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The socio-ecological functioning of Barcelona's metropolitan area in ten indicators

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Metropolitan systems are introducing a new paradigm into their approach: that open spaces constitute a green infrastructure providing a whole series of ecosystemic services, dependent on which are both the quality of life of people living in built-up spaces and also the possibility of developing a more circular and sustainable economy than the one in the current economic model. The debate that has been held to sharpen this new focus on interdependency between built-up space and open space has also highlighted the need for discovering and assessing the interactions that occur, or could occur, between the two subsystems. This article is intended to present an assessment of recent socio-ecological dynamics occurring in the Barcelona metropolis, through a selection of ten socio-environmental indicators. Conclusions and implications will then be drawn from these for the purposes of metropolitan management and planning.

Introduction

Metropolitan areas are introducing a new paradigm into their approach: that open spaces constitute a green infrastructure providing a whole series of ecosystemic services, dependent on which are both the quality of life of people living in built-up spaces and also the possibility of developing a more circular and sustainable economy than the one in the current economic model. This paradigm shift is considered crucial if metropolises are to be able to play their rightful role in achieving the sustainable development goals (SDGs) proposed in the UN 2030 Agenda and taken on by the Spanish Central government and the Catalan regional government.

The debate that has been held to sharpen this new focus on interdependency between built-up space and open space has also highlighted the need for discovering and assessing the interactions that occur, or could occur, between the two subsystems. It is currently accepted that this challenge requires another look at metropolitan socio-environmental systems that will identify their role in the functioning of the system and allows quantification of their energy and material flows, moving in both directions. This will enable us to study how such an exchange shapes a specific biodiversity and specific structures of land uses expressed in landscapes that need to provide vital ecosystem services for the network of cities and adaptations to global changes.

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The Metropolitan Laboratory of Ecology and Territory of Barcelona (LET) was launched in 2018 to take on this challenge[1]. The LET was set up under an agreement between the Barcelona Metropolitan Area (AMB), the Barcelona Institute of Regional and Metropolitan Studies (IERMB) and the Ecological and Forestry Applications Research Centre (CREAF). The LET proposes three basic goals:

1. To complete and update databases and geographical information on the most significant biophysical variables in the metropolis of Barcelona, in accordance with the authorities involved, so that they can be used in the region's sustainable planning.

2. To monitor key aspects (metabolic efficiency, biodiversity conservation, functioning of the landscape, ecosystem services, global change and social cohesion) and planning tools (green infrastructures, peri-urban agriculture etc.,) of the metropolitan system.

3. To promote applied research for creating knowledge on the metropolitan socio-ecological system and identifying critical or strategic elements for planning and managing the region.

The LET aims, in particular, to hone criteria and tools for analysing Barcelona's metropolitan system from this functional perspective of the region as a system, with the aim of affecting the necessary change in public policies and regional planning to meet the challenges and proposed goals. From the regional planning perspective, landscape ecology concepts and methods are becoming increasingly important for linking patterns of land use and the ecological processes associated with the maintenance of biodiversity and ecosystem services. Likewise, there is often a failure to incorporate the perspective of how human activity, beyond its capacity for upsetting ecosystems, changes the general functioning of the metropolitan system with specific material and energy exchange processes. The conceptual and methodological framework of the ecological economy, and the focus on social metabolism in particular, also allow us to approach this new functional vision of the interactions between society and nature. In short, accounting for material and energy flows that are internal or with other regions, together with the renewed perspective of landscape ecology, enables a multi-dimensional and multi-scale assessment of the contribution of open spaces in the functioning of the metropolitan system and the design of multifunctional green infrastructures in the Barcelona metropolis.

This article is intended to present an assessment of recent socio-ecological dynamics occurring in the Barcelona metropolitan area (AMB) and region (RMB), through a selection of indicators devised by the LET (published in "La metròpoli en 100 indicadors. L'AMB en xifres 2019")[2] based on several sources: climatic variability; land uses; state of vegetation; plant biomass; functional structure of the landscape; state of biodiversity; water consumption for the green infrastructure; ecological state of rivers; energy consumption and greenhouse gas emissions and atmospheric pollution. Conclusions and implications will then be drawn from these for the purposes of managing and planning metropolitan socio-environmental systems.

1. Recent socio-ecological dynamics

1.1. Climatic variability

Monitoring annual meteorological indicators may prove useful for observing trends in climatic variables. Climate change is characterised by a sustained anomaly over time, despite any year-to-year variations there may be. That is why regional monitoring has been carried out, since 2008, of differences in annual average temperatures and rainfall with respect to a period of reference set by the IPCC (1961-1990), and recent climate variabilities are thereby observed.

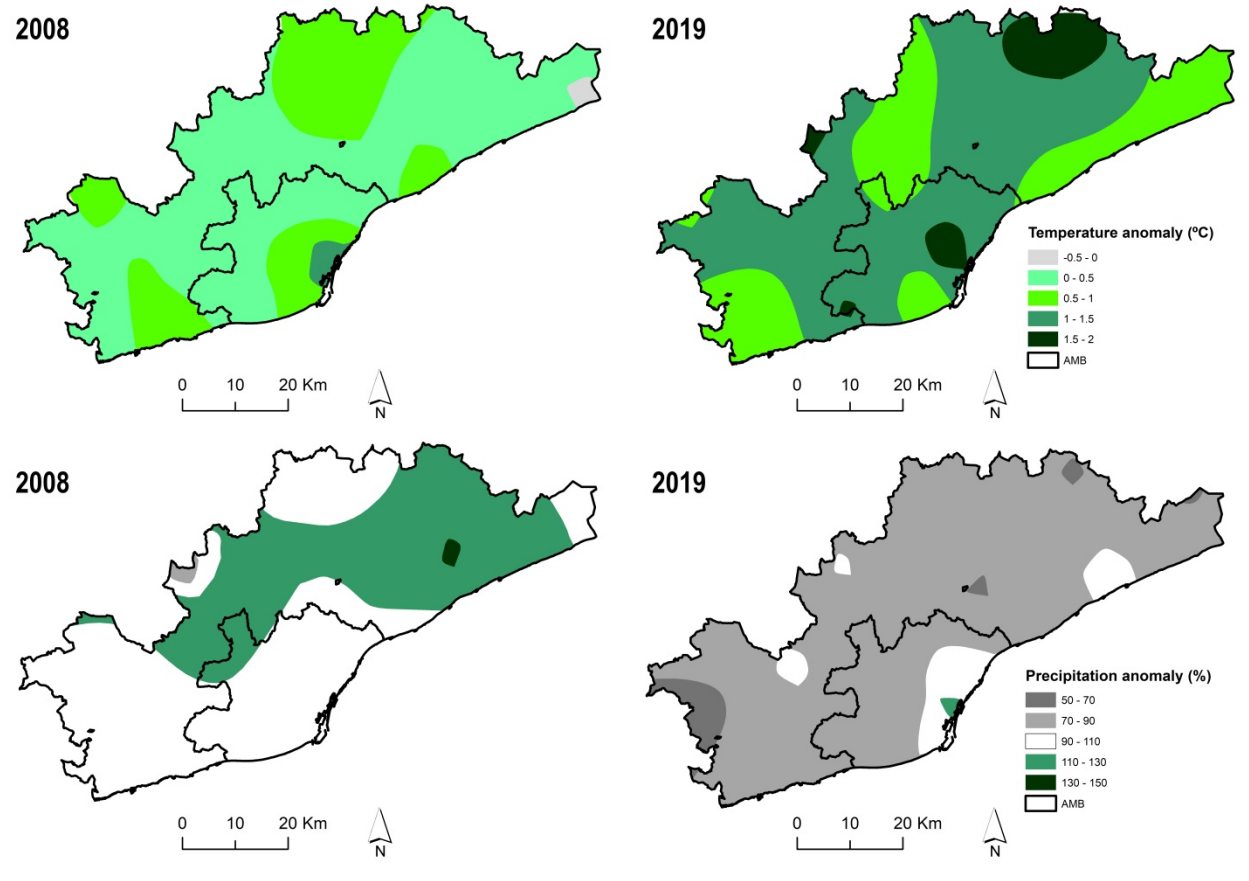
While it may have been a brief series since 2008 for defining trends in climatic terms, the last few years have seen a sustained anomaly effect in temperatures, which have been at least 1°C above

