ISSN 1831-9424

European Commission

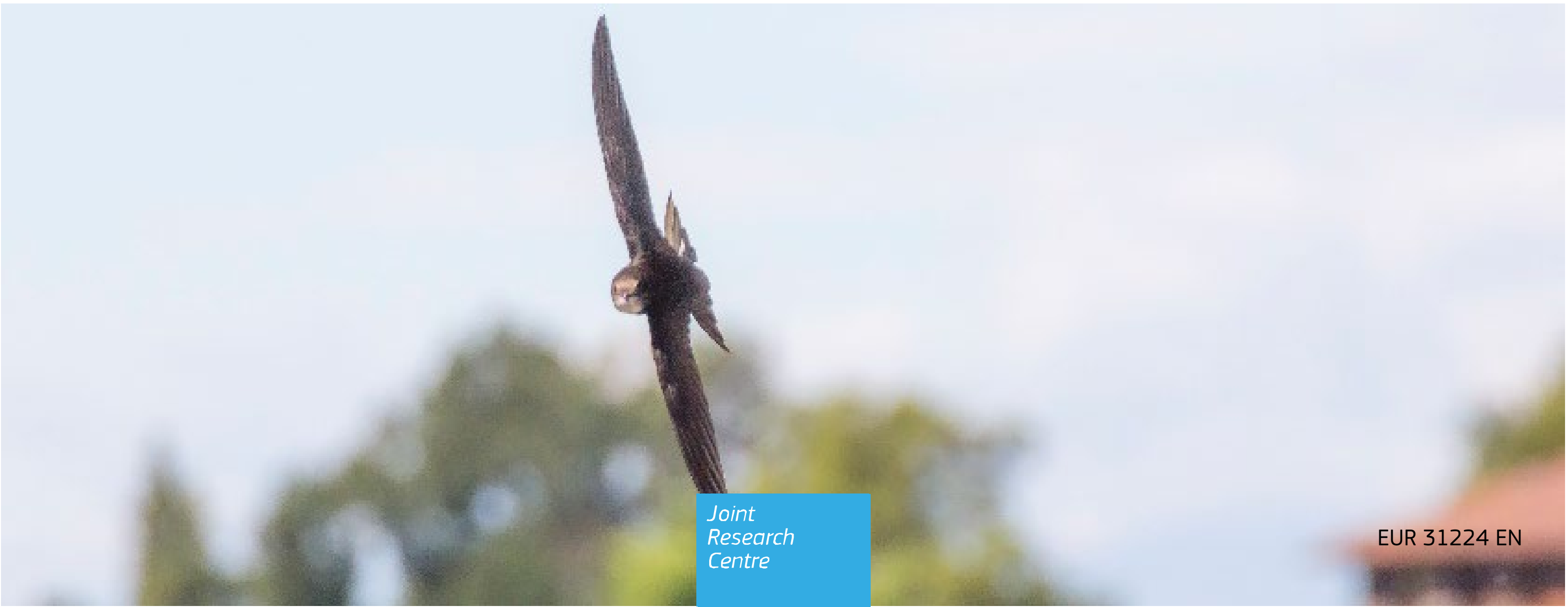
JRC TECHNICAL REPORT

BiodiverCities: A roadmap to enhance the biodiversity and green infrastructure of European cities by 2030

Second report

Zulian G., Marando F., Vogt P., Barbero Vignola G., Babí Almenar J., Zurbarán-Nucci M., Prince', K.

2022



Joint Research Centre

EUR 31224 EN

Contact information
Name: Grazia Zulian
Email: grazia.zulian@ext.ec.europa.eu

EU Science Hub
https://joint-research-centre.ec.europa.eu

JRC129888

EUR 31224 EN

PDF ISBN 978-92-76-57023-3 ISSN 1831-9424 doi:10.2760/21172 KJ-NA-31-224-EN-N

Luxembourg: Publications Office of the European Union, 2022

How to cite this report: Zulian G., Marando F., Vogt P., Barbero Vignola G., Babí Almenar J., Zurbarán-Nucci M., Prince' K. *BiodiverCities: A roadmap to enhance the biodiversity and green infrastructure of European cities by 2030*, Publications Office of the European Union, Luxembourg, 2022, Editors, Publisher, Publisher City, Year of Publication, doi:10.2760/21172, JRC129888.

Contents

Abstract

BiodiverCities is a European Parliament Pilot Project, developed with the aim of enhancing the use of Urban Green Infrastructure (UGI) to enhance the condition of urban ecosystems, providing benefits for people and nature. In this report, an evaluation around the most appropriate reporting unit for an urban ecosystems assessment is carried out, comparing Functional Urban Areas (FUA) and Local Administrative Units (LAU). Furthermore, UGI are assessed from a multi-scale perspective. The status and scenarios of UGI in European urbanised areas is first analysed measuring the urban green areas and the tree canopy cover. Secondly, the contribution of UGI to the overall European Green Infrastructure (EU-GI) is quantified, evaluating the respective role of FUA and LAU. Finally, the effect of urban characteristics on biotic homogenization is analysed exploring how urbanised areas impact on avian population and communities in French cities. The results of this study will inform the development of a roadmap for greening cities in Europe in the 2020-2030 decade.

Acknowledgements

Authors of the report would like to thanks colleagues from:

Joint Research Centre (JRC-D1): MARELLI Luisa; BORCHARDT Steve; BUSCAGLIA Daniela; MARONI Michele for the technical support provided for the analysis of policy documents.

Joint Research Centre (JRC-D5): Maria Luisa PARACCHINI and Carlo REGA for the methodological support provided for the updated version of the Hemeroby index.

Authors

Grazia Zulian[1],

Federica Marando[1],

Peter Vogt[1],

Giulia Barbero Vignola[1],

Javier Babí Almenar[1],

Mayra Zurbarán-Nucci[1],

Karine Prince[2],

1 European Commission, Joint Research Centre (JRC), Ispra, Italy

2 Associate Researcher CESCO-MNHN

Executive summary

This report considers three relevant aspects for the development of sustainable urban policies related to urban green infrastructure, biodiversity, and their quantification.

The first aspect concerns the definition and identification of the reporting units used to report on urbanized areas. Reporting units are the areas for which variables or indicators monitored are reported to support a policy action. In this context, we compared two reporting units officially used by the Commission (Functional Urban Areas, FUA and Lower Administrative Units, LAU) to understand which one is better suited to quantify urban green as a support of tailored policies. Several indicators were used to provide a comprehensive overview. The reporting units were analysed with respect to the extent, the population, the degree of urbanization, the degree of naturalness and the share of protected areas located within urban boundaries.

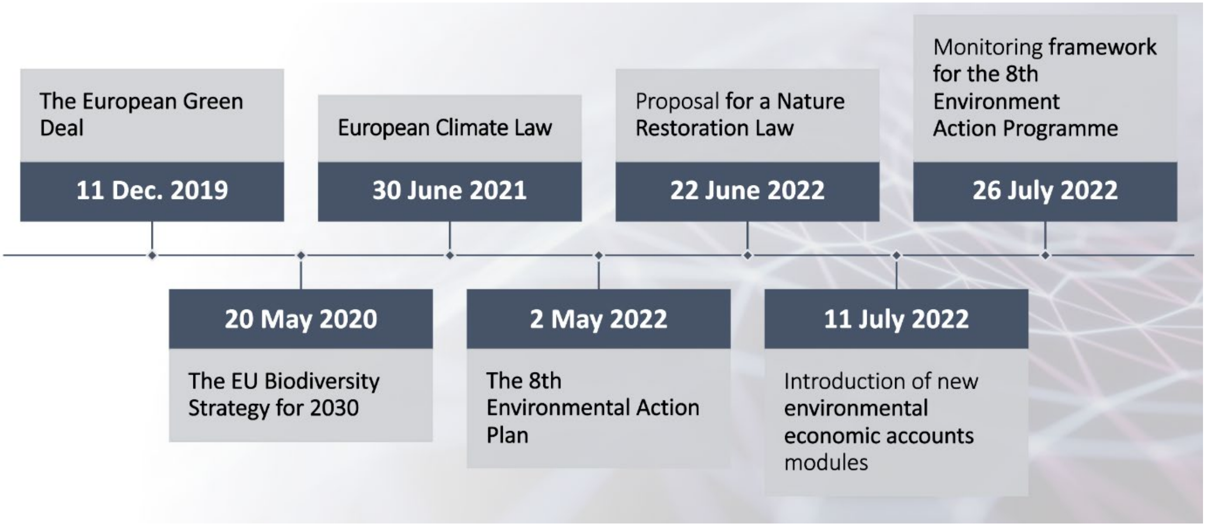
Secondly, urban green was quantified in a multi scale perspective. At the FUA level, urban green areas and tree canopy cover were measured in terms of status and future scenarios. At the FUA and LAU level, the contribution of urban green infrastructure to the overall green infrastructure was quantified to explore the effective contribution of green areas embedded in urbanized land to the transnational green network.

Lastly, the effects of urbanized areas on biodiversity were explored analysing the impact of urbanization on avian population and communities in French cities. This analysis used European spatial variables, anthropogenic and environmental descriptors, and birds' data collected from a nationwide standardized monitoring program that involves skilled volunteer ornithologists.

Policy context

Between 2019 and 2022, the European Commission promoted a number of initiatives to protect the environment and minimize risks to climate, human health and biodiversity, of which **Figure 1** provides an overview. In December 2019, the European Commission presented the European Green Deal, which includes a set of proposals to make the EU's climate, energy, transport and taxation policies fit for reducing net greenhouse gas emissions by at least 55% by 2030, compared to 1990 levels. In May 2020, the European Commission adopted the new Biodiversity Strategy for 2030, a comprehensive, ambitious and long-term plan to protect nature and reverse the degradation of ecosystems. In June 2021, the European Commission adopted the European Climate law, which translates into a law the goals set in the European Green Deal, setting a legally binding target of net zero greenhouse gas emissions by 2050. In May 2022, the European Commission adopted the 8th Environmental Action Plan to guide the European environmental policy until 2030. In June 2022, the Commission adopted a Proposal for a Nature Restoration Law, which aims at restoring damaged ecosystems, bringing nature back across Europe, from agricultural land and seas, to forests and urban environments. In July 2022, the European Commission proposed the introduction of ecosystem accounts amending the regulation (EU) No 691/2011. These initiatives have implications for the plan and management of EU urbanized areas, which should also contribute to fulfil their objectives.

Figure 1: main initiatives on the environment promoted by the European Commission between the end of 2019 and 2022.



Source: JRC elaboration

Urbanized areas are human settlements with a high population density and infrastructure of built environment. They cover 22% of the European territory, playing a pivotal role to face several of the environmental challenges related to the above-mentioned policies. Some of the most harmful environmental problems, such as global warming, poor air and water quality, waste-disposal inefficiencies, high energy consumption and loss of biodiversity, are exacerbated by an increasing urban population and urbanized land. Local policies aimed at transitioning towards a sustainable management of resources could minimize those impacts. Specifically, the shift to a sustainable management of urban ecosystems would minimize the environmental impact of cities and increase human wellbeing. It will also contribute to improve ecosystem condition in urban ecosystems, as well as in other ecosystem types, such as forests, agro-ecosystems, fresh-water ecosystems, grassland and wetlands located in peri-urban areas. Therefore, a transformative change in the way we behave and manage the urbanized territory, in harmony with the policy actions at all levels, is needed to ensure that targets of policy initiatives can be achieved.

Main findings

FUA and LAU (only consisting in cities, towns and suburbs) cover approximately the same share of the European territory, around 22% each. FUA and LAU consist in areas partially covered by settlements and artificial surfaces but they both cover other ecosystem types. The proportion of forest and semi-natural vegetation is equivalent but FUA cover more agro-ecosystems. Most of the population lives in the core cities (cities with more than 50,000 inhabitants) but a consistent share of people lives in rural areas in both the territorial units (around 12%). The average EU-27 value of the degree of naturalness quantified in LAU is slightly higher than the one in FUA. Nevertheless, high variability characterizes urbanized land across member states. Out of the total area protected by Natura 2000 (18.5%), 20% is located within FUA and 16% within LAU. Which means that FUA include 2 million hectares of protected areas more than LAU.

In addition, one must consider three additional aspects that affect the choice of a territorial unit against the other, especially when the territorial unit become the reference for a territorial policy, which is the case, for instance of the proposal for a Nature Restoration Law. The first aspect pertains to the actual correspondence of the territorial units with the local administrative units (which ultimately affects the governance at the local level). The second is related to the consistency across member states for what concern how the territorial unit is defined. The third refers to the availability, at the European level, of validated spatially explicit datasets to be used to support policies.

Despite sharing similarities in their extent, FUA and LAU do not completely overlap and are based on a different rationale for their definition. The LAU correspond to the actual administrative units and, ultimately, they cover a higher proportion of urbanised land in Europe. Instead, FUA depend on a modelling exercise and do not correspond to administrative boundaries. When considering spatial extent and relation to specific administrative levels, FUA size is not consistent across the different Member States. This difference depends on the basic unit used for the FUA definition. For instance, in Germany FUA are extremely large because the basic units are at the NUTS 3 level and this might affect the results in measuring and reporting spatial attributes at the EU level.

In terms of availability of European validated datasets, for assessing and monitoring urban ecosystems condition, there are also differences among FUA and LAU. For instance, Urban Atlas (which is a widely used validated high-resolution land use/cover map of urban areas) covers exclusively the territory within FUA boundaries. In other words, part of the territory occupied by LAU (cities towns and suburbs) is not included. In addition to that Urban Atlas, does not allow to detect and monitor the presence of small urban green patches, which are very important for ecosystem condition. Moreover, Urban Atlas maps each FUA as a single entity without considering the larger territorial context beyond its boundaries, this might generate possible edge effects when it comes to spatial analysis. For instance, when connectivity of urban green is quantified, the extent of an urban green patch that partially covers a municipality and extends beyond the administrative boundaries has to be entirely considered. In practice, this might imply that Urban Atlas, originally prepared to monitor land use/land cover in urbanised areas, is not adequate for the assessment of urban ecosystem condition and, additionally, cannot be used to support tailored territorial policies (for instance the proposal for a Nature Restoration Law). This will be the case if LAU are selected as territorial units to represent urbanised areas. Consequently, new and more effective validated datasets are needed for effective ecosystems assessment and policy support.

Urban green infrastructure

When considering FUA, urban green areas cover around 30% of the territory, whereas tree covered areas cover approximately 25% of it. Most FUA present a major downward trend of urban green infrastructure over time. The loss of green is expected to continue unless specific policy measures are adopted.

In 2018, the urban green infrastructure within FUA contributed by 7.3% to the overall EU-green infrastructure extent and the urban green infrastructure within LAU contributed by 7.6%. Moreover, LAU show a higher contribution to the integrity[1] of the overall network (3.02%) compared to the contribution of FUA (0.66%) and both territorial units do not provide a contribution to connectivity. With respect to the three indicators, a downward trend between 2000 and 2018 is always detected at all territorial levels, which underlines once more that urbanised land is losing green spaces across Europe.

The extent of urban green infrastructure in Germany, Sweden, Finland, France and Spain provide the higher contribution to the extent of the overall green infrastructure. The urban green infrastructure in Bulgaria, Italy, Finland and Sweden contribute the most to the overall green infrastructure integrity. The structure of urban green infrastructure in Romania, Finland and Sweden contribute the most to the overall green infrastructure connectivity.

Urban avian population and communities

[1] Network integrity: provides the proportion of the total network area that is reachable but does not make any statement with respect to the shape, spatial extent, location, or degree of perforations within the individual network objects. Connectivity allows to consider shape, spatial extent, location of green features.

Regarding how urban characteristics affect birds' population and communities, the pilot study developed in French FUA, confirmed previous analyses: dense urban settlements deal with the biotic homogenization in birds' communities. With the increase of the settlement density in fact, we found a decrease in number of specialists and an increase of generalists. Nevertheless, the presence of the urban green infrastructure has the potential to reduce biotic homogenization, by supporting richer and more diverse communities as well as greater abundance of a majority of common bird species. Also blue infrastructure increases bird taxonomic and functional diversity, and bird overall abundance. In addition, sustainable land use practices (in agriculture and forestry) in peri-urban areas can help support richer and more diverse bird communities. In fact, more birds are associated with low intensity agricultural practices and with a high share of forest close to a natural state. To conclude, since out of the 170 species found within FUA, 51 (30%) are classified under threat in the IUCN Red list (France), a sustainable management of urbanised areas might have a role halting the loss of biodiversity.

Looking ahead

The debate on the most appropriate reporting unit for tailored policy support on urban ecosystems is still open and more work is needed in order to unbundle some emerging problems.

Currently, in the proposal for a Nature Restoration Law, specific urban targets have been proposed for LAU (cities towns and suburbs). However, a common agreement is still needed regarding the selection of an official reporting unit to consistently report on urban ecosystems for policy support.

This specific issue is a political decision and goes beyond the responsibilities of this research. Nevertheless, the choice might be supported by additional work related to a comprehensive examination of different options related to the European datasets needed to consistently monitor the condition of urban ecosystems.

A second line of work would consist in replicating the analysis on the impact of urbanization on avian populations and communities at the EU level. This study would extend to all FUA in Europe (EU27) the exploratory study carried out in France. Birds are responsive indicators of a changing environment. If the habitat does not fulfil their ecological requirements, they can quickly move to a different spot. With appropriate training, birds are easy to detect. It makes them a good target for citizen science activities, whose data will provide the basis for EU level datasets. Since many cities need to report on biodiversity, this analysis will be useful also to explore to what extent citizen-science data can support the development of an urban biodiversity profile.

A third possible future work stream could focus on the adaptation of urban vegetation to the ecological stress caused by climate change, with a specific reference to the targets proposed in the upcoming Nature Restoration Law. Urban vegetation is strongly affected by climate change at all latitudes and scientific evidence is needed to support a clear guidance for vegetation management in urbanized areas.

Key facts and highlights

- FUA and LAU (classified as cities town and suburbs) cover approximately the same share of the European territory, respectively 21.9% for FUA and 21.5% for LAU (cities towns and suburbs).
- A consistent share of European population lives in rural areas within FUA (12.5%) and LAU (10.2%)
- Out of the total area protected by Natura 2000 (18.5%), 19.6% is located within FUA and 16.6% within LAU (cities towns and suburbs)

- Urban green areas cover around 30% of the FUA territory. The average share of urban green areas among Member States is equal to 32% of the EU territory. Tree covered area in FUA is equal to 23 million hectares (25% of the EU territory). Average tree cover among Member States is equal to 23%.
- Most FUA present a major downward trend of UGI in time. The loss of green is expected to continue unless specific policy measures are adopted.
- At EU-27 level, UGI contribute to the EU GI extent (7.3% FUA contribution; 7.6% LAU contribution) and integrity (0.39% FUA contribution; 3.02% LAU contribution).
- The extent of UGI in Germany, Sweden, Finland, France and Spain provide the higher contribution to the extent of the EU-GI.
- Urban dense settlements face biotic homogenisation in bird communities
- Urban green infrastructures have the potential to reduce biotic homogenization, by supporting richer and more diverse communities, as well as greater abundance of a majority of common bird species
- Urban blue infrastructures in FUA increase bird taxonomic and functional diversity
- Sustainable land use practices (agriculture and forestry) can help support richer and more diverse bird communities

1 Introduction

Europe experienced an increase in urban areas over the last 20 years equal to 3.4 % per decade (2000 – 2018). Europe's urban population is expected to continue to grow by up to 30 million additional people by 2050 (European Environment Agency, 2020). Additional housing and infrastructure will need to be built to accommodate Europe's growing total population as well as its urban population. This rapid transformation of ecosystems means that urbanization is the second largest pressure on terrestrial and marine ecosystems (European Environment Agency, 2020).

The 1st of December 2019, the Commission published The European Green Deal a set of policy initiatives with the overarching aim of making Europe climate neutral in 2050 and revert environmental degradation and biodiversity loss (European Commission, 2019). The EU Biodiversity Strategy for 2030 is one of its main pillars (European Commission 2020). The Strategy aims to: "…ensure that Europe's biodiversity will be on the path to recovery by 2030 for the benefit of people, the planet, the climate and our economy…" (European Commission 2020). Specifically, it intends to protect and restore nature in the European Union by "improving and widening our network of protected areas and by developing an ambitious EU Nature Restoration Plan" (European Commission 2020).

Between June 2021 and July 2022 other EU initiatives were adopted aiming at:

1. Setting binding targets to greenhouse gas emissions (EU Climate Law, Regulation (European Commission, 2021);
2. Guiding the overall European environmental policy (8th Environmental Action Plan, DECISION (European Commission, (2022a);
3. Restoring damaged ecosystems (proposal for a Nature Restoration Law, (European Commission (2022b);
4. Introducing ecosystem accounts (amendment to the regulation (EU Commission (2022c);
5. Monitoring the 8th Environmental Action Plan (EU Commission (2022d).

The role urban areas can have on biodiversity recovery has been acknowledged in several sections of the EU Biodiversity Strategy for 2030. Section 2.1 focuses on the development of "*A coherent network of protected areas*", expressing the need to enlarge and improve the "Trans-European Nature Network", a plan to halt biodiversity loss and ecosystem degradation in the European Union by enhancing the connectivity of the existing Natura 2000 network. In this section, Urban Green Infrastructure (Urban GI) is acknowledged for its pivotal role in supporting Trans-European network connectivity and enhancing the provision of ecosystem services, especially in dense urbanised areas. Section 2.2 of the Strategy outlines the "new EU Nature Restoration Plan" and provides ten spheres of action to "*improve the health of existing and new protected areas and bring diverse and resilient nature back to all landscapes and ecosystems*". One of the ambits of interests are cities. Specifically, Section 2.2.8 refers to "*greening urban and peri-urban areas"* to halt and reverse the loss of urban green. Cities with more than 20,000 inhabitants are called on to develop an Urban Greening Plan to increase urban biodiversity and improve Urban GI such as forests, parks and gardens. To facilitate and support the process in 2021, the Commission initiated the "Green City Accord" (GCA)[2], a movement of European cities committed to safeguarding the environment. GCA aims to improve the quality of life of citizens and accelerate the implementation of the European Green Deal. By signing the GCA, cities commit to step up their efforts in five key areas by 2030: air, water, nature/ biodiversity, waste/circular economy, and noise (Zulian et al 2022).

Since 2015 urbanised areas are part of the United Nations' 2030 Agenda for Sustainable Development under goal 11, that aims, to "Make cities and human settlements inclusive, safe, resilient and sustainable"[3]. The Sustainable Development Goals (SDGs) are addressed both in the EU Green Deal and in the Biodiversity Strategy for 2030. The mapping of EU actions into the space of the SDGs contributes to the mainstreaming of the 2030 Agenda in the European Union. A better understanding of the relationship between European policies and the 169 targets defined by the United Nations can support policy coherence for sustainable development. It also helps to identify potential areas of intervention where more efforts are needed, supporting policymakers in finding adequate responses to sustainability challenges.

As an initial exercise to better understand the relationships between EU policies and SDGs, the relationships between the SDG targets, the European Green Deal (Box 1) and the EU Biodiversity Strategy (to 2020 and for

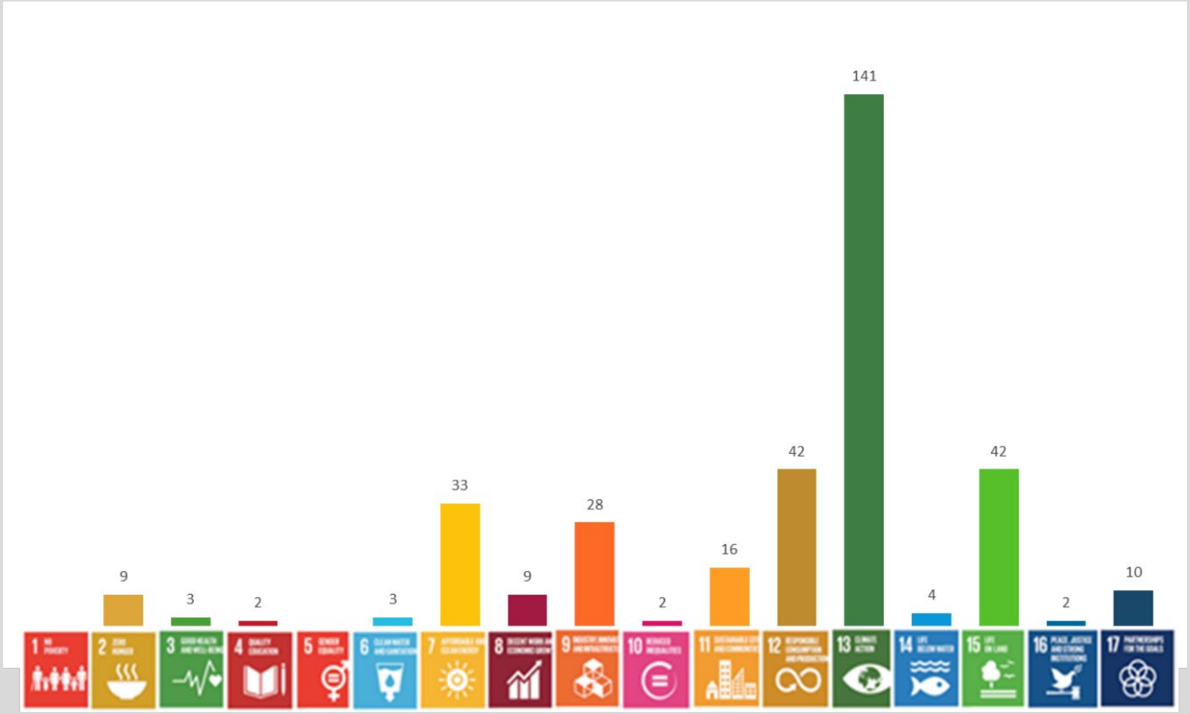
[2] https://ec.europa.eu/environment/green-city-accord_en
[3] https://sdgs.un.org/goals/goal11

2030) (Box 2) are visualised below. These relationships were mapped by applying an automated text mining tool based on relevant keywords (Borchardt et al., 2020). The same methodology is applied for the mapping of all the EU policies currently in force (https://knowsdgs.jrc.ec.europa.eu). This exercise is meant to explore the intrinsic connection between the SDGs and the latest Commission priorities.

Box 1. EU Green Deal and SDGs

"The Green Deal is an integral part of this Commission's strategy to implement the United Nations' 2030 Agenda and the Sustainable Development Goals, and the other priorities announced in President von der Leyen's political guidelines"[4]. The textual analysis revealed strong connections with the 2030 Agenda, especially with 14 of its goals. The main one is SDG 13 on climate action, followed by SDG 12 on sustainable consumption and production, SDG 7 on clean and affordable energy and SDG 15 on sustainable use of terrestrial ecosystems and (**Figure 1-box1**). **Table 1 in Appendix 1** provides the detail of all the goals and targets detected.

Figure 1- box1: keywords connected to the SDGs retrieved analysing the European Green Deal (European Commission 2019).



Source: European Commission, 2019

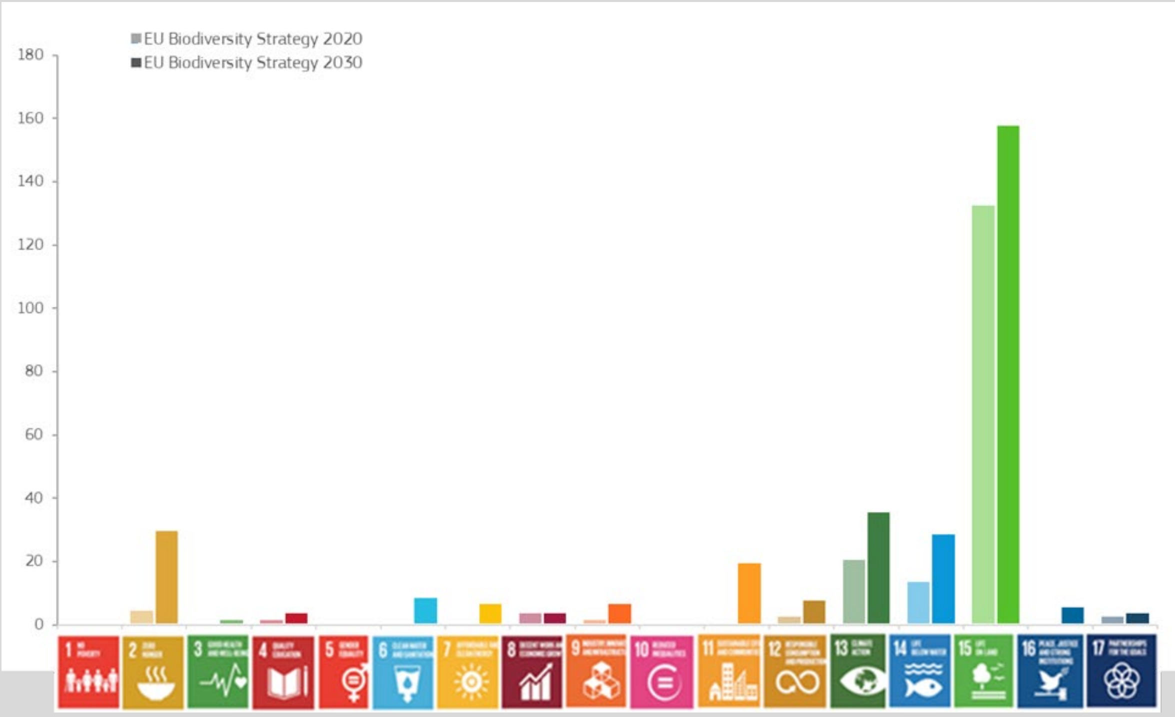
Box 2. Biodiversity strategy 2020 and 2030 and SDGs

The semantic analysis revealed that there are strong connections between the EU Biodiversity Strategies and the SDG framework, especially in the 2030 strategy, where a link with 14 goals has been detected. The results at goal level show high prevalence of detected keywords related to SDG 15 on protection, restoration and sustainable use of terrestrial ecosystems, followed by SDG 13 on climate action, and SDG 14 on

[4] A Union that strives for more. My agenda for Europe. Political Guidelines for the Next European Commission 2019-2024. https://ec.europa.eu/info/sites/info/files/political-guidelines-next-commission_en_0.pdf

conservation and sustainably use of the oceans, seas and marine resources (figure 1). Table 2 in Appendix 1 provides the detail of all the goals and targets detected.

Figure 1- box2: keywords connected to the SDGs retrieved analysing the Biodiversity Strategy to 2020 (European Commission, 2011). and for 2030.



Source: European Commission, 2020.

By comparing the EU Biodiversity Strategy to 2020 and for 2030, what emerges is:

- An increase in the number of keywords detected related to the three prevalent SDGs, SDG 15, 13 and SDG 14.
- An increase in the number of keywords detected related to SDG2 (on food and sustainable agriculture), SDG 11 (on sustainable cities), SDG 12 (on sustainable consumption and production), SDG 9 (on innovation and sustainable industrialization), SDG 4 (on quality education);
- Three additional goals are identified in the 2030 strategy: SDG 6 on clean water, SDG 7 on sustainable energy and SDG 16 on peace, justice and strong institutions.

Looking at the detailed results, most of the UN targets for SDG 15 are detected in both EU Biodiversity strategy to2020 and for 2030, with specific references to halt biodiversity loss (15.5), forest management (15.2), restore terrestrial ecosystem (target 15.1), reduce the impact of invasive alien species (15.8), ecosystem services (15.9), and mobilize resources for biodiversity (15.a).

In the EU Biodiversity strategy for 2030, there are references to two additional targets, regarding land restoration (15.3) and wildlife trafficking (15.7). On the contrary, target 15.6 on genetic resources is present only in the 2020 strategy.

Focusing on SDG 11 "Make cities and human settlements inclusive, safe, resilient and sustainable", the number of references increase from 2020 to 2030 strategy. In particular, the mapping results highlight relations to three additional targets: target 11.7 to "provide universal access to safe, inclusive and accessible, green and public spaces, in particular for women and children, older persons and persons with disabilities", target 11.3 regarding "inclusive and sustainable urbanization and capacity for participatory, integrated and sustain

nable human settlement planning and management", and target 11.6 to "reduce the adverse per capita environmental impact of cities, including by paying special attention to air quality and municipal and other waste management".

As demonstrated by the above exercise, the importance of urban areas is stressed in both the EU Green Deal and the Biodiversity Strategy for 2030.

As some cities and urbanised areas are expected to grow in the future, it is important to gain more evidence to support a shift in urban development priorities, taking into account the importance to protect and restore nature as part of urban development. To do so, understanding the various benefits and co-benefits that UGI can deliver is key. In fact, UGI are considered important Nature-Based Solutions (NBS), which are defined as: "Solutions that are inspired and supported by nature, which are cost-effective, simultaneously provide environmental, social and economic benefits and help build resilience. Such solutions bring more, and more diverse, nature and natural features and processes into cities, landscapes and seascapes, through locally adapted, resource-efficient and systemic interventions" (European Commission, 2022). In this way, NBS and compensation policies (compensate for a no-net loss) might help urban areas to develop in a more sustainable way.

Previous JRC research activities on urban ecosystems demonstrated the importance of knowledge development for evidence-based policy support.

The MAES urban pilot was the first attempt to develop a thematic assessment of urban ecosystems in the context of the MAES initiative[5] . In a posterior project, EnRoute, the framework developed in the MAES pilot was implemented and 25 indicators were calculated at EU-level. EnRoute[6] was a project of the European Commission developed in the framework of the EU Biodiversity Strategy to 2020 (European Commission, 2011) and the Green Infrastructure Strategy (European Commission, 2013). EnRoute provided scientific knowledge of how urban ecosystems can support local and European urban planning at different stages of policy and for various spatial scales as well as how to support policymaking for sustainable cities. It aimed to promote the deployment of UGI at local level and delivered guidance on the creation, management and governance of urban green infrastructure. Importantly, it illustrated how collaboration between and across different policy levels can lead to concrete green infrastructure policy setting (Zulian et al 2018; Maes et al 2019; https://oppla.eu/groups/enroute).

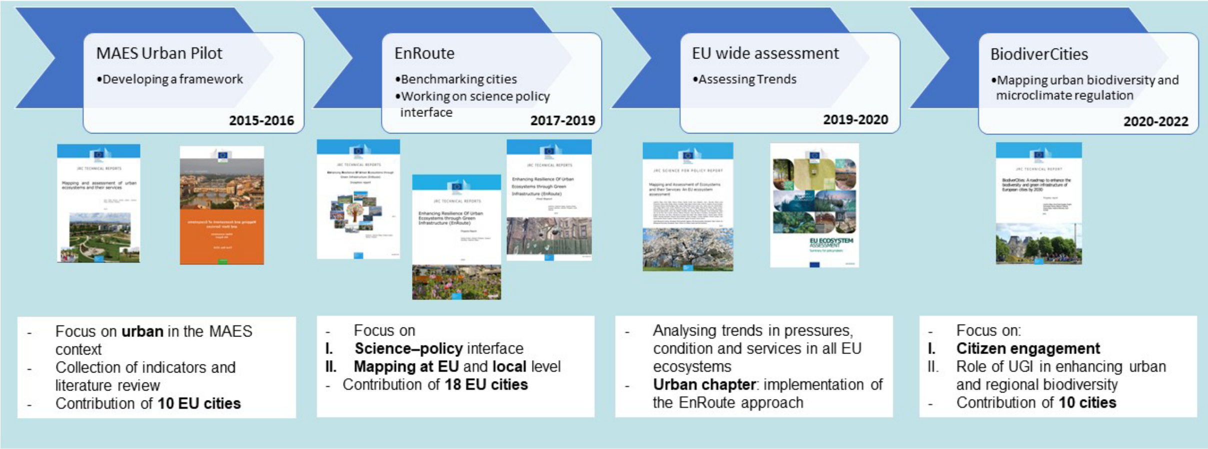
The MAES framework was also adapted to be part of the first EU Ecosystem Assessment, which covers the total land area of the EU as well as the EU marine region (Maes et al 2020). A subset of 10 indicators was implemented to map and assess urban ecosystem condition and analyse long term trends.

BiodiverCities is a European Parliament Pilot Project and represents the fourth step along activities carried on in the last seven years on the topic of urban ecosystems and UGI (**Figure 2**). The project aims to enhance civil society participation in local and urban decision-making, leading to build a joint vision of the green city of tomorrow shared among civil society, scientists and policymakers. It also explores how urban green infrastructure can be used to provide local benefits for people and nature and how it can contribute to enhancing regional biodiversity (Maes et al 2021; https://oppla.eu/groups/biodivercities).

[5] MAES stands for Mapping and Assessment of Ecosystems and their Services and supported the Action 5 of the Biodiversity Strategy to 2020, which was a Commission's initiative to promote mapping and assessment of Ecosystems in the member states (Maes et al 2016).

[6] Enhancing Resilience of urban ecosystems through green infrastructure

Figure 2. Overview of the key JRC research activities on urban ecosystems and UGI carried on in the last seven years



Source: JRC elaboration

1.1 Objectives

The BiodiverCities project is implemented along two main strands of work:

1. Local engagement of citizens in urban nature: how can cities engage stakeholders and citizens to:
   (a). set ambitions and targets for urban biodiversity and urban green infrastructure;
   (b). help monitor the state of urban nature;
   (c). co-design solutions to tackle urban challenges based on green infrastructure and nature-based solutions?
2. Regional embedding and upscaling: How to frame a smart implementation of UGI to enhance urban biodiversity and improve the connection to the regional nature network?

This report will focus on the second strand of work, with emphasis on the local and regional benefits of urban green infrastructure. Specifically contributes to the knowledge development to support a Roadmap to greener cities in Europe as requested in the EU Biodiversity Strategy for 2030 (European Commission 2020).

1.2 What in this report

The document is divided in two sections:

– **Section 1** describes the European UGI from a multi scale perspective, analysing its extent and structure. It also explores the relevant reporting units aimed to assess urban ecosystems and how to enhance UGI at the local and European level. In particular, the section reflects over three principal points:
  - What is the appropriate reporting unit for urban ecosystems? Pro and cons of Functional Urban Areas (FUA) and Local Administrative Units (LAU).
  - Status and scenarios analysis of UGI and urban trees to support the development of urban targets in the context on the new EU Nature Restoration Law (methods and results)
  - What is the contribution of UGI to the overall EU-GI.

- **Section 2** evaluates the role of urban characteristics on biotic homogenization. Urban characteristics are measured using anthropogenic descriptors (for instance, population density, degree of urbanisation, presence of protected areas) and environmental descriptors (for instance the presence of tree canopy cover, the amount of vegetation, the presence of natural riparian zones). The work is based on a case study implemented in France, using the bird data from the French Breeding Bird Survey, a structured citizen science monitoring program. The modelling framework relied on a multi-scale approach, to explore the links between urban land composition metrics and avian biodiversity metrics.

2 The European GI in a multiscale perspective

2.1 The debate around FUA and LAU

Urban Ecosystems are socio-ecological systems where most people live (Maes et al., 2020a). Following Marzluff et al., 2008, "*The urban ecosystem includes abiotic spheres (the atmosphere, hydrosphere, lithosphere, and soil or pedosphere) and biotic spheres (often viewed as an interacting biosphere of urban plants and animals plus the socio-economic world of people, the anthroposphere)…*". Urban ecosystems are almost completely artificial, but they include vegetation, parks (public and private), forests, lakes, rivers, other waterbodies and agricultural areas. All these ecosystem types are strongly influenced by human activities (Maes et al., 2020). Cities are both drivers of, and driven by, ecological processes within and beyond their boundaries (Marzluff et al 2008). For this reason, the analysis of urban ecosystems implies the consideration of the city itself plus its immediate surroundings.

It has been demonstrated that spatial parameters, in this case the reporting units, strongly affect the measurement of indicators for the assessment of ecosystem condition in urban areas (Taubenbook et al 2021). In this section, we discuss the options available to consistently analyse and report on urban ecosystems at the European level. We briefly describe the available spatially explicit territorial units in terms of share of the European territory covered, share of population, extent of land cover classes, share of settlements typologies, degree of naturalness and presence of Protected Areas. This discussion will support future developments in the assessment and monitoring of urban ecosystems for policy support.

