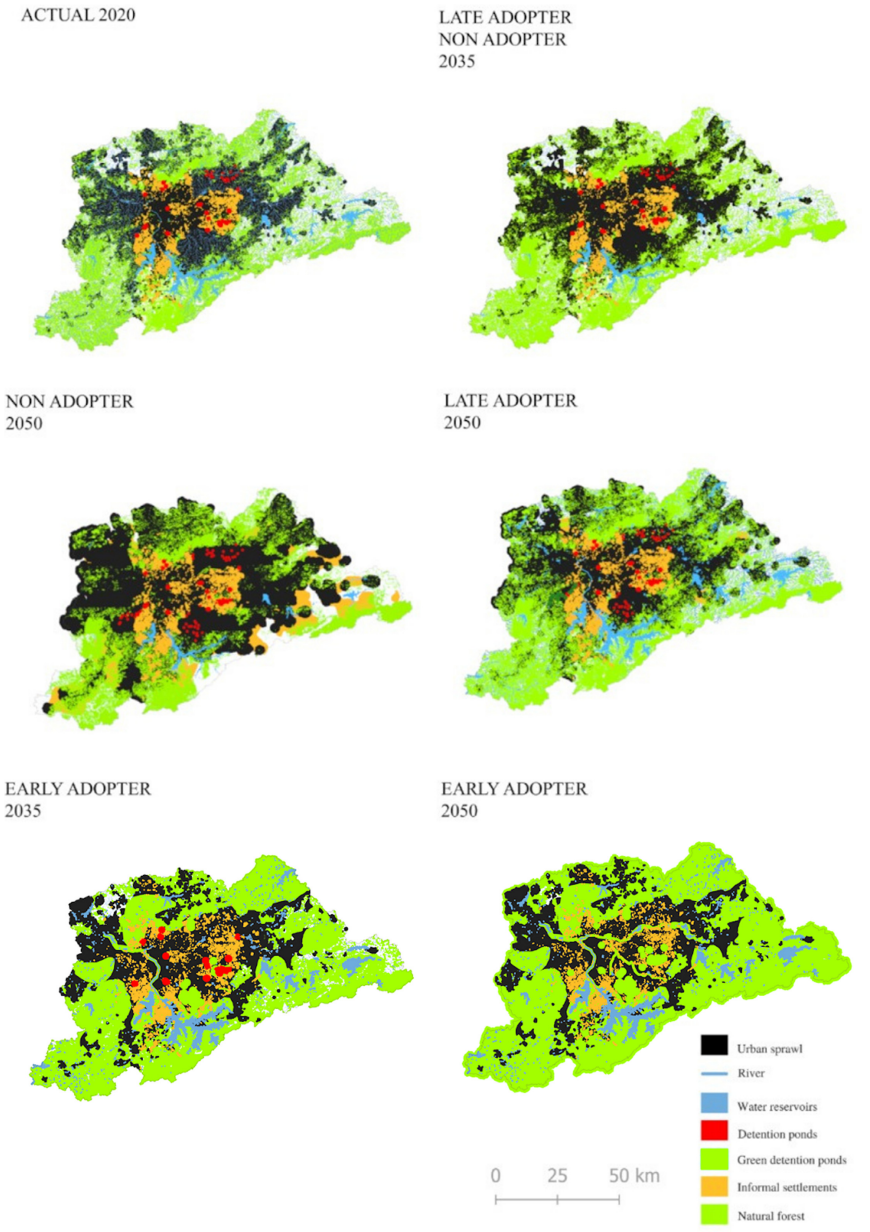

Fig. 2. Spatial distribution of the most relevant layers of the Metropolitan Region of São Paulo for the actual scenario (2020) and the prediction changes for 2035 and 2050 according to the early, late and non-adopters' approach described in Table 1

3 Conclusion

Using the Geodesign principles and framework, supported by the GISColab Platform, allowed the group to list the main problems related to the green infrastructure in the MASP, and create three theoretical scenarios, I) non-adopters, II) late-adopters and III) early-adopters, for 2035 and 2050. The scenarios based on the business as usual from the non-adopter approach point to a significant reduction in the recharge of water reservoirs and the natural forest areas. There is one exception related to the total number of street trees that are likely to increase, which may not reflect on the ecosystem services they provide as the number of old growth trees are expected to decrease sharply. These changes in the overall vegetation cover are expected to sustain the current environmental degradation by increasing the Urban Heat Islands and reducing the water supply.

Similar trends are expected in the scenarios of the late adopters up to 2035, when changes in planning and management of the urban green infrastructure take place. This scenario then assumes innovative technologies, based on green infrastructure, among others that lead to more favorable predictions compared to the non-adopter scenario. In the early adopters, such innovative technologies are implemented by 2020 resulting in a significant increase in the number of trees and carbon biomass in the MASP.

The experience of working with the GISColab platform made it possible to bring together several researchers from different areas to collaborate in the elaboration of different scenarios for tree cover and carbon sink across the MASP for 2035 and 2050. This was only possible based on a successful remote work, which would otherwise be much more difficult to carry out in the current moment of the coronavirus pandemic.

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