1. See them on: https://iermb.uab.cat/ca/let-bcn/
2. See them on: https://iermb.uab.cat/es/amb-en-xifres/la-metropoli-en-100-indicadors-lamb-en-xifres-2019-2/

the average for the 1961-1990 period since 2014. These differences over the last five years have been above the average in Barcelona's case, a situation that has worsened the heat island effect there (figure 1). An above-average increase has also been maintained during the same period in the Montseny massif, with the impact this may have on its ecosystems. During the eleven-year series of data on average temperatures running from 2008 to 2019, it was only in 2010 that they came close to those of the reference period.

As for the precipitation anomaly, the variability is much higher than in the case of temperatures. So, while in 2018 the average precipitation was 50% above the reference, in 2019 it was 20% below in the Barcelona Metropolitan Region (RMB). The anomaly was distributed quite uniformly throughout the region (figure 1). No clear trend has been observed, given that a certain downward trend was broken in 2018, given that there has been no year since 2010 with an average precipitation above that of the period of reference.

Figure 1. Temperature and precipitation anomaly in the Barcelona Metropolitan Region (RMB). 2008 and 2019

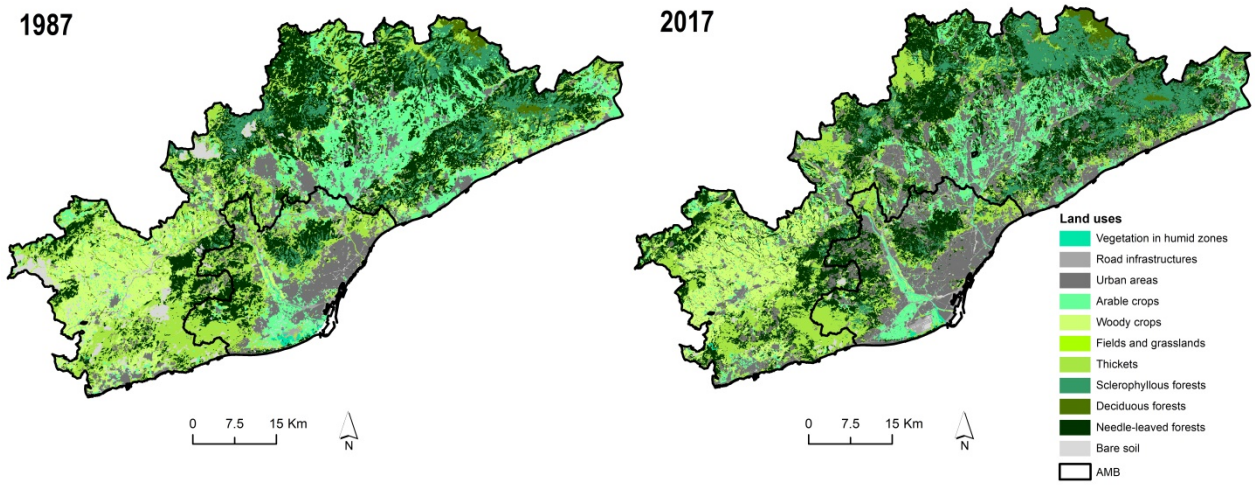


Source: Metropolitan Laboratory of Ecology and Territory of Barcelona (LET) based on the Figures produced by the Catalan Meteorological Service (SMC, 2020).

1.2. Land uses

As we all know, the most important change of land use in absolute terms over the last 30 years in the Barcelona metropolis has been its urban expansion (having increased by 70% in the RMB and by 37% in the AMB, according to data from the Landsat satellite), a process that has been accompanied by a very significant rise in road infrastructures (figure 2). The trend from 1987 to 2017 was not just generation of continuities and completions in urban sections but also the appearance of new, disperse urban developments. Despite the fact that open spaces still prevail, the impact that such urban space — whether dense or disperse — has on the fragmentation of the region and functionality of the landscape is the key to understanding the metropolis's present socio-ecological challenges.

Figure 2. Land uses in the Barcelona Metropolitan Region (RMB). 1987 and 2017



Source: Metropolitan Laboratory of Ecology and Territory of Barcelona (LET) based on Figures prepared by the Catalan Ministry of Territory and Sustainability (DTES) and the UAB-CREAF (GRUMETS, 2018).

Urban expansion, along with the abandonment of agricultural activity, has led to a constant reduction in agricultural land to the point where it dropped by 25% in the AMB and by 18% in the RMB between 1987 and 2017. An large part of this land has become urban space, although some has ended up enlarging forest areas, mainly needle-leaved forests — dominated by Aleppo pine trees — and sclerophyllous forests — mostly holm-oaks—. Both processes also occurred in thickets, which dropped by 9% and 22% in the RMB and the AMB, respectively. There was also a lot of bare soil in 1987, as can be seen above all in the north-west, resulting from the areas burnt by the fires of 1986 (see the plant-biomass indicator).