Regulation (EU) 2017/2391[7] establishes a common statistical classification of territorial units and the relative reliable and comparable datasets for different territorial typologies (Regulation (EU) 2017/2391; EUROSTAT, 2018). Of specific interest for urban ecosystems are two local territorial typologies: the Local Administrative Units (LAU) classified considering the Degree of Urbanisation (EUROSTAT, 2021), and the Functional urban Areas (FUA) (see table 01 EUROSTAT 2018, p. 8). The local territorial typologies, in line with the entire territorial system, are spatially interlinked as they are based on the same building block: the population grid (EUROSTAT, 2018). This interlinkage guarantees consistency in a multilevel perspective.

The LAU consist in a system for dividing up a territory for the purpose of developing statistics at a local level. These units are usually low-level administrative divisions within a country, ranked below a province, region, or state (EUROSTAT, 2018). In most cases LAU are municipalities or communes across the EU. The Degree of Urbanisation classifies LAU as cities, towns and suburbs or rural areas based on a combination of geographical contiguity and population density, measured by minimum population thresholds applied to 1 km² population grid cells; each LAU belongs exclusively to one of these three classes. Once all grid cells have been classified and urban centres, urban clusters and rural grid cells identified, the next step concerns overlaying these results onto LAU as follows:

- Cities (densely populated areas) — where at least 50 % of the population lives in one or more urban centres;
- Towns and suburbs (intermediate density areas) — where less than 50 % of the population lives in an urban centre, but at least 50 % of the population lives in an urban cluster;
- Rural areas (thinly populated areas) — where more than 50 % of the population lives in rural grid cells.

In the following section a short comparative analysis is presented to understand similarities and differences in the FUA and LAU land patterns, focusing on extent, type of settlements typologies, population, degree of naturalness and presence of Natura 2000 sites.

The analysis is based on LAU-2020[8] , the most updated one, and FUA-2018[9], which was chosen for consistency with all the analysis carried on during the project and because few inconsistencies were identified when comparing FUA-2018 and FUA 2020 (see Figure 1 Annex 3). For this report the LAU dataset was corrected to

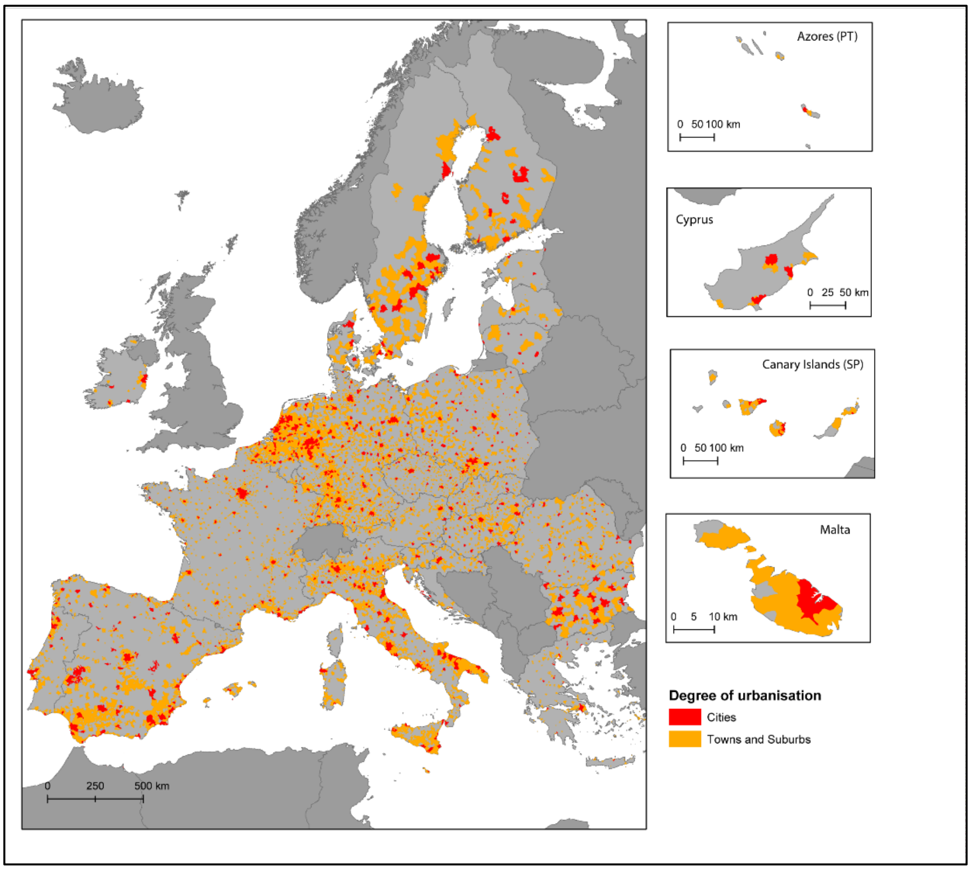
[7] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex:32017R2391

[8] https://ec.europa.eu/eurostat/web/gisco/geodata/reference-data/population-distribution-demography/degurba

[9] https://ec.europa.eu/eurostat/web/gisco/geodata/reference-data/administrative-units-statistical-units/urban-audit

remove LAU misclassified as 'cities', 'towns and suburbs'. Annex 3 contains the rules applied for the re-classification. In EU 27, 94995 LAU are identified, respectively 2350 cities (2.48%); 12632 towns and suburbs (13.32%) and 79832 rural LAUs (84.20%). **Figure 3** shows the spatial patterns of urbanised LAU in EU-27.

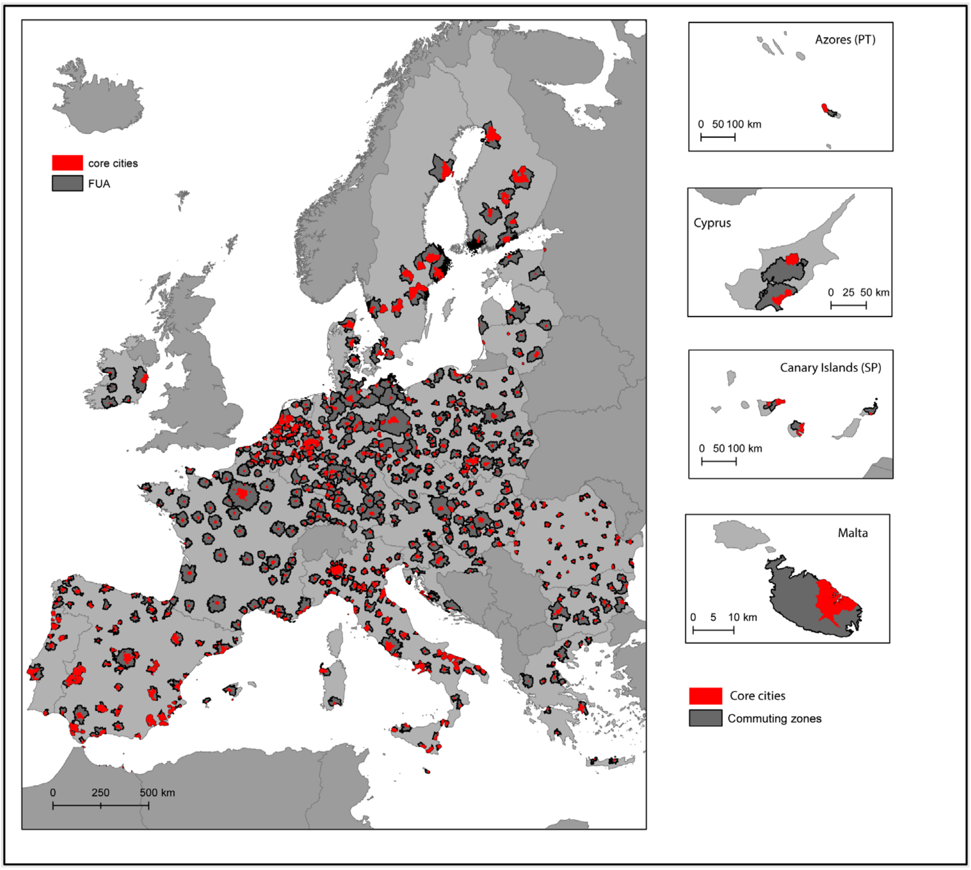
Figure 3. Spatial patterns of urbanised LAUs in EU-27.



Source: JRC analysis

FUA consist in a city and a commuting zone. At an initial level core cities are identified as urban centres (or high-density clusters) recognized as groups of grid cells with a population density of at least 1 500 inhabitants/ km^2 and collectively a population of at least 50 000 inhabitants. Each core city is part of its own commuting zone or a polycentric commuting zone covering multiple cities. These commuting zones are significant, especially for larger cities and consist in LAUs surrounding a city characterised by at least 15 % of their population commuting to work in the city (EUROSTAT, 2018). For several urban centres stretching far beyond the city, a 'greater city' level was created to improve international comparability (EUROSTAT, 2017). In EU 27, 611 FUA have been identified in 2018 as shown in **Figure 4**. In 2020 the share of land occupied by FUA decreased by 2.7% at EU scale because in SI, SK, LT, EE commuting zones were not identified (see Figure 1 Annex 3 for additional details).

Figure 4. Map of FUAs-2018 (EU-27).



Source: JRC analysis

FUA and LAU (as cities town and suburbs) cover approximately the same share of the European territory, respectively 21.9% FUA and 21.5% LAU (cities towns and suburbs). By definition, FUA-Core cities and LAU-cities correspond (EUROSTAT, 2018), and they practically overlap covering respectively 3.5 and 3.7% of EU land (see **Table 1**). Commuting zones and LAU classified as towns and suburbs, on the contrary, differ. Not really in terms of share of land occupied (respectively 18.5% by the Commuting zone and 17.8% by LAU towns and suburbs) but in terms of spatial pattern. In fact, as shown in *Source: JRC analysis*

Figure 5, a part of LAU -towns and suburbs extends beyond the boundaries of FUA in almost all MS. At the same time, many rural LAU are present inside FUA.

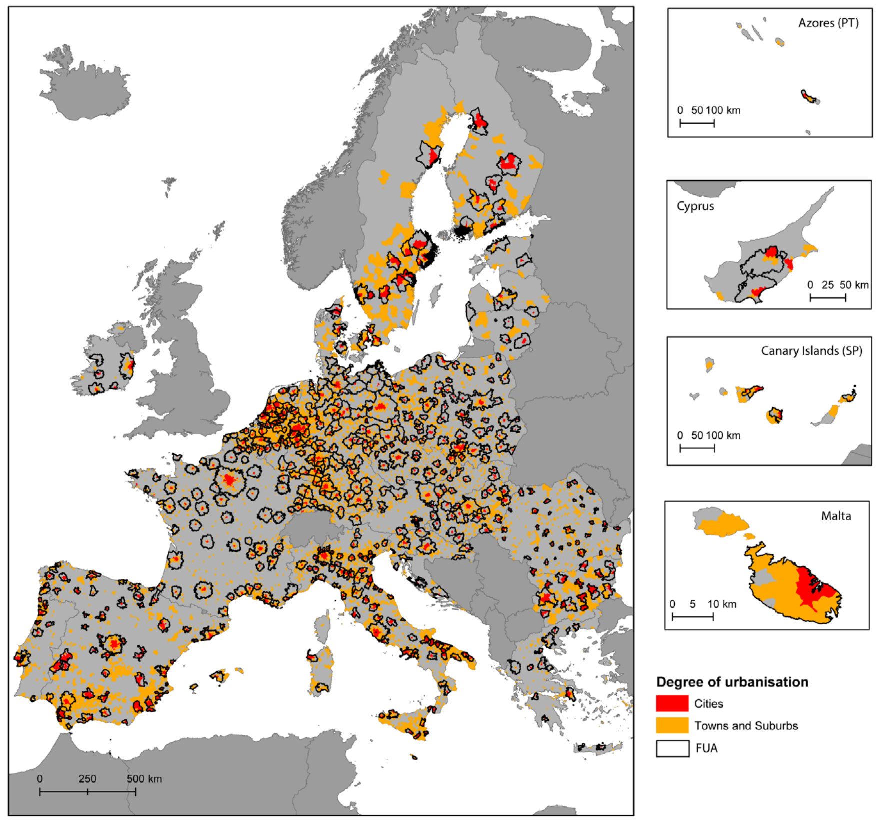
Table 1. Share of EU-27 covered by LAU and FUA.

local territorial typologies		**Share EU-27 territory (%)**
FUA	FUA	21.9

	Commuting zone	18.5
	Core city	3.5
LAU	Cities, towns and suburbs	21.5
	Cities	3.7
	towns and suburbs	17.8

Source: JRC analysis

Figure 5. LAU cities, towns and suburbs and FUA boundaries (EU-27).



Source: JRC analysis

The share of land cover types inside FUA and LAU (cities towns and suburbs) is presented in **Table 2**. Artificial surfaces cover respectively 12.5% of LAU and 10.6% of FUA. Interestingly, forests and semi-natural and agricultural areas represent together most of the land (respectively 83.2% of LAU and 86.5% of FUA). The land configuration (namely the relative arrangement of different land types) inside FUA, has already been analysed in previous studies (Maes, 2019; Maes 2020) and in more than 50% of the FUA agricultural land is among the dominant ecosystem types (Maes, 2019).

Table 2. Share of land types inside LAU and FUA. The share % is always with respect to the total area of LAU cities towns and suburbs (cts) and FUA.

CLC LEVEL 1	LAU cts	cities	towns and suburbs	FUA	core cities	commuting zones
	share (%)					
Artificial surfaces	12.5	4.7	7.8	10.6	4.3	6.2
Agricultural areas	47.8	6.8	41.0	53.0	5.9	47.1
Forest and semi natural areas	35.5	4.9	30.6	33.5	4.4	29.0
Wetlands	0.8	0.1	0.7	0.7	0.1	0.6
Water bodies	3.4	0.7	2.7	2.2	0.6	1.6
CLC LEVEL 1	**LAU cts**	**cities**	**towns and suburbs**	**FUA**	**core cities**	**commuting zones**
	km2					
Artificial surfaces	111.04	41.37	69.67	95.62	39.35	56.27
Agricultural areas	425.23	60.30	364.94	479.92	53.70	426.21
Forest and semi natural areas	315.46	43.64	271.82	302.71	39.88	262.82
Wetlands	7.51	1.33	6.19	6.55	1.28	5.26
Water bodies	30.05	6.23	23.81	20.14	5.74	14.40

Source: JRC analysis

LAU (cities towns and suburbs) and FUA do not differ substantially when considering the dominant settlement typologies. The territorial units were analysed using the GHS Settlement Model grid (GHS-SMOD[10]) (Florczyk et al., 2019). GHS-SMOD is a global 1 km grid which classifies the land in seven settlement categories and represents a refined version of the Degree of Urbanisation method described by EUROSTAT (EUROSTAT, 2018). The GHS-SMOD dataset consents to extrapolate the share of land characterized by the following settlement typologies (here denominated SMOD):

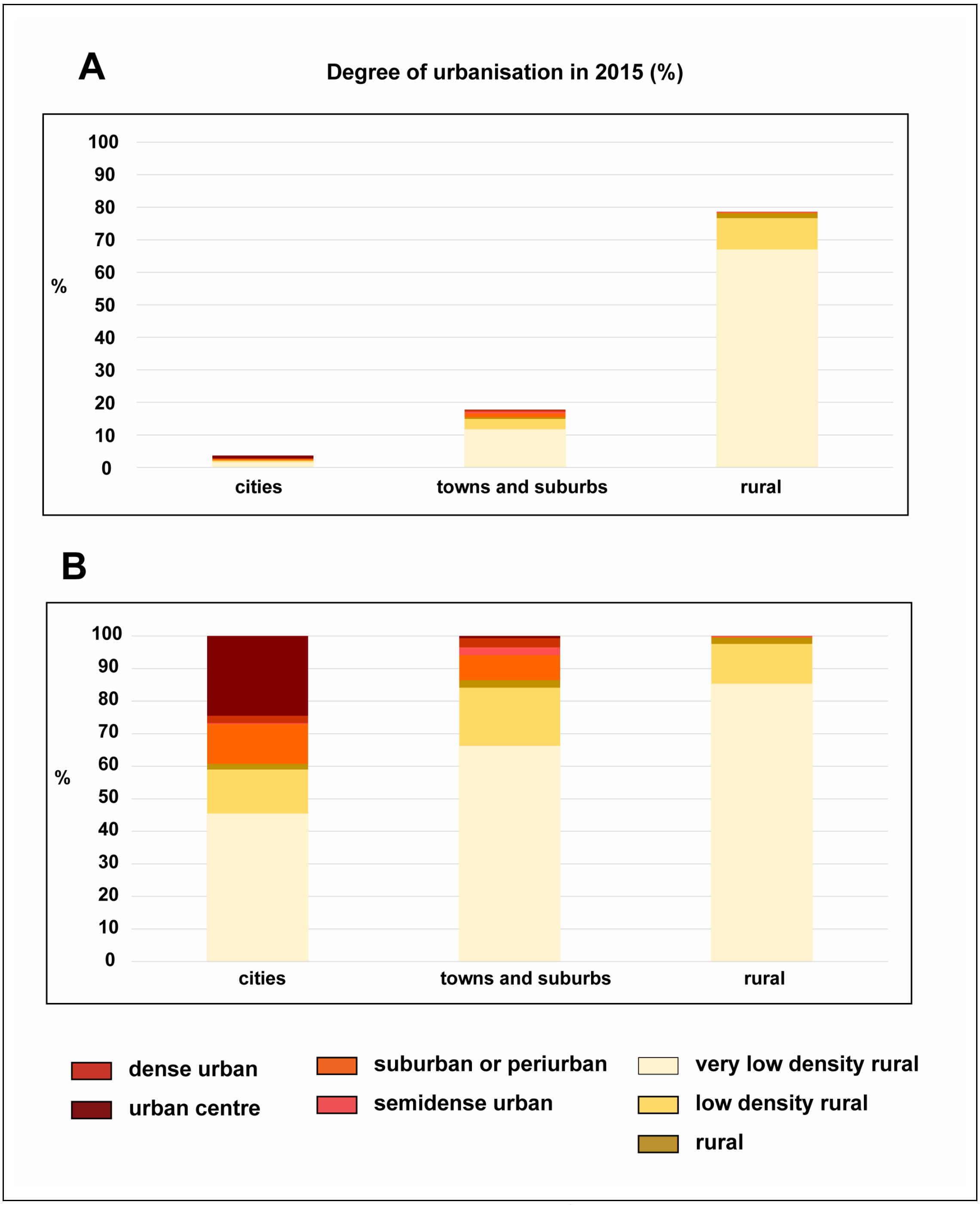
1. Urban centre: cities, large settlements;
2. Dense urban: dense town, medium settlements;
3. Semi-dense urban: semi-dense town, semi-dense medium settlements;
4. Suburban or peri-urban: suburban or peri-urban areas, semi-dense area;
5. Rural: village, small settlement;

[10] https://ghsl.jrc.ec.europa.eu/ghs_smod2019.php

6. Low density rural: dispersed rural area, low density area;
7. Very low-density area: mostly uninhabited area, very low-density area.

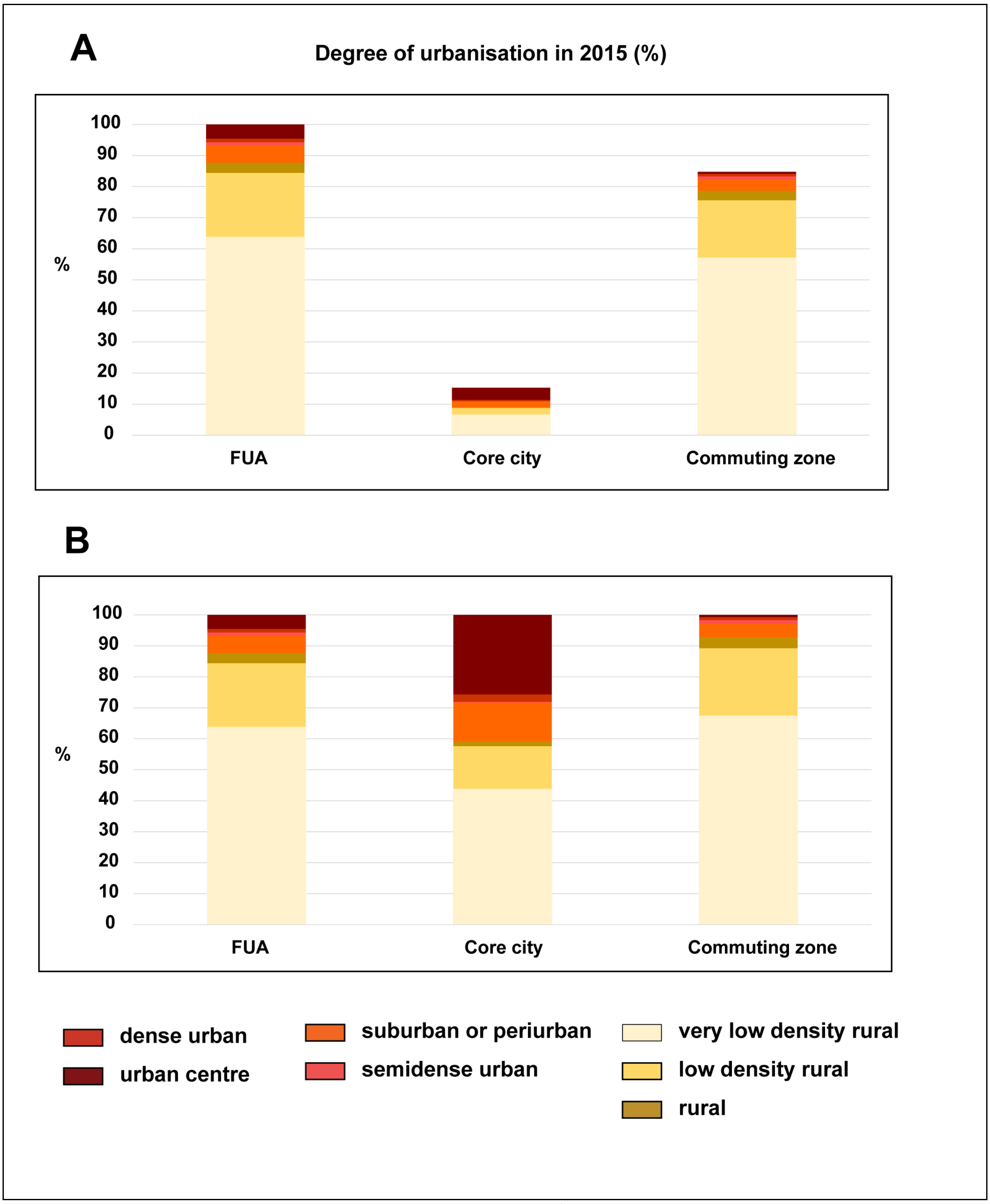
Figure 6 and **Figure 7** shows the share of land by settlements categories respectively in LAU and FUA. As expected, the urban centre typology dominates both, LAU-cities and FUA-core cities. All the other categories are identified in cities, towns and suburbs and commuting zone. Sub-urban and semidense urban settlements characterise LAU-cities (12.2%) and FUA core cities (12.4%).

Figure 6. Share of settlements categories (SMOD) in cities towns and suburbs and rural LAUs. A. share computed within each LAU class; B. share computed with respect to the extent of the entire EU-27 territory.



Source: JRC analysis

Figure 7. Share of settlements categories (SMOD) in FUAs. A. share computed within each FUA class, Core cities and Commuting zones typology; B. share computed considering the territory covered by FUAs

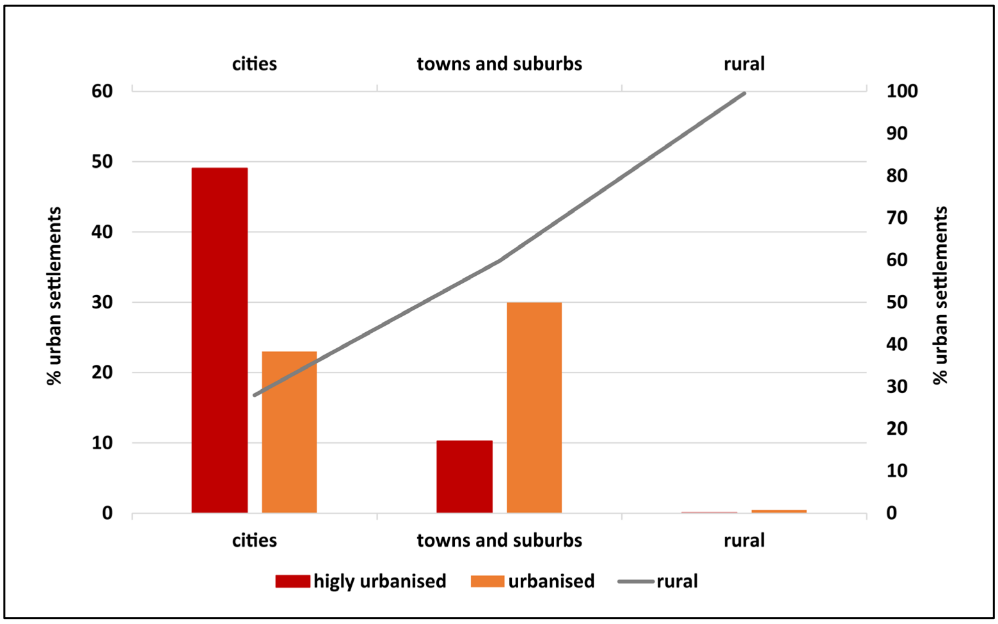


Source: JRC analysis

The degree of urbanisation, type rural (in all the proposed ranks, see legend in Figure 5, 6), are identified in both FUA and LAU (cities towns and suburbs). Figure 8 and *Source: JRC analysis*

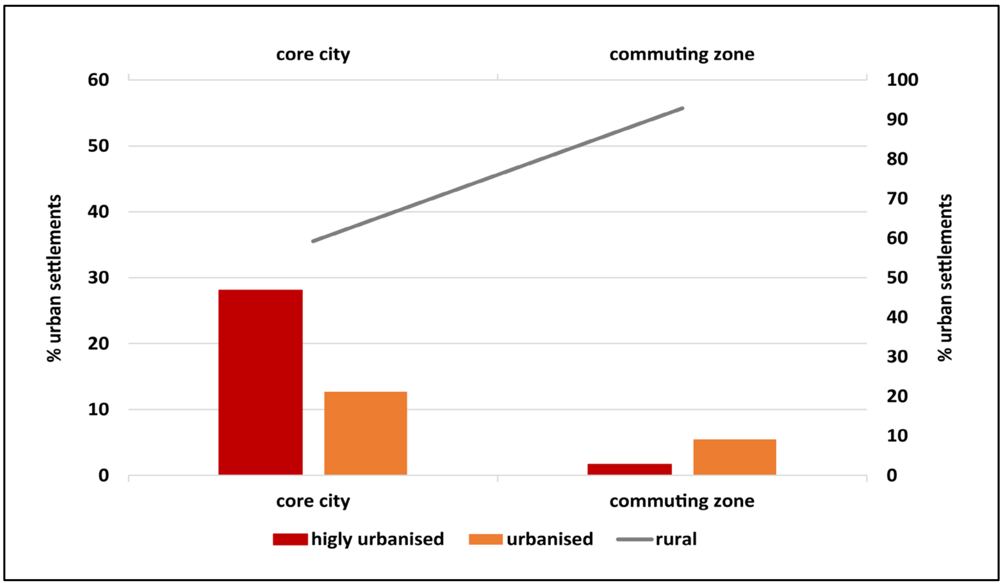
Figure 9 provide a synthesis by aggregating the seven settlement typologies (SMOD) in highly urbanised (typology 1 and 2), urbanised (typology 3 and 4) and rural (typology 5, 6 and 7). Rural settlements cover 59.7% of LAU-towns and suburbs and 92.8% of Commuting zones respectively. Together with the semi-dense urban and peri-urban settlements they represent the land where most of the densification process can still take place. In this context we are referring to a horizontal expansion process, rather than a vertical densification. We can argue that, for the specific focus of this study, areas that are not yet densely urbanised and are located within cities, towns and suburbs or commuting zones are of specific interest. In fact, the densification processes, in form of infill development or increase of urbanised land, are identified as one of the main causes of urban green loss (Balikçi et al. 2021, Haaland and van den Bosch 2015, Colsaet et al. 2018). Balikçi et al., 2021 identified the "*lack of new greenspace planning in the initial stages of the infill development process*" and "*Competition due to land cost*" among the principal determinants of green loss associated with densification processes. Lack of planning regulations and not taking environmental constraints into account were identified also by Colsaet et al. (2018). Other contextual factors, such as "demographic, economic, and social processes, as well as infrastructure and transport" are also identified as strong determinants of green loss. (Balikçi et al. 2021, Colsaet et al. 2018).

Figure 8: Share of highly urbanised, urbanised and rural land in LAUs.



Source: JRC analysis

Figure 9. Share of highly urbanised, urbanised and rural land in FUAs.



Source: JRC analysis

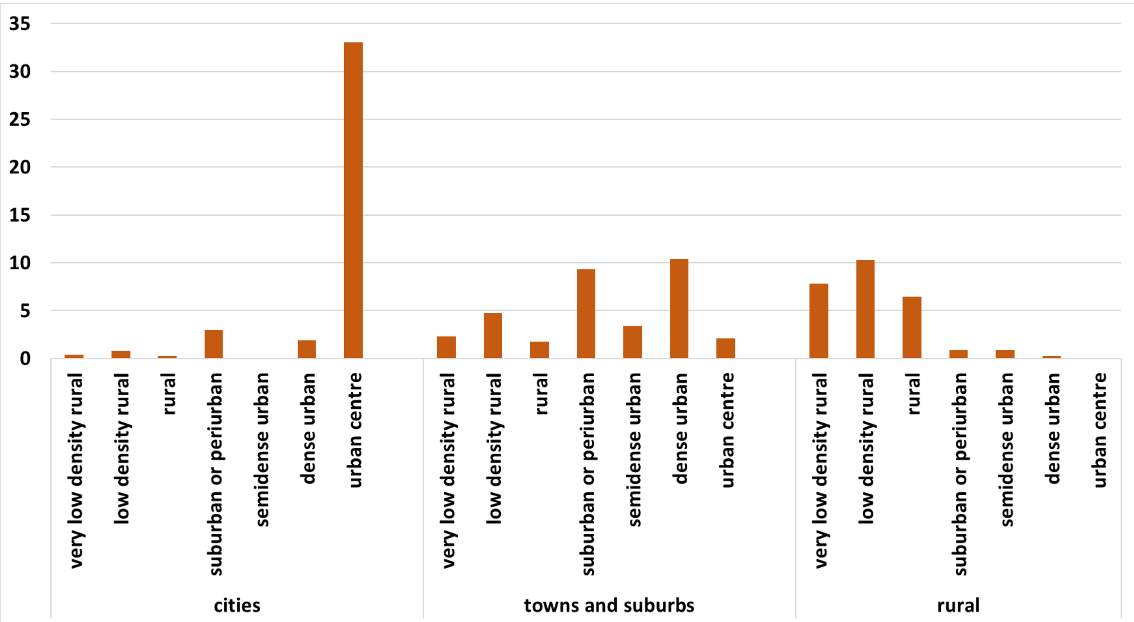
As expected, most of population lives in cities, nevertheless a proportion of European citizens lives in rural settlements (see **Figure 10** and **Figure 11** and **Table 3**), respectively 54 million in FUA and 44 million in LAU.

Table 3. Population in LAU and FUA. Percentages and total inhabitants are reported in each territorial unit.

Territorial Units		Population % (inhabitants)		
		highly urbanised	**urbanised**	**rural**
FUA	FUA	40.13 (174241143)	9.78 (42448221)	12.53 (54395583)
	outside FUA	7.64 (33184803)	7.7 (33460167)	22.21 (96427505)
LAU	cities-towns-suburbs	47.44 (205984590)	15.75 (68358748)	10.23 (44430596)
	rural	0.33 (1441356)	1.74 (7549640)	24.51 (106392492)

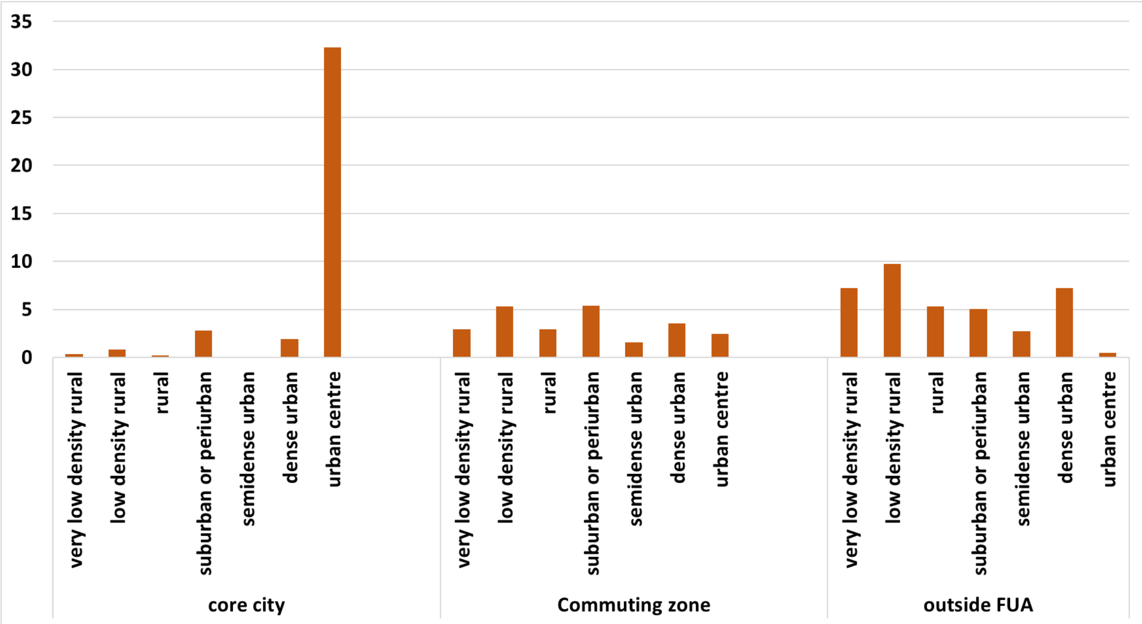
Source: *JRC analysis*

Figure 10. Population (%) in LAU (cities towns and suburbs) in each settlement typology (SMOD).



Source: *JRC analysis*

Figure 11. Population (%) FUA (core cities and commuting zones) in each settlement typology.



Source: JRC analysis

The territorial units were analysed with respect to the degree of naturalness and the presence of protected areas. The degree of naturalness was measured using an updated version of the Hemeroby map, expressly implemented for this study. Hemeroby is an index for landscape monitoring (Steinhardt et al., 1999; Paracchini & Capitani, 2011), which provides a measure of the degree of artificiality, i.e. the modification of the ecosystem from the potential natural condition due to human activities. In this application the indicator was calculated following the approach developed by Paracchini and Capitani (2011). To fit the European level the authors updated the original Hemeroby classification,adding two additional classes. **Table 4** provides the description of the nine Hemeroby classes.

Table 4. Updated Hemeroby classes.

<table>
<tr><th>Hemeroby level</th><th>degree</th><th>Description</th></tr>
<tr><td>Ahemerobe</td><td>1</td><td>Natural
Bogs, tundra, forest untouched by man or currently protected</td></tr>
<tr><td>Oligohemerobe</td><td>2</td><td>Close to natural
Forest with species typical for the site and diverse; semi-natural grasslands</td></tr>
<tr><td>Mesohemerobe</td><td>3</td><td>Semi-natural
Forest with low species diversity and increasing presence of atypical species; extensive grasslands</td></tr>
<tr><td>B-euhemerobe-a</td><td>4</td><td rowspan="2">Relatively far from natural
Forest dominated by species atypical for the site or with high presence of alien species; annual crops associated with permanent crops (extensive), agro-forestry</td></tr>
<tr><td>B-euhemerobe-b</td><td>5</td></tr>
</table>

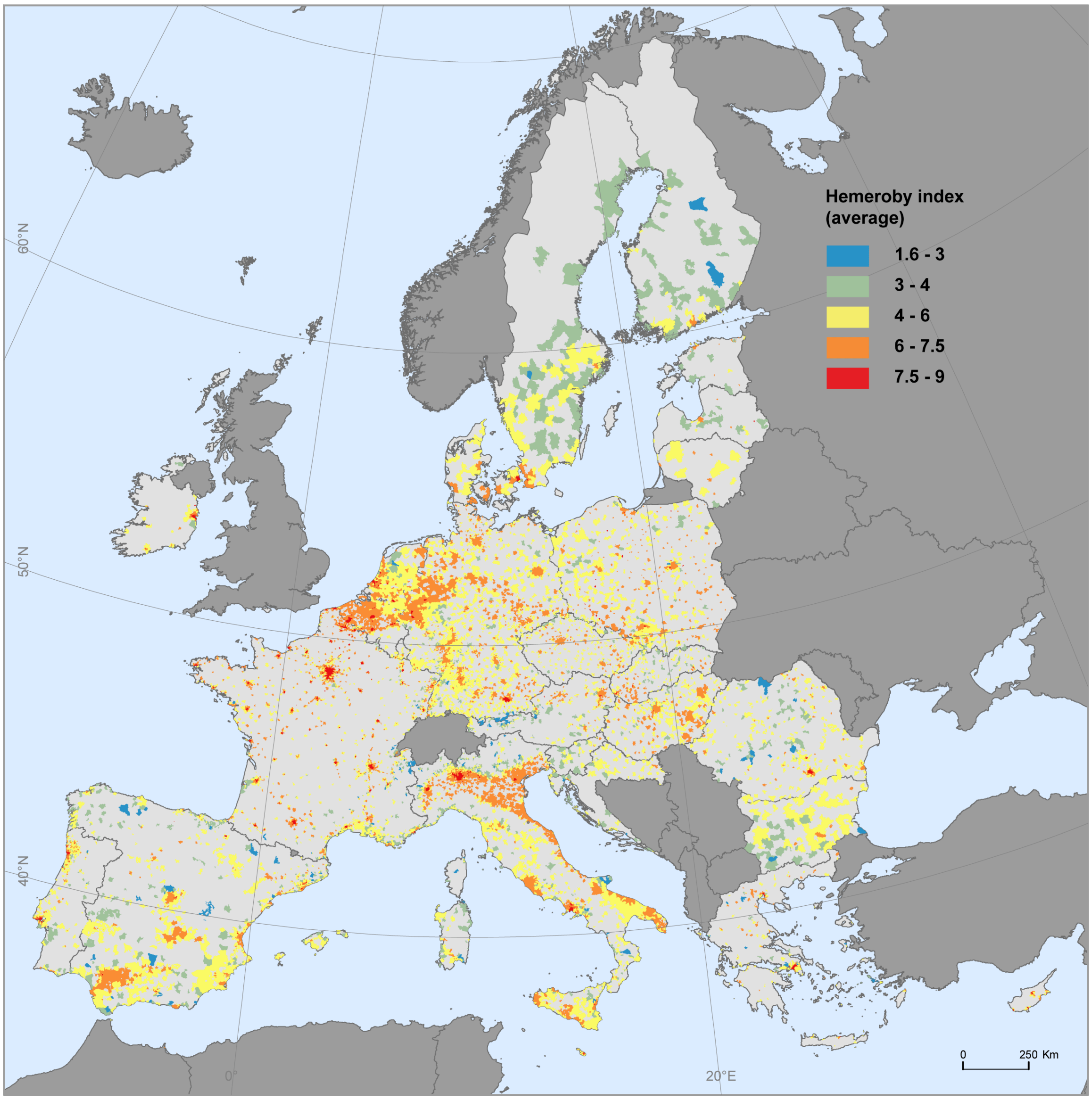
		Intensive grassland, extensive arable land, olive groves with permanent vegetation cover
Hemeroby level	**degree**	**Description**
A-euhemerobe-a	6	Far from natural Forest dominated by alien species; intensive arable land (short rotations), intensive vineyards
A-euhemerobe-b	7	Cereal monocultures, rice fields and irrigated crops (intensive)
Polyhemerobe	8	Strange to natural City green, golf courses, pits
Metahemerobe	9	Artificial Streets, buildings

Source: *Paracchini & Capitani, 2011*

The updated version was calculated using Corine Land Cover 2018; forest management data were derived from the work published by Nabuurs et al (2019); agricultural management data were derived from the work published by Rega et al. (2020). In addition, to classify artificial land types, the greenest dataset for 2015-2018 derived from Landsat was used. All datasets are described in Annex 2.