As for agricultural uses, the area of cultivated land in the AMB is 8.1% of the total, whereas in the RMB it is still as much as 16.9%. The process of abandonment of this area of land has actively continued over the last decade, with an average annual loss of 231 hectares in the RMB and 37 hectares in the AMB, leading to a steady reduction in the food sovereignty of the Barcelona metropolis. Irrigated herbaceous crops (mainly in the Parc Agrari del Llobregat) and a fresh-fruit zone in Ordal predominate in the AMB (2019). By contrast, in the RMB, grapevines continue to predominate in the RMB, in the Penedès, treeless land intended for cereals on the Vallès plain and cultivated land in the Maresme.

1.3. State of vegetation

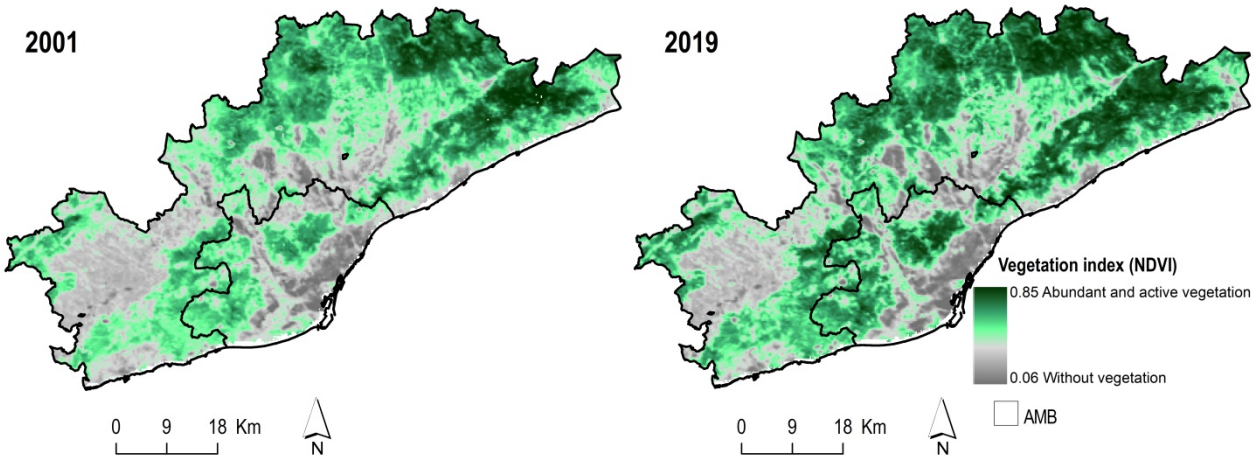
The normalised difference vegetation index (NDVI), obtained with Terra satellite data (MODIS), indicates the state and the abundance of vegetation. This is a relative measure (value between 0 and 1) of the photosynthetic vigour and activity of plant masses, widely accepted internationally. Values close to 1 indicate a better vegetative state, intermediate values relate to more stressed states of vegetation and low values correspond to non-plant covers.

In the Mediterranean context, this indicator relates strongly to the availability of water for the vegetation and is therefore used a lot in indicators for adaptation to climate change (see the water-consumption and climate-variability indicators). Even so, care should be taken when interpreting this indicator's values as they may vary with the most recent climate.

As can be seen in figure 3, the average NDVI values in the RMB are slightly above those in the AMB, given that this region incorporates large massifs with climate conditions that are more favourable to the development of large forest formations. The areas with more foliage correspond to the especially rainy massifs of the north-east (Montseny and Montnegre). By contrast, the values are lower in the southern slopes of the Garraf's massifs as well as in other areas where thickets predominate. As for the Penedès region, the NDVI is low in vineyards. This is due to the fact that

this is an annual datum and because they are deciduous crops, the land is bare for a large part of the year.

Figure 3. Annual average value of the NDVI vegetation index in the Barcelona Metropolitan Region (RMB). 2001 and 2019



Source: Metropolitan Laboratory of Ecology and Territory of Barcelona (LET) based on data from the Terra satellite (MODIS).

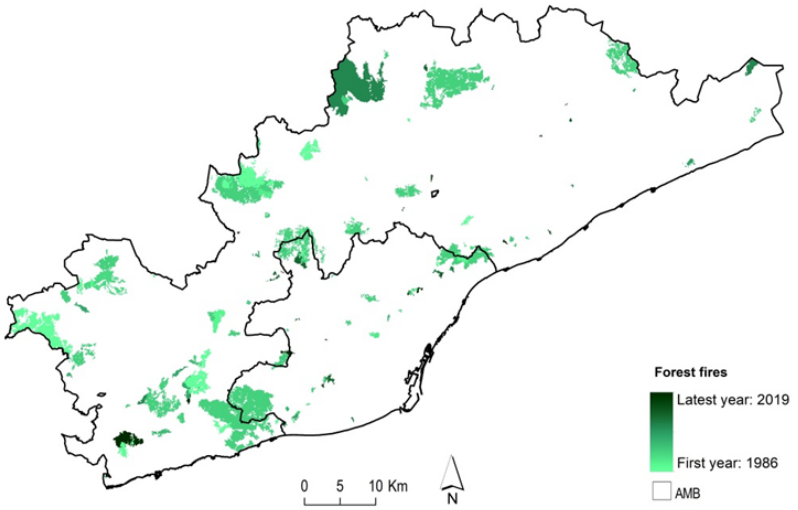
The NDVI values in 2018 and 2019 were above the average of the series, especially in the autumn of 2018, which represented the maximum in 18 years of the data series, for the RMB and the AMB alike. Spring and the whole year in general were likewise wet. This effect of strong autumn rain in 2018 (see the climate variability indicator) also favoured a high-index spring in 2019. The fact that this was an especially wet year helped to increase the NDVI value in plant covers with intermediate values, whereas those that already had high values (such as Montseny or Montnegre) did not rise so much.

1.4. Plant biomass

Biomass accumulations in forests depend on multiple factors, such as the very growth of the forest masses or their management. The loss of an important part of the forests' management over the last few decades, woodlands have helped to bring about a state of forest masses prone to large forest fires. The areas with the highest biomass accumulation in trees (measured in carbon stock) are in Montseny and Montnegre, and in Collserola too, matching the high NDVI values (see the indicator for the state of vegetation). Between 2001 and 2013, biomass is estimated to have continued accumulating in most of the region, especially in forest masses which were already presenting high values because of the favourable climatology.

Over the last 30 years or so, some 32,000 hectares have been burnt in RMB (figure 4), almost 10% of the region's total area. The most devastating fires were the ones in 1986 and 1994 (in Garraf and Montserrat, as well as in several more of the RMB's municipalities, with 6 fire sources of over 1,000 hectares) and in 2003 (Sant Llorenç del Munt), which involved 60% of the area burnt throughout the period. As many as 1,700 hectares were burnt at least twice between 1986 and 2019, as were more than 900 hectares between Vacarisses and Collbató in 1986 and again in 1994. These re-occurrences pose further obstacles to the recovery of ecosystems after such serious disturbances. While a good part of the fires broke out in pre-coastal counties and in the Garraf, above all in the south-west half of the RMB where climatic (temperature and rainfall) conditions and weather (wind) conditions are especially favourable for outbreaks and the spread of fire, areas such as Montnegre have a large accumulation of biomass and high potential ignitability (unlike Montseny, which has a low ignitability value) and a large continuity of forest mass which pose a serious fire risk.