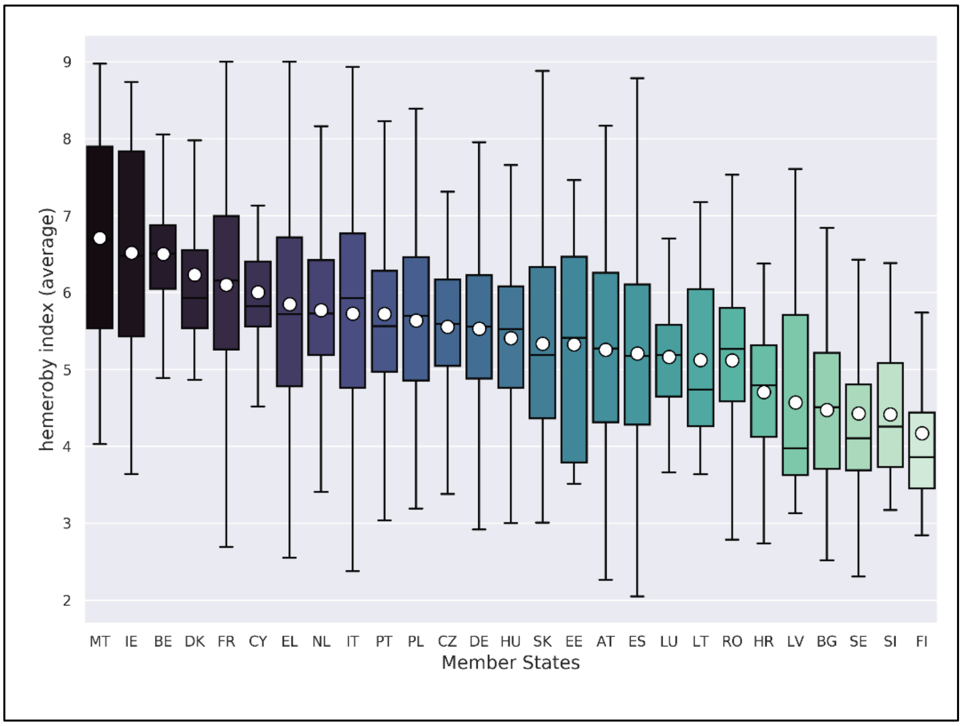
Figure 12 shows the LAU (cities towns and suburbs) classified using the Hemeroby average value. The average value in EU-27 is 5.68. As expected, most part of the urbanised LAU are far from natural. Nevertheless, the spatial pattern is very diverse across Europe, with northern and eastern countries showing a degree of naturalness relatively high. At the LAU level, (**Figure 13**), the analysis shows a high variability among cities in the same country (see France, Spain, Italy for instance).

Figure 12. LAU cities, towns and suburbs (EU-27) classified by average degree of naturalness.



Source: JRC analysis

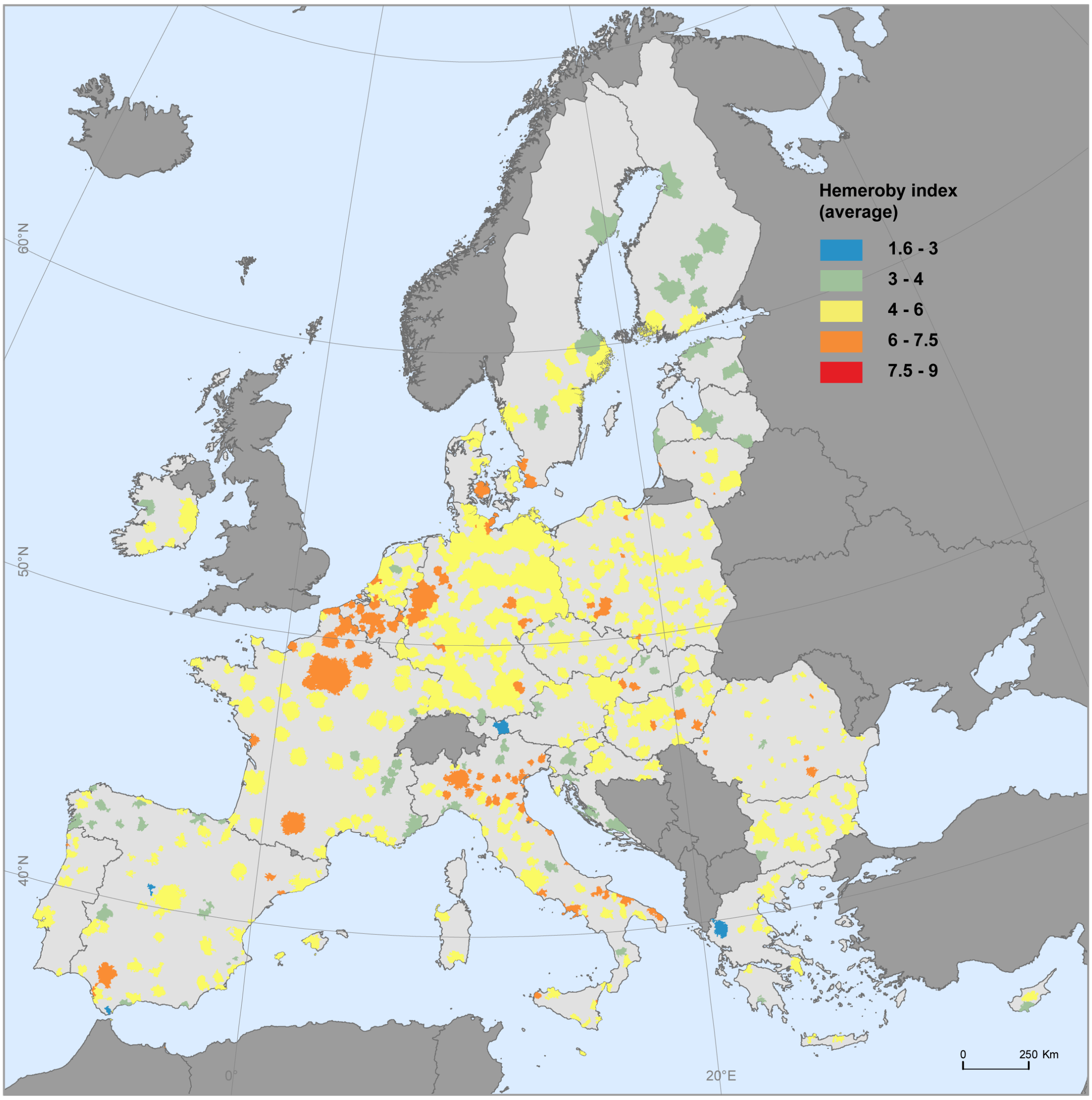
Figure 13. LAU cities, towns and suburbs (EU-27) classified by average degree of naturalness, distribution across LAU per MS.



Source: JRC analysis

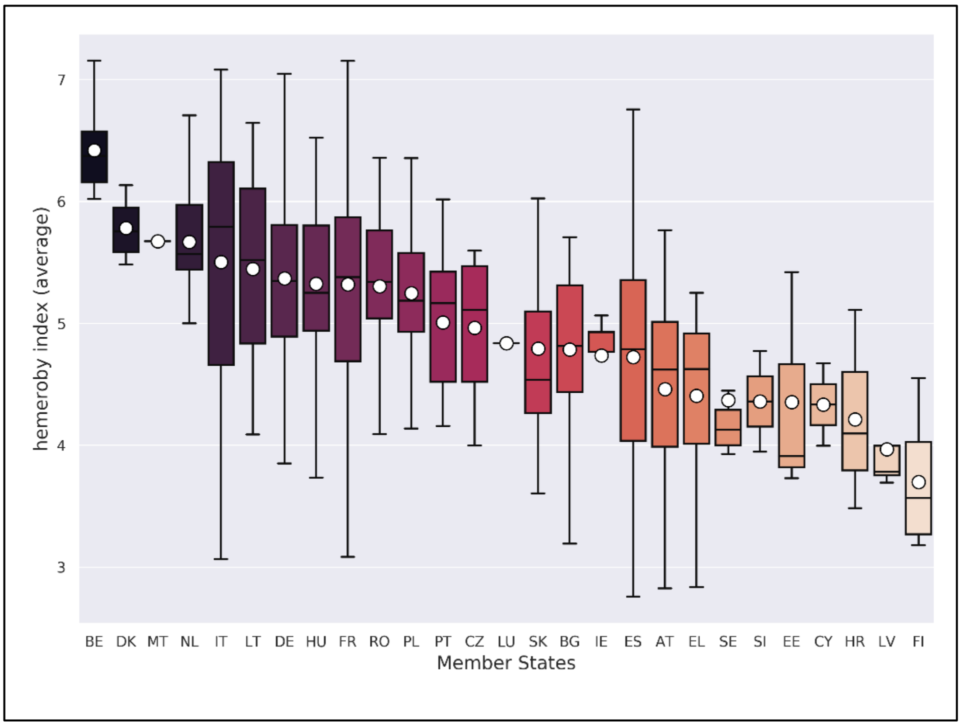
Figure 14 and **Error! Reference source not found.** show the FUA classified using the hemeroby average value. The average value in EU-27 is 5.17, slightly lower respect to the one of the LAU. The map shows less variability in the spatial pattern of FUA compared to the one computed at the LAU level, with most of the FUA classified as far from natural.

Figure 14. FUA (EU-27) classified by average degree of naturalness.



Source: JRC analysis

Figure 15. FUA (EU-27) classified by average degree of naturalness, distribution across FUA per MS.



Source: JRC analysis

Natura 2000 is the largest coordinated network of protected areas in the world. Stretching over 18.5% of the EU-27's (76 million hectares) land area and more than 8% of its marine territory[11]. Out of the total area protected by Natura 2000 19.61% (15 million hectares) is located within FUA and 16.66% (12.7 million hectares) within LAU (respectively 2.4% in cities and 14.2% in towns and suburbs). This means that, due to their structure, FUA include 2 million hectares of protected areas more than LAUs.

Table 5 presents a synthesis of pro and cons of using FUA and LAU for urban ecosystem assessment. The two territorial units represents highly populated and urbanised areas in Europe. They cover approximately the same share of territory, and they are characterised by similar land cover coverage and settlement typologies. LAU are useful units to be employed when local administrations have to be involved in EU level policy options delineation or analysis. FUA allow to consistently consider cities surroundings and all the interrelation between the core city and the context. They can be for this reason well suited for the assessment of urban ecosystem condition and ecosystem services. Nevertheless, in some MS the delineation of FUA is problematic (Germany for instance) and determines an over representation of the territory. The optimum solution would be to develop an integrated additional local land typology classification which combines the concept of FUA with the delineation of LAU-degree of urbanisation.

An additional problem is related to the data available to monitor urban ecosystem condition and urban green in general. Recent legislations, for instance the Proposal for a Nature Restoration Law (EU Commission 2022), make direct reference to the Copernicus Land Monitoring Service (NRL, art 3(13),(14)). Currently the available product only partially cover the data needed to monitor and assess urban green. Urban Atlas[12], for instance, which provides reliable, inter-comparable, high-resolution land use and land cover data with integrated population estimates is available only for FUA. In addition this dataset does not capture the small green patches, for instance urban green inside private gardens,, that are extremely important in urban areas. A new product

[11] https://ec.europa.eu/environment/nature/natura2000/index_en.htm
[12] https://land.copernicus.eu/local/urban-atlas

would possibly be available in the future. The CLC+ Backbone[13]. This dataset will provide a new LC/LU standard from the reference year 2018 onwards. Based mainly on Sentinel-2 time-series (pixel based 10m).

Table 5. Pros and cons of using the two-territorial level for urban ecosystems assessment.

Territorial unit	pro	cons
LAU	Harmonised definition of cities and urban areas (based on population and degree of urbanisation)	Urban Atlas does not cover LAU cities towns and suburbs A high-resolution land cover dataset is not yet available to measure urban green in all European LAU
	LAU cover a more populated territory of EU compared to FUA. 73.4% of the population live in cities towns and suburbs (based on the above exercise).	LAU classified as towns and suburbs do not cluster homogeneously in proximity of the main city.
	Represent local administration	In Case of Portugal LAU are very small, they match with wards, what could be problematic when comparing with this MS.
	LAU are characterised by more diversity in term of degree of naturalness compared to FUA, due to their higher spatial disaggregation that allow a more accurate view.	
FUA	Harmonised definition of cities and urban areas (based on population and commuters)	A part of the EU territory classified as towns and suburban (DEGURBA) is left out (missing 20.7% of suburban population and a significant part of urbanised settlements)
	Possibility to disaggregate using LAU's as sub-territorial unit.	In the case of Germany, FUAs are very large since they match NUTS-3 level (due to the level at which they collect commuting data) what could be problematic when comparing with this MS.
	FUA are occupied by a relatively higher share of Natura 2000 (19.61%) compared to LAU (16.66%).	

Source: *JRC analysis*

Key messages

– FUA and LAU (as cities town and suburbs) cover approximately the same share of the European territory, respectively 21.9% FUA and 21.5% LAU (cities towns and suburbs).

– FUA and LAU consist in settlements and artificial surfaces but they both contains other ecosystem types, the proportion of forest and semi natural vegetation is equivalent but FUA have more agriculture.

[13] https://land.copernicus.eu/pan-european/clc-plus

- LAU (classified as cities towns and suburbs) and FUA do not differ substantially even when considering the dominant settlement typologies, the rural typologies are identified in all territorial classes.
- Rural settlements and not densely urbanised land located in cities, towns and suburbs and commuting zones are of specific interest.
- A consistent share of European population lives in rural areas within FUA (12.5%) and LAU (10.2%)
- The average EU-27 value of degree of naturalness in LAU is slightly higher than the one in FUA (5.68 against 5.17). High variability characterizes urbanised land across MS
- Out of the total area protected by Natura 2000 (18.5%), 19.61% is located within FUA and 16.66% within LAU (cities towns and suburbs)

2.2 Urban green and urban tree cover

European cities are extremely diverse in structure, size, and land configuration (Maes et al 2019). They are characterized by a different share and structure of public and private green spaces (Maes et al 2020; Maes et al 2019, Kabisch, et al, 2013).

In this section we provide a multi-level analysis of UGI:

- First, we report on the status in 2018 and potential future scenarios of two UGI core elements: urban trees and urban green areas.
- Second, we analyse the contribution of the UGI to the European GI focusing on extent and structural attributes.

2.2.1 Status, scenarios analysis

This section provides an overview of the status of urban green and urban tree canopy cover in European FUA together with a scenario analysis. This work has been developed to support the selection of urban targets to be included in the proposal for a Nature restoration Law (NRL) (European Commission, 2020).

Data and methods

In order to derive the abundance and distribution of trees in the FUAs, the Copernicus High Resolution Layer tree cover density map (2018) was retrieved. Tree canopy cover is defined as the total proportion of trees in a FUA and expressed as a percentage. The Tree Cover Density map provides this information on the proportional crown coverage per pixel at 10 m^2 spatial resolution. Access to data is open and free as established by the Copernicus data and information policy Regulation (EU): https://land.copernicus.eu/pan-european/high-resolution-layers/forests/tree-cover-density/status-maps/tree-cover-density-2018?tab=metadata

Urban green areas were obtained in accordance with the mapping guidance of the EU Urban Atlas dataset (2018) (https://www.eea.europa.eu/data-and-maps/data/data-viewers/land-take-in-functional-urban), which is generated over the city and its surroundings, according to the FUA definition and provided at a spatial resolution of 0.25 ha in urban areas and 1 ha in rural areas. In **Table 6**, the Urban Atlas classes selected for the definition of urban green areas within FUAs are displayed.

Table 6. Urban Atlas classes selected for the definition of urban green areas (https://land.copernicus.eu/user-corner/technical-library/urban-atlas-mapping-guide).

UA classes	Description
Artificial Surfaces	Green urban areas: Public green areas for predominantly recreational use such as gardens, zoos, parks, castle parks and cemeteries. Suburban

	natural areas that have become and are managed as urban parks. Forests or green areas extending from the surroundings into urban areas are mapped as green urban areas when at least two sides are bordered by urban areas and structures, and traces of recreational use are visible.
Complex and mixed cultivation patterns	Agro-forestry areas
Forest	Broad-leaved forest
	Coniferous forest
	Mixed forest
Herbaceous Vegetation Association	Natural grasslands
	Moors and heathland
	Sclerophyllous vegetation
	Transitional woodland-shrub
Open Spaces with Little or No Vegetation	Sparsely vegetated areas
Wetlands	Peat bogs

Source: JRC analysis

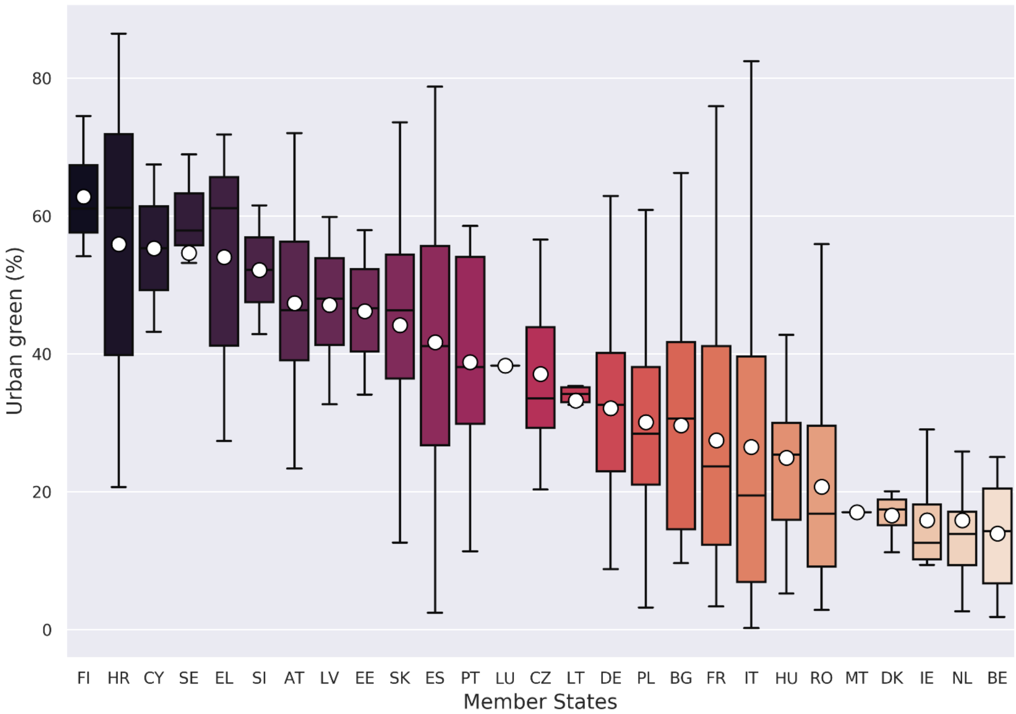
High quality Copernicus satellite data is already available going back to 2000 and will be available every three years through together with the Urban Atlas dataset showing urban growth, soil sealing, tree cover density, and various layers of urban green at high resolution scale (up to the 10m² level of detail). This data can very easily be set over the Functional Urban Area and are all available online. They can be used for setting the baselines, measuring and monitoring.

Status analysis of share of urban green and share of tree canopy cover

FUAs cover around 90 million hectares (21.9%) of the EU land (EU-27). Inside this area, currently urban green spaces occupy 31 million hectares, a proportion more than 30% of the FUA surface[14]. Below: range of green areas currently seen in FUAs per MS across the EU (**Figure 16**). With an average already of 32%, but with some MS as low as 5%.

[14] Data: Urban Atlas (2018) (EEA Urban Atlas 2018 - Euro Data Cube Public Collections)

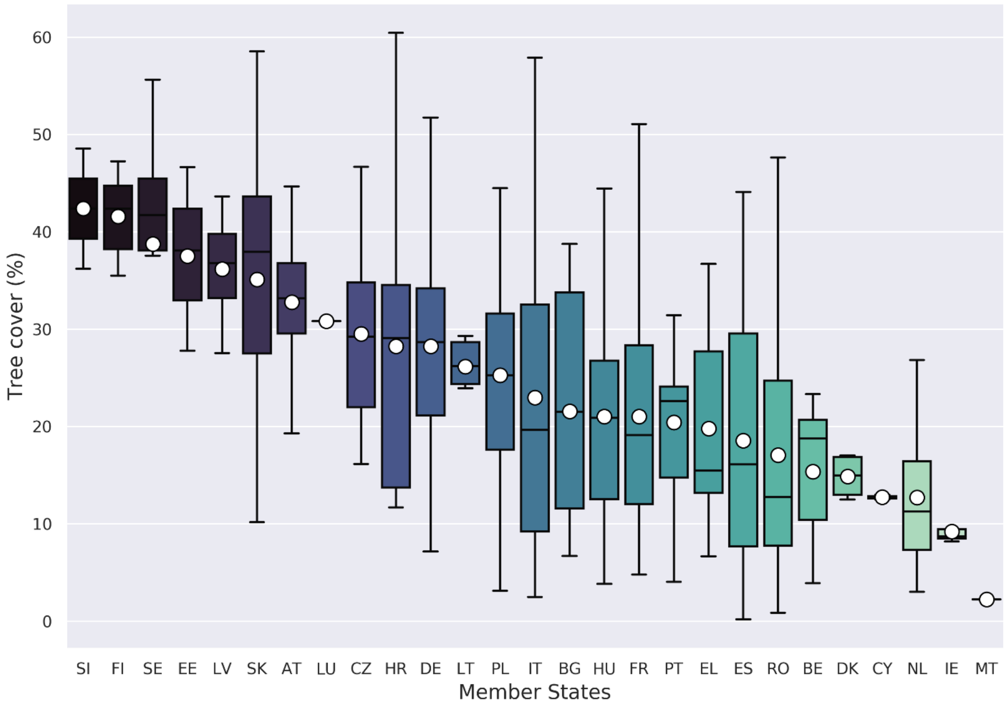
Figure 16. Amount (%) of urban green areas in FUA represented per MS.



Source: JRC analysis

Regarding tree cover, it covers approximately 23 million hectares of FUA land (25%). Average TC among MS is equal to 23%. North-eastern countries show higher proportion of trees in their FUAs, with values as high as around 45% average tree canopy cover in Slovenia and Finland, whereas countries like Malta or Ireland present the lower values (below 10%) as shown in **Figure 17**. Tree canopy cover is a relevant element in the urban ecosystem health. Trees are known to provide a range of ecosystem services to a higher degree with respect to other types of urban green (I.e. lawns, shrubs). In particular, they contribute to biodiversity, mitigation of heat by higher evapotranspiration and shade, and the reduction of risk posed by extreme events, as well as increasing property value.

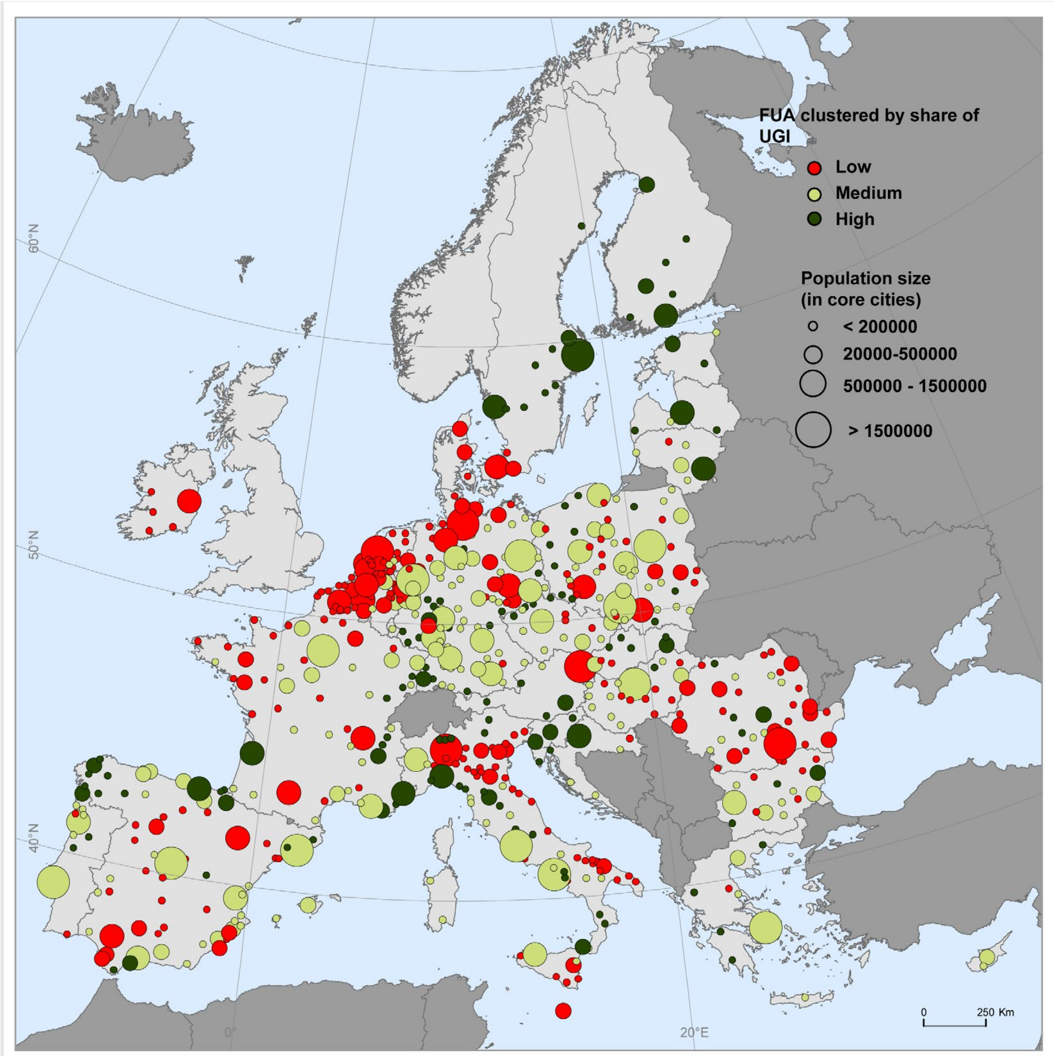
Figure 17. Amount (%) of TC in FUA represented per MS.



Source: JRC analysis

FUAs with the lower share of both urban green areas and tree canopy cover (**Figure 18**) can be found particularly some areas in northern–west of Europe (i.e. Belgium, Ireland, Denmark) as well as in coastal areas of countries such as Italy and Spain. The lower availability of UGI in these areas also reflects a lower capability to provide important ecosystem services such as microclimate regulation (Maes et al., 2021; Marando et al., 2022). Other areas such as the Po Plain in Italy are also characterized by a low share of UGI. This particular area also suffers from high levels of air pollutants such as PM10, PM2.5 and NOx (Maes et al 2020; Maes et al 2019). A high share of UGI in these areas is particularly needed to enhance the air filtering potential and mitigate the impact of air pollution on human health. It has been found that UGI can significantly reduce the amount of air pollution by deposition on the surface of leaves (for particulate matter) or absorption through the stomata (for gaseous pollutants) (Manes et al., 2016; Marando et al., 2019). On the other hand, a higher number of FUAs present higher share of UGI, particularly in wide areas of central Europe, and can be found in countries such as Germany, Bulgaria, Spain and Portugal. The highest share of UGI can then be found in the northernmost Member States (Sweden, Finland, Estonia, Latvia, Lithuania) as well as in northern Spain and Italy and in Slovakia.

Figure 18. Functional Urban Areas clustered by share of UGI (tree canopy cover and urban green areas).



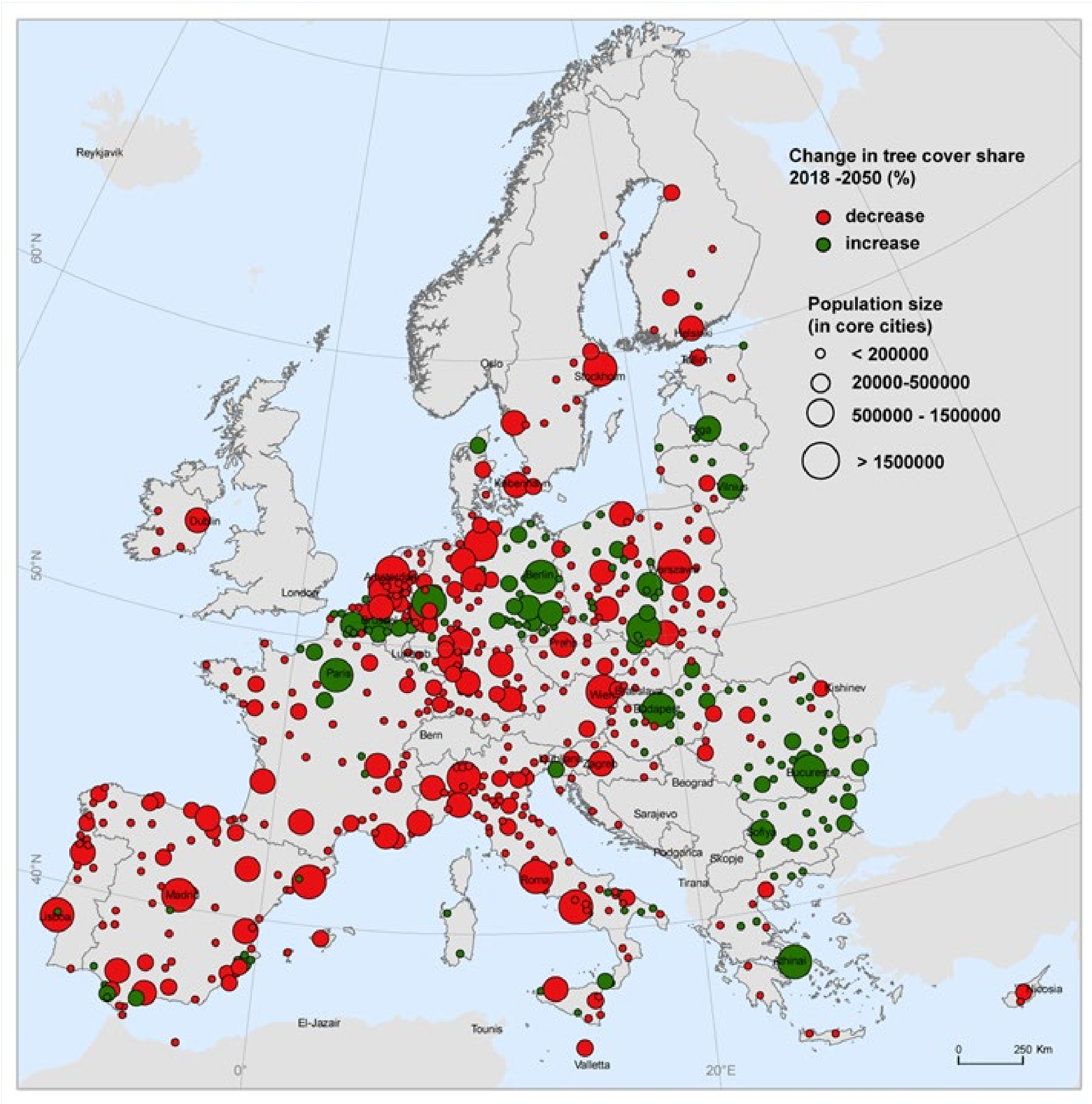
Source: JRC analysis

Trend in urban green areas

The analysis of changes in vegetation cover takes into consideration a business as usual (BAU) scenario. This scenario, based on a trend analysis implemented within the EU Ecosystem Assessment (Maes et al., 2020), is developed with the assumption that trends seen from 2000 to 2018 would continue linearly in the future. These trends are measured through remote-sensing data, Landsat missions and Copernicus data 1996-2018 (Landsat-7 image courtesy of the U.S. Geological Survey) and are in line also with expected increase in urban population and growth. The percent change over time was then used as a BAU trend to project data in the future. The change (%) in tree cover share expected in the period 2018-2050 is mapped at FUA level in Figure 19; results have been aggregated at MS level in Source*: JRC analysis*

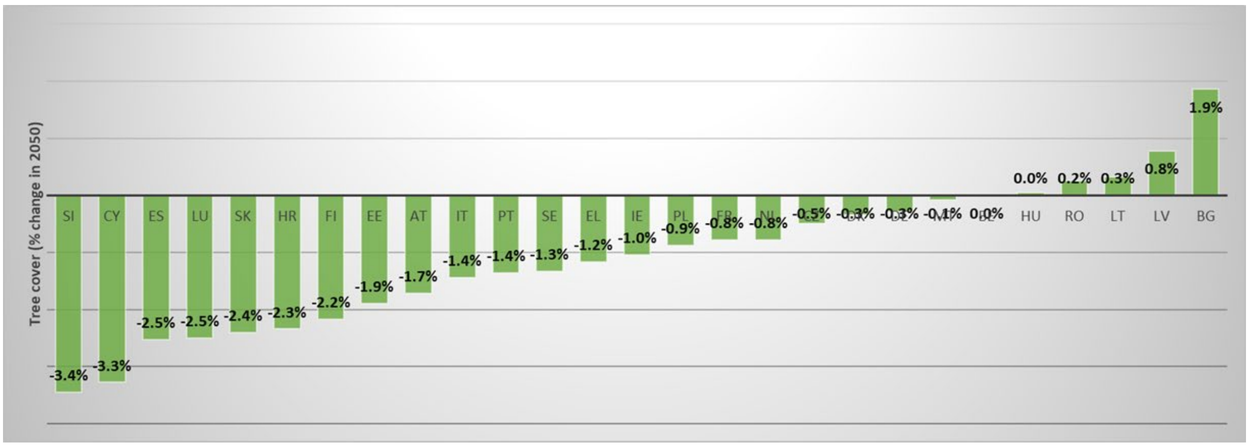
Figure 20. The vast majority of FUAs present a major downward trend of UGI (that is, their UGI decreased sharply) and it is expected that this trend will continue in the future unless specific policy measures, aimed to stop and reverse the loss of green areas, are adopted. Some countries have a high share of FUAs where an upward trend in green areas was observed, particularly in Eastern Europe as well as in some FUAs in Belgium and Germany. However, other countries such as Hungary and Romania, despite increasing their UGI since 2000, still have a low share of it (**Figure 16** and **Figure 17**). If the trend continues as in the BAU scenario, it will be expected that most countries will further strengthen their UGI.

Figure 19. Business As Usual scenario - Projected change in tree cover within Functional Urban Areas between 2018 and 2050.



Source: JRC analysis

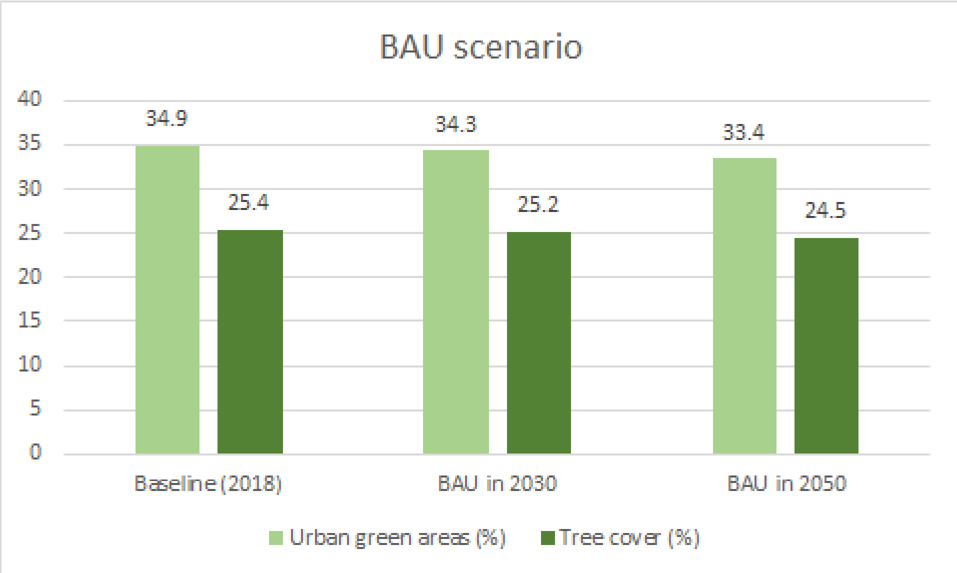
Figure 20. Projected change in tree cover within functional urban area between 2018 and 2050 at MS level.



Source: JRC analysis

However, at EU level, over the BAU scenario it is expected that the overall amount of UGI, considering both urban green areas and tree canopy cover, will decrease over time (**Figure 21**), with a decrease equal to 0.6% and 0.2% for urban green areas and tree cover, respectively, by 2030, and a decrease of 1.5% and 0.9% for urban green areas and tree cover, respectively, by 2050.

Figure 21. BAU scenario, expected change in urban green and Tree Canopy cover at EU-27 level.



Source: JRC analysis

2.2.2 Urban green in the context of the proposal for a EU Nature Restoration law

The European Commission has put forward a proposal for legally binding EU nature restoration targets in 2021. Protecting and enhancing EU's ecosystems will be key to implement the objectives of the EU biodiversity strategy for 2030 and to restore urban ecosystems.

Urban ecosystems, and the ecosystem services they provide (Maes et al., 2013; Maes 2019), have a major role in enhancing human quality of life and well-being, reducing impacts of natural disasters and mitigating and adapting to climate change, as well as to meet international goals for biodiversity conservation. Currently, comprehensive regulations for the protection of urban ecosystems are lacking. For this reason, the inclusion of urban ecosystems in the proposal for the EU Nature Restoration law is key to ensure a sustainable quality of life and to avert pressures on urban biodiversity, especially in the light of the intensive pressures occurring in urban areas.

As seen in the previous sections, urban ecosystems are becoming more environmentally degraded over time, and it is expected that this trend will continue in the future. This results in the loss of ecosystem services that are vital for the health and well-being of the urban dwellers, such as habitat provision for wildlife, including pollinators, the mitigation of the urban heat island effect, the mitigation of flooding risk, amelioration of air quality, as well as providing recreational opportunities (Marando et al., 2022, Fisher et al. 2018).

For this reason, different target options might be considered to protect and enhance UGI, namely urban green areas and tree canopy cover. Among the various options, the following have been screened for FUAs:

– **No net loss of urban green and blue infrastructure in FUAs and in their core cities by 2030 and a 5% increase in urban green in FUAs by 2050**. Urban green areas are fundamental elements in providing essential benefits to citizens. This target will ensure that BUA scenario of projected loss in UGI is halted by 2030 and reversed by 2050.

– **Average native tree cover in FUAs equal to 20% by 2030, and an average native cover in FUAs equal to 25% by 2050 (baseline: 2018).** This target aims to complement the first target on urban green, ensuring that an adequate level of trees is available in FUAs.

These targets are mutually supportive and are in line with other national and EU objectives for tree planting (I.e. billion trees initiative), as well as facilitating the improvement in the condition level of urban ecosystems (United Nations et al., 2021). **Table 7** shows the area that would have been needed to sustain the screened targets.

Table 7. Example of area (ha; % of FUA) that would have been needed to sustain the screened targets

Possible target	**Area (ha)**	**Area (% of FUA)**
Total area of additional tree cover needed to achieve the 2030 target of **20%** tree cover (ha)	795,104	0.88%
Total area of additional tree cover needed to achieve the 2050 target of **25%** tree cover(ha)	1,973,148	2.20%
Total area of additional urban green space needed to achieve **no net loss by 2030** (ha)	281,911	0.31%
Total area of additional urban green space needed to achieve **no net loss by 2050** (ha)	380,620	0.42%
Total area of additional urban green space needed to achieve the **+5%** urban green space target by 2050 (ha)	974,151	1.08%
Total	4,404,933	4.90%

Source: JRC analysis

Key messages

– Urban green areas cover around 30% of the FUA territory. The average share of urban green areas among MS is equal to 32%. Tree covered area in FUA is equal to 23 million hectares (25%). Average tree cover among MS is equal to 23%.

– The occurrence of environmental and anthropogenic burdens in a large number of FUA, coupled with a low share of green spaces in such areas, entail a mismatch between supply and demand of ecosystem services.

– Most FUA present a major downward trend of UGI in time. The loss of green is expected to continue unless specific policy measures are adopted.

– The upcoming EU nature restoration targets will ensure the protection of urban ecosystems. The adoption of legally binding targets is aimed to counteract the expected loss in time of urban green areas, and the enhancement of UGI up to 2050.

2.3 Contribution of UGI to the European GI network

Recent literature reviews on the current status of GI research provide evidence that in this field there is a focus on urban areas with a clear emphasis on ecosystem services, multifunctionality and biodiversity protection (Chatzimentor et. Al 2020; Ying et al 2021). Ying and colleagues (2021) stressed the fact that future GI studies should address "*ecological, social and economic effects of urbanization, giving full play to the multi-function green infrastructure in dealing with the urban sustainable development*".

As previously recalled in the EU Biodiversity strategy for 2030 (European Commission 2020), UGI has a key role in supporting the Trans-European network connectivity (Section 2.1). Protecting nature in the EU represents Pillar one of the Biodiversity Strategy for 2030 which aims to legally protect at least 30% of the EU's land area and 30% of its seas. A key commitment of pillar 1 is to "*create and integrate ecological corridors as part of a Trans-European Nature Network, ensuring a coherent Trans-European nature network".* In order to have a truly coherent and resilient Trans-European Nature Network, the Biodiversity Strategy calls on Member States to create ecological corridors between protected sites.

A crucial point in this regard is to quantify the role of urbanised land in the deployment of a coherent Trans-European nature network. More specifically, to quantify how much the urban green deployed within city boundaries contribute to the overall continental network. This question represents an often-underrepresented topic in GI research.

In this section, an innovative approach is proposed to quantify the contribution of urbanised land on the network of European Green Infrastructure (EU-GI). The assessment is carried out by measuring GI extent and GI structure. Structural attributes of GI affect the ecosystem services provision and the biodiversity support. For instance, large green patches have a higher capacity to reduce UHI effects (Aram et al., 2019), protect from flooding events and manage the surface water run-off. In addition, large urban forests and urban parks provide more opportunities for nature-based recreation activities. However, also small patches are valuable, they can provide shelter to insects (Hall, 2016) or cultural ecosystem services in form of daily opportunities for local recreation or increasing the citizen's exposure to nature (Gascon et al. 2016; Ponjoan et al. 2021).

In a recent literature review, Monteiro and colleagues identified key principles that sustain the deployment of GI, in particular connectivity, integration, multiscale and contiguity (Monteiro, Ferreira, & Antunes, 2020). Connectivity is one of the most used measures of spatial structure of GI (Chatzimentor et. Al 2020; Ying et al 2021; Wang et al., 2022; Staccione et al., 2022).

Additional measures are needed to describe the overall spatial configuration of a GI, to account for the relationship with the territorial context and, as requested in this case, with urbanised land.

Key questions in this regard are:

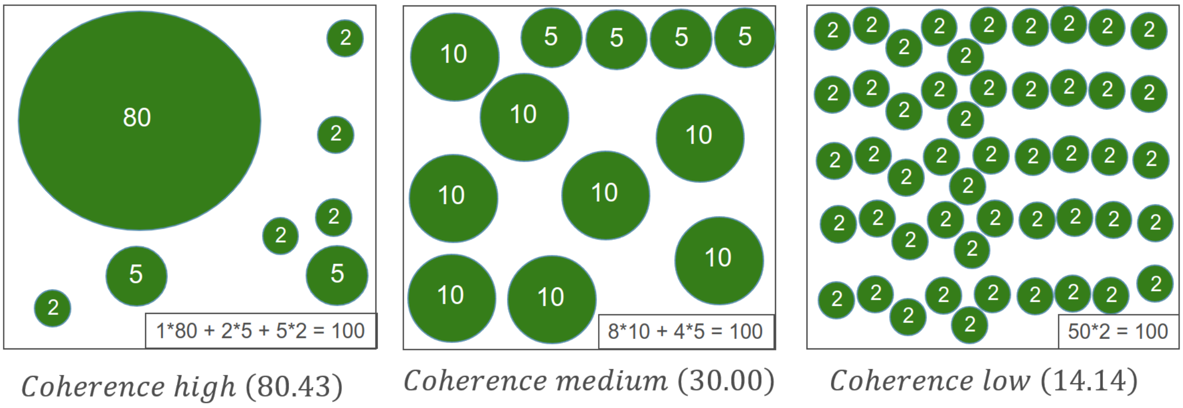
- To what extent does UGI contributes to the EU GI?
- How do urbanised areas affect the spatial configuration of EU GI?

An answer to these questions may help to streamline the deployment of UGI also in the regional or continental environmental policies.

The **GI extent** was measured as the network area proportion with respect to map data area (%). To measure the spatial configuration of the GI we use two concepts: integrity and connectivity.

Integrity (or network coherence) is defined as the degree of connectedness of the surface of all network objects. Integrity is based on the most important network aspect: the equivalent connected area. It does not consider the shape of the objects or the distance between individual network objects. Integrity is measured at the network level and describes the status of a network at a given point of time [Vogt, 2021, Restoration Planner]. **Figure 22** shows an example of network integrity (Coherence) values in three different scenarios, each with the same total area but divided in varying numbers of green patches of different size. From the example we can see that splitting the network into more, and especially small patches will reduce network integrity, which is quantified in a lower value for Coherence.

Figure 22. Schematic example of integrity values, under three different scenarios.



Source: JRC analysis

Connectivity is defined as the way and degree to which resources, species, or social actors disperse, migrate, or interact across ecological and social landscapes (Biggs et al., 2012). In this report we refer to structural connectivity of a GI. A network consists of individual components such as linear features, patches and big forested areas, representing nodes and connectors of the GI network. Structural connectivity of the GI is defined as the inverse of fragmentation, i.e., highly connected is little fragmented and vice versa. Because fragmentation/connectivity depends on the scale- of observation, a suitable, fixed observation scale must be chosen to adequately capture and quantify the degree of connectivity in the GI network. Here, we use the analysis scheme FOS (Fragmentation at Fixed Observation Scale), measuring fragmentation in a local neighbourhood of 9 hectares, resulting in 5 categories from highly fragmented to very little fragmented. Connectivity is measured and reported at the patch level. The methodology is based on geometric principles only; as such, it can be applied to any kind of forest raster maps, independent of the definition of forest and the spatial resolution of the forest map. In contrast to many existing fragmentation schemes, the outlined methodology provides a normalised index quantifying fragmentation within the range of [0, 100] %.

Network integrity: provides the proportion of the total network area that is reachable but does not make any statement with respect to the shape, spatial extent, location, or degree of perforations within the individual network objects.

Both, network integrity and network connectivity are measured via the freeware GuidosToolbox (Vogt et al 2017; Vogt et al., 2022). The analysis has been performed at two territorial levels: European and Member State level, **Table 8** describes the metrics selected.

Table 8. The metrics selected to evaluate the extent and structure of the GI[15]

Metric	**Name**	**Description and units of measure**
RAC	Reference Area Coverage	Share of reporting unit covered by GI (%)

[15] https://forest.jrc.ec.europa.eu/en/activities/lpa/gtb/; https://ies-ows.jrc.ec.europa.eu/gtb/GTB/psheets/GTB-RestorationPlanner.pdf

COH	Normalised degree of network coherence.	Measure of integrity, the equivalent connected area. It represents the degree of network coherence (%)
FOS	Fragmentation at Fixed Observation Scale	Measure of connectivity (%)

Source: *JRC analysis*

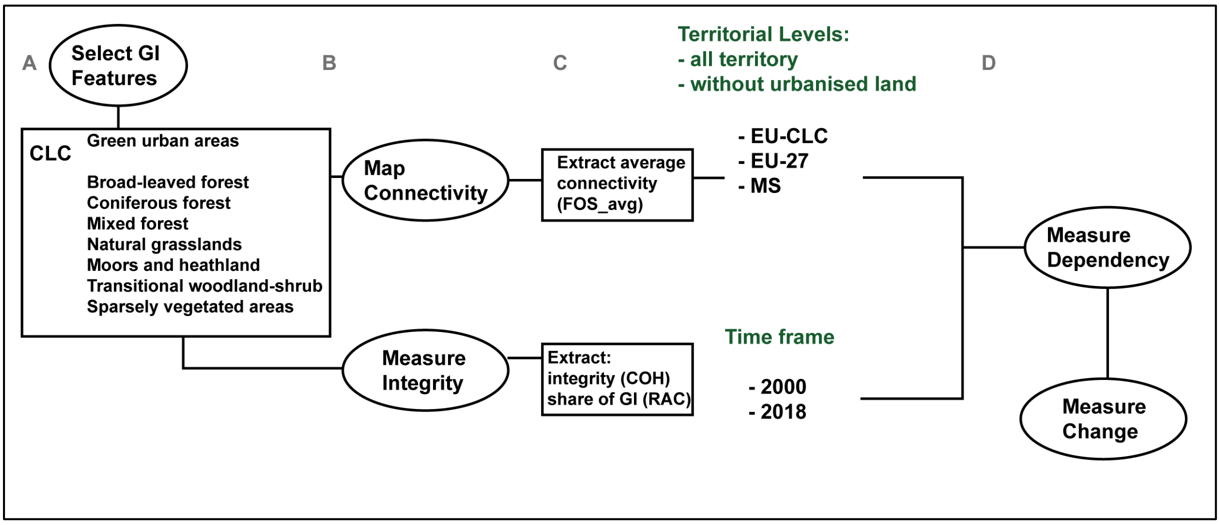
Data used in this exercise were: Corine Land Cover data (v2020_20u1) 2000- 2018[16]; boundaries of FUA and Countries; boundaries of LAU (degree of urbanisation). All input data are described in Table 1, Annex 2.

The procedure was repeated as follow:

– European level:
  - To estimate the overall contribution of UGI to EU GI
  - To evaluate the role of the urbanised land within each MS on the overall EU GI.
    - A map of EU GI was realized masking out each MS' FUA, LAUs cities, LAUs cities towns and suburbs but maintaining the overall European GI extent

– Member State level:
  - To estimate the contribution of UGI to GI within each MS (in this case the result is relative only on the GI within the MS boundaries and it's indicative because the bias of the boundary effect could not be avoided)
    - A map of EU GI was created for each MS, masking out MS' urbanised land using the MS extent.

Figure 23. Key steps of the procedure.



Source: JRC analysis

A: Select GI features

[16] https://www.eea.europa.eu/data-and-maps/data/corine-land-cover-accounting-layers

The key features representing the European GI were extracted from the Corine Land Cover maps (CLC 2000 and 2018). The following land cover types were considered, in line with previous similar works (Davies et al., 2015; ESPON GRETA. 2019):

- From Artificial surfaces (level1) Green Urban Areas were retained.
- From forest and seminatural areas (Level 1), Broad-leaved Forest, Coniferous Forest, Mixed Forest, Natural grasslands, Moors and heathland, Transitional woodland-shrub and sparsely vegetated areas were considered.

B: Measure connectivity and integrity.

To avoid any boundary effect, connectivity and integrity were measured at the entire EU-CLC map coverage extent, but excluding Turkey. Spatial analysis inevitably refers to a finite region, a small bounded segment of an infinite space. Because of this finiteness of a study region, a boundary always exists, while any spatial phenomenon within the study region is most likely to extend beyond its boundary. Therefore, analysis confined within a bounded study region may be biased because of the lack of information of the outside of the study region. This problem of potential bias in spatial analysis is referred to as edge effects (or boundary effects). Edge effects are important for any type of spatial analysis because methods for spatial analysis always require that spatial relationships between observations be defined based on their proximity, adjacency, or other criteria, which may be biased due to unrecorded data located outside the study region (Yamada, I. 2009). In this context the edge effect might occur if, for instance, ones would use as input data the EU-27 extent. In this way the GI within Switzerland would not be considered and a false degree of connectivity/integrity would be computed. A similar problem would occur if we measure the connectivity only within FUAs (or LAUs) without considering the GI that exists immediately outside the city boundary.

The metrics (RAC, CEH and FOS, see Table 2.7) were calculated at all territorial levels (EU-CLC; EU-27; MS) in 2000 and 2018.

In a second step, to measure the contribution of urban green areas to the EU-GI network, the same procedure was applied again across the all territory but “virtually” excluding the urbanised land, at the FUA and LAU level. This was done masking-out the green elements respectively from the FUA and the LAU extent.

C: Extract metrics at all territorial levels

The three metrics were extracted at the above-mentioned territorial levels, specifically:

EU level:

- COH-RAC measured and extracted at EU-CLC and EU-27 with and without urbanised land, maintaining the overall European GI extent
- COH-RAC measured and extracted at EU-CLC maintaining the overall European GI extent but excluding the urbanised land in each MS

MS Level:

COH- RAC measured and extracted at MS level with and without urbanised land, using the MS extent.FOS was measured once at the EU-CLC level with and without considering FUA and LAUs. This model produces a spatially explicit output so the average FOS value was extracted for all territorial levels.

D: Measure the contribution of urban GI (dependency)

The contribution of UGI to the overall GI (dependency) was quantified as the difference between the indicators computed at EU level and the indicators computed excluding the urbanised land.

For instance:

Dep-All_EU-Integrity = All_EU_integrity - All_EU_integrity_NO_urban

Dep-All_EU-Integrity = Contribution of UGI to all EU integrity

All_EU_integrity = Integrity measured on the EU-GI

All_EU_integrity_NO_urban = Integrity measured on the EU-GI excluding the UGI (urban green inside urbanised land, identified inside FUA and LAUs

The procedure was repeated for 2000 and 2018 and a change in percentage was computed to evaluate the contribution trend.

At the EU level and MS level, MS have been grouped considering the status indicators (2018) and the trend indicators. Hierarchical clustering technique was implemented using the ward's linkage methods.

When the contribution of UGI to integrity (COH) or connectivity (FOS) is positive the GI is distributed also within and around cities and, more importantly, the UGI contributes to an improvement of the overall GI spatial configuration. When the contribution of UGI is negative the GI is clumped mainly outside cities. When the contribution of UGI to the GI extent (RAC) is low the role of UGI is negligible. Nevertheless, a high value in the contribution to the extent does not necessarily determine a contribution of UGI to integrity or connectivity because this type of contribution depends on the overall structure of the territory.

2.3.1.1 The overall contribution of urbanised land to the EU GI

The UGI contribute to the European GI for what concern the extent and integrity as presented in **Table 9**.

In 2018 UGI within FUA contributed by 7.31% to the EU-GI share and UGI within LAU contributed by 7.61% (of which 1.10% represent UGI within cities). In 2018 UGI contributed to EU-GI integrity by 0.65% in FUA and 3.02% in LAU (of which 0.39 relative to cities). In 2018 –0.83% of connectivity depended on land within FUAs; -0.10% depended on land within cities and –0.43% depended on land within cities towns and suburbs.

Table 9. Contribution of UGI to the overall GI in EU 27. Share of GI; integrity and connectivity are quantified for FUA, cities and cities towns and suburbs. A. presents the numerical values and B shows the contribution (%) of pertinence EU 27.

A

territorial level	**EU**								
	Contribution UGI on share GI			**Contribution UGI on integrity**			**Contribution UGI on connectivity**		
	2000	**2018**	**change (%)**	**2000**	**2018**	**change (%)**	**2000**	**2018**	**change (%)**
EU 27 FUA	7.33	7.31	-0.02	0.70	0.66	-0.04	-0.83	-0.84	No change
EU 27 LAU c*	1.11	1.11	-0.01	0.40	0.39	-0.01	-0.11	-0.11	No change
EU 27 LAU cts*	7.65	7.62	-0.03	3.04	3.02	-0.02	-0.43	-0.43	No change
B									
Contribution EU 27 to EU 35 (for COH and RAC)	98.30	98.31	0.005	86.22	86.14	-0.079			

Source: JRC analysis

*LAU c = cities; LAU cts = LAU cities towns and suburbs

FUAs and LAUs (cities towns and suburbs) cover approximately the same share of territory (respectively 21.9% of EU for FUAs and 21.5% of EU for LAUs). Notably GI within LAUs provide a higher contribution to the extent and the integrity of the EU-GI. They are more urbanized and populated than FUA but with relatively less agroecosystems and the same amount of forest and semi natural vegetation (see Table 2.1).

Urbanised land does not provide a contribution to the EU-GI connectivity. This metric depends on the size of the green patches and their reciprocal distance within a defined observation scale. Green patches are predominantly smaller within urbanised land, and this explains the absence of dependency at the continental scale. Nevertheless, it is important to mention that both at FUA and LAUs level a downward trend is registered on the three metrics; this is the result of the general loss of UGI that characterised European cities (Maes et al 2020; Zulian et al 2022).

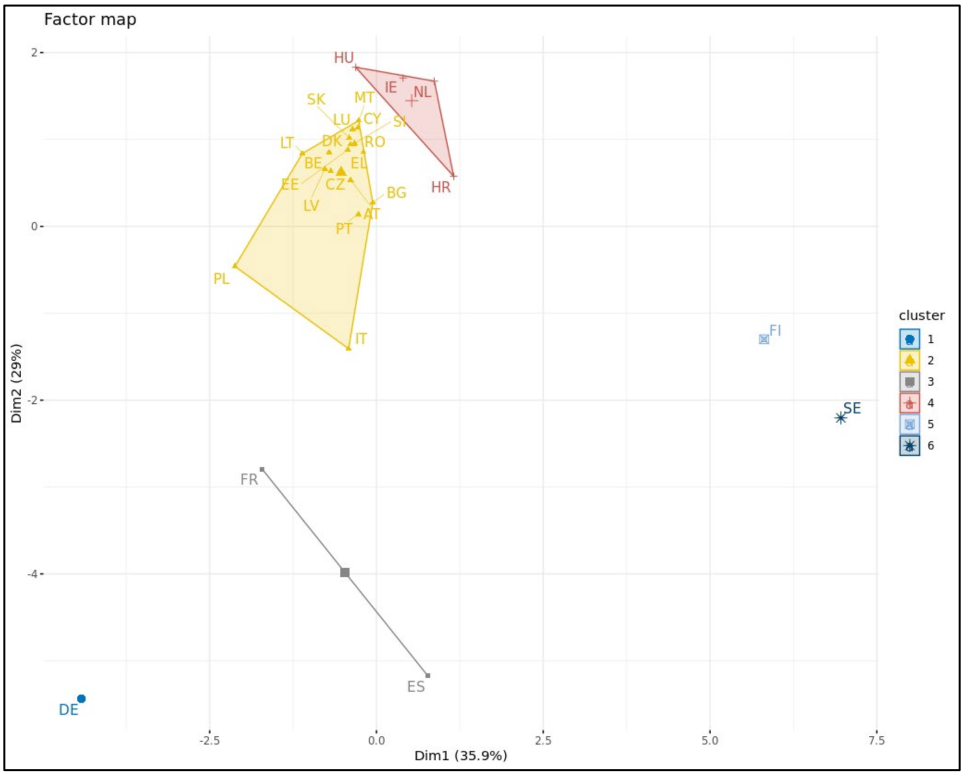
2.3.1.2 The role of each MS Urban GI on the overall EU GI

A principal component analysis (PCA) and an agglomerative hierarchical cluster analysis (AHCA) were performed using the status and trend variables. The PCA was supplied with the normalized version of the original indicators. Here, normalization and centralization of the data by the feature scaling method were first applied (Venables et.al., 202). The classification model aimed at identifying the impact of each indicator on the contribution of UGI on the overall EU GI, considering the status (labelled *_dependency_* in Table 10) and trends (labelled *_change in Table 10) values. The goal was to explore the role of urbanised land within each MS on the overall EU GI. We used two R packages: FactoMineR, for computing HCPC and factoextra, for visualizing the results.[17]

As a result, six clusters were identified. Germany, Sweden and Finland present very peculiar characteristics and were classified each in a separate cluster. **Figure 24** presents the Factor Map, **Figure 25** shows the relative role of MS urban land to sustain the overall EU-GI and **Table 10** shows the variables significantly associated with the clusters and the clusters description.

[17] see Glossary for a description of the statistical methods

Figure 24. The Factor Map obtained by the HC, shows the 6 clusters of MS grouped according to relative contribution of UGI to the overall EU-GI. The individuals (MS) are located according to their contribution to the group.



Source: JRC analysis

Table 10. Variables significantly associated with the clusters.

All variables are significantly associated with the clusters				
Variable	**v.test**	**Mean in category**	**Overall mean**	**Description**
Cluster 1				
FUA_RAC_contribution_2018	3.441	1.144	0.218	Contribution UGI to the overall GI extent within FUA higher than the overall mean
FUA_COH_ contribution_2018	-2.115	-0.906	0.008	Contribution of UGI to Integrity and connectivity negative and lower than the overall mean
cts_FOS_ contribution_2018	-3.499	-0.136	-0.014	
FUA_FOS_ contribution_2018	-3.780	-0.196	-0.024	
Cluster 2				
cts_FOS_change	3.604	-0.008	-0.008	Downward trend in the contribution of UGI to connectivity, but lower than the overall average in LAUs and FUAs
FUA_FOS_change	2.694	-0.008	-0.008	
cts_RAC_ contribution_2018	-2.560	0.117	0.226	Contribution of UGI to the overall GI extent lower than the overall mean
FUA_RAC_ contribution_2018	-2.881	0.111	0.218	

All variables are significantly associated with the clusters				
Variable	**v.test**	**Mean in category**	**Overall mean**	**Description**
Cluster 3				
FUA_RAC_contribution_2018	2.167	0.622	0.218	Contribution UGI within FUA to the overall GI extent slightly higher than the overall mean
FUA_FOS_ contribution _2018	-2.273	-0.096	-0.024	Low contribution of UGI to connectivity (lower than the overall average in FUA)
FUA_RAC_change	-2.907	-0.005	0.000	Downward trend in the contribution of UGI to the GI extent, in FUAs and LAU.
cts_RAC_change	-3.410	-0.008	-0.001	
Cluster 4				
FUA_RAC_change	2.345	0.002	0.000	Upward trend in the contribution of UGI to the overall GI extent, in FUA
cts_FOS_change	-2.886	-0.009	-0.008	Downward trend in the contribution of UGI to connectivity FUA and LAUs, higher than the average
FUA_FOS_change	-3.507	-0.009	-0.008	
Cluster 5				
FUA_COH_change	-4.507	-0.019	-0.001	Downward trend in the contribution of UGI to the integrity at all territorial levels
cts_COH_change	-4.878	-0.019	0.000	

All variables are significantly associated with the clusters				
Variable	**v.test**	**Mean in category**	**Overall mean**	**Description**
Cluster 6				
cts_COH_contribution_2018	4.478	2.503	0.073	High contribution of UGI to the integrity at all territorial levels
FUA_COH_ contribution_2018	4.198	1.823	0.008	
cts_RAC_contribution_2018	3.416	1.280	0.226	High contribution of UGI to the overall GI extent in LAU
cts_FOS_contribution_2018	2.483	0.072	-0.014	Contribution of UGI to connectivity in FUA positive and higher than the overall average

Source: *JRC analysis*

Cluster number 1 includes only Germany. The contribution of UGI located inside FUA to the EU GI is particularly high if compared to the overall average. This is due to the specific structure of FUA in Germany, where the commuting data is collected at NUTS-3 for all Germany (Germany does in fact not follow the same rationale of the other MS for the definition of FUA) and FUA cover 54% of the German Territory. The contribution of UGI inside FUA to the EU GI integrity is negative and lower than the overall mean. Likewise, the GI within urbanised land (in FUA or LAU) does not contribute to connectivity.

One possible explanation of this result is that even if in average most part of the GI is within FUA, this GI is most likely highly fragmented and this is probably due by a dense road network, high population density. Similar hypothesis were reported also in the recent report published by ESPON (2019), that indicates network infrastructure and accessibility among the main aspects that can be detrimental to connectivity of a GI (table 2, p. 34 ESPON 2019, Final Report).

Cluster number 2 includes 18 MS characterized by similar effects of UGI on the EU-GI extent and structure. They all are characterised by a share of GI dependent on FUA lower than the overall mean and a downward trend in the degree of connectivity dependent on UGI, even if lower than the overall mean, both at FUA and LAUs level. The contribution of urbanised land in MS clustered in group 2 is not very relevant at EU level. But interestingly, a downward trend in connectivity dependent on urbanised land is registered, even if the trend is relatively lower than the overall mean. The trend interests most of the MS.

Cluster number 3 includes France and Spain, both characterised by a contribution of UGI located in FUA to the EU GI higher than the overall average; low levels of connectivity dependent on urban in 2018 and a downward trend in the share of GI dependent on FUA and LAUs. This result confirms previous studies (Maes 2020; Zulian et al 2022 in press) that demonstrated relatively rapid increase in settlement densification in FR and, even more, in ES and the loss of UGI in core cities and commuting zones (which characterised Spanish urbanised areas between 1996 and 2018).

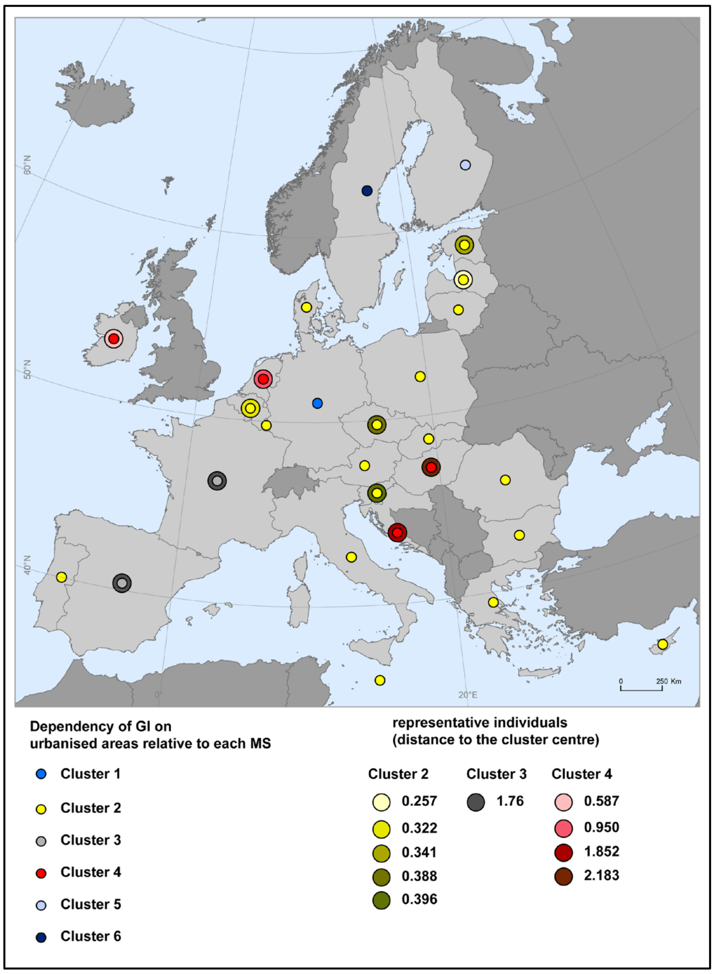
Cluster number 4 includes four MS characterised by a slightly upward trend in the contribution of UGI to the extent of the EU GI in FUA and downward trends of the contribution of UGI to connectivity at both FUA and LAUs level.

Cluster number 5 includes Finland, which is mainly defined by the downward trend in the integrity dependent by urbanised land which reveals a sharp drop if compared to the overall mean.

Finland is also characterised by a high contribution of UGI to the EU GI extent (at LAUs, 0.68 and FUA 0.52 levels respectively in 2018, see Figure 2.20) and a downward trend of this metric at all urban levels. This result confirms previous studies (Maes 2020; Zulian et al 2022 in press) that demonstrated a loss of UGI in core cities and commuting zones in FI.

Cluster number 6 includes Sweden, which is characterised by a high contribution of UGI to extent, integrity and connectivity of EU GI.

Figure 25. Relative role of MS urban land to sustain the overall EU-GI. MS are classified according to the dependency of the EU-GI on green areas inside urbanised land. Graduated colours describe the representative individuals of cluster 2, 3 and 4.

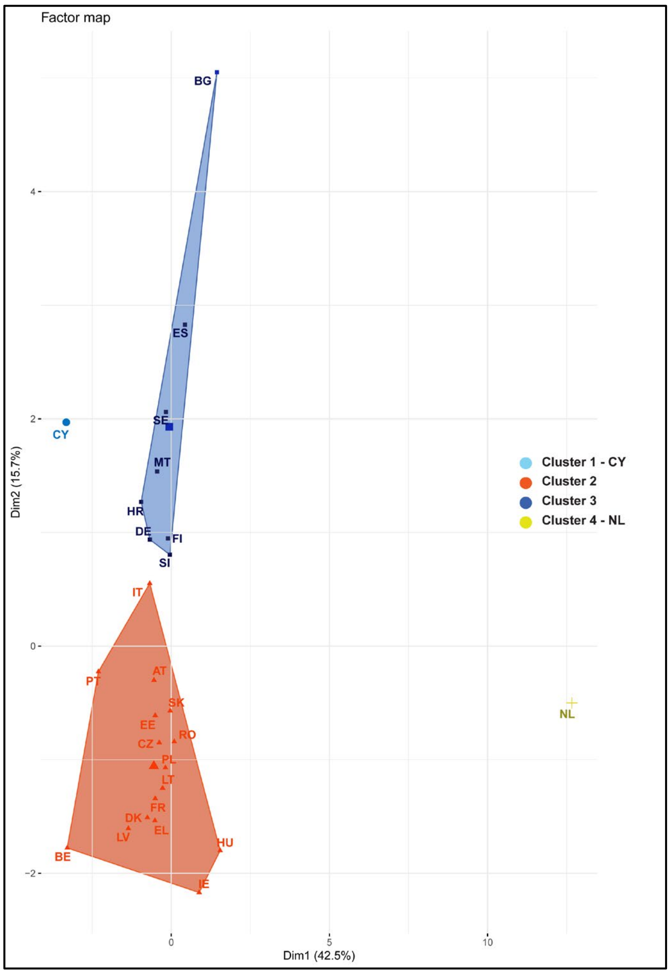


Source: JRC analysis

2.3.1.3 *The contribution of Urban GI to the National GI within MS*

Considering the contribution of UGI at the MS level, four clusters were identified: cluster number 1 and cluster number 4 include only one MS, namely Cyprus and The Netherlands, respectively, whereas cluster 2 and 3 include all the other MS, with the exclusion of LU which is analysed separately due to the peculiar structure of its FUA. **Table 11** shows the variables significantly associated with the clusters. And **Figure 26** presents the Factor map.

Figure 26. The Factor Map shows the 4 clusters of MS grouped according to the absolute role of their urban land to sustain the GI deployed within the MS.



Source: JRC analysis

Table 11. Variables significantly associated with the clusters.

All variables are significantly associated with the clusters				
Variable	**v.test**	**Mean in category**	**Overall mean**	**Description**
Cluster 1				
CEH_FUA_change	4.911	9.974	0.541	upward trend in the contribution of UGI to the GI integrity in FUA
RAC_cities_change	-3.013	-0.102	-0.005	downward trend in the contribution of UGI to the GI extent in cities
Cluster 2				
FOS_FUA_change	2.252	-0.002	-0.022	upward trend in the contribution of UGI to the GI integrity and connectivity in FUA and cities
CEH_cities_change	2.019	0.007	-0.019	
CEH_FUA_2018	-2.451	0.777	3.336	contribution of UGI to integrity and connectivity in 2018 lower than the overall average. contribution of UGI to GI extent lower than the overall average at all territorial levels
RAC_FUA_2018	-2.942	6.070	7.698	
RAC_cities_t_s_2018	-3.447	4.790	7.029	
RAC_cities_2018	-3.505	0.501	0.937	

All variables are significantly associated with the clusters				
Variable	**v.test**	**Mean in category**	**Overall mean**	**Description**
Cluster 3				
RAC_cities_t_s_2018	4.013	11.975	7.029	Contribution of UGI to integrity FUAs higher than the overall average; contribution of UGI to GI extent higher than the overall average at all territorial levels
RAC_cities_2018	2.823	1.603	0.937	
RAC_FUA_2018	2.390	10.208	7.698	
CEH_FUA_2018	2.155	7.605	3.336	
RAC_FUA_change	-2.090	-0.063	0.002	Downward trend in the contribution of UGI to the GI extent in FUA

All variables are significantly associated with the clusters				
Variable	**v.test**	**Mean in category**	**Overall mean**	**Description**
Cluster 4				
FOS_cities_2018	4.314	0.810	-0.103	Contribution of UGI to GI extent higher than the overall average at all territorial levels. contribution of UGI to connectivity and integrity higher than the overall mean at all territorial levels
RAC_cities_change	3.641	0.111	-0.005	
RAC_cities_t_s_change	3.572	0.311	-0.011	
FOS_cities_t_s_2018	3.467	3.771	-0.378	
CEH_cities_2018	3.183	7.885	0.596	
RAC_FUA_change	2.707	0.282	0.002	
RAC_cities_2018	2.216	2.681	0.937	
CEH_cities_t_s_change	-2.283	-0.850	0.035	Downward trend in the contribution of UGI to the GI connectivity and integrity
FOS_FUA_change	-3.957	-0.247	-0.022	
CEH_cities_change	-4.351	-0.373	-0.019	
FOS_cities_change	-4.695	-0.110	-0.003	
FOS_cities_t_s_change	-4.726	-0.545	-0.033	

Source: *JRC analysis*

Cluster number 1 describes Cyprus, which presents an upward trend in the contribution of UGI to the GI integrity in FUA which is extremely high compared with the overall average. This is mainly due to the transition of a large share of land from 'Burnt areas' (in 2000) to 'Transitional woodland' in 2018. On the other hand, CY is characterized by a downward trend in the contribution of UGI to the GI extent in cities.

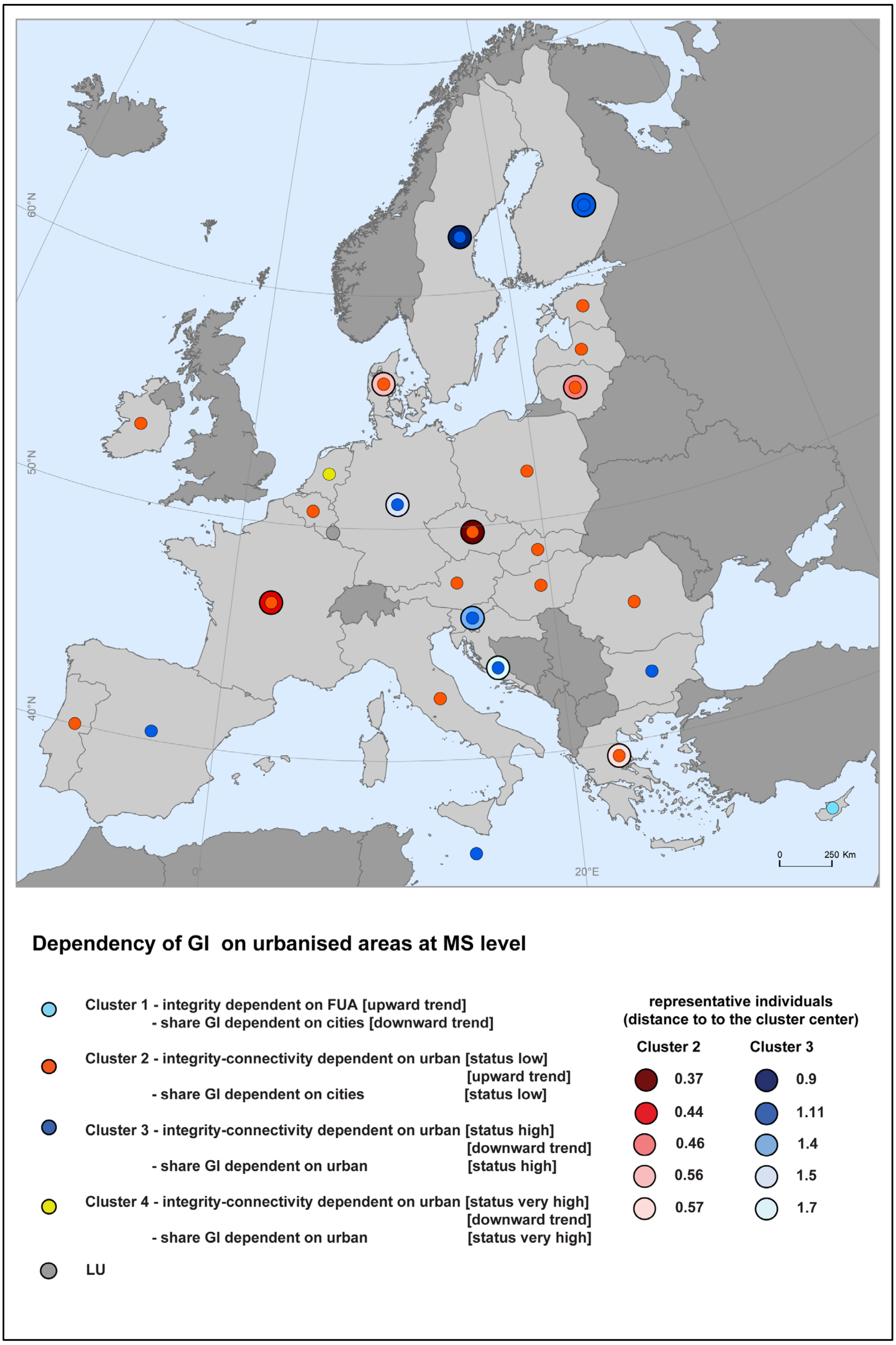
Cluster number 2 includes 14 MS characterised by a relatively low contribution to UGI integrity and extent in 2018 at all territorial levels. Interestingly the cluster is characterized by an upward trend in the contribution of UGI to the GI integrity and connectivity in FUA and cities.

Cluster number 3 is characterized by a high contribution of UGI to integrity and connectivity in 2018 (higher than the overall average) and by a contribution of UGI to the GI extent at all territorial levels. A downward trend in the contribution to the GI extent in FUA also characterizes this cluster.

Cluster number 4 describes The Netherlands which is characterized by an opposite situation. Here the contribution of UGI to GI extent, integrity and connectivity is higher than the overall average at all territorial levels. The area is characterized by a downward trend related to the contribution of UGI to integrity and connectivity. This picture is in line with previous assessments of urban greenest (Maes et al., 2020, Zulian et al., 2022).

Figure 27 shows the spatial pattern of the classification, graduated colours describe the representative individuals of cluster 2, 3 and 4.

Figure 27. Dependency of GI on urbanised land at MS level. MS are classified according to the dependency of GI on green areas inside urbanised land. Graduated colours describe the representative individuals of cluster 2 and 3.

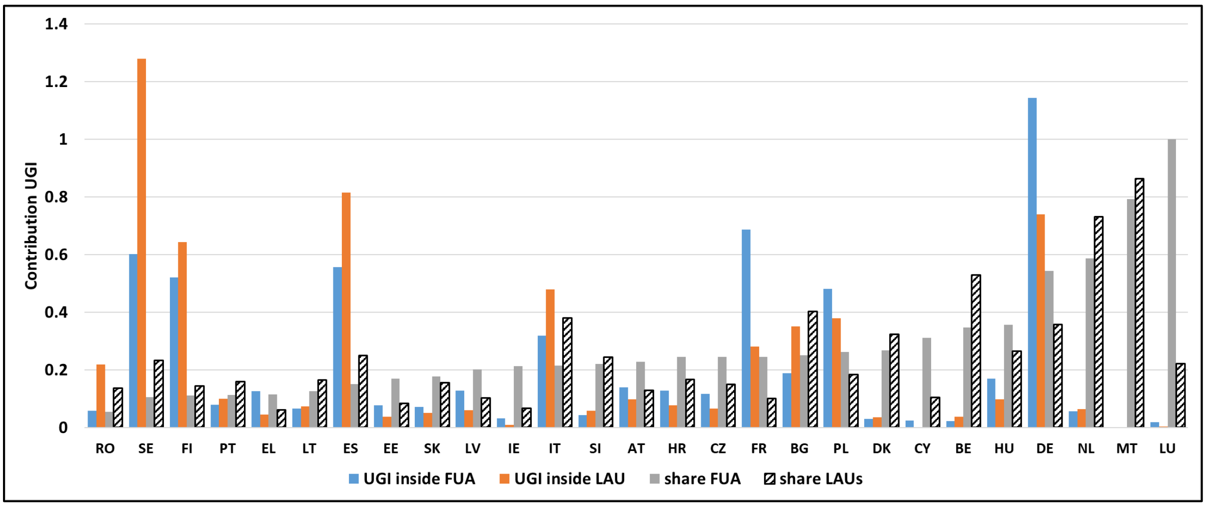


Source: JRC analysis

The role of UGI on extent and structure of the regional and continental GI depends on many factors, among others the structure of the GI, the type of urban expansion (polycentric or monocentric, dispersed/sprawled or compact), the extent and density of road network.