Figure 4. Burnt area (>1 ha) in the Barcelona Metropolitan Region (RMB). 1986-2019

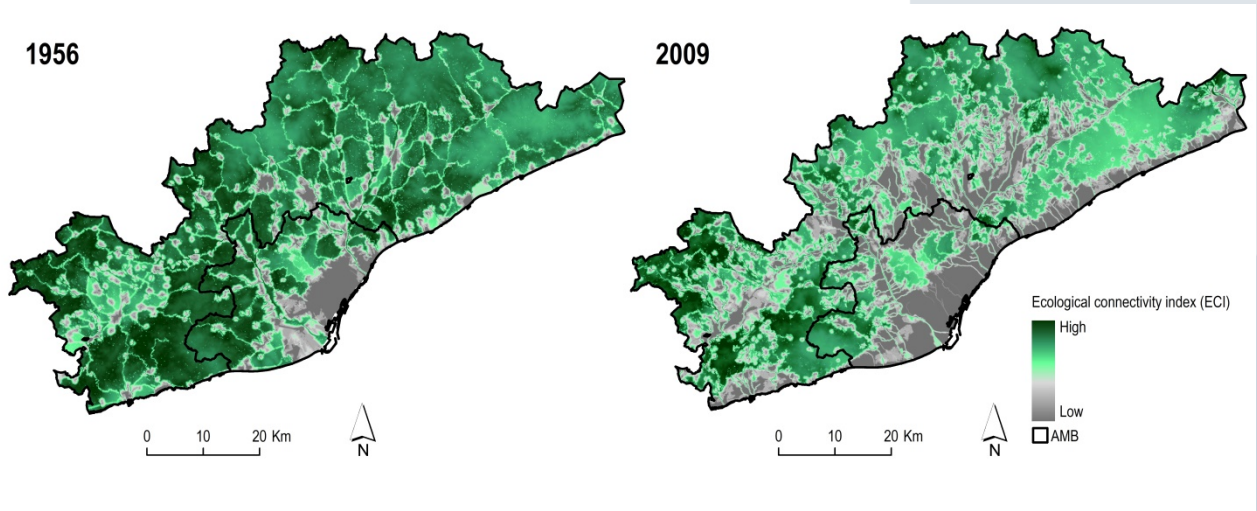


Source: Metropolitan Laboratory of Ecology and Territory of Barcelona (LET) based on data from the Catalan Ministry of Territory and Sustainability (2020) and the Catalan Ministry of Agriculture, Livestock, Fisheries, Food and Environment (DAAM, 2015).

1.5. Functional structure of the landscape

The ecological functioning of landscapes in the RMB is considerably affected not just by the progressive construction of urban uses but also by the transport infrastructures that connect them (see the land use indicator), as well as by the various disturbances that occur in the ecosystems (see the plant biomass indicator). There has been a continuous drop in the ecological connectivity of landscapes since 1956, although the index has always stayed above the AMB's in the rest of the region (figure 5). The effect of anthropic barriers (urban, infrastructures) on connectivity is very high, isolating some forest masses such as the Collserola, or even fragmenting larger-area spaces such as Montnegre, affecting their biodiversity (see the state of biodiversity indicator). By comparing the difference between 1956 and 2009 on Figures of the RMB, Garraf and the Llacuna area, above Vilafranca, [we can see] they are the only areas to keep their ecological connectivity index (ECI) values relatively similar to those of the baseline year. Urban expansion has fragmented the region in the Vallès plain, along with the barrier effect of the urban space and infrastructures, though this also extends to the entire coast, from Vilanova and Geltrú to the high Maresme.

Figure 5. Ecological connectivity index (ECI) in the Barcelona Metropolitan Region (RMB). 1956 and 2009



Source: Metropolitan Laboratory of Ecology and Territory of Barcelona (LET) based on the Land Cover Figure of Catalonia (CREAF, 2015).

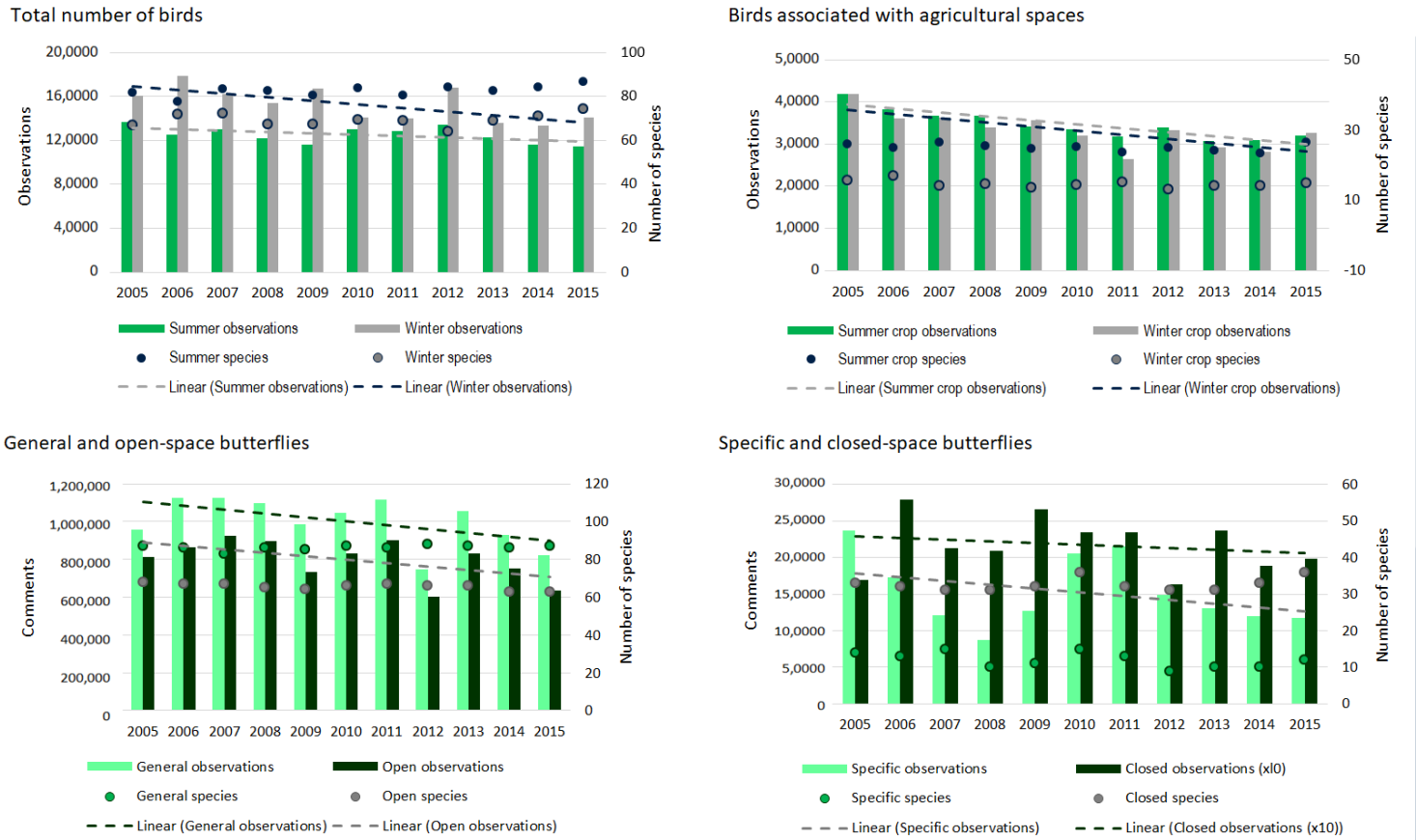
A feature that also has an important effect on the ecological functioning and capacity for accommodating biodiversity is the complexity of landscapes, which not only take account of connectivity but also the diversity of their land covers. So, spaces with a dynamised agroforestry mosaic, such as the Penedès, are favourable to ecological processes, as they have a diversity of covers, besides good connectivity, and therefore heterogeneous habitats. To conclude, regions with less diverse uses but with important forest masses, such as Montseny, the cliffs of Bertí or Sant Llorenç del Munt and the Obac mountain range, present average levels of landscape complexity.