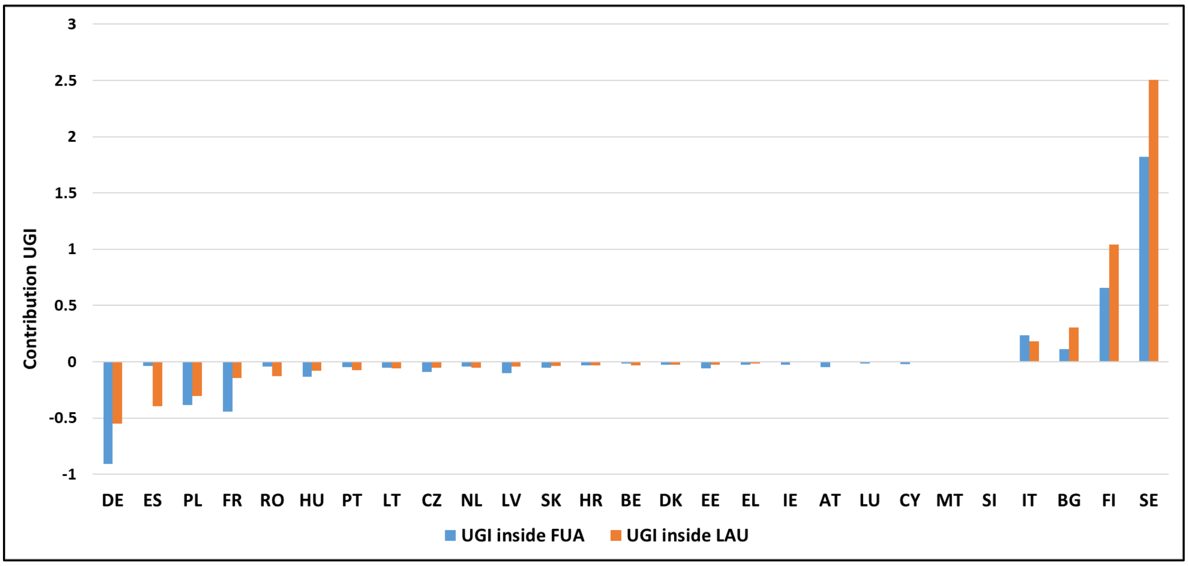
This exercise is meant to demonstrate that urban green has an effect in a multi-level perspective which should be considered when implementing territorial policies. **Figure 28**, shows the share of EU-GI dependent on urban areas at FUA and LAU levels, **Figure 29** shows the relative contribution of UGI to the overall EU GI integrity and **Figure 30** shows the relative contribution of UGI to the overall EU GI connectivity.

Figure 28. Share of EU-GI dependent on urban areas at FUA and LAU levels (MS are ordered per share of land covered by FUAs).



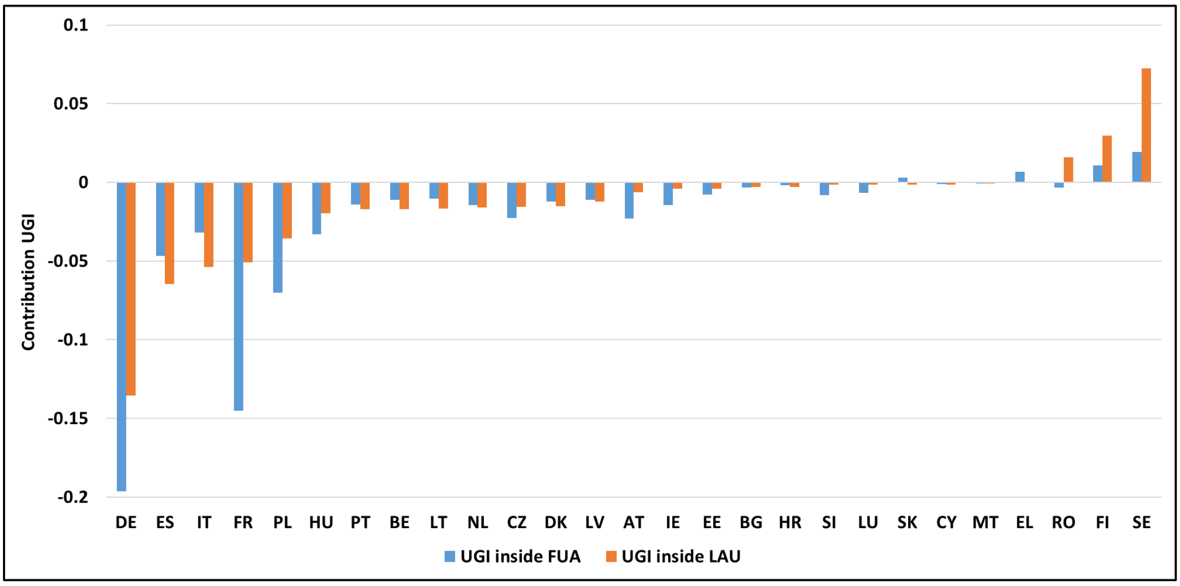
Source: JRC analysis

Figure 29. Relative contribution of UGI to the overall EU GI integrity.



Source: JRC analysis

Figure 30. Relative contribution of UGI to the overall EU GI connectivity.



Source: JRC analysis

Key messages:

- At EU-27 level the UGI contributes to the European GI for what concern the extent and integrity.
- In 2018 UGI within FUA contributed by 7.31% to the EU-GI share and UGI within LAU contributed by 7.61% (of which 1.10% represent UGI within cities)
- In 2018 UGI contributed to EU-GI integrity by 0.65% in FUA and 3.02% in LAU (of which 0.39 relative to cities).
- The extent of UGI in Germany, Sweden, Finland, France and Spain provide the higher contribution to the extent of the overall GI.
- The structure of UGI in Bulgaria, Italy, Finland and Sweden contribute the most to the overall GI integrity.
- The structure of UGI in Romania, Finland and Sweden contribute the most to the overall GI connectivity.

3 Urbaneness and biotic homogenisation

3.1 Birds in French cities

Human activities transform the ecosystems with a tendency to generate homogeneous and non-native habitats. In addition, anthropization (the conversion of open spaces by the human action) tends to fragment native habitat patches, resulting in qualitative and quantitative loss of habitats and ecological functions (Kowarik, 2011).

Box 3. What is Biotic homogenization

Biotic homogenisation (BH) is a response to environmental and anthropic alterations. BH is the process by which species invasions and extinctions increase the genetic, taxonomic or functional similarity of two or more locations over a specified time interval. From a broader perspective, BH is a process whereby some species (losers) are systematically replaced by others (winners).

BH presents three aspects: genetic, taxonomic and functional.

- **taxonomic homogenization**: describes the increase in the compositional similarity among ecological communities

- **functional diversity**: composition of and variation in community functional traits, and its spatial distribution across landscapes. Modifying the functional diversity of a community might result in functional homogenization involving the replacement of ecological specialists by the same widespread generalists. Although functional homogenization can increase the vulnerability to large-scale environmental events and it is considered one of the most prominent forms of biotic impoverishment.

Source: Olden et al 2004; Olden et al 2006; Olden et al. 2016

Urban ecosystems are highly modified ecosystems and are considered one of the main threats to global biodiversity (Kondratyeva et. al., 2020). At high levels of urbanization, species richness generally decreases and urban biota tend to become more and more similar dominated by a few common native species and some ubiquitous non-native species (McKinney 2002, 2006; Clergeau et al., 2006; Lososová et al,. 2012, b; Le Viol et al. 2012; Aronson et al. 2014; La Sorte et al., 2014). Studies have shown that urbanization leads to both a larger spatial distribution of generalist communities and an increase in specialist instability over time (Devictor et al; 2007).

Nevertheless, urban ecosystems are characterised by the co-occurrence of various habitat types that, if managed correctly, can host plants and animals' species (Kawaric, 2011). For this reason, it is extremely important to identify the key elements that may help to mitigate biodiversity loss in highly modified ecosystems (Morelli et. al 2021).

Previous studies on BH related to cities demonstrated the positive effects of urban blue/green infrastructure and the negative effects of highly urbanised land on birds' communities (Morelli et al. 2021; Devictor et al., 2007). In addition, scholars have underlined the role of High Nature Value farmlands for halting in some cases biodiversity loss and BH in bird communities and potentially in other taxa in French farmlands (Doxa et al., 2010, 2012; Aue 2014; Morelli et al. 2014). Finally, urban riparian corridors have the capacity to maintain high levels of bird abundance and biodiversity (Rehman et al., 2021; Beaugeard et al., 2020; Keten et al., 2020).

Green infrastructures and ecological corridors are a key element of the urban landscape as they promote avian biodiversity, and allow less common species to colonise cities (Filazzola et al., 2020; Vergnes et al., 2012; Vergnes et al. 2013). Understanding potential management options aimed at retaining native species, maintaining avifauna diversity across urbanised landscapes is critical to conservation success.

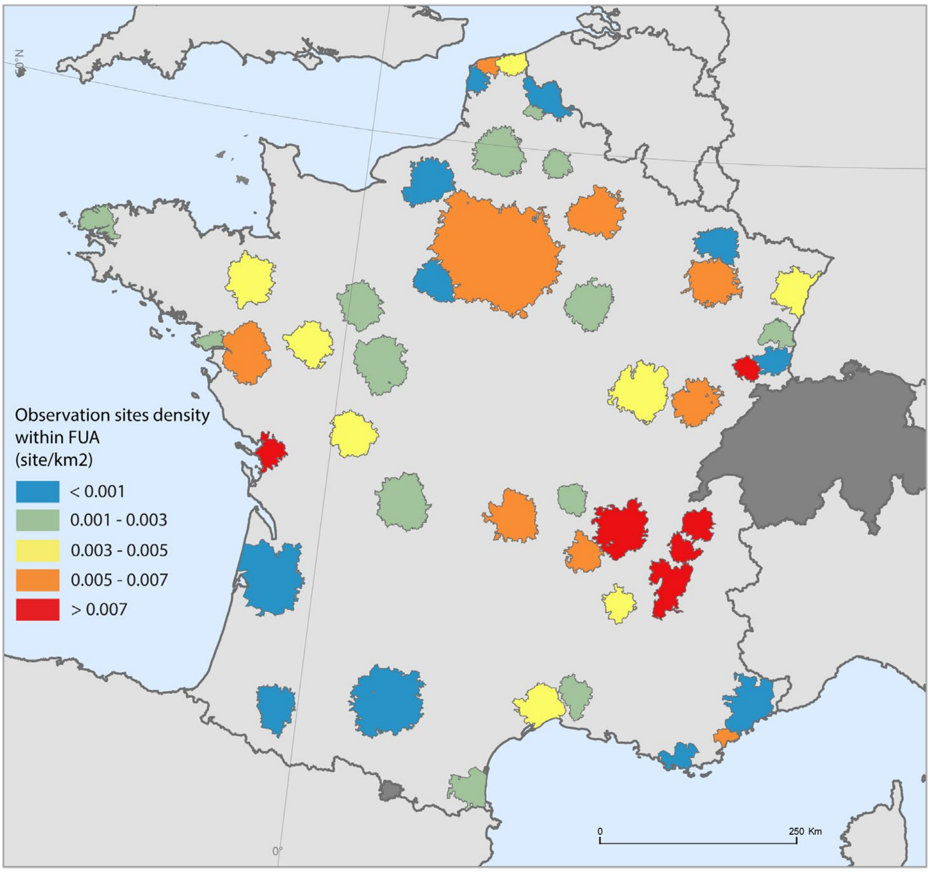
In this exploratory study, we analysed the effect of a set of spatial predictors, characterising urban ecosystems in France, on common bird populations and communities. Urban ecosystems were analysed at the FUA level. FUA includes a large variability of ecosystem types and are suitable territorial units to analyse the characteristics that affect animals or plants. Bird data were obtained from a structured citizen science dataset collected in France (Jiguet et al. 2012).

3.1.1 Study sites / design

The study was implemented in France. Bird data collected within the FUA boundaries were extracted and analysed with respect to a series of spatial predictors characterising the urbanized land in France. France has 64 FUA covering 25% of the territory.

Bird data were extracted from the French Breeding Bird Survey (FBBS) (Jiguet et al., 2012). The FBBS is a nationwide, standardized monitoring program conducted by skilled volunteer ornithologists who monitor common breeding birds in randomly selected sites each spring (Jiguet et al., 2012). Each FBBS site consists of a 2 × 2 km square, in which 10 point counts are evenly distributed and placed no less than 300 m apart. All point counts are unbounded, and observers record every individual bird either heard or seen, along with the distance of contact (< 25 m, 25–100 m, > 100 m), during a 5-min survey conducted twice every spring (before and after May the 8th, at least 4 weeks apart). We focused our analysis on bird data collected from 2015 to 2019, for 170 common bird species with complete trait information (Table 1, Annex 5), representing 99.2% of all records over that period. The observation sites within FUA (34 over 64) are presented in **Figure 31**.

Figure 31. Observation sites density inside FUA (site/km^2).



Source: JRC analysis

Table 12. Species grouped according to the global and local risk status categories established by the IUCN Red list. (Source: UICN, 2020).

IUCN Red list		IUCN Categories				
		CR	EN	VU	NT	LC
France	count	1	6	19	25	119
	share	0.6	3.5	11.2	14.7	70.0
Global	count	//	//	2	6	162
	share	//	//	1.2	3.5	95.3

Source: *JRC analysis*

Table 12 groups the species located within French FUA, classified according to the global and local risk status categories established by the IUCN Red list. (Source: UICN, 2020). The IUCN Red List of Threatened Species™ is the world's most comprehensive information source on the global extinction risk status of animal, fungus and plant species (IUCN, 2012). The classification consists in a consistent and comparable system, developed to provide a clear guidance on how to evaluate different factors which affect the risk of extinction (Maes et.al, 2021).

Out of the 170 species found within FUA, 51 (30%) are classified under threat in the IUCN Red list (France).

Out of the 170 species found within the FUA, one (0.6%) is classified as critically endangered (CR) in France. It is the Common Snipe (*Gallinago gallinago*), see Figure 32, a water bird inhabiting a wide range of wetland habitats, from damp meadows to saltmarshes. At the global level, this species is not threatened. Populations on the southern fringes of the breeding range in Europe are however declining with local extinction in some areas, mainly due to field drainage and agricultural intensification (Common snipe - Wikipedia). In France, the main breeding sites are in the *Bassin du Drugeon*; in the *Massif Central* and in *Brière*.

Figure 32. Common Snipe (*Gallinago gallinago*)

Source: Bécassine des marais - *Gallinago gallinago* (oiseaux.net)

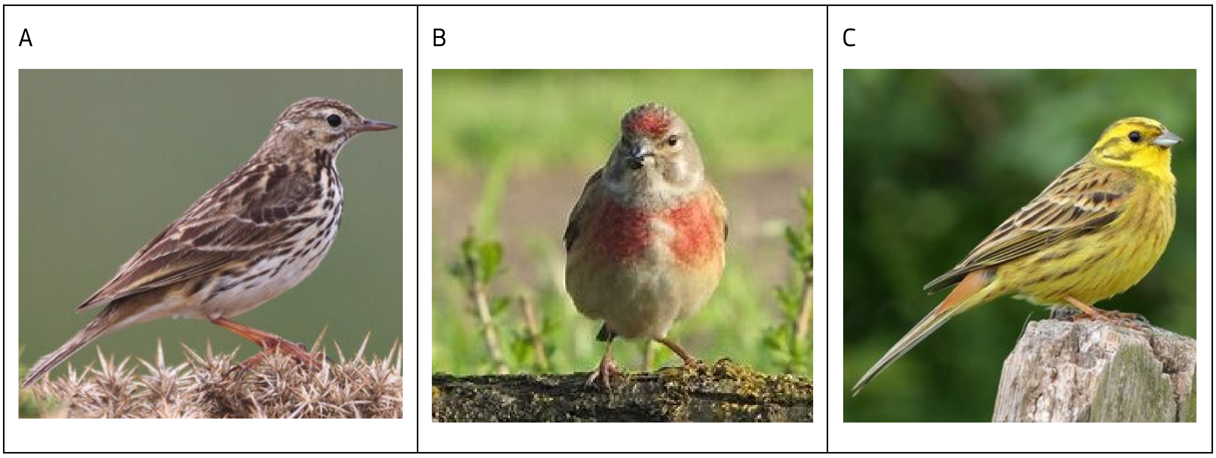
Six species (3.5%), out of 170 species found within the FUA, are classified as endangered (EN) in France. Among them we recognize the Eurasian Tree Sparrow (Passer montanus), see Figure 32, which can be found also in cities. The Eurasian tree sparrow has a large range estimated as 98.3 million square kilometres (38.0 million sq mi) and a population of 190–310 million individuals. Although the population is declining, at the global level, the species is not believed to approach the thresholds for the population decline criterion of the IUCN Red List. However, the populations have been declining in much of Western Europe. The large decline in Eurasian tree sparrow numbers is probably the result of agricultural intensification and specialisation, particularly the increased use of herbicides and a trend towards autumn-sown crops (at the expense of spring-sown crops that produce stubble fields in winter). The change from mixed to specialised farming and the increased use of insecticides has reduced the amount of insect food available for nestlings (Eurasian tree sparrow - Wikipedia).

Figure 33. Eurasian Tree Sparrow (*Passer montanus*)

Source: Eurasian Tree Sparrow - Passer montanus (oiseaux.net)

Nineteen species (11.2%), out of 170 species found within the FUA, are classified as Vulnerable (VU) in France. Among them, three Farmland species, the Meadow Pipit (Anthus pratensis); the Eurasian Linnet (Carduelis cannabina) and the Yellowhammer (Emberiza citronella) are identified, see **Figure 34**.

Figure 34. A: Meadow Pipit (*Anthus pratensis*); B: Eurasian Linnet (*Carduelis cannabina); C:* Yellowhammer (*Emberiza citronella*)



Source : A : Meadow Pipit - Anthus pratensis (oiseaux.net) *B: https://www.biolib.cz/en/image/id116025/ C:* Yellowhammer - Emberiza citrinella (oiseaux.net)

The species classified as Neat Threatened (NT) are 25 out of 170 (14.7%). Among them an urban specialist can be mentioned: the Common Swift (*Apus apus*). It has adapted over the centuries to human habitations and structures. Currently one of the main threats is the renovation and thermal insulation of buildings. Owing to modern architectural techniques and restorations of old buildings, the Common Swifts are disadvantaged in that crack and crevices that existed are obliterated preventing them from breeding in urban areas.

Figure 35. Common Swift (*Apus apus*)

Source: Common Swift - Apus apus (oiseaux.net)

3.1.2 Avian diversity and Community Metrics

We used four diversity metrics as descriptors of bird communities. We first considered two popular metrics used to measure taxonomic diversity (Magurran 2004): the species richness (S), measured as the observed number of species in local communities, and the true diversity (TD), or the effective number of species, based on exponential Shannon diversity and representing the number of equally abundant species necessary to produce the observed value of diversity (Jost, 2006).

We then considered two trait-based metrics: the Community Specialization Index (CSI); (Julliard et al., 2006) and the Community Trophic Index (CTrI) (Princé et al. 2013, Teillard et al., 2015). The CSI is computed as the community mean of species specialization index (SSI) weighted by species abundances and represents a measure of the functional diversity of communities. The SSI is expressed as a coefficient of variation of species' abundance across different habitats and has been successfully used to characterize habitat specialization in birds (Devictor et al., 2010; Filippi-Codaccioni et al., 2010; Barnagaud et al., 2011). Functional diversity refers to those components of biodiversity that influence how an ecosystem operates or functions. Functional diversity is of ecological importance because it, by definition, is the component of diversity that influences ecosystem dynamics, stability, productivity, nutrient balance, and other aspects of ecosystem functioning. Homogenization of biotic communities often results in the disappearance of specialist species, thus the higher the CSI, the less homogenized the communities (Clavel et al., 2011).

The CTrI discriminates between communities with more granivorous species (e.g., low trophic level), and communities with more insectivorous and carnivorous species (e.g., high trophic level). Species trophic level is determined on the basis of the three diet proportions (vegetables, invertebrates and vertebrates, with weights of 1, 2 and 3, respectively) of each species (BWPI, 2006). **Table 13** presents a synthetic description of the Community Diversity metrics.

Table 13. Community Diversity Metrics, synthesis of the indices and description to support the interpretation of the results.

Metric	**Description**

S= Species Richness	observed number of species in local communities
TD = True Diversity (exp(Shannon))	the effective number of species, number of equally abundant species necessary to produce the observed value of diversity
CSI = Community Specialization Index	Represents a measure of the functional homogenization of communities. the higher the CSI -> the less homogenized the communities
CTrI = Community Trophic Index	Low trophic level = communities with more granivorous species High trophic level = communities with more insectivorous and carnivorous species Longer trophic chains and are less biologically homogeneous

Source: *JRC analysis*

3.1.3 Environmental data

The analysis was performed at two spatial levels, the observation site level and the FUA level. The first represents the immediate neighbourhood (area/location) of the observation (Level 1) and its characteristics are expected to directly influence (affect) the birds' communities. The second represents the administrative units of reference, in this case the FUA (Level 2) and its characteristics are expected to contribute as a more extended environmental context. Spatial variables related to level 1 were extracted within a 1-km radius buffer around each location, similar distances were used also by Guetté et al. (2017), to measure the synanthropy of common birds. All variables used in this study are spatially explicit and available at European level, they represent two groups of key descriptors that influence birds' ecology: anthropogenic descriptors or human made land characteristics; and environmental descriptors. Table 14 describes the variables used as spatial descriptors (Annex 2 includes the references of all input data used in this report).

Table 14. Variables used as spatial descriptors.

Variable	Unit of measure	Resolution input (m)	Short description	level
Anthropogenic descriptors				
Land configuration	%	100	Share of land occupied by dominant land types	1/2
Settlement dispersion	dimensionless	10*	degree of settlement dispersion	2
	%	10*	Share of land occupied by the settlement dispersion categories	2
Degree of Urbanisation	%	1000	Share of land settlements typologies	2
Variable	**Unit of measure**	**Resolution input (m)**	**Short description**	**level**
Population	inhab/km2	250	Population density	1

		FUA		2
Natura 2000	%	Vectors	Share of land protected under Natura 2000 network	1
Nationally designated areas (CDDA)	%	Vectors	Share of protected land	
Intensity of management in agricultural land	%	1000	Share of land classified by management intensity classes	2
HNV	%	100	Share of land occupied by High nature Value Farmland	1/2
Forest management	%		Share of land classified by management classes	2
Environmental descriptors				
Riparian zone	%	30	Share of land covered by natural riparian zones	1
Imperviousness	%	20	Share of sealed land	1
Tree canopy cover (2018)	%	10	Tree Cover Density	1
Greenest (2015-2018)	Average	30	The greenest value represents the pixel with the highest value of Normalized Difference Vegetation Index (NDVI) of the year	1/2
Greenest change	%	30	Relative change in greenest values reported per decade (1996-2018)	1/2
Balance between abrupt greening and browning	Difference	30	Difference between share of land characterized by abrupt greening and browning changes	1/2

Source: JRC analysis

Anthropogenic descriptors

Land configuration

Land composition is a measure of spatial distribution of elements or components of a landscape. To quantify land composition we use the Landscape Mosaic (LM), model available in Guido's tool box (Vogt and Riitters, 2017). A land mosaic is a tri-polar classification scheme that represents the land type dominance, the interface zone and the mix zone within a defined area. The classification uses the threshold values of 10%, 60%, and 100% along each axis to partition the tri-polar space into 19 classes. These threshold values are indicative for the presence (10%), dominance (60%), or uniqueness (100%) of each land cover type. The application used in this report was already used to inform the first EU wide ecosystem assessment (Maes et al., 2020).

We grouped dominant land composition classes together (Agricultural dominant = A+AA; Urban dominant = D+DD; Natural dominant = N+NN), and land classes related to interface and mix land together (interface/mix land = Ad + An + Dn + Da + Na + Nd + Adn + Dan + Nad + ad + an + adn).

Settlements dispersion

A dispersed settlement is a form of settlement, common in rural regions, characterised by a scattered pattern of buildings. The Settlement Dispersion Index provides a spatially explicit metric to describe the built-up area pattern within a given zone. The indicator has been derived, and adapted at European scale, from the sprinkling (SPX) index. The SPX index is defined as the "mean Euclidean nearest neighbour distance" and measures the degree of fragmentation of urban settlements through a purely geometric point of view (Romano et al. 2017; Saganeiti et al. 2018). The SPX is a dimensionless metric. The higher the value the higher the degree of fragmentation of land due to the presence of built-up infrastructures within the FUA. Values greater than 100 represents no-built up areas. In terms of changes negative values represent a progressive densification of built-up areas. To make the interpretation easier the indicator has been classified in six classes which represent categories of urban form having an impact on city performance in terms of mobility, urban resilience, ecosystem services and biodiversity (Cortinovis et al. 2019). The dataset used in this report was developed to inform the first EU wide ecosystem assessment (Maes et al., 2020).

Degree of Urbanisation

The Degree of Urbanization (Eurostat, 2018) is a classification that indicates the type of settlements characterizing an area. Additional details are reported in Chapter 2 section 1 of this report.

Based on the share of local population living in urban clusters and in urban centres, it classifies the territory in three types of areas:

- Cities (densely populated areas)
- Towns and suburbs (intermediate density areas)
- Rural areas (thinly populated areas)

Statistics by degree of urbanization provide an analytical and descriptive lens on urban and rural areas.

Population

Population density at the site level is extracted by modelled data, namely the Global Human Settlement Layer (Florczyk et al., 2019)[18]. Population density at the FUA level is derived from the EUROSTAT city-statistics database.

Natura 2000

Natura 2000 is an ecological network of protected areas, set up to ensure the survival of Europe's most valuable species and habitats. Natura 2000 is based on the Birds Directive (Directive 2009/147/EC)[19] and the Habitats Directive (Habitats Directive 92/43/EEC)[20] and represents a key instrument to protect biodiversity in the EU.

[18] The GHSL has been updated in 2022. Please check https://ghsl.jrc.ec.europa.eu/datasets.php for new updates and make sure to scroll down to be able to see all the data that is available. (E.g.: the GHSL Data Package 2022)

[19] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32009L0147

[20] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A31992L0043

Nationally designated areas (CDDA)

The Common Database on Designated Areas (CDDA) is more commonly known as Nationally designated areas. It is the official source of protected area information from European countries to the World Database of Protected Areas (WDPA). The data set complements the Nature 2000 database with protected areas not included in the above mentioned Directives.

High Nature value Farmland (HNV)

The HNV farmland map provides the distribution and extent of farmland that holds a special biodiversity value (Paracchini et al., 2008). Data used in this application are based on Corine Land Cover 2012 data.

Intensity of management in agricultural land

This variable represents the total energy input in agricultural land (Rega et al., 2020). Agro ecosystem are classified in:

- Low energy input
- Medium energy input
- High energy input

In each FUA we extracted the share of the agroecosystem managed under the three levels of intensity.

Forest management

This variable represents the forest management types (Nabuurs et al., 2019). Forested areas are classified in:

- Strict nature management
- Close-to-nature management
- Low-intensity management
- Multifunctional management
- Intensive management
- Very intensive management

In each FUA we extracted the share of forested area managed under the five level of intensity.

Environmental descriptors

Riparian zone

Riparian zones represent transitional areas occurring between land and freshwater ecosystems, characterized by distinctive hydrology, soil and biotic conditions and strongly influenced by the stream water.

Imperviousness

"Soil sealing is the covering of the soil surface with materials like concrete and stone, as a result of new buildings, roads, parking places but also other public and private space. Depending on its degree, soil sealing reduces or most likely completely prevents natural soil functions and ecosystem services on the area concerned" (EEA 2011). This indicator measures the percentage of land covered by surfaces that do not allow water to soak into the soil.

Tree cover

The Copernicus High Resolution Layer Forest 2018 primary status layer Tree Cover Density (TCD) has been created in frame of the tender "EEA/IDM/R0/18/009 - High Resolution land cover characteristics for the 2018 reference year" as part of the EEA Copernicus Land Monitoring Service (CLMS, https://land.copernicus.eu). The TCD raster product provides information on the proportional crown coverage per pixel at 10m spatial resolution and ranges from 0% (all non-tree covered areas) to 100%, whereby Tree Cover Density is defined as the "vertical projection of tree crowns to a horizontal earth's surface".

Greenness

Greenness is defined as "the amount of vegetation present in urbanised areas" (Corbane et al., 2018). Gradual and abrupt changes of the greenness of UGI have been measured with a focus on magnitude and direction of change, using data representing the "greenest value", namely the pixel with the highest value of Normalized Difference Vegetation Index (NDVI) of the year.

The "greenest" values are derived from Landsat annual Top-of-Atmosphere (TOA) reflectance composites available in the Google Earth Engine (GEE) platform for the period 1996–2018. Data were corrected following Corbane et al. 2018 in order images to be comparable. These "greenest" maps are created by considering the highest value of the NDVI as the composite value. The annual maximal NDVI corresponds to high photosynthetic activity during a year and it can indicate the best status of vegetation activity under the best weather conditions in a year (Han et al., 2013). From the dataset 3 metrics were derived:

- *The* average greenest per sites between 2015 and 2018
- *The long term change per FUA, measured as percentage per decade between 1996 and 2018* Trend detection in Normalized Difference Vegetation Index (NDVI) time series helps identify and quantify recent changes in ecosystem properties. The trend analysis employed a non-parametric approach, namely the Theil–Sen regression. The slopes of the regression were tested for their statistical significance using the p-value of the Mann–Kendall test for slopes. Only pixels where the p-value (Mann–Kendall) was equal or less than 0.05 (95% confidence interval) have been considered to have a significant medium-term trend and used as a mask to extract data to derive the indicators. To make the interpretation easier, changes in vegetation cover were reported as percentage of change per decade (using the equation proposed by (Maes et al., 2020 equation 2.4, section 2.9.4).
- *Balance between abrupt greening and browning.* The "greening-browning balance" represents the difference between the share of UGI where major upward and downward trends in vegetation cover take place. In particular, a negative balance occurs in case of vegetation loss. This phenomenon is called "Abrupt browning change", generally caused by a relatively fast land use change, by land take with no compensation policies in place or by extreme weather and climate events (Zulian et al. 2022).

3.1.4 Statistical Analyses

Prior to analysis, we calculated a Pearson Product-Moment correlation coefficient for each pair of the environmental variables to identify any multi-collinearity at the site level and FUA level separately (Annex 6). As a result, we found that the environmental variables were highly correlated one to another. We addressed the problem of multi-collinearity in the environmental variables by first using a Principal Component Analysis (PCA) to derive a set of uncorrelated, synthetic components to reduce the number of spatial predictors at the FUA level (level 2). We run a PCA on green balance variables extracted at the FUA level, as well as on environmental variables related to trends (i.e. settlement change, greenest change, green balance, change in degree of urbanisation). The resulting components that had an eigenvalue summed to >1 were selected to represent the original variation in the environmental data (Kaiser, 1960). Components were interpreted based on their variable loadings, where variables with the largest scores for each component had a larger weight when defining its characteristics (Legendre & Legendre, 1998). We then used the synthetic components derived from the PCA as independent variables in subsequent statistical analysis to eliminate multi-collinearity.

Greening balance in core and commuting areas in artificial areas, as well as in interface areas, were highly correlated. We decided to sum the greening balance variables at the FUA to keep only 2 variables (green balance interface vs. artificial areas).

We then examined the correlations among explanatory variables using pairwise scatter-plots comparing covariates to detect obvious correlation at each spatial level (Appendix Fig. XXX). We also performed a Variance

Inflation Factor (VIF) analysis to assess collinearity among covariates at each spatial level. Correlated variables we removed until all VIF values were below the threshold of four, suggesting low collinearity (Zuur et al., 2009). The same procedure was run a last time with selected variables at both FUA and site level, all together. The resulting set of uncorrelated variables is the following: "A_dominant", "N_dominant", "percentage_rp", "percentage_HNV_level1", "mean_greennes", "balance", "shareN2k", "perc_CDDA", "envtrends_pca1", "envtrends_pca3", "share_1_low", "share_2_medium", "share_1_strict_nature", "share_2_close_to_nature", "share_3_low_intensity", "share_5_intensive", "share_6_very_intensive", "dense_urban", "land_configuration" (see Annex 6 for corresponding VIF values).

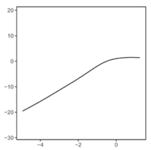
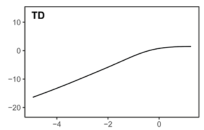
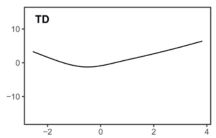
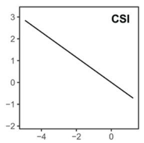
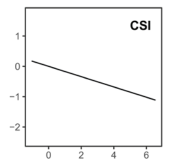
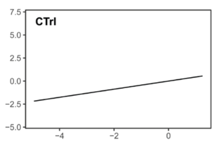
We then investigated the relationships between anthropogenic and environmental predictors and avifauna abundance and community diversity parameters.

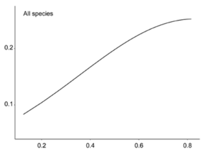
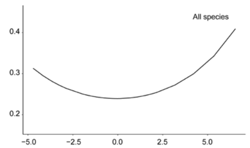
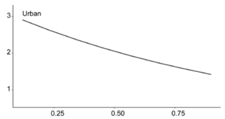
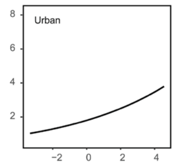
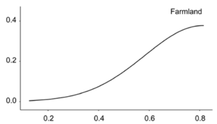
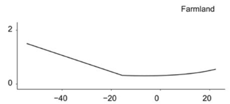
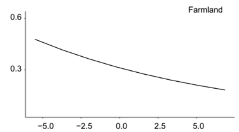
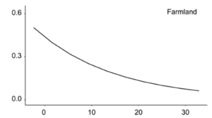
We used Generalized Additive Mixed Models (GAMMs) to quantify the relationship between anthropogenic and environmental predictors and each community metric (species richness, true diversity, CSI and CTrI). GAMMs allow testing for non-linear relationships between the response variable (community metric) and the independent predictors, modelled by smoothing functions. To account for spatial-autocorrelation, Longitude (X) and Latitude (Y) were added in the GAMM as a smoothed, interaction term (i.e. s(x,y)).

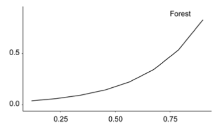
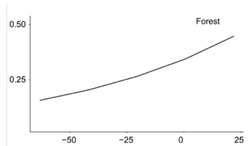
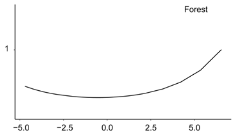
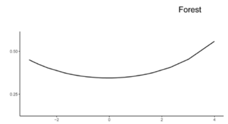
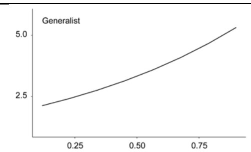
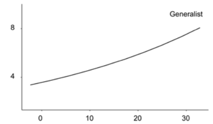
Avifauna abundance was analysed through different species groups: the overall common bird population (n = 170 species) and habitat guilds (farmland, woodland and generalist). Habitat guilds consist of 14 generalist species, 24 farmland and 24 woodland specialists that have been classified according to their habitat requirements at the national level (Jiguet et al., 2012; and see Annex XX for the list of species for each group). We did not use GAMMs to model abundance, as the available set of family distributions was not suitable in our case, and models were too computationally heavy. We used, for each species group, a GLMM assuming a Poisson error with the set of uncorrelated variables as independent predictors. Given the nature of the response variable (bird count), we tested for potential over dispersion in the model residuals, and fitted the abundance models using a negative binomial error distribution and a zero-inflation parameter when needed (DETAILS). We ensured this new model distribution provided a good fit after checking for over dispersion, heterogeneity and residual patterns and non-linearity (Zuur et al., 2009; Zuur and Ieno, 2016). Longitude (X) and latitude (Y) of FBBS sites were included in the GLMMs to account for potential spatial patterns. We also tested for more complex spatial structure, by adding the interaction between Longitude and Latitude, and a quadratic term for both variables.

To account for different correlation structures in our data and the lack of independence in bird observations, we included 'year', 'site', and 'FUA' as random terms in both GAMMs and GLMMs. For abundance models (GLMMs), 'species was also added as a random effect.

Table 15. Effect of spatial predictors related to high-urbanized land on the Community Diversity and Abundance metrics.

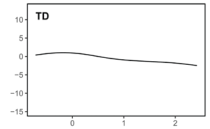
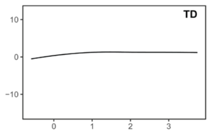
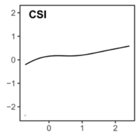
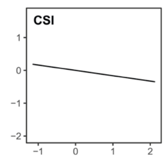
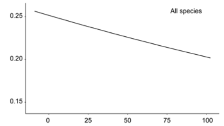
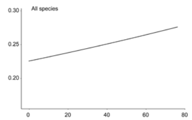
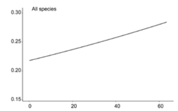
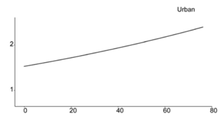
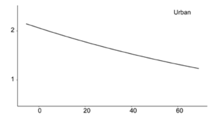
Metric		1 - urban Greenness (average)	1 - Balance - abrupt greening and browning (diff)	2 - Environmental trends -decrease in urban greenness (PCA-dim1)	2 - Environmental trends –sprinkling in rural settlements (PCA-dim3)	2 - Land characterized by Highly urbanized areas (%)
CDM	**S**	 **+ non-linear**				
	TD	 **+ non-linear**		 **convex**		
	CSI	 **- linear**				 **- linear**
	CTrI	 **+ linear**				

Metric		1 - Urban Greenness (average)	1 - Balance - abrupt greening and browning (diff)	2 - Environmental trends -decrease in urban greenness (PCA-dim1)	2 - Environmental trends –sprinkling in rural settlements (PCA-dim3)	2 - Land characterized by Highly urbanized areas (%)
AM	**Overall**	 **+ non-linear**		 **+ non-linear** (significantly positive at high values)		
	Urban	 **- linear**			 **+ linear**	
	Farmland	 **+ non-linear**	 **+ non-linear** (significantly positive at high values)	 **- linear**		 **- linear**

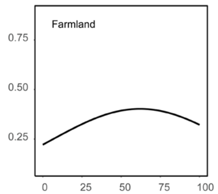
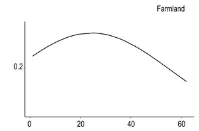
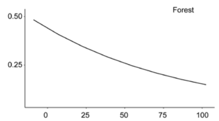
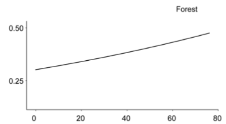
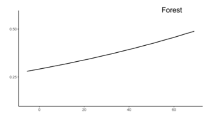
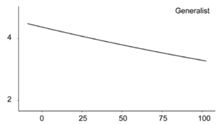
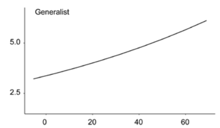
Metric		**1 – urban Greenness (average)**	**1 – Balance – abrupt greening and browning (diff)**	**2 - Environmental trends -decrease in urban greenness (PCA-dim1)**	**2 - Environmental trends –sprinkling in rural settlements (PCA-dim3)**	**2 - Land characterized by Highly urbanized areas (%)**
AM	**Forest**	 **+ linear**	 **+ linear**	 **+non-linear** (significantly positive at high values)	 **+ non-linear** (significantly positive at high values)	
	Generalists	 **+ linear**				 **+ linear**

Source: *JRC analysis*

Table 16. Effect of spatial predictors related to agricultural land on the Community Diversity and Abundance metrics.