1.6. State of biodiversity

Butterflies and birds are groups of animal species used internationally as bio-indicators thanks to their extensive distribution, easy recognition and sensitivity to changes in socio-environmental dynamics. Number of species and abundance of butterflies and birds have been monitored in the Barcelona metropolis, under the Museu de Ciències Naturals de Granollers' Catalan Butterfly Monitoring Scheme (CBMS) — 41 transects — and the Catalan Common Bird Survey (SOCC) at the Catalan Institute of Ornithology (ICO) —91 transects—. The data obtained from them between 2005 and 2015 will now be presented.

In general, the trend observed (graph 1) is a reduction in abundance (number of observations), much clearer in the case of butterflies in open spaces and birds associated with agricultural spaces. This would tally with the fact that the loss of agroforestry area and ecological connectivity in the RMB (see the land-use and landscape-ecology indicators) is an important vector in the drop in biodiversity, given that these trends are stronger in open-space species, normally associated with agricultural activity (crops, pastures, etc.) Despite the fall in abundance, the number of identified species has been maintained with few variations throughout the 11 years of the series, but if the trend in population reductions continues, it will inevitably affect the wealth and diversity of species in the metropolis.

Graph 1. Diversity of butterflies and birds in the RMB between 2005 and 2015



Source: LET based on data from CBMS (2016) and SOCC (2016).

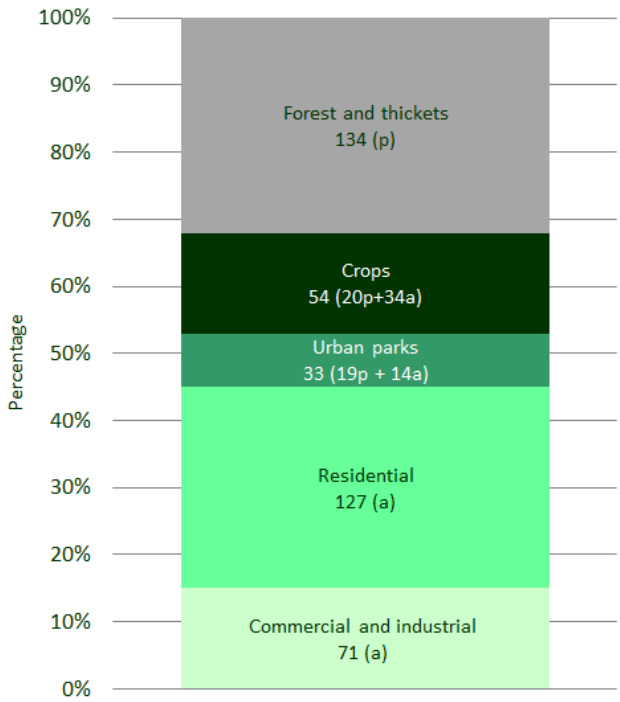
1.7. Water consumption per green infrastructure

Water consumption per green infrastructure in the AMB, according to the vegetation's water requirements, is calculated through the evapotranspiration of agricultural covers, forests, thickets and urban parks (see the land-use indicator).

This datum allows us to estimate the green infrastructure's use of water and the water from precipitation that remains potentially available in each municipality. According to the municipality, between 20% and 80% of the precipitation in the AMB is estimated to be used directly for vegetation and naturally, it is the municipalities with the most urbanised areas of land which consume a smaller part of the precipitation in the green infrastructure.

Finally, as for water supplies (graph 2), it can be seen that the amount of water originating from the Ter dropped from 51% to 36% between 2002 and 2018, a trend that has been strengthened under the Ter Board's Agreement for a steady reduction in dependence on water transfers from this external basin. In addition, the total volume of supply dropped by 23% during the period analysed.

Graph 2. Provenance of water supplies (left) for all the sectors from 2002 to 2018, and water consumption (right) in the main sectors in the AMB in 2015 (hm^3)

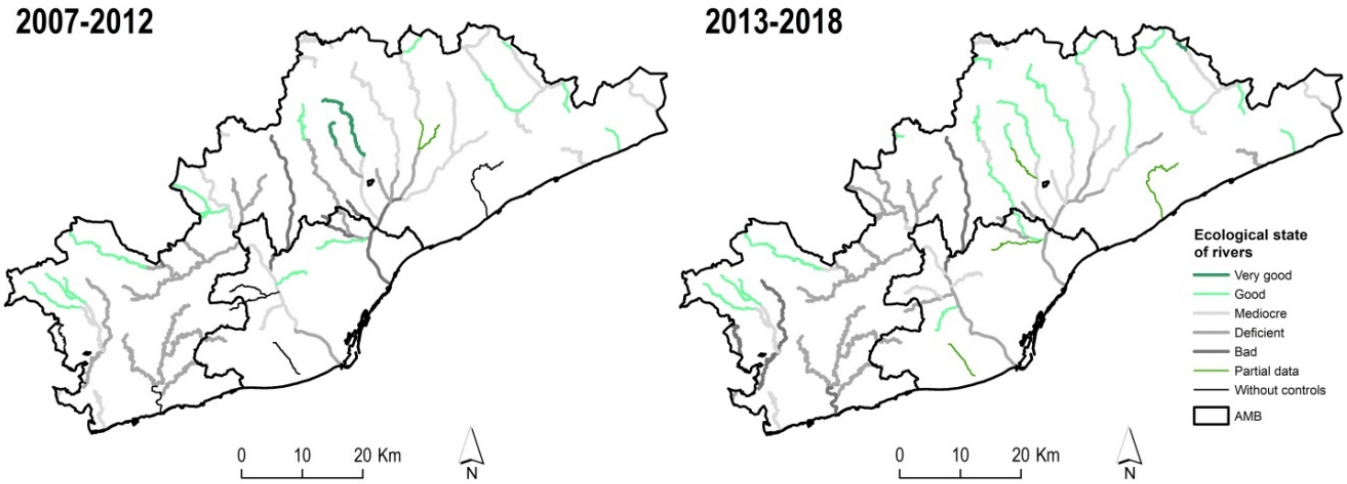


NB: *(p) = precipitation, (a) = supply. Source: Metropolitan Laboratory of Ecology and Territory of Barcelona (LET) and AMB.

1.8. Ecological state of rivers

The ecological state of rivers (figure 6) is a combination of their biological, physico-chemical and hydromorphological qualities, which are monitored in various sections of Barcelona's metropolitan rivers (IMPRESS, ACA). Biological qualities are a measure of the presence of macro-invertebrates, diatom algae, macrophytes and fish. Physico-chemical qualities are a measure of the concentrations of ammonium, nitrates, phosphates, organic load, conductivity, chlorides and other specific pollutants. And, finally, hydromorphological qualities are an assessment of whether there have been changes to the river which affect its fluvial continuity, hydrological regime or morphology.

Figure 6. Ecological state of rivers in the Barcelona Metropolitan Region (RMB). 2007-2012 and 2013-2018 periods



Source: Metropolitan Laboratory of Ecology and Territory of Barcelona (LET) based on data from the Catalan Water Agency (ACA).

If we compare the two periods analysed (2007-2012 i 2013-2018) [it can been that] sections inside the AMB went through different changes in their ecological state: eight sections improved, five stayed the same and only two became worse. Despite such variability, it can be said that the general trend was one of improvement, with the exceptions of the Riera de Vallvidrera and the Llobregat river, from the Riera de Rubí to Sant Joan Despí.

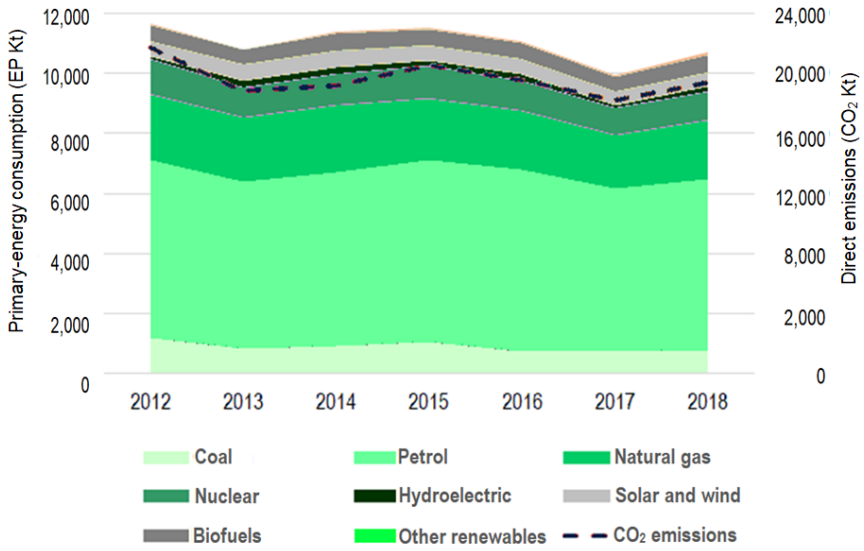
The chemical state of the rivers is an assessment of a series of pollutants (metals, pesticides, solvents and other chemical substances) according to the thresholds tolerated under legal regulations. In general, chemical pollution is concentrated in the river courses that pass through the more industrialised and populated areas, especially in the Llobregat and Anoia basins, and in the Besòs, where heavy metals and various industrial compounds are detected.

1.9. Energy consumption and greenhouse gas emissions

The light-intensity distribution provided by satellite data (NTL) are directly related to the total energy consumption in the regions. So, the distribution of primary-energy consumption (PEC) on regional scales can be estimated on the basis of State consumption (which is obtained from the energy balances provided by Eurostat). The PEC is concentrated above all in the Barcelona plain and also, very importantly, on the Vallès plain, and has been expanding through the Llobregat axis. At the same time, it can be seen that there was a slight general drop in the PEC values between 2012 and 2018 (Graph 3).

Primary-energy consumption since 2012 has tended to fall in the RMB (graph 3). While the drop in PEC reached 15% in 2017 compared to the initial year of the series, it went up again in 2018 by 8%, thereby breaking the trend towards a reduction in total energy consumption. Based on these PEC data, we can estimate the CO_2 values according to the sources of origin of the energy consumed in the RMB. Fossil fuels continue to represent practically 80% of the total primary energy consumption, a proportion that has experienced little variation. The second group as far as energy sources go are renewable energies, which are also a minority and range from 10% to 12% of our total primary energy consumption, followed closely by nuclear energy, which is following a downward trajectory and dropped from 9.8% contribution in 2012 to 8.6% in 2018. No substantial changes can be seen in the renewable energies throughout the period analysed, so the challenge for a genuine ecological transition is still very considerable.

Graph 3. Evolution of primary-energy consumption (PEC) in the RMB, sources of origin and effect of associated greenhouse gases (CO_2). 2012-2018



Source: Metropolitan Laboratory of Ecology and Territory of Barcelona (LET) based on data from State-energy balances (Eurostat, 2019) and the Catalan Climate Change Observatory's emission factors.

Even so, the direct CO_2 gas emissions associated with this energy consumption, calculated on the basis of criteria from the Catalan Office for Climate Change, ranged between 18,200 and 21,700 thousand tons throughout the 2012-2018 period, without any sustained downward trend having been observed.