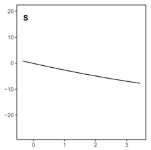
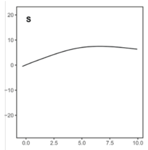
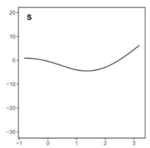
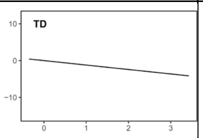
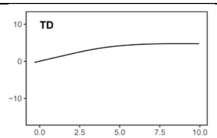
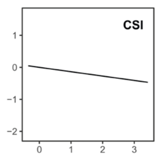
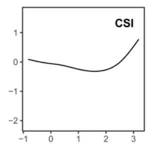
Metric		1 Land Composition Agricultural dominant	1 Land occupied by High Natural Value Farmland (%)	2 Agricultural land with low management intensity (%)	2 Agricultural land with medium management intensity (%)
CDM	**TD**	 **- non-linear**	 **+ non-linear**		
	CSI	 **+ non-linear**			 **- linear**
AM	**Overall**	 - **linear**		 **+ linear**	 **+ linear**
	Urban				 **- linear**

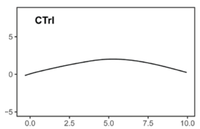
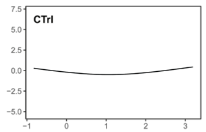
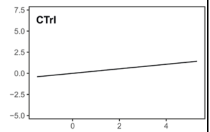
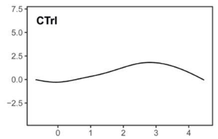
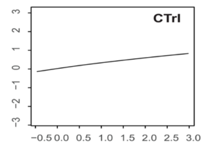
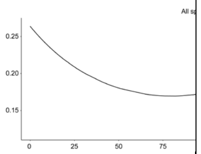
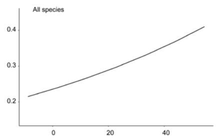
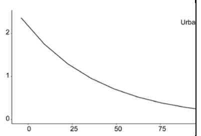
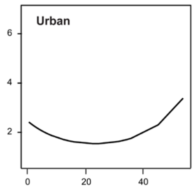
				+ linear	

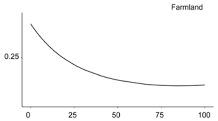
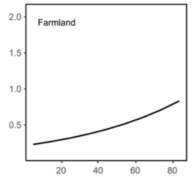
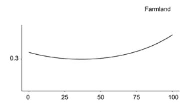
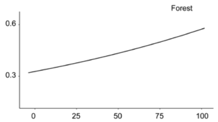
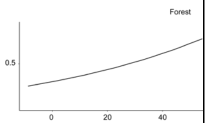
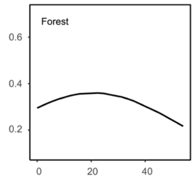
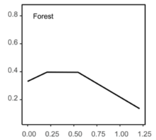
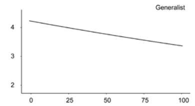
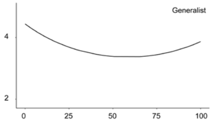
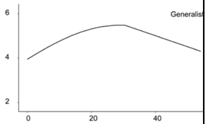
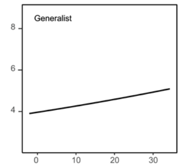
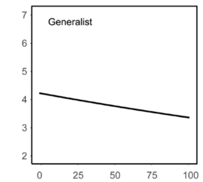
Metric		1 Land Composition Agricultural dominant	1 Land occupied by High Natural Value Farmland (%)	2 Agricultural land with low management intensity (%)	2 Agricultural land with medium management intensity (%)
AM	**Farmland**	 **concave**			 **–non linear** (significantly negative at high values)
	Forest	 – **linear**		 **+ linear**	 **+ linear**
	Generalists	 – **linear**			 **+ linear**

Source: *JRC analysis*

Table 17. Effect of spatial predictors related to forest, riparian zones and protected areas on the Community Diversity and Abundance metrics.

Metric		1 Land Composition Natural dominant	1 Riparian zones (%)	2 forest close to nature (%)	2 forest low intensity management (%)	2 forest intensive management (%)	2 forest high intensity management (%)	1 Land occupied by Natura 2000 (%)
CDM	**S**	 **- non-linear**	 **+ non-linear**	 **convex**				
	TD	 **- linear**	 **+ non-linear**					
	CSI	 **- linear**		 **convex**				

Metric		1 Land Composition Natural dominant	1 Riparian zones (%)	2 forest close to nature (%)	2 forest low intensity management (%)	2 forest intensive management (%)	2 forest high intensity management (%)	1 Land occupied by Natura 2000 (%)
CDM	**CTrl**		 **concave**	 **convex**	 **+ linear**	 **non-linear**		 **+ non linear**
AM	**Overall**	 **– non linear**	 **+ linear**					
	Urban	 **– linear**		 **convex**				

Metric		1 Land Composition Natural dominant	1 Riparian zones (%)	2 forest close to nature (%)	2 forest low intensity management (%)	2 forest intensive management (%)	2 forest high intensity management (%)	1 Land occupied by Natura 2000 (%)
	Farmland	 **non linear**			 **+ linear**			 **+ non linear** (significantly positive at high values)
	Forest	 **+ linear**	 **+ linear**	 **– non-linear** (significantly negative at high values)			 **– non linear** (significantly negative at high values)	 **-linear**
	Generalist	 **convex**	 **concave**			 **+ linear**		 **- linear**

Source: *JRC analysis*

Biotic homogenization in presence of highly urbanized settlement is confirmed at the FUA level. **Table 15** shows the effect of spatial predictors related to high-urbanized land. A higher functional homogenization was found in highly urbanized settlements. Community specialization (CSI) decreases linearly within high-urbanized settlements. In addition, at the population level, the abundance of generalist bird species (see **Figure 36** for few examples of generalists) increases with urban density, while the abundance of farmland specialists decreases (see **Figure 37** for few examples of farmland specialists).

Figure 36. Examples of generalist bird species.

Eurasian Blackbird *(Turdus merula)*

Eurasian magpie (*Pica pica*)

Carrion crow (*Corvus corone*)

Common woodpigeon (*Columba palumbus*)

Source: *Eurasian Blackbird* *https://www.oiseaux.net/birds/common.blackbird.html* - *Eurasian magpie: Eurasian Magpie - Pica pica (oiseaux.net)* – *Carrion crow: Carrion Crow - Corvus corone (oiseaux.net)* – *Common woodpigeon: Common Wood Pigeon - Columba palumbus (oiseaux.net)*

Figure 37. Examples of Farmland specialists (in France).

Common Kestrel *(Falco tinnunculus)*

Eurasian skylark *(Alauda arvensis)*

Yellowhammer *(Emberiza citrinella)*

Meadow Pipit *(Anthus pratensis)*

Source: *Common Kestrel:* *https://www.oiseaux.net/birds/common.kestrel.html*- *Eurasian skylark:* *https://www.oiseaux.net/birds/eurasian.skylark.html* - *Yellowhammer:* *Yellowhammer - Emberiza citrinella (oiseaux.net)* - *Meadow pipit:* *Meadow Pipit - Anthus pratensis (oiseaux.net)*

The same effect is related to an upward trend in the “sprinkling phenomenon” in rural areas. As explained by Romano et al. (2017) and Saganeiti et al. (2018) this process, which is slightly different from urban sprawl, is characterized by a fragmentation of build-up areas in rural settlements. These built-up areas are not homogeneous in size and use, with a mixture of rural, residential, industrial, and tertiary functions (Romano et al. 2017). When the rural landscape is affected, the sprinkling phenomenon generates problems fragmenting large patches of natural habitats that, in this case, affect Species richness.

On the other hand, at the local level, the presence of urban green demonstrates clear positive relationships with bird population abundances and community diversity. Three over four Community Diversity Metrics increase as urban greenness increases, as well as the overall population abundance, forest, farmland and generalist abundances. Species richness is positively related with high levels of urban vegetation cover. The effect is confirmed by the True Diversity Index (TD), which indicates a relatively higher species diversity in presence of urban vegetation and when abrupt greening changes occurred over time. The two relationships are not linear and they reach a plateau with high values of greenness. The same relationship exists also with the overall abundance of bird populations, and with farmland bird abundances. Greenness has also a positive linear relationship with the Community Trophic Index meaning that with the increase of urban vegetation we find communities with more insectivorous and carnivorous species. It is then possible to infer that a moderate level of urban greenness can support high species abundances and diversity. Urban greenness, on the other hand, shows a linear negative relationship with the Community Specialization Index. Although this pattern seems counter-intuitive at glance, it can be explained by focusing on the identity of species occurring in human settlements. Here, the urban green areas are occupied by generalists (e.g. Blackbird or Eurasian magpie) expanding from their forest or farmland habitats where they still breed too. At the same time, specialists are species associated with extreme environments represented by buildings in human settlements and these species (such as Black Redstart), avoid green areas as well as other habitats. Similarly, only urban specialist abundance (see **Figure 38** for an example of urban specialists) demonstrates a negative relationship with urban green. Table 15 shows effect of spatial predictors related to high-urbanized land on the Community Diversity and Abundance metrics.

Figure 38. Examples of Urban specialists (in France).

Common swift *(Apus apus)*

Black redstart (*Phoenicurus ochruros*)

European Goldfinch *(Carduelis carduelis)*

Source: Common swift: https://www.oiseaux.net/birds/common.swift.html - Black redstart: https://www.oiseaux.net/birds/black.redstart.html - European goldfinch: European Goldfinch - Carduelis carduelis (oiseaux.net)

High share of Agro ecosystems (Agricultural land) at the site level, has a nonlinear positive effect on the Community Specialization index (CSI) as well as on farmland bird abundance (except at very high share of agricultural land, where farmland specialists' abundance tends to decrease). These results suggest that the specialists benefiting from high share of agroecosystems form only a small subset of species included in farmland bird index. Conversely, it has a negative nonlinear effect on the True Diversity Index (TD) which indicates a relatively low species diversity and that once again, only a few specialists (adapted to the rather extreme agricultural environment) benefit from its high share. Nevertheless, if sustainable practices are in place, agricultural land can support birds' diversity. If land is managed with low intensity practices, it has a positive linear effect on species richness (S) at the FUA level, although not statistically significant; on the contrary, with medium intensity management practices the effect on CSI is linear and negative indicating a decrease of specialist species. This is likely associated with a strong decline in farmland bird abundance at high rates of medium-intensity agricultural management practices. Bird community diversity (TD) has a tendency to increase with the proportion of land occupied by High Nature Value farmlands. Other community diversity metrics, such as CSI, or abundance metrics did not show any significant relationship with the proportion of HNV farmlands, although previous studies have highlighted the role of HNV farmland in preventing biotic homogenization of farmland bird communities (Doxa et al. 2010, 2012). The lack of similar response pattern may be due to a lack of representativeness of HNV in FUA across France. HNV farmland areas in France are mostly located in low-intensity agricultural areas and/or pasture mountain areas. Table 16 shows the effect of spatial predictors related to agricultural land on the Community Diversity and Abundance metrics.

The presence of areas characterized by natural and semi natural land types has a negative non-linear effect on three over four Community Diversity Metrics at the local level. With a relatively high share of natural land, we see a negative non-linear effect on species richness (S), confirmed by a similar effect on True Diversity Index (TD). A negative linear effect is related also to the CSI which slightly declines revealing species homogenization.

On the other hand, at the FUA level, the forest management clearly demonstrated an effect on birds' communities. In case of relatively large patches of forest close to nature, a non-linear effect on Species diversity, community specialization and community Trophic index occurs, demonstrating that a "close-to – nature" management increases the species richness and species specialization. A similar effect on the Community Trophic index is clear in forests with low intensity management practices and, even if not statistically significant, in forests close to nature (where a positive linear relationship with the Community specialization Index is observed).

An important element for bird's communities is the presence of natural riparian areas. These features show non-linear positive relationships with species richness (S), with the True Diversity Index (TD) and the Community Trophic Index. Natural riparian areas promote community specialization and richness. Increasing riparian features in local urban habitat also enhance overall bird population abundance, and more especially forest specialist (Figure 39 show an example of forest specialists) bird abundance. Generalist species abundance on the other hand, tends to increase at low levels of riparian features, but decrease at high levels. Overall, these results are consistent with other studies highlighting the importance of riparian corridors to enhance bird diversity in urban landscapes (Sanders 1998; Keten et al. 2020).

The presence of protected areas positively, but not linearly, affect the Community Trophic index and are related with the Community specialization Index. At the population level, the increase of Natura 2000 areas decreases the abundance of forest specialist and generalist birds. However, a higher share of Natura 2000 sites increases the abundance of farmland birds. These results are supported by findings from previous studies in France (Pellissier et al. 2013; Princé et al. 2020), highlighting that bird communities inside N2000 sites were more specialized and exhibited higher trophic indices than communities outside N2000 sites.

Table 17 shows the effect of spatial predictors related to forest, riparian zones and protected areas on the Community Diversity and Abundance metrics. Significant relationships exist between the spatial predictors related to urban forest, riparian zones and protected areas and the Community Diversity and Abundance Metrics. At the population level, the increase of Natura 2000 areas decreases the abundance of forest specialist and generalist birds.

Figure 39. Examples of Forest specialists (in France).

 **European Robin *(Erithacus rubecula)***	 **Crested tit (*Lophophanes cristatus*)**
 **Common Chiffchaff *(Phylloscopus collybita)***	

Source: European robin: https://www.oiseaux.net/birds/european.robin.html - Crested tit: Grey Crested Tit - Lophophanes dichrous (oiseaux.net) - Common chiffchaff Common Chiffchaff - Phylloscopus collybita (oiseaux.net)

Key messages:

– Out of the 170 species found within FUA, 51 (30%) are classified under threat in the IUCN Red list for France.

– Urban dense settlements face biotic homogenisation in bird communities

– Urban green infrastructures have the potential to reduce biotic homogenization, by supporting richer and more diverse communities, as well as greater abundance of a majority of common bird species

– Similarly, blue infrastructures in FUA increase bird taxonomic and functional diversity

– Sustainable land use practices (agriculture and forestry) can help support richer and more diverse bird communities

4 Conclusions

Both, FUA and LAU (cities, towns and suburbs) represent highly populated and urbanised areas in Europe, covering similar land cover typologies and extent. However, LAU are more suitable for administrative and policy considerations, whereas FUA can be used for the assessment of ecosystem conditions and services. Nevertheless, FUA are scarcely comparable among MS due to differences in definition across the EU. The delineation of an integrated additional local land typology classification which combines the concept of FUA and LAU would be needed to support comprehensive assessments.

As regards FUA composition, it emerges that the coverage of urban green areas and trees largely varies among Member States (MS), currently occupying 32% and 23% average green areas and tree covered areas, respectively. Currently, the presence of UGI is seeing a decline over time, with a projected total decrease in all MS equal to 1.5% and 0.9% for green areas and trees, respectively, by 2050. The projected decrease, coupled with a scarcity of UGI in a large number of FUA and the occurrence of environmental stressors such as air pollution and high summer temperatures, entail that urban dwellers are exposed to a mismatch between supply and demand of important ecosystem services. In this regard, the upcoming Nature Restoration Law could enhance the availability of UGI in EU-27 by setting legally binding targets for urban ecosystems, thereby improving environmental quality and human health and well-being.

It is indeed fundamental to protect and restore UGI. It has been found, in fact, that UGI exerts a significant contribution to the European GI in terms of extent and integrity, with some countries such as Finland and Sweden, followed by Bulgaria and Italy, contributing the most to the overall European GI.

The exploratory study implemented in French FUA confirmed a pattern of biotic homogenization in common bird communities in highly urbanised settlements. Nevertheless, through Nature Based Solutions and sustainable management practices the situation can be improved. For instance, the presence of urban green supports higher species richness and diversity and less homogenized communities. The presence of natural riparian areas, especially at low to intermediate-level, have an effect on bird species richness and functional diversity, demonstrating the importance of blue infrastructures. Sustainable agricultural practices in peri-urban areas can support bird diversity. Urban forests have a positive effect on species richness and community specialisation only if sustainable forestry practices are in place. Also, the presence of Natura 2000 sites within FUA contributes to increase the community diversity, with higher trophic level and higher abundance of farmland species. Urban areas, in conclusion, might support biodiversity with the correct sustainable practices in place. The case study confirmed, with a quite extensive sample (34 cities located in different bio-geographic regions) the effect of urban characteristics (biotic and abiotic) on birds' communities and populations. This research represents a pilot study that will be successively replicated at the EU level. The work implemented in France will be extremely useful for the selection of the spatial variables to be included at the EU level and for the fine-tuning of the statistical analysis.

5 Glossary

Boundary effect

Spatial analysis inevitably refers to a finite region, a small bounded segment of an infinite space. Because of this finiteness of a study region, a boundary always exists, while any spatial phenomenon within the study region is most likely to extend beyond its boundary. Therefore, analysis confined within a bounded study region may be biased because of the lack of information of the outside of the study region. This problem of potential bias in spatial analysis is referred to as edge effects (or boundary effects). Edge effects are important for any type of spatial analysis because methods for spatial analysis always require that spatial relationships between observations be defined based on their proximity, adjacency, or other criteria, which may be biased due to unrecorded data located outside the study region (Yamada, I., 2009).

Pearson Product-Moment correlation coefficient

The Pearson Product-Moment correlation coefficient is a measure of the linear relationship between two questions/measures/variables, X and Y. The correlation value can range from +1 to -1. A positive correlation (e.g., +0.78) means there is a positive relationship between X and Y. (https://statistics.laerd.com/statistical-guides/pearson-correlation-coefficient-statistical-guide.php)

Multi-collinearity

Multi-collinearity is a statistical concept where several independent variables in a model are correlated. Two variables are considered to be perfectly collinear if their correlation coefficient is +/- 1.0. Multicollinearity among independent variables (covariates) will result in less reliable statistical inferences. In statistics, multicollinearity (also collinearity) is a phenomenon in which one predictor variable in a multiple regression model can be linearly predicted from the others with a substantial degree of accuracy.

https://en.wikipedia.org/wiki/Multicollinearity

Spatial autocorrelation

Spatial autocorrelation is the term used to describe the presence of systematic spatial variation in a variable and positive spatial autocorrelation, which is most often encountered in practical situations, is the tendency for areas or sites that are close together to have similar values (Haining, R.P., 2001).

Principal Component Analysis (PCA)

Principal component analysis (PCA) is a technique for reducing the dimensionality of datasets, increasing interpretability but at the same time minimizing information loss. It does so by creating new uncorrelated variables that successively maximize variance (Jolife et. Al 2016).

Cluster analysis

Cluster Analysis is the process to find similar groups of objects in order to form clusters that share certain properties. It is an unsupervised machine learning-based algorithm that acts on unlabelled data.

Hierarchical clustering (HC)

HC is an agglomerative clustering method. Initially it considers every data point as an individual Cluster and at every step, merges the nearest pairs of the cluster. (It is a bottom-up method). At first, every dataset is considered as an individual entity or cluster. At every iteration, the clusters merge with different clusters until one cluster is formed. We used the HCPC method, as implemented in the FactoMineR package (http://www.sthda.com/english/articles/31-principal-component-methods-in-r-practical-guide/117-hcpc-hierarchical-clustering-on-principal-components-essentials/#case-1-continuous-variables)

Factor map

A Factor map can be obtained using the results from the principal component (PCA) and agglomerative hierarchical cluster analysis. It allows to visualize individuals on the PCA map and to colour individuals according to the cluster they belong to.

v.test

The v.test discriminates those variables that are significantly contributing to the inertia of the dimension. A value of the v.test greater than 1.96 corresponds to a p-value less than 0.05; the sign of the v.test indicates if the mean of the cluster is lower or greater than the overall mean (Husson, 2010).

Generalized Additive Mixed Models (GAMMs)

Generalized additive mixed models (GAMMs) are an extension of generalized additive models incorporating random effects. A generalized additive mixed model is a generalized linear mixed model in which the linear predictor depends linearly on unknown smooth functions of some of the covariates ('smooths' for short). GAMMs are widely used to model correlated and clustered responses. For example, the dependence structure of longitudinal data and of designs with repeated measurements can be captured (Groll et al., 2012).

Species Diversity

Species diversity is defined as the number of species and abundance of each species that live in a particular location. The number of species that live in a certain location is called ***species richness.*** If you were to measure the species richness of a forest, you might find 20 bird species, 50 plant species, and 10 mammal species. **Abundance** is the number of individuals of each species.

Shannon diversity

Shannon diversity index (or Shannon entropy or "Shannon-Wiener index") considers both species richness and evenness. The index is derived from information theory and represents the uncertainty with which we can predict of which species will be one randomly selected individual in the community. The maximum value of Shannon index for community of given richness occurs at situation that it is perfectly even (all species have the same relative proportion).

True diversity (TD)

TD is the effective number of species, and is calculated by taking on the exponential of ***Shannon diversity.*** TD refers to the number of equally abundant species within a population needed for the average proportional abundance of the species to equal that observed (where all species may not be equally abundant).

Community Specialization Index

The Community Specialization Index (CSI, Julliard et al. 2006), is a measure of the average degree of habitat specialization of a local bird community, defined as the mean of the SSI of the censused species weighted by the abundances. The CSI allows for discrimination between generalist and specialized communities.

Community Trophic Index.

The Community Trophic Index (CTrI), is a measure of the average trophic level of a local bird community (Princé et al., 2013). To compute this index, we estimated the proportion of plant, invertebrate and vertebrate items in each bird species' diet as available from (BWPi, 2006). The species trophic index is defined as the exponential of the weighted mean of the diet item proportion values using weight values of 1, 2 and 3 for plant, invertebrate and vertebrate items, respectively. The CTrI discriminates between communities with more granivorous species (e.g., low trophic level), and communities with more insectivorous and carnivorous species (e.g., high trophic level). Longer trophic chains and are less biologically homogeneous.

Peri Urban Areas

Areas that are in some form of transition from strictly rural to urban. These areas often form the immediate urban-rural interface and may eventually evolve into being fully urban. Peri-urban areas are places where people are key components: they are lived-in environments.

https://inspire.ec.europa.eu/codelist/SupplementaryRegulationValue/7_1_4_7_PeriUrbanAreas

Ecosystem Assessment

An Ecosystem assessment, which might take many forms, is a specific type of assessment that analyse the factors having an impact on the health and functioning of ecosystems. Examples of ecosystem assessments were produced as part of the Mapping and Assessment of Ecosystems and their Services (MAES) https://ec.europa.eu/environment/nature/knowledge/ecosystem_assessment/index_en.htm

Examples of Farmland specialists (in France):

- **Common Kestrel (*Falco Tinnunculus*)**

Red-list category in France = NT, trend = decreasing, Red-list category world level = LC (IUCN, 2020)

Habitat: Forest: Boreal, Temperate ; Shrubland : Temperate, Mediterranean-type Shrubby Vegetation ; Grassland: Tundra, Temperate, Subtropical/Tropical Dry; Artificial/Terrestrial: Arable Land, Pastureland, Plantations, Urban Areas

Source: *https://www.oiseaux.net/birds/common.kestrel.html*

- **Eurasian skylark (*Alauda Arvensis*)**

Red-list category in France = NT, trend = decreasing, Red-list category world level = LC (IUCN, 2020).

Habitats: Shrubland : Temperate, Mediterranean-type Shrubby Vegetation ; Grassland : Temperate, Subtropical/Tropical Dry ; Wetlands (inland) : Bogs, Marshes, Swamps, Fens, Peatlands ; Marine Intertidal : Rocky Shoreline, Sandy Shoreline and/or Beaches, Sand Bars, Spits, Etc, Shingle and/or Pebble Shoreline and/or Beaches, Salt Marshes (Emergent Grasses), Tidepools ; Marine Coastal/Supratidal : Coastal Sand Dunes ; Artificial/Terrestrial : Arable Land, Pastureland

Source: https://www.oiseaux.net/birds/eurasian.skylark.html

- **Yellowhammer (*Emberiza citrinella*)**

Red-list category in France = VU, trend = decreasing, Red-list category world level = LC (IUCN, 2020)

Habitats: Forest : Temperate ; Shrubland : Temperate ; Grassland : Temperate ; Artificial/Terrestrial : Arable Land, Pastureland

Source: [Yellowhammer - Emberiza citrinella (oiseaux.net)]()

- **Meadow Pipit *(Anthus pratensis*)**

Red-list category in France = VU, trend = decreasing, Red-list category world level = NT (IUCN, 2020)

Habitat: Grassland : Tundra, Temperate ; Wetlands (inland) : Bogs, Marshes, Swamps, Fens, Peatlands ; Marine Intertidal : Rocky Shoreline, Sandy Shoreline and/or Beaches, Sand Bars, Spits, Etc, Shingle and/or Pebble Shoreline and/or Beaches, Salt Marshes (Emergent Grasses), Tidepools ; Marine Coastal/Supratidal : Coastal Sand Dunes ; Artificial/Terrestrial : Pastureland

Source: Meadow Pipit - Anthus pratensis (oiseaux.net)

Three examples of Urban specialists (in France):

- **Eurasian collared-dove (*Streptopelia decaocto*)**

Habitats: shrubland: Boreal, Temperate, Subtropical/Tropical Dry, Mediterranean-type Shrubby Vegetation; Artificial/Terrestrial: Arable Land, Plantations, Rural Gardens, Urban Areas, Subtropical/Tropical Heavily Degraded Former Forest

Source: https://www.oiseaux.net/birds/eurasian.collared.dove.html

– **Common swift (*Apus apus*)**

Red-list category in France = NT, trend = decreasing, Red-list category world level = LC (IUCN, 2020)

Habitats: Forest : Subtropical/Tropical Moist Lowland, Subtropical/Tropical Moist Montane ; Savanna : Dry ; Shrubland : Mediterranean-type Shrubby Vegetation ; Grassland : Temperate, Subtropical/Tropical Dry, Subtropical/Tropical Seasonally Wet/Flooded, Subtropical/Tropical High Altitude ; Wetlands (inland) : Permanent Freshwater Lakes (over 8ha), Seasonal/Intermittent Freshwater Lakes (over 8ha), Permanent Freshwater Marshes/Pools (under 8ha), Seasonal/Intermittent Freshwater Marshes/Pools (under 8ha) ; Rocky areas (eg. inland cliffs, mountain peaks); Desert: Hot; Artificial/Terrestrial: Arable Land, Urban Areas

Source: https://www.oiseaux.net/birds/common.swift.html

– **Black redstart (*Phoenicurus ochruros*)**

Red-list category world level = LC (IUCN, 2020)

Habitats: Shrubland: Temperate, Subtropical/Tropical Dry; Grassland: Temperate; Rocky areas (eg. inland cliffs, mountain peaks); Marine Coastal/Supratidal: Sea Cliffs and Rocky Offshore Islands; Artificial/Terrestrial: Urban Areas

Source: https://www.oiseaux.net/birds/black.redstart.html

– **European Goldfinch (*Carduelis carduelis*)**

Red-list category in France = VU, trend = decreasing, Red-list category world level = LC (IUCN, 2020)

Habitat: Forest: Temperate; Shrubland: Temperate, Mediterranean-type Shrubby Vegetation; Grassland: Temperate; Wetlands (inland): Permanent Rivers/Streams/Creeks (includes waterfalls); Artificial/Terrestrial: Arable Land, Pastureland, Plantations, Rural Gardens, Urban Areas

Source: [European Goldfinch - Carduelis carduelis (oiseaux.net)]

Examples of Generalists (in France):

– **Eurasian Blackbird (*Turdus merula*)**

Red-list category world level = LC (http://datazone.birdlife.org/species/factsheet/eurasian-blackbird-turdus-merula/details)

Habitat : Forest : Boreal, Temperate, Subtropical/Tropical Moist Montane ; Shrubland : Temperate, Mediterranean-type Shrubby Vegetation ; Grassland : Temperate ; Artificial/Terrestrial : Arable Land, Plantations, Rural Gardens, Urban Areas

Source: https://www.oiseaux.net/birds/common.blackbird.html

- **Great tit (*Parus major*)**

Red-list category world level = LC (http://datazone.birdlife.org/species/factsheet/great-tit-parus-major)

Habitat: Forest : Boreal, Temperate, Subtropical/Tropical Dry, Subtropical/Tropical Moist Lowland, Subtropical/Tropical Mangrove Vegetation Above High Tide Level, Subtropical/Tropical Moist Montane; Shrubland : Temperate, Subtropical/Tropical Dry ; Grassland : Temperate ; Desert : Temperate ; Artificial/Terrestrial : Arable Land, Plantations, Rural Gardens, Urban Areas.

Source: [Great Tit - Parus major (oiseaux.net)]

- **Eurasian magpie (*Pica pica*)**

Red-list category world level = LC ([Eurasian Magpie (Pica pica) - BirdLife species factsheet])

Habitat: Forest : Temperate, Subtropical/Tropical Dry ; Shrubland : Temperate, Subtropical/Tropical Dry, Mediterranean-type Shrubby Vegetation ; Grassland : Temperate, Subtropical/Tropical Dry ; Rocky areas (eg. inland cliffs, mountain peaks); Artificial/Terrestrial : Arable Land, Pastureland, Rural Gardens, Urban Areas

Source: [Eurasian Magpie - Pica pica (oiseaux.net)]

– **Carrion crow (*Corvus corone*)**

Red-list category world level = LC (Carrion Crow (Corvus corone) - BirdLife species factsheett)

Habitat: Forest : Boreal, Temperate, Subtropical/Tropical Dry ; Shrubland : Temperate ; Grassland : Temperate ; Wetlands (inland) : Permanent Rivers/Streams/Creeks (includes waterfalls), Permanent Freshwater Lakes (over 8ha) ; Rocky areas (eg. inland cliffs, mountain peaks) : ; Marine Intertidal : Rocky Shoreline, Sandy Shoreline and/or Beaches, Sand Bars, Spits, Etc, Shingle and/or Pebble Shoreline and/or Beaches, Mud Flats and Salt Flats, Tidepools ; Marine Coastal/Supratidal : Sea Cliffs and Rocky Offshore Islands ; Artificial/Terrestrial : Arable Land, Pastureland, Rural Gardens, Urban Areas

Source: Carrion Crow - Corvus corone (oiseaux.net)

– **Common woodpigeon (*Columba palumbus*)**

Red-list category world level = LC (http://datazone.birdlife.org/species/factsheet/common-woodpigeon-columba-palumbus);

Habitats: Forest: Boreal, Temperate, Subtropical/Tropical Moist Montane ; Shrubland : Boreal, Temperate, Mediterranean-type Shrubby Vegetation ; Artificial/Terrestrial : Arable Land, Pastureland, Plantations, Rural Gardens

Source: Common Wood Pigeon - Columba palumbus (oiseaux.net)

Examples of Forest Specialists (in France):

- **European Robin (*Erithacus rubecula*)**

Red-list category in France = LC, trend = decreasing, Red-list category world level = LC (IUCN, 2020)

Habitat : Forest : Boreal, Temperate, Subtropical/Tropical Moist Montane ; Shrubland : Boreal, Temperate, Mediterranean-type Shrubby Vegetation ; Grassland : Temperate ; Artificial/Terrestrial : Arable Land, Pastureland, Plantations, Rural Gardens, Urban Areas

Source: https://www.oiseaux.net/birds/european.robin.html

Crested tit (*Lophophanes cristatus*)

Red-list category in France = LC, trend = decreasing, Red-list category world level = LC (IUCN, 2020)

Habitat: Forest : Subtropical/Tropical Moist Montane

Source: Grey Crested Tit - Lophophanes dichrous (oiseaux.net)

– **Common Chiffchaff (*Phylloscopus collybita*)**

Red-list category in France = LC, trend = decreasing, Red-list category world level = LC (IUCN, 2020)
Habitats: Forest : Boreal, Temperate, Subtropical/Tropical Mangrove Vegetation Above High Tide Level, Subtropical/Tropical Moist Montane ; Savanna : Dry ; Shrubland : Subtropical/Tropical Dry, Mediterranean-type Shrubby Vegetation ; Wetlands (inland) : Permanent Rivers/Streams/Creeks (includes waterfalls), Shrub Dominated Wetlands, Seasonal/Intermittent Freshwater Marshes/Pools (under 8ha), Freshwater Springs and Oases ; Artificial/Terrestrial : Rural Gardens

Source : Common Chiffchaff - Phylloscopus collybita (oiseaux.net)

6 References

Aronson MFJ, La Sorte FA, Nilon CH, Katti M, Goddard MA, Lepczyk CA, Warren PS, Williams NSG, Cilliers S, Clarkson B, Dobbs C, Dolan R, Hedblom M, Klotz S, Kooijmans JL, Kühn I, MacGregor-Fors I, McDonnell M, Mörtberg U, Pysek P, Siebert S, Sushinsky J, Werner P, Winter M (2014) A global analysis of the impacts of urbanization on bird and plant diversity reveals key anthropogenic drivers A global analysis of the impacts of urbanization on bird and plant diversity reveals key anthropogenic drivers. Proc R Biol Sci 281:20133330.

Barnagaud, J. Y., V. Devictor, F. Jiguet, and F. Archaux. 2011. When species become generalists : on-going large-scale changes in bird habitat specialization. GlobalEcology and Biogeography 20:630–640.

Beaugeard, E., Brischoux, F. & Angelier, F. Green infrastructures and ecological corridors shape avian biodiversity in a small French city. Urban Ecosyst 24, 549–560 (2021). https://doi.org/10.1007/s11252-020-01062-7

BWPI, 2006. Birds of the Western Palearctic interactive. BirdGuides Ltd, UK.

Balikçi, S., Giezen, M., & Arundel, R. (2021). The paradox of planning the compact and green city: analyzing land-use change in Amsterdam and Brussels The paradox of planning the compact and green city: analyzing land-use change in Amsterdam and Brussels. https://doi.org/10.1080/09640568.2021.1971069

Borchardt, S., Buscaglia, D., Barbero Vignola, G., Maroni, M., & Marelli, L. (2020). A sustainable recovery for the EU. JRC Science for Policy Report, EUR 30452. https://www.researchgate.net/profile/Giulia_Barbero_Vignola/publication/347659805_A_sustainable_recovery_for_the_EU_-_A_text_mining_approach_to_map_the_EU_Recovery_Plan_to_the_Sustainable_Development_Goals/links/5fe3087a45851553a0e34179/A-sustainable-reco

Chatzimentor, A., Apostolopoulou, E., & Mazaris, A. D. (2020). A review of green infrastructure research in Europe: Challenges and opportunities. Landscape and Urban Planning, 198(March 2019), 103775. https://doi.org/10.1016/j.landurbplan.2020.103775

Clavel, J., Julliard, R. & Devictor, V. (2010) Worldwide decline of specialist species: toward a global functional homogenization? Frontiers in Ecology and Environment, 9,222–228.

Clergeau P, Croci S, Jokimäki J, Kaisanlahti-Jokimäki M-L, Dinetti M (2006) Avifauna homogenisation by urbanisation: Analysis at different European latitudes. Biol Conserv 127:336–344.

Colsaet, A., Laurans, Y., & Levrel, H. (2018). What drives land take and urban land expansion? A systematic review. Land Use Policy, 79(August), 339–349. https://doi.org/10.1016/j.landusepol.2018.08.017

Cortinovis, C., Haase, D., Zanon, B., & Geneletti, D. (2019). Is urban spatial development on the right track? Comparing strategies and trends in the European Union. Landscape and Urban Planning, 181(August 2018), 22–37. https://doi.org/10.1016/j.landurbplan.2018.09.007

Davies, C., Hansen, R., Rall, E., Pauleit, S., Lafortezza, R., De Bellis, Y., Santos, A., Tosics, I., (2015) Green Infrastructure Planning and Implementation (GREEN SURGE). Report 5.1. The Status of European Green Space Planning and Implementation Based on an Analysis of Selected European City-regions. (GREEN SURGE, FP7-ENV.2013.6.2-5-603567; 2013–2017) https://ign.ku.dk/english/green-surge/rapporter/D5_1_Green_Infrastructure_Planning_and_Implementation1.pdf

Devictor, V., Mouillot, D., Meynard, C., Jiguet, F., Thuiller, W., Mouquet, N., 2010. Spatial mismatch and congruence between taxonomic, phylogenetic and functional diversity: the need for integrative conservation strategies in a changing world: spatial mismatch between diversity facets. Ecol. Lett. 13, 1030–1040.

ESPON GRETA. 2019. Green Infrastructure: Enhancing Biodiversity and Ecosystem Services for Territorial Development. https://www.espon.eu/green-infrastructure

European Commission, (2013). Building a Green Infrastructure for Europe. https://doi.org/10.2779/54125

European Commission, (2019). The European Green Deal. http://eur-lex.europa.eu/resource.html?uri=cellar:208111e4-414e-4da5-94c1-852f1c74f351.0004.02/DOC_1&format=PDF

European Commission, (2020). Bringing nature back into our lives: An EU Biodiversity Strategy for 2030. In Communication from the Commission to the European Parliament, the Council, the Economic and Social

Committee and the Committee of Regions, Brussels, Belgium (p. 26). https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52020DC0380

European Commission, (2021) Regulation of the European Parliament and of the Council of 30 June 2021 establishing the framework for achieving climate neutrality and amending Regulations (EC) No 401/2009 and (EU) 2018/1999 ('European Climate Law')

https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32021R1119

European Commission, (2022a) DECISION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 6 April 2022 on a General Union Environment Action Programme to 2030 (EU) 2022/591 https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32022D0591

EU Commission (2022b), Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on nature restoration, Brussels, 22.6.2022, COM(2022) 304 final, 2022/0195 (COD), https://environment.ec.europa.eu/publications/nature-restoration-law_en

EU Commission (2022c), Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL amending Regulation (EU) No 691/2011 as regards introducing new environmental economic accounts modules COM/2022/329 final

https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM:2022:329:FIN

EU Commission (2022d), COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS on the monitoring framework for the 8th Environment Action Programme: Measuring progress towards the attainment of the Programme's 2030 and 2050 priority objectives, Brussels, 26.7.2022, COM(2022) 357 final

https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2022%3A357%3AFIN

European Environment Agency EEA. (2020). The European environment-state and outlook 2020. Knowledge for transition to a sustainable Europe. In European Environment Agency (Vol. 60, Issue 3, pp. 391–394). https://doi.org/10.15196/TS600305

Eurostat. (2017). Methodological manual on city statistics – 2017 edition. https://doi.org/10.2785/765198

Eurostat. (2021). Applying the Degree of Urbanisation A NEW INTERNATIONAL MANUAL FOR DEFINING CITIES, TOWNS AND RURAL AREAS 2021 EDITION. http://ec.europa.eu/regional_policy/sources/docgener/work/2014_01_new_urban.pdf.

EUROSTAT. (2018). Methodological manual on territorial typologies. 2018 Edition. General and Regional Statistics, Manuals and guidelines, 132. https://ec.europa.eu/eurostat/web/products-manuals-and-guidelines/-/ks-gq-18-008

Fischer, L. K., Honold, J., Botzat, A., Brinkmeyer, D., Cvejić, R., Delshammar, T., Elands, B., Haase, D., Kabisch, N., Karle, S. J., Lafortezza, R., Nastran, M., Nielsen, A. B., van der Jagt, A. P., Vierikko, K., & Kowarik, I. (2018). Recreational ecosystem services in European cities: Sociocultural and geographical contexts matter for park use. Ecosystem Services. https://doi.org/https://doi.org/10.1016/j.ecoser.2018.01.015.

Filazzola A, Shrestha N, MacIvor JS (2019) The contribution of constructed green infrastructure to urban biodiversity: a synthesis and meta-analysis. J Appl Ecol 56:2131–2143. https://doi.org/10.1111/1365-2664.13475

Filippi-Codaccioni, O., Devictor, V., Bas, Y., Julliard, R., 2010. Toward more concern for specialisation and less for species diversity in conserving farmland biodiversity. Biol.Conserv. 143, 1493–1500. http://dx.doi.org/10.1016/j.biocon.2010.03.031.

Florczyk, A. J., Corbane, C., Ehrlich, D., Freire, S., Kemper, T., Maffenini, L., Melchiorri, M., Pesaresi, M., Politis, P., Schiavina, M., Sabo, F., & Zanchetta, L. (2019). GHSL data package 2019. In Eur (Vol. 29788). https://doi.org/10.2760/0726

Gascon, M., Triguero-Mas, M., Martínez, D., Dadvand, P., Rojas-Rueda, D., Plasència, A., & Nieuwenhuijsen, M. J. (2016). Residential green spaces and mortality: A systematic review. Environment International, 86, 60–67. https://doi.org/10.1016/j.envint.2015.10.013

Guetté, A., Gaüzère P., Devictor V., Jiguet F., Godet L. 2017. Measuring the synanthropy of species and communities to monitor the effects of urbanization on biodiversity, Ecological Indicators 79:139-154. https://doi.org/10.1016/j.ecolind.2017.04.018.