1.10. Atmospheric pollution

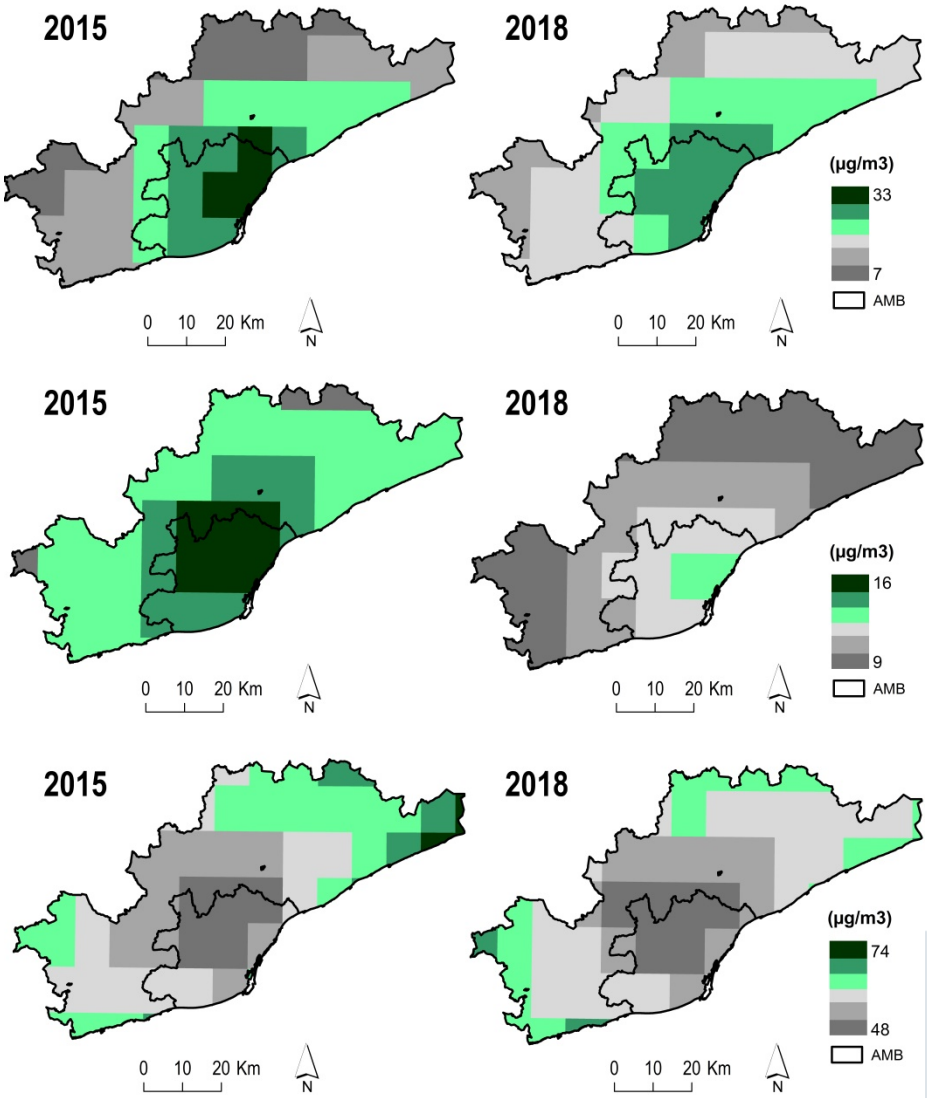
The data on atmospheric pollutants (NO_2, $PM_{2,5}$ and O_3) in the Barcelona metropolis obtained by satellite (Sentinel-5) are based on annual observation averages, offering complementary information to the models interpolating sample data. That helps to give us a picture of the distribution of pollutants throughout the RMB. These satellite data, for example, enable us to observe the effect of the halt of economic activity caused by the COVID-19 health crisis.

Nitrogen dioxide (NO_2) is gas that causes respiratory diseases, acid rain and photochemical smog. In addition, it is the precursor of $PM_{2,5}$ and O_3. It is produced by combustion in motorbikes, thermal power plants and butane gas heaters. Concentrations are usually higher during the cold months of the year. Reductions in diesel vehicle numbers and improvements in technology at plants and factories have led to a drop in NO_2 concentrations over the last few years (figure 7, above).

Suspended particulate matter measuring under 2.5 micrometres ($PM_{2,5}$) represent a risk because they have a high penetration capacity in our respiratory tracts. Unlike the larger PM_{10} particles, which arise from natural sources such as sand, $PM_{2,5}$ particles come mainly from diesel fuel. There has been a slight downward trend in $PM_{2,5}$ levels over the last few years as a result of the new regulations for vehicles (figure 7, in the middle).

Finally, tropospheric ozone (O_3) is a gas which causes respiratory problems on ground level. It is a secondary pollutant, created through interaction of other precursor pollutants with solar light, which is why increases are observed during the hot months. It is not as abundant in large population centres as those in the AMB, as the precursors that come from these places have to be combined with other elements, which are spread outside this region, and it is therefore there where O_3 is mainly produced (figure 7, below).

Figure 7. Annual average concentration of NO_2, $PM_{2,5}$ and O_3 (µg/m^3) in the Barcelona Metropolitan Region (RMB). 2015 and 2018



Source: Metropolitan Laboratory of Ecology and Territory of Barcelona (LET) based on a re-analysis of the ENSEMBLE model using data from the Sentinel-5 - Copernicus Atmosphere Monitoring Service (CAMS) satellite.

2. Conclusions

This article has assessed the main recent socio-ecological dynamics occurring in the Barcelona Metropolitan Area (AMB) and Region (RMB), through a selection of ten socio-environmental indicators prepared by the LET and based on several sources, enabling us to understand the interdependence between built-up and open spaces for the proper management and planning of the Barcelona metropolitan system. The results obtained from the application of these indicators are summarised below.

The results highlight several factors of change that have a direct or indirect impact on the functioning of the metropolitan area and on its capacity to integrate biodiversity and provide ecosystem goods and services: climate change and changes in land covers and uses.

Climate change in the metropolitan region is characterised by the appearance of a sustained anomaly over time. The last few years have seen a sustained anomaly effect in temperatures, which have been at least 1°C above the average for the 1961-1990 period since 2014. It can be observed that the year-on-year variability is much higher in the precipitation anomaly than it is in the temperature anomaly. Despite being a global phenomenon, the local repercussions of climate

change are clear. This thermal anomaly over the last five years has been above the average in Barcelona's case in particular, thereby worsening the heat island effect there.

As for land uses and covers, it is evident that the metropolitan area has undergone a spectacular change over the last half a century, caused mainly by urbanisation. As we all know, urban expansion in the metropolis has led to considerable fragmentation of the region and the consequent loss of the landscape's ecological functionality. But it is the abandonment of agricultural activity that has been even more important in terms of area, having brought about a constant reduction in the agricultural area which fell by 25% in the AMB and by 18% in the RMB (between 1987 and 2017), steadily reducing the metropolis's food sovereignty, an especially important aspect for closing the urban system's metabolic cycles.

On the other hand, this change in land covers and uses is also the result of the socio-economic change caused by a rural exodus and the disappearance of traditional uses. This brought about an expansion of forests, at the expense of the agroforestry mosaic, and the disappearance of pasture which, together with the practical disappearance of forest management, encouraged (along with other factors such as climate change and the growing recreational use of natural spaces) a state of forest masses prone to big fires in the Barcelona metropolis. The last 30 or so years have seen some 32,000 ha burnt in the RMB. The recurrence of fires in some areas poses a further obstacle to the recovery of ecosystems, causing degraded landscapes with little resilience against disturbances.

Since 1956, the first year in which we have historical data on land covers in the Barcelona metropolis, the drop in the landscape's ecological connectivity has been continuous and has affected the biodiversity and ecosystem services that it contributes to society. The loss of cultural landscapes, as expressed in agroforestry mosaics with an integrated circular economy, which also included livestocks, has diminished the functionality of the open spaces and their relationship to urban spaces, making the metropolitan system less and less resilient and more and more dependent on external inputs (energy, materials), and thereby increasing its ecological footprint.

The increase in forest covers has taken us to a new paradigm that is emerging with strength in the face of the current climate emergency: vegetation and society are increasingly competing for water. According to the municipality, between 20% and 80% of the precipitation in the AMB is estimated to be used directly by the vegetation. The green infrastructure (forests, crops and parks) in the AMB is consuming more than half of the region's water flows. Changes in land uses may alter the distribution of available internal water and therefore dependence on supply, an important aspect in climate change scenarios. The total volume of supply dropped by 23% during the period analysed (2002-20018), a positive trend. Satellite data have enabled an assessment to be made of the state and abundance of vegetation (NDVI) in the Barcelona metropolis, which relates to water availability and adaptation to climate change. Years with higher rainfall, such as in the last two years (2018 and 2019), present NDVI values above the (2001-2019) series.

As for biodiversity, the trend is towards its reduction and levelling down as a result of changes in land uses and covers, as well as the growing pressure on natural systems. It can be seen that there was a steady reduction in the abundance of butterflies (mainly in open spaces) and birds (above all those associated with agricultural spaces) in the RMB between 2005 and 2015. This has to do with the loss of agroforestry land areas and ecological connectivity in the Barcelona metropolis. The data are worrying given that, if this trend in population decline continues, it will inevitably affect the wealth and diversity of species and ecosystem services (supply, support, regulation and cultural) that they contribute to society, including the health and well-being of the population. It should be pointed out, in the current health-crisis context, that biodiversity is associated with the health and well-being of a population, and with the prevention of pandemics such as the COVID-19 one.

Likewise, the efforts made over the last few decades in the RMB to improve the region's green and blue infrastructures have yielded results. The trend (2007-2018) in the ecological state of rivers

was towards improvements, with exceptions such as the Riera de Vallvidrera and the Llobregat River, from the Riera de Rubí to Sant Joan Despí. Chemical pollution is concentrated in the courses that pass through the most industrialised and populated areas, above all in the Llobregat and Anoia basins or in the Besòs River, where heavy metals and various industrial compounds have been detected which need to be properly managed if we are to prevent spills with a high ecological impact such as the last one that occurred in the Besòs River (2019).

As regards the indicators for anthropic processes, note that there was a general reduction in primary-energy consumption (PEC) values in the Barcelona metropolis from 2012 to 2018. Fossil fuels continue to represent practically 80% of the total PEC, a proportion that has experienced little variation. Renewable energies are a minority and range from 10% to 12% of the PEC, followed by nuclear energy. The CO_2 emissions associated with the PEC range from 18,200 to 21,700 thousand tons throughout the 2012-2018 period, without any sustained downward trend having been observed, so the challenge for a socio-ecological transition continues to be very important.

The data on atmospheric pollutants (NO_2, $PM_{2,5}$, O_3) in the Barcelona metropolis obtained by satellite already show the effect of the halt of economic activity caused by the COVID-19 health crisis during the first months of 2020. Reductions in diesel vehicle numbers and improvements in technology at plants and factories have led to a drop in NO_2 concentrations over the last few years. A slightly downward trend in $PM_{2,5}$ has been observed over the last few years as a result of the new regulations for vehicles (2015-2018). Even so, the challenge of sustainable mobility in the Barcelona metropolis remains an outstanding issue.

The application of the ten indicators for assessing the Barcelona metropolis's socio-ecological dynamics highlights the strong relationship between open spaces and built-up spaces, as well as the need to take on five big challenges when it comes to understanding and therefore managing the urban system: i) multifunctional networks: we need to move from being a city to a network of cities (for example, the importance of the green infrastructure as a structuring ecological network of the region); complex systems: we need to move from being an urban economy to a metropolitan system (for example, the importance of peri-urban agriculture as a water-energy-food-society nexus); iii) dissipative systems: we need to move from urban metabolism to integrated socio-ecological analysis (for example a metabolic-regional model: energy cycles - land uses, emissions); iv) multi-scale analysis: we need to move from urban-scale to metropolitan scale (for example, resource management: water cycle, mosaic agricultural landscapes); v) multidimensional analysis: we need to move from sectoral policies to cross-cutting policies (system planning: strategic assessment of plans and programmes).

Starting from the conceptualisation of the contribution of open spaces to the metropolitan system, the LET is working on an integrated socio-ecological analysis (ISA), a model that is noted for a series of inter-related indicators that quantitatively support the contribution of the green infrastructure in the metropolis's sustainability, by considering six fundamental dimensions: metabolic efficiency (energy, water, waste), biodiversity conservation, landscape functioning, climate change, ecosystem services (provision, support, regulation) and social cohesion. The aim behind ISA is to advise on public policies, bearing in mind the five challenges for understanding and properly managing the region as a system. The ISA is currently being applied in the strategic environmental assessment of the Barcelona Metropolitan Area's Urban Development Master Plan.

The LET is therefore taking on the challenge of a socio-ecological transition in the Barcelona metropolis, incorporating the new paradigm mentioned in the introduction of this article into territorial planning: the need for a functional green infrastructure that enables us to provide a series of essential ecosystem services, on which the quality of life of the city's residents depend, as does the possibility of developing a more circular and sustainable economy than the current economic model, mitigating global change and adapting to it.

The LET, then, provides for the achievement of the following types of impact in the socio-ecological assessment of the Barcelona metropolis: i) strengthening the criteria and methods for treating the

region as a socio-ecological system; ii) completing the databases and knowledge regarding significant regional variables; iii) devising a support system for the metropolis's planning and management; iv) collaborating in designing policies and metropolitan governance, and v) enabling the transfer of ecological and regional information to citizens.

This paradigm shift is crucial if cities are to deploy the United Nations Sustainable Development Goals (SDGs), although that will require new criteria and innovative methods for planning cities in relation to their metropolises, in addition to political will.