Haaland, C., & van den Bosch, C. K. (2015). Challenges and strategies for urban green-space planning in cities undergoing densification: A review. Urban Forestry & Urban Greening, 14(4), 760–771. https://doi.org/https://doi.org/10.1016/j.ufug.2015.07.009

Husson, F., Josse, J., (2010) Principal component methods - hierarchical clustering - partitional clustering: why would we need to choose for visualizing data? Technical Report – Agrocampus Applied Mathematics Department, September 2010. http://factominer.free.fr/more/HCPC_husson_josse.pdf

IUCN. (2012). IUCN Red List Categories and Criteria: Version 3.1. Second edition. IUCN Red List categories and criteria, version 3.1, second edition | IUCN Library System

Jiguet, F., Devictor, V., Julliard, R., & Couvet, D. (2012). French citizens monitoring ordinary birds provide tools for conservation and ecological sciences. Acta Oecologica, 48–56.

Jolliffe, IT, Cadima J. (2016) Principal component analysis: a review and recent developments. Phil.Trans.R.Soc.A374:20150202.http://dx.doi.org/10.1098/rsta.2015.0202

Jost, L. (2006) Entropy and diversity. Oikos, 113, 363–375.

Julliard, R., Clavel, J., Devictor, V., Jiguet, F., Couvet, D., (2006) Spatial segregation of specialists and generalists in bird communities, Ecology Letters, (2006) 9: 1237–1244, https://onlinelibrary.wiley.com/doi/10.1111/j.1461-0248.2006.00977.x

Keten, A., Eroglu, E., Kaya, S., & Anderson, J. T. (2020). Bird diversity along a riparian corridor in a moderate urban landscape. Ecological Indicators, 118, 106751.

Kabisch, N., & Haase, D. (2013). Green spaces of European cities revisited for 1990–2006. Landscape and Urban Planning, 110, 113–122. https://doi.org/http://dx.doi.org/10.1016/j.landurbplan.2012.10.017

La Sorte FA, Aronson MFJ, Williams NSG, Celesti-Grapow L, Cilliers S, Clarkson BD, Dolan RW, Hipp A, Klotz S, Kühn I, Pyšek P, Siebert S, Winter M (2014) Beta diversity of urban floras among European and non-European cities. Glob Ecol Biogeogr 23: 769–779.

Leong, M., & Trautwein, M. (2019). A citizen science approach to evaluating US cities for biotic homogenization. PeerJ, 2019(4). https://doi.org/10.7717/peerj.6879

Le Viol I, Jiguet F, Brotons L, Herrando S, Lindström A, Pearce-Higgins JW, Reif J, Van Turnhout C, Devictor V (2012) More and more generalists: two decades of changes in the European avifauna. Biol Lett 8:780–782

Lososová Z, Chytrý M, Tichý L, Danihelka J, Fajmon K, Hájek O, Kintrová K, Láníková D, Otýpková Z, Řehořek V (2012) Native and alien floras in urban habitats: a comparison across 32 cities of central Europe. Glob Ecol Biogeogr 21:545–555.

Magurran, A., 2004. Measuring Biological Diversity. Blackwell Science, Oxford; UK.

Maes J., Teller A., Erhard M., Liquete C., Braat L., Berry P., Egoh B., Puydarrieux P., Fiorina C., Santos F., P. M. L., Keune H., Wittmer H., Hauck J., Fiala I., Verburg P.H., Condé S., Schägner J.P., San Miguel J., Estreguil C., O. O., Barredo J.I., Pereira H.M., Stott A., Laporte V., Meiner A., Olah B., Royo Gelabert E., Spyropoulou R., Petersen J.E., M., & C., Zal N., Achilleos E., Rubin A., Ledoux L., Brown C., Raes C., Jacobs S., Vandewalle M., Connor D., B. G. (2013). Mapping and Assessment of Ecosystems and their Services. An analytical framework for ecosystem assessments under action 5 of the EU biodiversity strategy to 2020.

Maes, J., Zulian, G., Günther, S., Thijssen, M., & Reynal, J. (2019). Enhancing Resilience Of Urban Ecosystems through Green Infrastructure (EnRoute) Final Report. https://doi.org/10.2760/602928

Maes, J., Quaglia, A., Guimarães Pereira, Â., et al., BiodiverCities : a roadmap to enhance the biodiversity and green infrastructure of European cities by 2030 : progress report, Publications Office, 2021, https://data.europa.eu/doi/10.2760/288633

Manes, F., Marando, F., Capotorti, G., Blasi, C., Salvatori, E., Fusaro, L., Ciancarella, L., Mircea, M., Marchetti, M., Chirici, G., & Munafò, M. (2016). Regulating Ecosystem Services of forests in ten Italian Metropolitan Cities: Air quality improvement by PM10 and O3 removal. Ecological Indicators, 67, 425–440. https://doi.org/10.1016/j.ecolind.2016.03.009

Marando, F., Heris, M. P., Zulian, G., Udías, A., Mentaschi, L., Chrysoulakis, N., Parastatidis, D., & Maes, J. (2022). Urban heat island mitigation by green infrastructure in European Functional Urban Areas. Sustainable Cities and Society, 77(November 2021), 103564. https://doi.org/10.1016/j.scs.2021.103564

Marando, F., Salvatori, E., Sebastiani, A., Fusaro, L., & Manes, F. (2019). Regulating Ecosystem Services and Green Infrastructure: assessment of Urban Heat Island effect mitigation in the municipality of Rome, Italy. Ecological Modelling, 392(July 2018), 92–102. https://doi.org/10.1016/j.ecolmodel.2018.11.011

Marzluff, J., Shulenberger, E., Endlicher, W., Bradley, G., Simon, U., Alberti, M., Ryan, C., & ZumBrunnen, C. (2008). Urban Ecology: An International Perspective on the Interaction Between Humans and Nature. In Urban Ecology: An International Perspective on the Interaction Between Humans and Nature (Springer). https://doi.org/10.1007/978-0-387-73412-5_35

McKinney ML (2002) Urbanization, biodiversity, and conservation. BioScience 52:883–890.

McKinney, M. L. (2006). Urbanization as a major cause of biotic homogenization. Biological Conservation, 127(3), 247–260. https://doi.org/10.1016/j.biocon.2005.09.005

Monteiro, R., Ferreira, J. C., & Antunes, P. (2020). Green infrastructure planning principles: An integrated literature review. Land, 9(12), 1–19. https://doi.org/10.3390/land9120525

Nabuurs, G. J., Verweij, P., Van Eupen, M., Pérez-Soba, M., Pülzl, H., & Hendriks, K. (2019). Next-generation information to support a sustainable course for European forests. Nature Sustainability, 2(9), 815–818. https://doi.org/10.1038/s41893-019-0374-3

Olden, Julian D; Comte, Lise; and Giam, Xingli (August 2016) Biotic Homogenisation. In: eLS. John Wiley & Sons, Ltd: Chichester. DOI: 10.1002/9780470015902.a0020471.pub2

Paracchini, M. L., & Capitani, C. (2011). Implementation of a EU wide indicator for the rural-agrarian landscape. In support of COM(2006)508 "Development of agri-environmental indicators for monitoring the integration of environmental concerns into the Common Agricultural Policy" (E. U. R. 25114 EN (ed.)). Publications Office of the European Union. http://agrienv.jrc.ec.europa.eu/publications/pdfs/EUR_25114.pdf

Ponjoan, A., Blanch, J., Alves-Cabratosa, L., Martí-Lluch, R., Comas-Cufí, M., Cirach, M., Nieuwenhuijsen, M., Garcia-Gil, M. del M., & Ramos, R. (2021). Impact of residential greenness on myocardial infarction in population with diabetes: A sex-dependent association? Environmental Research, 112449. https://doi.org/10.1016/J.ENVRES.2021.112449

Princé, K., Lorrillière, R., Barbet-Massin, M., Jiguet, F., 2013. Predicting the fate of French bird communities under agriculture and climate change scenarios. Environ.Sci. Pol. 33, 120–132.

Rega, C., Short, C., Pérez-Soba, M., & Luisa Paracchini, M. (2020). A classification of European agricultural land using an energy-based intensity indicator and detailed crop description. Landscape and Urban Planning, 198(December 2018), 103793. https://doi.org/10.1016/j.landurbplan.2020.103793

Rehman, S., Tiwary, N.K. & Urfi, A.J. Conservation monitoring of a polluted urban river: an occupancy modeling study of birds in the Yamuna of Delhi. Urban Ecosyst 24, 1399–1411 (2021). https://doi.org/10.1007/s11252-021-01127-1

Romano, B., Zullo, F., Fiorini, L., Ciabò, S., & Marucci, A. (2017). Sprinkling: An approach to describe urbanization dynamics in Italy. Sustainability (Switzerland), 9(1). https://doi.org/10.3390/su9010097

Roswell, M., Dushoff, J., Winfree, R., 2021 A conceptual guide to measuring species diversity, Oikos, https://doi.org/10.1111/oik.07202

Saganeiti, L., Favale, A., Pilogallo, A., Scorza, F., & Murgante, B. (2018). Assessing urban fragmentation at regional scale using sprinkling indexes. Sustainability (Switzerland), 10(9), 1–23. https://doi.org/10.3390/su10093274

Regulation (EU) 2017/2391 of the European Parliament and of the Council of 12 December 2017 amending Regulation (EC) No 1059/2003 as regards the territorial typologies (Tercet)

https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex:32017R2391

Sanders Todd A (1998) Breeding bird community composition in relation to riparian vegetation structure in the western United States. J Wildl Manage 62:461–473

Schwartz, M. W., Thorne, J. H., & Viers, J. H. (2006). Biotic homogenization of the California flora in urban and urbanizing regions. Biological Conservation, 127(3), 282–291. https://doi.org/10.1016/j.biocon.2005.05.017

Steinhardt, U., Herzog, F., Lausch, A., Mu¨ller, E., & Lehmann, S. (1999). Hemeroby index for landscape monitoring and evaluation. In Y. A. Pykh Hyatt, D.E., Lenz, R.J. (Eds.) (Ed.), Environmental Indices—Systems Analysis Approach. (pp. 237–254). EOLSS.

Taubenboock, H., Reiter, M., Dosch, F., Leichtle, T., Weigand, M., & Wurm, M. (2021). Which city is the greenest ? A multi-dimensional deconstruction of city rankings. Computers, Environment and Urban Systems, 89. https://doi.org/10.1016/j.compenvurbsys.2021.101687

Teillard F, Jiguet F, Tichit M (2015) The Response of Farmland Bird Communities to Agricultural Intensity as Influenced by Its Spatial Aggregation. PLoS ONE 10:e0119674. doi: 10.1371/journal.pone.0119674

Venables, W.N.; Ripley, B.D. Modern Applied Statistics with S. Statistics and Computing; Springer: New York, NY, USA, 2002

Vergnes A, Kerbiriou C, Clergeau P (2013) Ecological corridors also operate in an urban matrix: a test case with garden shrews. Urban Ecosyst 16:511–525. https://doi.org/10.1007/s11252-013-0289-0

Vergnes A, Le Viol I, Clergeau P (2012) Green corridors in urban landscapes affect the arthropod communities of domestic gardens. Biol Conserv 145:171–178. https://doi.org/10.1016/j.biocon.2011.11.002

Vogt, P. (2020). User Guide of GuidosToolbox. October, 1–74.

Vogt, P., & Riitters, K. (2017). GuidosToolbox: universal digital image object analysis. European Journal of Remote Sensing, 50(1), 352–361. https://doi.org/10.1080/22797254.2017.1330650

Vogt, P., Riitters, K., Rambaud, P., Lindquist, E., & Pekkarinen, A. (2022). Software note. 1–7. https://doi.org/10.1111/ecog.05864

Yamada I., in International Encyclopedia of Human Geography, 2009 (https://www.sciencedirect.com/topics/earth-and-planetary-sciences/spatial-analysis#:~:text=Edge%20effects%20are%20important%20for,be%20biased%20due%20to%20unrecorded)

Ying, J., Zhang, X., Zhang, Y., & Bilan, S. (2021). Green infrastructure: systematic literature review. Economic Research-Ekonomska Istrazivanja, 0(0), 1–22. https://doi.org/10.1080/1331677X.2021.1893202

UICN Comité français & MNHN (2020). La Liste rouge des espèces menacées en France. Paris, France Liste-rouge-Oiseaux-de-France-metropolitaine.pdf (uicn.fr)

United Nations et al. (2021). System of Environmental-Economic Accounting-

Ecosystem Accounting (SEEA EA). White cover publication, pre-edited text subject to official editing.

Available at: https://seea.un.org/ecosystem-accounting

Zulian, G., Thijssen, M., Günther, S., & Maes, J. (2018). Enhancing Resilience Of Urban Ecosystems through Green Infrastructure (EnRoute). Progress report. Publications Office of the European Union. https://doi.org/10.2760/958542

Zulian G, Marando F, Mentaschi L, Alzetta C, Wilk B, Maes J (2022) Green balance in urban areas as an indicator for policy support: a multi-level application. One Ecosystem 7: e72685. https://doi.org/10.3897/oneeco.7.e72685

List of abbreviations and definitions

GI: Green Infrastructure

GCA: Green City Accord

SDGs: United Nations Sustainable Development Goals

NBS: Nature Based Solutions

EnRoute: Enhancing Resilience of urban ecosystems through green infrastructure

List of boxes

List of Annexes

List of figures

List of tables

Annexes

Annex 1: SDGs and the European Policies

Author: Giulia Barbero Vignola

Annex 1 - Table 1: Detail of goals and targets detected, EU Green Deal.

GOAL 2: ZERO HUNGER **End hunger, achieve food security and improved nutrition and promote sustainable agriculture**
2.1 By 2030, end hunger and ensure access by all people, in particular the poor and people in vulnerable situations, including infants, to safe, nutritious and sufficient food all year round
2.2 By 2030, end all forms of malnutrition, including achieving, by 2025, the internationally agreed targets on stunting and wasting in children under 5 years of age, and address the nutritional needs of adolescent girls, pregnant and lactating women and older persons
2.3 By 2030, double the agricultural productivity and incomes of small-scale food producers, in particular women, indigenous peoples, family farmers, pastoralists and fishers, including through secure and equal access to land, other productive resources and inputs, knowledge, financial services, markets and opportunities for value addition and non-farm employment
2.4 By 2030, ensure sustainable food production systems and implement resilient agricultural practices that increase productivity and production, that help maintain ecosystems, that strengthen capacity for adaptation to climate change, extreme weather, drought, flooding and other disasters and that progressively improve land and soil quality
2.a Increase investment, including through enhanced international cooperation, in rural infrastructure, agricultural research and extension services, technology development and plant and livestock gene banks in order to enhance agricultural productive capacity in developing countries, in particular least developed countries
GOAL 4: QUALITY EDUCATION **Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all**
4.4 By 2030, substantially increase the number of youth and adults who have relevant skills, including technical and vocational skills, for employment, decent jobs and entrepreneurship
GOAL 6: CLEAN WATER AND SANITATION **Ensure availability and sustainable management of water and sanitation for all**
6.3 By 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally
6.4 By 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity
GOAL 7: AFFORDABLE AND CLEAN ENERGY **Ensure access to affordable, reliable, sustainable and modern energy for all**
7.1 By 2030, ensure universal access to affordable, reliable and modern energy services
7.2 By 2030, increase substantially the share of renewable energy in the global energy mix
7.3 By 2030, double the global rate of improvement in energy efficiency

GOAL 8: DECENT WORK AND ECONOMIC GROWTH **Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all**
8.1 Sustain per capita economic growth in accordance with national circumstances and, in particular, at least 7 per cent gross domestic product growth per annum in the least developed countries
8.3 Promote development-oriented policies that support productive activities, decent job creation, entrepreneurship, creativity and innovation, and encourage the formalization and growth of micro-, small- and medium-sized enterprises, including through access to financial services
8.4 Improve progressively, through 2030, global resource efficiency in consumption and production and endeavour to decouple economic growth from environmental degradation, in accordance with the 10-year framework of programmes on sustainable consumption and production, with developed countries taking the lead
8.8 Protect labour rights and promote safe and secure working environments for all workers, including migrant workers, in particular women migrants, and those in precarious employment
8.a Increase Aid for Trade support for developing countries, in particular least developed countries, including through the Enhanced Integrated Framework for Trade-Related Technical Assistance to Least Developed Countries

GOAL 9: INDUSTRY, INNOVATION AND INFRASTRUCTURE **Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation**
9.1 Develop quality, reliable, sustainable and resilient infrastructure, including regional and transborder infrastructure, to support economic development and human well-being, with a focus on affordable and equitable access for all
9.4 By 2030, upgrade infrastructure and retrofit industries to make them sustainable, with increased resource-use efficiency and greater adoption of clean and environmentally sound technologies and industrial processes, with all countries taking action in accordance with their respective capabilities
9.5 Enhance scientific research, upgrade the technological capabilities of industrial sectors in all countries, in particular developing countries, including, by 2030, encouraging innovation and substantially increasing the number of research and development workers per 1 million people and public and private research and development spending
9.a Facilitate sustainable and resilient infrastructure development in developing countries through enhanced financial, technological and technical support to African countries, least developed countries, landlocked developing countries and small island developing States

GOAL 10: REDUCED INEQUALITIES **Reduce inequality within and among countries**
10.b Encourage official development assistance and financial flows, including foreign direct investment, to States where the need is greatest, in particular least developed countries, African countries, small island developing States and landlocked developing countries, in accordance with their national plans and programmes

GOAL 11: SUSTAINABLE CITIES AND COMMUNITIES **Make cities and human settlements inclusive, safe, resilient and sustainable**
11.2 By 2030, provide access to safe, affordable, accessible and sustainable transport systems for all, improving road safety, notably by expanding public transport, with special attention to the needs of those in vulnerable situations, women, children, persons with disabilities and older persons
11.3 By 2030, enhance inclusive and sustainable urbanization and capacity for participatory, integrated and sustainable human settlement planning and management in all countries
11.6 By 2030, reduce the adverse per capita environmental impact of cities, including by paying special attention to air quality and municipal and other waste management
11.a Support positive economic, social and environmental links between urban, peri-urban and rural areas by strengthening national and regional development planning

GOAL 12: RESPONSIBLE CONSUMPTION AND PRODUCTION
Ensure sustainable consumption and production patterns

12.2 By 2030, achieve the sustainable management and efficient use of natural resources
12.3 By 2030, halve per capita global food waste at the retail and consumer levels and reduce food losses along production and supply chains, including post-harvest losses
12.4 By 2020, achieve the environmentally sound management of chemicals and all wastes throughout their life cycle, in accordance with agreed international frameworks, and significantly reduce their release to air, water and soil in order to minimize their adverse impacts on human health and the environment
12.5 By 2030, substantially reduce waste generation through prevention, reduction, recycling and reuse
12.7 Promote public procurement practices that are sustainable, in accordance with national policies and priorities
12.8 By 2030, ensure that people everywhere have the relevant information and awareness for sustainable development and lifestyles in harmony with nature
12.a Support developing countries to strengthen their scientific and technological capacity to move towards more sustainable patterns of consumption and production
12.c Rationalize inefficient fossil-fuel subsidies that encourage wasteful consumption by removing market distortions, in accordance with national circumstances, including by restructuring taxation and phasing out those harmful subsidies, where they exist, to reflect their environmental impacts, taking fully into account the specific needs and conditions of developing countries and minimizing the possible adverse impacts on their development in a manner that protects the poor and the affected communities

GOAL 13: CLIMATE ACTION
Take urgent action to combat climate change and its impacts

13.1 Strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries
13.2 Integrate climate change measures into national policies, strategies and planning
13.3 Improve education, awareness-raising and human and institutional capacity on climate change mitigation, adaptation, impact reduction and early warning
13.a Implement the commitment undertaken by developed-country parties to the United Nations Framework Convention on Climate Change to a goal of mobilizing jointly $100 billion annually by 2020 from all sources to address the needs of developing countries in the context of meaningful mitigation actions and transparency on implementation and fully operationalize the Green Climate Fund through its capitalization as soon as possible
13.b Promote mechanisms for raising capacity for effective climate change-related planning and management in least developed countries and small island developing States, including focusing on women, youth and local and marginalized communities

GOAL 14: LIFE BELOW WATER
Conserve and sustainably use the oceans, seas and marine resources for sustainable development

14.2 By 2020, sustainably manage and protect marine and coastal ecosystems to avoid significant adverse impacts, including by strengthening their resilience, and take action for their restoration in order to achieve healthy and productive oceans
14.3 Minimize and address the impacts of ocean acidification, including through enhanced scientific cooperation at all levels
14.4 By 2020, effectively regulate harvesting and end overfishing, illegal, unreported and unregulated fishing and destructive fishing practices and implement science-based management plans, in order to restore fish stocks in the shortest time feasible, at least to levels that can produce maximum sustainable yield as determined by their biological characteristics
14.5 By 2020, conserve at least 10 per cent of coastal and marine areas, consistent with national and international law and based on the best available scientific information

GOAL 15: LIFE ON LAND **Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, halt and reverse land degradation and halt biodiversity loss**
15.1 By 2020, ensure the conservation, restoration and sustainable use of terrestrial and inland freshwater ecosystems and their services, in particular forests, wetlands, mountains and drylands, in line with obligations under international agreements
15.2 By 2020, promote the implementation of sustainable management of all types of forests, halt deforestation, restore degraded forests and substantially increase afforestation and reforestation globally
15.3 By 2030, combat desertification, restore degraded land and soil, including land affected by desertification, drought and floods, and strive to achieve a land degradation-neutral world
15.5 Take urgent and significant action to reduce the degradation of natural habitats, halt the loss of biodiversity and, by 2020, protect and prevent the extinction of threatened species
15.9 By 2020, integrate ecosystem and biodiversity values into national and local planning, development processes, poverty reduction strategies and accounts
15.a Mobilize and significantly increase financial resources from all sources to conserve and sustainably use biodiversity and ecosystems
15.b Mobilize significant resources from all sources and at all levels to finance sustainable forest management and provide adequate incentives to developing countries to advance such management, including for conservation and reforestation
GOAL 16: PEACE, JUSTICE AND STRONG INSTITUTIONS **Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels**
16.3 Promote the rule of law at the national and international levels and ensure equal access to justice for all
16.b Promote and enforce non-discriminatory laws and policies for sustainable development
GOAL 17: PARTNERSHIP FOR THE GOALS **Strengthen the means of implementation and revitalize the global partnership for sustainable development**
17.6 Enhance North-South, South-South and triangular regional and international cooperation on and access to science, technology and innovation and enhance knowledge-sharing on mutually agreed terms, including through improved coordination among existing mechanisms, in particular at the United Nations level, and through a global technology facilitation mechanism
17.10 Promote a universal, rules-based, open, non-discriminatory and equitable multilateral trading system under the World Trade Organization, including through the conclusion of negotiations under its Doha Development Agenda
17.13 Enhance global macroeconomic stability, including through policy coordination and policy coherence
17.17 Encourage and promote effective public, public private and civil society partnerships, building on the experience and resourcing strategies of partnerships

Annex 1 - Table 2: Detail of goals and targets detected, EU Biodiversity Strategy 2020-2030

	2020 STRATEGY	2030 STRATEGY
GOAL 2: ZERO HUNGER **End hunger, achieve food security and improved nutrition and promote sustainable agriculture**	✓	✓
2.1 By 2030, end hunger and ensure access by all people, in particular the poor and people in vulnerable situations, including infants, to safe, nutritious and sufficient food all year round		✓
2.2 By 2030, end all forms of malnutrition, including achieving, by 2025, the internationally agreed targets on stunting and wasting in children under 5 years of age, and address the nutritional needs of adolescent girls, pregnant and lactating women and older persons		✓
2.4 By 2030, ensure sustainable food production systems and implement resilient agricultural practices that increase productivity and production, that help maintain ecosystems, that strengthen capacity for adaptation to climate change, extreme weather, drought, flooding and other disasters and that progressively improve land and soil quality	✓	✓
2.5 By 2020, maintain the genetic diversity of seeds, cultivated plants and farmed and domesticated animals and their related wild species, including through soundly managed and diversified seed and plant banks at the national, regional and international levels, and promote access to and fair and equitable sharing of benefits arising from the utilization of genetic resources and associated traditional knowledge, as internationally agreed.	✓	✓
GOAL 4: QUALITY EDUCATION **Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all**	✓	✓
4.4 By 2030, substantially increase the number of youth and adults who have relevant skills, including technical and vocational skills, for employment, decent jobs and entrepreneurship	✓	✓
4.7 By 2030, ensure that all learners acquire the knowledge and skills needed to promote sustainable development, including, among others, through education for sustainable development and sustainable lifestyles, human rights, gender equality, promotion of a culture of peace and non-violence, global citizenship and appreciation of cultural diversity and of culture's contribution to sustainable development		✓
GOAL 6: CLEAN WATER AND SANITATION **Ensure availability and sustainable management of water and sanitation for all**		✓
6.4 By 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity		✓
6.5 By 2030, implement integrated water resources management at all levels, including through transboundary cooperation as appropriate		✓
6.6 By 2020, protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes		✓
GOAL 7: AFFORDABLE AND CLEAN ENERGY **Ensure access to affordable, reliable, sustainable and modern energy for all**		✓
7.2 By 2030, increase substantially the share of renewable energy in the global energy mix		✓
GOAL 8: DECENT WORK AND ECONOMIC GROWTH **Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all**	✓	✓
8.1 Sustain per capita economic growth in accordance with national circumstances and, in particular, at least 7 per cent gross domestic product growth per annum in the least developed countries	✓	
8.2 Achieve higher levels of economic productivity through diversification, technological upgrading and innovation, including through a focus on high-value added and labour-intensive sectors		✓
8.3 Promote development-oriented policies that support productive activities, decent job creation, entrepreneurship, creativity and innovation, and encourage the formalization and growth of micro-, small- and medium-sized enterprises, including through access to financial services		✓
8.4 Improve progressively, through 2030, global resource efficiency in consumption and production and endeavour to decouple economic growth from environmental degradation, in accordance with the 10-year framework of programmes on sustainable consumption and production, with developed countries taking the lead	✓	
8.9 By 2030, devise and implement policies to promote sustainable tourism that creates jobs and promotes local culture and products	✓	

8.a Increase Aid for Trade support for developing countries, in particular least developed countries, including through the Enhanced Integrated Framework for Trade-Related Technical Assistance to Least Developed Countries		✓
GOAL 9: INDUSTRY, INNOVATION AND INFRASTRUCTURE **Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation**	✓	✓
9.5 Enhance scientific research, upgrade the technological capabilities of industrial sectors in all countries, in particular developing countries, including, by 2030, encouraging innovation and substantially increasing the number of research and development workers per 1 million people and public and private research and development spending	✓	✓
GOAL 11: SUSTAINABLE CITIES AND COMMUNITIES **Make cities and human settlements inclusive, safe, resilient and sustainable**	✓	✓
11.3 By 2030, enhance inclusive and sustainable urbanization and capacity for participatory, integrated and sustainable human settlement planning and management in all countries		✓
11.4 Strengthen efforts to protect and safeguard the world's cultural and natural heritage	✓	
11.6 By 2030, reduce the adverse per capita environmental impact of cities, including by paying special attention to air quality and municipal and other waste management		✓
11.7 By 2030, provide universal access to safe, inclusive and accessible, green and public spaces, in particular for women and children, older persons and persons with disabilities		✓
11.a Support positive economic, social and environmental links between urban, peri-urban and rural areas by strengthening national and regional development planning	✓	✓
GOAL 12: RESPONSIBLE CONSUMPTION AND PRODUCTION **Ensure sustainable consumption and production patterns**	✓	✓
12.2 By 2030, achieve the sustainable management and efficient use of natural resources	✓	
12.4 By 2020, achieve the environmentally sound management of chemicals and all wastes throughout their life cycle, in accordance with agreed international frameworks, and significantly reduce their release to air, water and soil in order to minimize their adverse impacts on human health and the environment		✓
12.5 By 2030, substantially reduce waste generation through prevention, reduction, recycling and reuse		✓
12.7 Promote public procurement practices that are sustainable, in accordance with national policies and priorities		✓
GOAL 13: CLIMATE ACTION **Take urgent action to combat climate change and its impacts**	✓	✓
13.1 Strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries	✓	✓
13.2 Integrate climate change measures into national policies, strategies and planning		✓
GOAL 14: LIFE BELOW WATER **Conserve and sustainably use the oceans, seas and marine resources for sustainable development**	✓	✓
14.1 By 2025, prevent and significantly reduce marine pollution of all kinds, in particular from land-based activities, including marine debris and nutrient pollution	✓	✓
14.2 By 2020, sustainably manage and protect marine and coastal ecosystems to avoid significant adverse impacts, including by strengthening their resilience, and take action for their restoration in order to achieve healthy and productive oceans	✓	✓
14.4 By 2020, effectively regulate harvesting and end overfishing, illegal, unreported and unregulated fishing and destructive fishing practices and implement science-based management plans, in order to restore fish stocks in the shortest time feasible, at least to levels that can produce maximum sustainable yield as determined by their biological characteristics	✓	✓
14.5 By 2020, conserve at least 10 per cent of coastal and marine areas, consistent with national and international law and based on the best available scientific information	✓	✓
14.6 By 2020, prohibit certain forms of fisheries subsidies which contribute to overcapacity and overfishing, eliminate subsidies that contribute to illegal, unreported and unregulated fishing and refrain from introducing new such subsidies, recognizing that appropriate and effective special and differential treatment for developing and least developed countries should be an integral part of the World Trade Organization fisheries subsidies negotiation	✓	✓
14.c Enhance the conservation and sustainable use of oceans and their resources by implementing international law as reflected in the United Nations Convention on the Law of the Sea, which provides the legal framework for the conservation and sustainable use of oceans and their resources, as recalled in paragraph 158 of "The future we want"		✓

GOAL 15: LIFE ON LAND **Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, halt and reverse land degradation and halt biodiversity loss**	✓	✓
15.1 By 2020, ensure the conservation, restoration and sustainable use of terrestrial and inland freshwater ecosystems and their services, in particular forests, wetlands, mountains and drylands, in line with obligations under international agreements	✓	✓
15.2 By 2020, promote the implementation of sustainable management of all types of forests, halt deforestation, restore degraded forests and substantially increase afforestation and reforestation globally	✓	✓
15.3 By 2030, combat desertification, restore degraded land and soil, including land affected by desertification, drought and floods, and strive to achieve a land degradation-neutral world		✓
15.5 Take urgent and significant action to reduce the degradation of natural habitats, halt the loss of biodiversity and, by 2020, protect and prevent the extinction of threatened species	✓	✓
15.6 Promote fair and equitable sharing of the benefits arising from the utilization of genetic resources and promote appropriate access to such resources, as internationally agreed	✓	
15.7 Take urgent action to end poaching and trafficking of protected species of flora and fauna and address both demand and supply of illegal wildlife products		✓
15.8 By 2020, introduce measures to prevent the introduction and significantly reduce the impact of invasive alien species on land and water ecosystems and control or eradicate the priority species	✓	✓
15.9 By 2020, integrate ecosystem and biodiversity values into national and local planning, development processes, poverty reduction strategies and accounts	✓	✓
15.a Mobilize and significantly increase financial resources from all sources to conserve and sustainably use biodiversity and ecosystems	✓	✓
15.b Mobilize significant resources from all sources and at all levels to finance sustainable forest management and provide adequate incentives to developing countries to advance such management, including for conservation and reforestation	✓	
15.c Enhance global support for efforts to combat poaching and trafficking of protected species, including by increasing the capacity of local communities to pursue sustainable livelihood opportunities		✓
GOAL 16: PEACE, JUSTICE AND STRONG INSTITUTIONS **Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels**		✓
16.3 Promote the rule of law at the national and international levels and ensure equal access to justice for all		✓
16.7 Ensure responsive, inclusive, participatory and representative decision-making at all levels		✓
GOAL 17: PARTNERSHIP FOR THE GOALS **Strengthen the means of implementation and revitalize the global partnership for sustainable development**	✓	✓
17.1 Strengthen domestic resource mobilization, including through international support to developing countries, to improve domestic capacity for tax and other revenue collection		✓
17.13 Enhance global macroeconomic stability, including through policy coordination and policy coherence		✓
17.14 Enhance policy coherence for sustainable development		✓
17.17 Encourage and promote effective public, public private and civil society partnerships, building on the experience and resourcing strategies of partnerships	✓	

Annex 2. Input data

Author: Grazia Zulian

Data set	Owner	Website	year	Data type	Used in Chapter(s)
Land	EEA	Corine Land Cover 2000,2018 (raster 100m) version 20 accounting layer, Jun. 2019 from EEA https://www.eea.europa.eu/data-and-maps/data/corine-land-cover-accounting-layers	2000, 2018	Raster 100 m	Chapter 2 Section 1 Section 2 Section 3
Riparian zone delineation	EEA	https://land.copernicus.eu/local/riparian-zones/riparian-zones-delineation?tab=download	2015	Raster 20 m	Chapter 3
Imperviousnes s	EEA	https://land.copernicus.eu/pan-european/high-resolution-layers/imperviousness/status-maps	2018	Raster 20 m	Chapter 3
HNV	EEA	https://sdi.eea.europa.eu/catalogue/srv/eng/catalog.search#/search?any=hnv&facet.q=status%2Fnotobsolete&from=1&to=30	2012	Raster 100 m	Chapter 3
Tree cover	EEA	https://land.copernicus.eu/pan-european/high-resolution-layers/forests/tree-cover-density/status-maps/tree-cover-density-2018	2018	Raster 10 m	Chapter 2 Section 2 Chapter 3
NDVI	GEE	https://developers.google.com/earth-engine/datasets/catalog/LANDSAT_LE07_C01_T1_ANNUAL_GREENEST_TOA	1996-2018	Raster 30 m	Chapter 2 Section 2 Chapter 3
Natura 2000	EEA	https://www.eea.europa.eu/data-and-maps/data/natura-11	2020	vector	Chapter 2

					Section 1 Chapter 3
CDDA	EEA	https://www.eea.europa.eu/data-and-maps/data/nationally-designated-areas-national-cdda-16	2021	vector	Chapter 3
Population	EUROSTAT	https://ec.europa.eu/eurostat/web/cities/data/database	2018	Tabular	Chapter 3 FUA level
Population	EUROSTAT	https://ec.europa.eu/eurostat/web/gisco/geodata/reference-data/population-distribution-demography/geostat	2018	Raster 1000 m	Chapter 2 Section 1
Population (GHS-POP grid)	JRC	https://ghsl.jrc.ec.europa.eu/datasets.php	2015	Raster 250 m	Chapter 3 site level
Degree of Urbanisation (GHS-SMOD grid)	JRC	https://ghsl.jrc.ec.europa.eu/datasets.php (Florczyk et al., 2019)	2015		Chapter 2 Section 1 Chapter 3
GHS-BUILD grid	JRC	https://ghsl.jrc.ec.europa.eu/datasets.php (Florczyk et al., 2019)	2015	Raster 10 m	Chapter 3
GHS-FUA	JRC	https://ghsl.jrc.ec.europa.eu/datasets.php Schiavina et al. 2019 Moreno-Monroy et al. 2020	2015	Raster	Chapter 2 Section 3
Degree of Urbanisation (LAU level)	EUROSTAT	https://ec.europa.eu/eurostat/web/gisco/geodata/reference-data/population-distribution-demography/degurba	2020	Vector (1:1	Chapter 2 Section 1

				million)	Section 3
Urban Audit 2018 (FUA)	EUROSTAT	https://ec.europa.eu/eurostat/web/gisco/geodata/reference-data/administrative-units-statistical-units/urban-audit	2018	Vector (1:1 million)	Chapter 2 Section 1 Section 2 Section 3 Chapter 3
Intensity of management in agricultural land	JRC	Rega, C., Short, C., Pérez-Soba, M., & Paracchini, M.L. (2020). A classification of European agricultural land using an energy-based intensity indicator and detailed crop description. *Landscape and Urban Planning, 198* doi:10.1016/j.landurbplan.2020.103793	2015	Raster 1000 m	Chapter 3
Forest Management		Nabuurs GJ, Verweij P, Van Eupen M, Pérez-Soba M, Pülzl H, Hendriks K (2019) Next-generation information to support a sustainable course for European forests. Nat Sustain 2(9): 815–818. doi: 10.1038/s41893-019-0374-3		Raster 1000 m	Chapter 3

Annex 3. LAU refined methodology

Authors: Javier Babi Almenar and Grazia Zulian

Rules applied to refine LAUs classified as DEGURBA Class 1 and 2 (version 2020)

1) LAUs below 1000 Population were removed.

They were not representing towns, sometimes were classified as class 2 because were adjacent to LAUs classified as Towns and the last raster cell classified as town was partially in this LAU. Other times it was not clear why they were class 2, there was not even a real settlement on some of them. After 1000 Population, from time to time LAUs were correctly classified, they were just very small. It was not possible to move beyond this threshold without removing few LAUs that were towns.

2) LAUs with a Population Density below 10 inhabitants/km2 were removed

Some LAUs are very large, especially in the north of EU (e.g .Sweden) and could end occupying a territory equivalent to 1/3 of Belgium. In Sweden, they contain clearly small settlements that in practice are towns (10.000-20.000 inhab), but in zones that occupy less than 10% of the LAU*. Then, those pop up as mistakes to other people. Putting the threshold at 10 permits to remove those areas, and also some in the south of Europe (mainly Spain) that are extremely small towns (in Spain they will be considered rural in our own classification system) in large LAUs. It was possible to raise this threshold but then many towns in Sweden were dissapearing, and some clearly have a town structure, the issue is that they are in a extremely large LAU.

3) DEGURBA classes were recalculated to spot mistakes using GEOSTAT2018_1kmGrid, everything that was not a Class 2 or 1 was removed

I have checked the population data and overlap the pop grid used, in principle GEOSTAT 2018 (or next version and is still not publicly available), for calculating the DEGURBA raster and then do the DEGURBA vector of 2018 and 2020. I did it because many LAUs were strange Class 2. Then I repeat the entire process, but only looking to exclude Class 3, not to differentiate Class 1 and Class 2. Then, I have identified cells above 300 inhb/km2 that form zones of at least 50.000inhab considering 8-neihbourhood adjacency (including cells in diagonal). Later, I have checked if those zones were corresponding to more than 50% of the population in each LAU. If they did it, they were classified as 2, if not as 3. As a result, I have identified LAUs classified as 2 that were class 3. Many of them did not have any cell classified as town or urban. I have double checked with google map. Most of those LAUs did not have any real settlement below.

Future works for further refinement of LAUs classified as DEGURBA 1 or 2

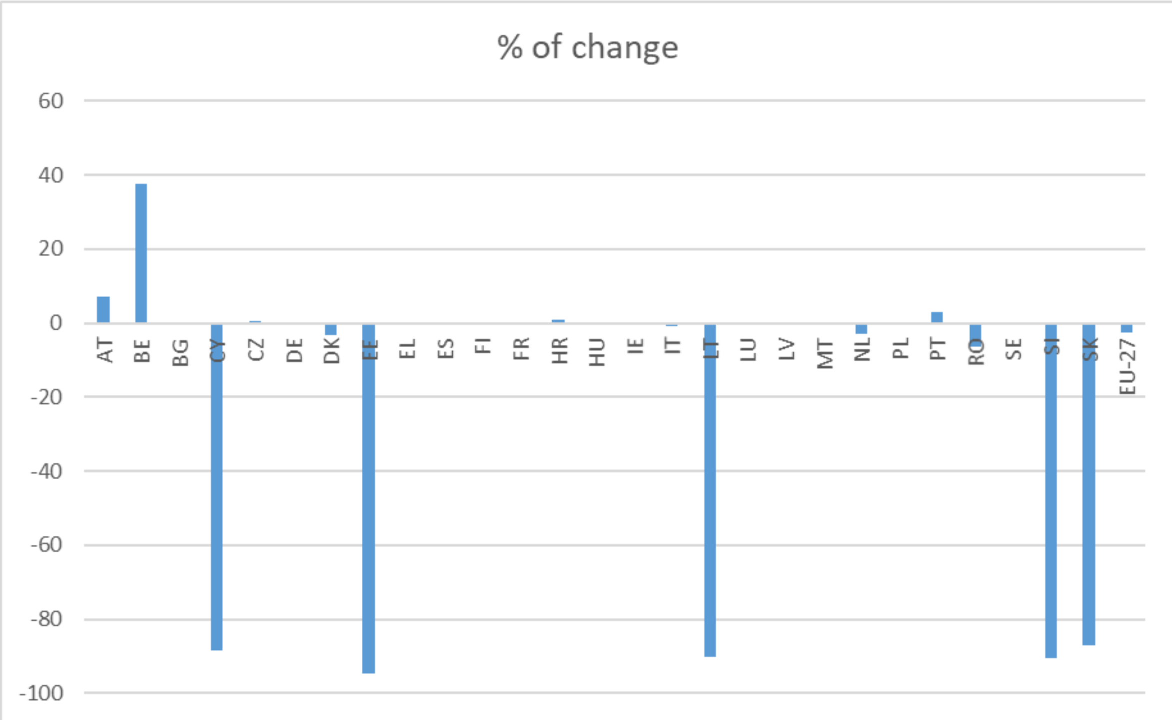
The main issue are the extremes (LAUs extremely large and extremely small) and the simplistic way in which the vector DEGURBA classes are generated. This procedure generates issues when working with LAUs extremely small or large.

The same methodology has been implemented to remove LAU in NO CH UK MK (needed for the GI integrity analysis). For Serbia-Montenegro Albania Bosnia the global FUA dataset was used (GHS-FUA).

Over 1524, LAU 196 removed

FUA change between 2018 and 2020 (error already communicated to EUROSTAT)

Annex 3-Figure 1: change (%) in FUA extent between 2018 and 2020. In Belgium one new FUA has been included in 2020. In CY, EE, LT, SI, SK FUA in 2020 correspond to core cities.


% of change
60
40
20
0
-20
-40
-60
-80
-100
AT
BE
BG
CY
CZ
DE
DK
EE
EL
ES
FI
FR
HR
HU
IE
IT
LT
LU
LV
MT
NL
PL
PT
RO
SE
SI
SK
EU-27

Annex 4. The Updated Hemeroby Index

Author: Grazia Zulian

The Hemeroby index is a measure for the "human influence on ecosystems" (Kowarik 1999). For this application we updated the European hemeroby map (originally developed by Paracchini and Capitani, 2011).

Each ecosystem type has been recoded according to the Hemeroby categories considering the ecosystem condition indicators developed in previous studies.

Artificial areas and settlements

Input data: Corine Land Cover (2018) and the GHSL-European Settlement-Map (which is a 100 m resolution map that provides the share of green per pixel).

Annex 4– Table 1:

CLC		ESM	
Level 1	Level 3	<0.5	>0.5
Artificial	Continuous urban fabric	9	8
Artificial	Discontinuous urban fabric	9	7
Artificial	Industrial or commercial units	9	8
Artificial	Road and rail networks and associated land	9	8
Artificial	Port areas	9	8
Artificial	Airports	9	8
Artificial	Mineral extraction sites	9	8
Artificial	Dump sites	9	8
Artificial	Construction sites	9	8
Artificial	Green urban areas	8	7
Artificial	Sport and leisure facilities	8	7

Forest

Input data: Corine Land Cover (2018) and a forest management dataset implemented by Nabuurs et al. (2019) where Forest is classified in 5 management practices levels.

Annex 4- Table 2:

	Forest management categories					
	Strict nature management	Close-to-nature management	Low-intensity management	Multifunctional management	Intensive management	Very intensive management
Broad-leaved forest	1	2	3	3	4	5
Coniferous forest	1	2	3	3	4	5
Mixed forest	1	2	3	3	4	5

Agro-ecosystems

Input data: Corine Land Cover (2018) and a forest management dataset implemented by Rega et al. (2020) where Agro-ecosystems are classified according to the total energy input in agriculture.

Annex 4- Table 3:

CLC		Total energy input in agricultural land		
LABEL1	LABEL3	low	medium	high
Agricultural areas	Non-irrigated arable land	5	6	7
	Permanently irrigated land	5	6	7
	Rice fields			
	Vineyards	4	5	6
	Fruit trees and berry plantations	4	5	6
	Olive groves	4	5	6
	Pastures	3	4	5
	Annual crops associated with permanent crops	4	5	6
	Complex cultivation patterns	4	5	6
	Land principally occupied by agriculture, with significant areas of natural vegetation	4	5	6

	Agro-forestry areas	3	4	5

Seminatural vegetation

Annex 4- Table 4:

CLC		
LEVEL 1	LEVEL 2	hemeroby
Forest and semi natural areas	Natural grasslands	3
	Moors and heathland	2
	Sclerophyllous vegetation	2
	Transitional woodland-shrub	2
	Beaches, dunes, sands	2
	Bare rocks	1
	Sparsely vegetated areas	2
	Burnt areas	6
	Glaciers and perpetual snow	1

Water bodies and wetlands

Annex 4- Table 5:

CLC		
LEVEL 1	LEVEL 3	hemeroby
Wetlands	Inland marshes	2
	Peat bogs	2
	Salt marshes	2
	Salines	6
	Intertidal flats	1
Water bodies	Water bodies	2
	Coastal lagoons	2
	Estuaries	2

Annex 5. Biotic homogenisation: birds data

Authors: Karine Princè and Grazia Zulian

Table A5 1. Species names (n=170), associated traits and IUCN red list category in France and at the global level (UICN, 2020). 'SSI', 'SGIc' and 'STrI' correspond respectively to the Species Specialization Index (Julliard et al. 2006), Species Generalization Index (Godet et al. 2015) and the Species Trophic Index (Princé et al. 2013). LC = Least Concern; NT=Near threatened; VU=vulnerable; EN=Endangered; CR=Critically Endangered; EW= Extinct in the wild; EX=Extinct.

English name	Scientific name	SSI	SGIc	exp(STrI)	IUCN red list France	IUCN red list Global
Common Snipe	Gallinago gallinago	3	46.3	20.1	CR	LC
Ortolan Bunting	Emberiza hortulana	1.3	40.7	19.1	EN	LC
Reed Bunting	Emberiza schoeniclus	2.4	18.5	10	EN	LC
Eurasian Tree Sparrow	Passer montanus	1.3	37.7	8.6	EN	LC
Gray-headed Woodpecker	Picus canus	1.3	35.4	20.1	EN	LC
Dartford Warbler	Sylvia undata	2.1	25.4	18.2	EN	NT
Little Bustard	Tetrax tetrax	2.2	40.1	9	EN	NT
Common Sandpiper	Actitis hypoleucos	2.6	29.5	20.1	NT	LC
Eurasian Skylark	Alauda arvensis	1.2	0	9.5	NT	LC
Common Swift	Apus apus	1.3	26.8	20.1	NT	LC
Great Egret	Ardea alba	3	44.3	44.7	NT	LC
Cetti's Warbler	Cettia cetti	1.4	21	20.1	NT	LC
Black-headed Gull	Chroicocephalus ridibundus	1.1	38.3	20.1	NT	LC
Eurasian Marsh-Harrier	Circus aeruginosus	2.1	32.1	54.6	NT	LC
Montagu's Harrier	Circus pygargus	1.7	41.3	36.6	NT	LC
European Roller	Coracias garrulus	1.2	44.2	20.1	NT	LC
Common House-Martin	Delichon urbicum	1.3	34.2	20.1	NT	LC
Eurasian Kestrel	Falco tinnunculus	0.7	29.2	47	NT	LC
Barn Swallow	Hirundo rustica	0.7	24.8	20.1	NT	LC
Red-backed Shrike	Lanius collurio	1.1	24.5	23.3	NT	LC
European Herring Gull	Larus argentatus	0.6	43.9	27.1	NT	LC
Common Grasshopper-Warbler	Locustella naevia	1.2	36.5	20.1	NT	LC

English name	Scientific name	SSI	SGIc	exp(STrI)	IUCN red list France	IUCN red list Global
Spotted Flycatcher	Muscicapa striata	1	42.9	20.1	NT	LC
Black-crowned Night-Heron	Nycticorax nycticorax	2.4	46.7	36.6	NT	LC
Northern Wheatear	Oenanthe oenanthe	1.7	34.6	19.1	NT	LC
Wood Warbler	Phylloscopus sibilatrix	1.7	15	19.1	NT	LC
Willow Warbler	Phylloscopus trochilus	1.1	28.3	19.1	NT	LC
Water Rail	Rallus aquaticus	2.3	37.8	22.2	NT	LC
Goldcrest	Regulus regulus	1.5	14.7	20.1	NT	LC
Garden Warbler	Sylvia borin	0.7	33.4	13.5	NT	LC
Sardinian Warbler	Sylvia melanocephala	0.8	20.6	14.9	NT	LC
Northern Lapwing	Vanellus vanellus	2.2	37.4	18.2	NT	NT
Great Reed-Warbler	Acrocephalus arundinaceus	2.9	41.1	19.1	VU	LC
Common Kingfisher	Alcedo atthis	1.9	27	45.2	VU	LC
Meadow Pipit	Anthus pratensis	1.4	36.8	15.6	VU	NT
Common Pochard	Aythya ferina	2.7	45.6	8.5	VU	VU
Eurasian Linnet	Carduelis cannabina	0.7	33.6	7.8	VU	LC
European Goldfinch	Carduelis carduelis	0.7	26	7.8	VU	LC
European Greenfinch	Carduelis chloris	0.7	18.9	7.8	VU	LC
Zitting Cisticola	Cisticola juncidis	2.1	16.6	20.1	VU	LC
Lesser Spotted Woodpecker	Dendrocopos minor	0.9	40.4	20.1	VU	LC
Yellowhammer	Emberiza citrinella	0.7	24.4	10	VU	LC
European Pied Flycatcher	Ficedula hypoleuca	1.3	45.7	20.1	VU	LC
Icterine Warbler	Hippolais icterina	2.1	43.2	19.1	VU	LC
Woodchat Shrike	Lanius senator	1.2	39.5	21.1	VU	LC
Red Kite	Milvus milvus	1.3	45.1	47	VU	NT
Eurasian Curlew	Numenius arquata	2.3	40.6	20.1	VU	NT
Eurasian Bullfinch	Pyrrhula pyrrhula	1.1	29.6	8.2	VU	LC
Whinchat	Saxicola rubetra	1.5	36	20.1	VU	LC
European Serin	Serinus serinus	0.8	24.1	7.4	VU	LC

English name	Scientific name	SSI	SGIc	exp(STrI)	IUCN red list France	IUCN red list Global
European Turtle-Dove	Streptopelia turtur	0.4	35.4	7.4	VU	VU
Eurasian Sparrowhawk	Accipiter nisus	0.8	47.3	54.6	LC	LC
Marsh Warbler	Acrocephalus palustris	1.5	33.7	20.1	LC	LC
Sedge Warbler	Acrocephalus schoenobaenus	2.3	34.1	19.1	LC	LC
Eurasian Reed-Warbler	Acrocephalus scirpaceus	2.2	23.8	19.1	LC	LC
Long-tailed Tit	Aegithalos caudatus	0.6	36.5	19.1	LC	LC
Red-legged Partridge	Alectoris rufa	1.1	29.2	8.2	LC	LC
Northern Shoveler	Anas clypeata	3.6	44.9	13.5	LC	LC
Mallard	Anas platyrhynchos	1.6	12.8	13.5	LC	LC
Tawny Pipit	Anthus campestris	2	33.1	19.1	LC	LC
Water Pipit	Anthus spinoletta	3.5	44.5	20.1	LC	LC
Tree Pipit	Anthus trivialis	0.9	28.3	19.1	LC	LC
Alpine Swift	Apus melba	2.2	45.4	20.1	LC	LC
Gray Heron	Ardea cinerea	1.1	21.5	47	LC	LC
Purple Heron	Ardea purpurea	3.2	40.9	33.1	LC	LC
Little Owl	Athene noctua	1.6	42.9	28.2	LC	LC
Canada Goose	Branta canadensis	3	42.1	7.4	LC	LC
Cattle Egret	Bubulcus ibis	1.9	42.6	20.1	LC	LC
Eurasian Thick-knee	Burhinus oedicnemus	1.9	33.5	19.1	LC	LC
Common Buzzard	Buteo buteo	0.5	27	49.4	LC	LC
Eurasian Siskin	Carduelis spinus	2.1	47.5	7.6	LC	LC
Short-toed Treecreeper	Certhia brachydactyla	0.6	29.3	20.1	LC	LC
Eurasian Treecreeper	Certhia familiaris	1.9	24	19.1	LC	LC
Little Ringed Plover	Charadrius dubius	2.4	39.8	20.1	LC	LC
White Stork	Ciconia ciconia	3	37.8	36.6	LC	LC
White-throated Dipper	Cinclus cinclus	2.6	36.5	20.1	LC	LC
Short-toed Snake-Eagle	Circaetus gallicus	1.3	44.4	54.6	LC	LC
Northern Harrier	Circus cyaneus	1.3	33.1	54.6	LC	LC

English name	Scientific name	SSI	SGIc	exp(STrI)	IUCN red list France	IUCN red list Global
Great Spotted Cuckoo	Clamator glandarius	1.2	41.5	20.1	LC	LC
Hawfinch	Coccothraustes coccothraustes	1	23.5	7.8	LC	LC
Rock Pigeon	Columba livia	2	14.3	7.5	LC	LC
Stock Dove	Columba oenas	1.3	42	7.5	LC	LC
Common Wood-Pigeon	Columba palumbus	0.3	35.3	7.5	LC	LC
Common Raven	Corvus corax	1.2	42.3	15.6	LC	LC
Carrion Crow	Corvus corone	0.3	36	12.3	LC	LC
Rook	Corvus frugilegus	0.8	31.6	13.9	LC	LC
Eurasian Jackdaw	Corvus monedula	1	39.8	8.2	LC	LC
Common Cuckoo	Cuculus canorus	0.4	34.1	20.1	LC	LC
Eurasian Blue Tit	Cyanistes caeruleus	0.4	37	16.4	LC	LC
Mute Swan	Cygnus olor	2.6	38	7.4	LC	LC
Great Spotted Woodpecker	Dendrocopos major	0.6	27.3	14.9	LC	LC
Middle Spotted Woodpecker	Dendrocopos medius	1.9	19.8	14.9	LC	LC
Black Woodpecker	Dryocopus martius	1.2	23.1	20.1	LC	LC
Little Egret	Egretta garzetta	2.4	35.5	33.1	LC	LC
Corn Bunting	Emberiza calandra	1.5	13.9	9.8	LC	LC
Rock Bunting	Emberiza cia	1.5	39	10	LC	LC
Cirl Bunting	Emberiza cirlus	0.6	26.6	10	LC	LC
European Robin	Erithacus rubecula	0.5	29.7	16.9	LC	LC
Peregrine Falcon	Falco peregrinus	2.1	42.6	54.6	LC	LC
Eurasian Hobby	Falco subbuteo	1.5	45.1	25.8	LC	LC
Common Chaffinch	Fringilla coelebs	0.3	38	8.2	LC	LC
Eurasian Coot	Fulica atra	2.5	24.9	8.7	LC	LC
Crested Lark	Galerida cristata	1.7	33.3	12.8	LC	LC
Eurasian Moorhen	Gallinula chloropus	1.6	17	10.5	LC	LC
Eurasian Jay	Garrulus glandarius	0.4	31	15.2	LC	LC
Black-winged Stilt	Himantopus himantopus	2.8	33.8	20.1	LC	LC

English name	Scientific name	SSI	SGIc	exp(STrI)	IUCN red list France	IUCN red list Global
Melodious Warbler	Hippolais polyglotta	0.7	32.7	19.1	LC	LC
Mediterranean Gull	Ichthyaetus melanocephalus	2.1	44	21.1	LC	LC
Eurasian Wryneck	Jynx torquilla	1	43.4	20.1	LC	LC
Lesser Black-backed Gull	Larus fuscus	1.2	47	27.1	LC	LC
Great Black-backed Gull	Larus marinus	1.8	47.5	44.7	LC	LC
Yellow-legged Gull	Larus michahellis	1	42.7	27.1	LC	LC
Crested Tit	Lophophanes cristatus	1.6	15.2	13.5	LC	LC
Red Crossbill	Loxia curvirostra	1.8	38	8.2	LC	LC
Wood Lark	Lullula arborea	0.9	23.1	12.2	LC	LC
Common Nightingale	Luscinia megarhynchos	0.5	28.4	20.1	LC	LC
Bluethroat	Luscinia svecica	3.1	37.8	20.1	LC	LC
European Bee-eater	Merops apiaster	0.9	43.5	20.1	LC	LC
Black Kite	Milvus migrans	0.8	38.6	46.1	LC	LC
White Wagtail	Motacilla alba	0.7	29.1	20.1	LC	LC
Gray Wagtail	Motacilla cinerea	1.6	28.6	20.1	LC	LC
Western Yellow Wagtail	Motacilla flava	2.1	7.7	20.1	LC	LC
Spotted nutcracker	Nucifraga caryocatactes	2.2	39.9	10	LC	LC
Eurasian Golden Oriole	Oriolus oriolus	0.5	31.5	19.1	LC	LC
Great Tit	Parus major	0.3	40.3	17.3	LC	LC
Willow Tit	Parus montanus	1.4	34.8	13.5	LC	LC
House Sparrow	Passer domesticus	1.3	0.3	9	LC	LC
Gray Partridge	Perdix perdix	2.1	8	8.2	LC	LC
Coal Tit	Periparus ater	1.4	13.3	13.5	LC	LC
European Honey-buzzard	Pernis apivorus	1.2	45.5	20.1	LC	LC
Rock Petronia	Petronia petronia	2.4	42.4	9.2	LC	LC
Great Cormorant	Phalacrocorax carbo	1.4	42.1	54.6	LC	LC
Ring-necked Pheasant	Phasianus colchicus	0.9	32.3	9.5	LC	LC
Black Redstart	Phoenicurus ochruros	1.1	11	17.3	LC	LC

English name	Scientific name	SSI	SGIc	exp(STrI)	IUCN red list France	IUCN red list Global
Common Redstart	Phoenicurus phoenicurus	1	32.9	18.7	LC	LC
Western Bonelli's Warbler	Phylloscopus bonelli	0.9	29.8	20.1	LC	LC
Common Chiffchaff	Phylloscopus collybita	0.5	31.3	19.1	LC	LC
Eurasian Magpie	Pica pica	0.7	20.5	12.3	LC	LC
Eurasian Green Woodpecker	Picus viridis	0.4	39.9	20.1	LC	LC
Great Crested Grebe	Podiceps cristatus	3.1	31.2	47	LC	LC
Marsh Tit	Poecile palustris	1	23.5	14.9	LC	LC
Dunnock	Prunella modularis	0.5	38.7	12.2	LC	LC
Eurasian Crag-Martin	Ptyonoprogne rupestris	2	46.6	20.1	LC	LC
Yellow-billed Chough	Pyrrhocorax graculus	3.3	45.6	14.9	LC	LC
Red-billed Chough	Pyrrhocorax pyrrhocorax	2.9	42.3	18.2	LC	LC
Pied Avocet	Recurvirostra avosetta	3.1	42.2	20.1	LC	LC
Firecrest	Regulus ignicapilla	1.1	21.2	20.1	LC	LC
Bank Swallow	Riparia riparia	1.9	47.7	20.1	LC	LC
European Stonechat	Saxicola torquata	0.8	25.4	20.1	LC	LC
Citril Finch	Serinus citrinella	2.7	35.9	7.4	LC	LC
Eurasian Nuthatch	Sitta europaea	0.9	17.7	13.9	LC	LC
Common Tern	Sterna hirundo	2	38.9	42.5	LC	LC
Eurasian Collared-Dove	Streptopelia decaocto	1	8.8	7.4	LC	LC
Tawny Owl	Strix aluco	1.4	40	51.9	LC	LC
European Starling	Sturnus vulgaris	0.6	30.3	12.2	LC	LC
Eurasian Blackcap	Sylvia atricapilla	0.3	39.6	13.5	LC	LC
Subalpine Warbler	Sylvia cantillans	1.3	26	16.4	LC	LC
Greater Whitethroat	Sylvia communis	0.7	25.2	13.5	LC	LC
Lesser Whitethroat	Sylvia curruca	1	41.4	16.4	LC	LC
Western Orphean Warbler	Sylvia hortensis	1.4	35.9	14.9	LC	LC
Little Grebe	Tachybaptus ruficollis	2.3	33.9	27.1	LC	LC
Common Shelduck	Tadorna tadorna	2.4	39.5	20.1	LC	LC

English name	Scientific name	SSI	SGIc	exp(STrI)	IUCN red list France	IUCN red list Global
Common Redshank	Tringa totanus	2.7	33.4	20.1	LC	LC
Eurasian Wren	Troglodytes troglodytes	0.4	31.5	20.1	LC	LC
Eurasian Blackbird	Turdus merula	0.2	39.1	13.5	LC	LC
Song Thrush	Turdus philomelos	0.4	33.1	13.1	LC	LC
Fieldfare	Turdus pilaris	1.4	46.1	13.5	LC	LC
Ring Ouzel	Turdus torquatus	2.8	35	14.9	LC	LC
Mistle Thrush	Turdus viscivorus	0.5	29.8	12.8	LC	LC
Eurasian Hoopoe	Upupa epops	0.6	36	20.1	LC	LC

Table A5 2. Descriptive table of the number of FBBS sites (NbSites) and number of bird observations (NbBirds; among the 170 studied species) per Functional Urban Area.

Functional Urban Area	NbSites	NbBirds
FUA of Amiens	11	5420
FUA of Angers	12	7963
FUA of Annecy	13	9847
FUA of Belfort	9	11039
FUA of Besançon	15	15054
FUA of Bordeaux	6	4121
FUA of Boulogne-sur-mer	1	961
FUA of Brest	4	1883
FUA of Calais	3	817
FUA of Chambéry	10	7837
FUA of Chartres	2	910
FUA of Clermont-Ferrand	17	18244
FUA of Colmar	4	3964
FUA of Dijon	19	11967
FUA of Dunkerque	4	1616
FUA of Fréjus	3	723
FUA of Grenoble	26	15071
FUA of La Rochelle	18	19390
FUA of Le Mans	7	3571
FUA of Lens	1	211
FUA of Lille	2	322
FUA of Limoges	8	2800
FUA of Lyon	33	36084
FUA of Metz	3	921
FUA of Montpellier	9	8960
FUA of Mulhouse	1	809
FUA of Nancy	21	8031
FUA of Nantes	22	21923

FUA of Nice	2	1653
FUA of Nîmes	4	4624
FUA of Pau	3	1720
FUA of Perpignan	4	2880
FUA of Poitiers	13	12104
FUA of Reims	18	8666
FUA of Rennes	15	15441
FUA of Roanne	3	5220
FUA of Rouen	3	1807
FUA of Saint-Étienne	11	7231
FUA of Saint-Nazaire	2	1640
FUA of Saint-Quentin	3	4608
FUA of Strasbourg	10	12614
FUA of the Greater City of Paris	115	62878
FUA of Toulon	2	389
FUA of Toulouse	4	2632
FUA of Tours	9	5340
FUA of Troyes	10	7657
FUA of Valence	6	6778

Annex 6: Biotic homogenisation preliminary statistical analysis

Author: Karine Princé

Management Spatial Data Level 1

Annex 6-Figure 1: PCA on land composition

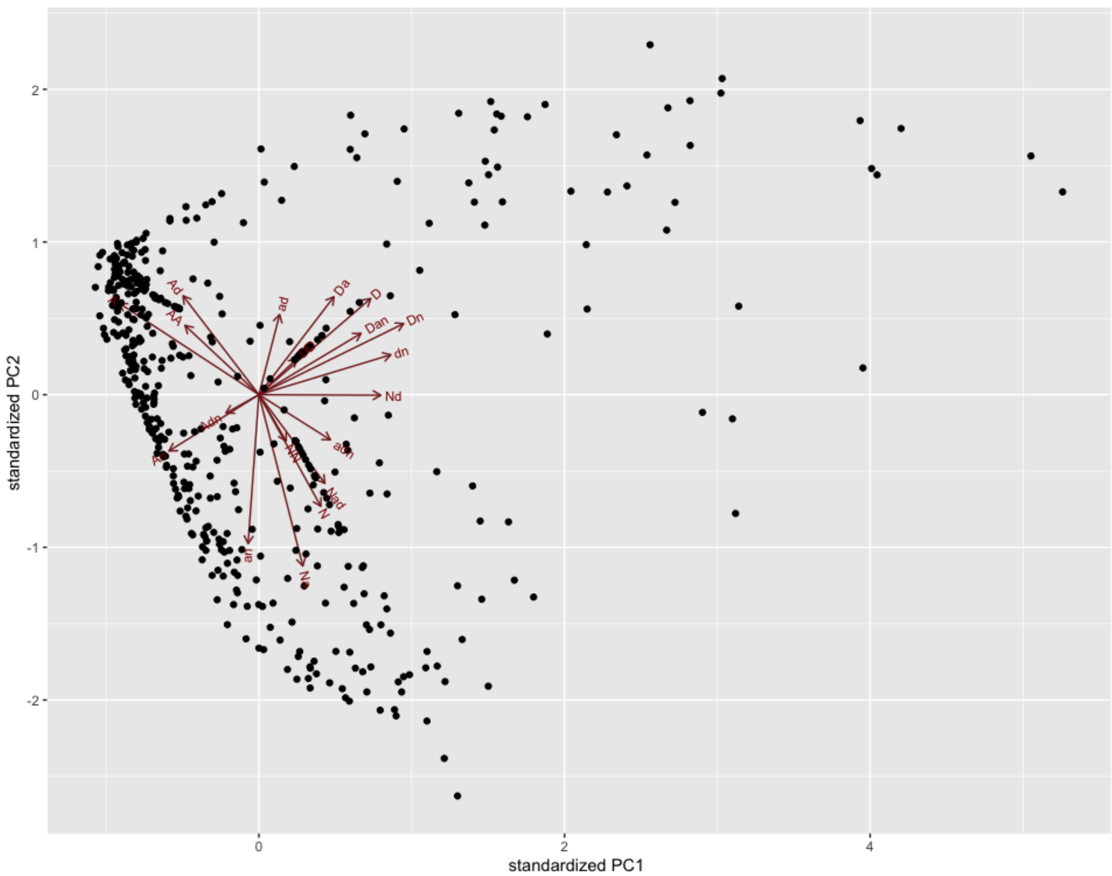


Table A6 1. Eigen Values PCA on land composition.

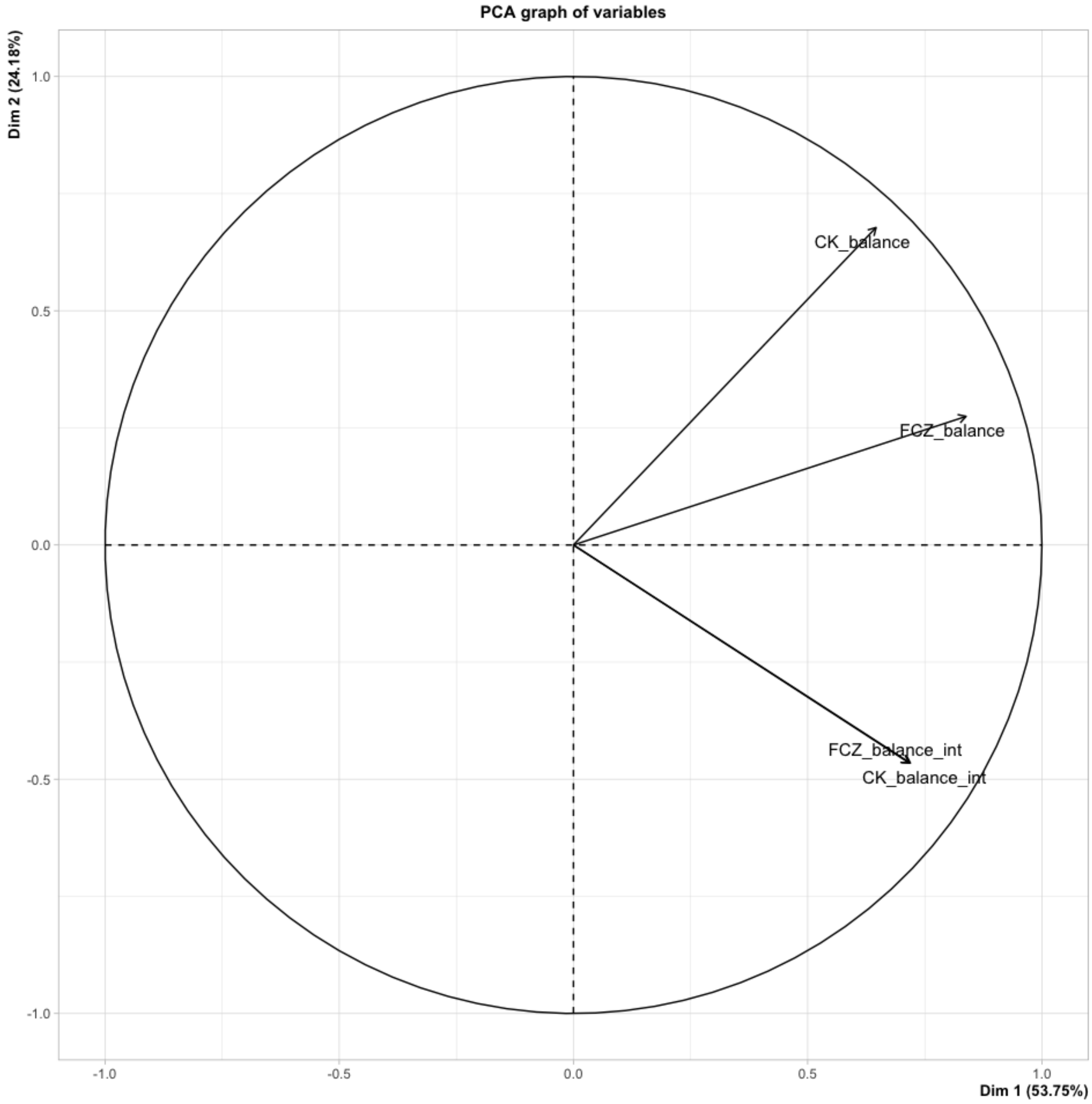
PC	eigenvalue	percentage.of.variance	cumulative.percentage.of.variance
comp 1	2.59	13.61	13.61
comp 2	2.32	12.23	25.84
comp 3	1.83	9.61	35.45
comp 4	1.70	8.96	44.41
comp 5	1.55	8.16	52.57

comp 6	1.27	6.67	59.24
comp 7	1.18	6.19	65.43
comp 8	1.06	5.58	71.01
comp 9	0.85	4.48	75.49
comp 10	0.81	4.28	79.77
comp 11	0.79	4.18	83.95
comp 12	0.67	3.53	87.49
comp 13	0.56	2.94	90.43
comp 14	0.46	2.45	92.87
comp 15	0.44	2.33	95.21
comp 16	0.35	1.86	97.07
comp 17	0.29	1.54	98.61
comp 18	0.25	1.31	99.92
comp 19	0.01	0.08	100.00

Dominant land composition classes (A+AA, D+DD,N+NN) and interface+mix land classes have been grouped.

```
envlevel1_merged.df <- envlevel1_merged.df %>% mutate(A_dominant = A + AA, D_dominant = DD + D, N_dominant = NN + N, interface_land = Ad + An + Dn + Da + Na + Nd + Adn + Dan + Nad, mix_land = ad + an + adn, allmix_land = Ad + An + Dn + Da + Na + Nd + Adn + Dan + Nad + ad + an + adn)
```

Annex 6-Figure 2: PCA on green balance variables (to reduce to a single principal components)



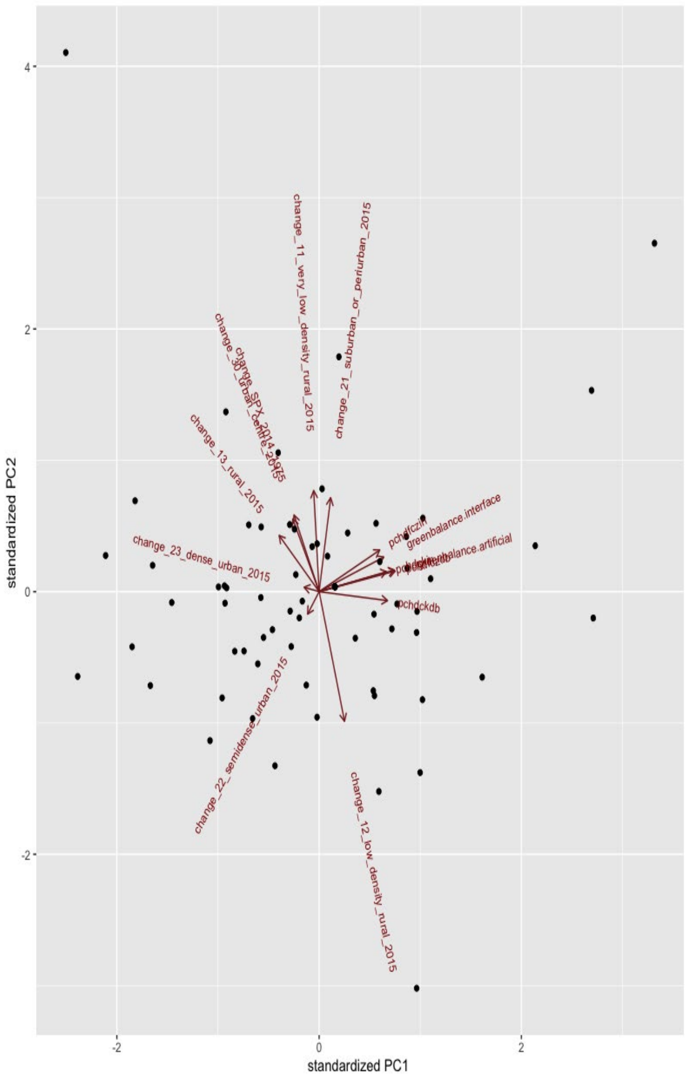
Looking at the PCA plot, it looks like greening balance in core and commuting areas in artificial (or interace areas) are higly correlated => we decide to summarize the greening balance variables, to keep only 2 variables (green balance interface vs. artificial)

We then **merge green balance variables**

```
green_balance.df <- envlevel2_merged.df %>%
  dplyr::select(CK_browning_plus_share.x, FCZ_browning_plus_share.x,
CK_browning_plus_share.y, FCZ_browning_plus_share.y,
CK_greening_plus_share.x, FCZ_greening_plus_share.x,
CK_greening_plus_share.y, FCZ_greening_plus_share.y) %>%
  replace(is.na(.), 0) %>%
  mutate(browning_plus_share.artificial = CK_browning_plus_share.x +
```

```
FCZ_browning_plus_share.x) %>%
  mutate(browning_plus_share.interface = CK_browning_plus_share.y +
FCZ_browning_plus_share.y,na.omit=T) %>%
  mutate(greening_plus_share.artificial = CK_greening_plus_share.x +
FCZ_greening_plus_share.x,na.omit=T) %>%
  mutate(greening_plus_share.interface = CK_greening_plus_share.y +
FCZ_greening_plus_share.y,na.omit=T)

green_balance.df <- green_balance.df %>%
  mutate(greenbalance.artificial = greening_plus_share.artificial -
browning_plus_share.artificial, greenbalance.interface =
greening_plus_share.interface - browning_plus_share.interface)

## add new variables to full table
envlevel2_merged.df <- cbind(envlevel2_merged.df,
green_balance.df[,c("greenbalance.artificial","greenbalance.interface")])
```

Annex 6-Figure 3: PCA on environmental variables related to trends (settlement change, greenest change, green balance, change in degree of urbanisation)



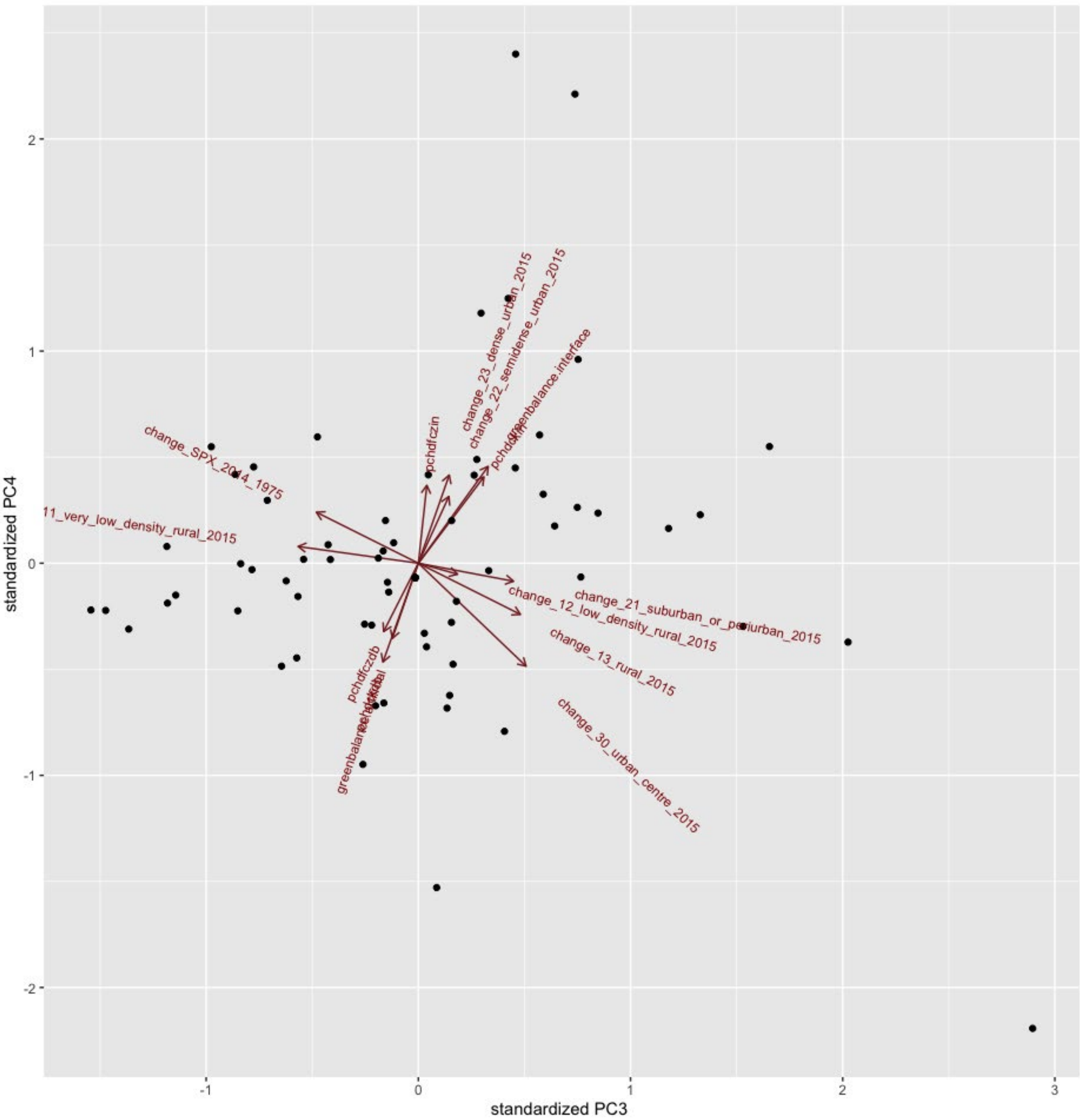


Table A6 2. Eigen Values *on environmental variables related to trends*.

PC	eigenvalue	percentage.of.variance	cumulative.percentage.of.variance
comp 1	3.89	27.82	27.82
comp 2	2.71	19.36	47.18
comp 3	1.98	14.12	61.30

comp 4	1.34	9.55	70.85
comp 5	1.15	8.20	79.04
comp 6	0.98	6.96	86.01
comp 7	0.54	3.84	89.84
comp 8	0.49	3.53	93.37
comp 9	0.35	2.52	95.90
comp 10	0.22	1.55	97.44
comp 11	0.17	1.20	98.65
comp 12	0.14	1.01	99.66
comp 13	0.04	0.27	99.93
comp 14	0.01	0.07	100.00

— We used PC 1, PC 2 and PC 3 (use of ggbiplot to visualize the first 4 PCs)
— Interpretation:
— Dim 1 ⇔ increase in greenness (greenness change)
— Dim 2 ⇔ urbaness, compact (compactness)
— Dim 3 ⇔ mix (decrease in remote rural areas)
—

Annex 6-Figure 4: *PCA on environmental variables related to status* (agri management, forest management, share of urbanisation)

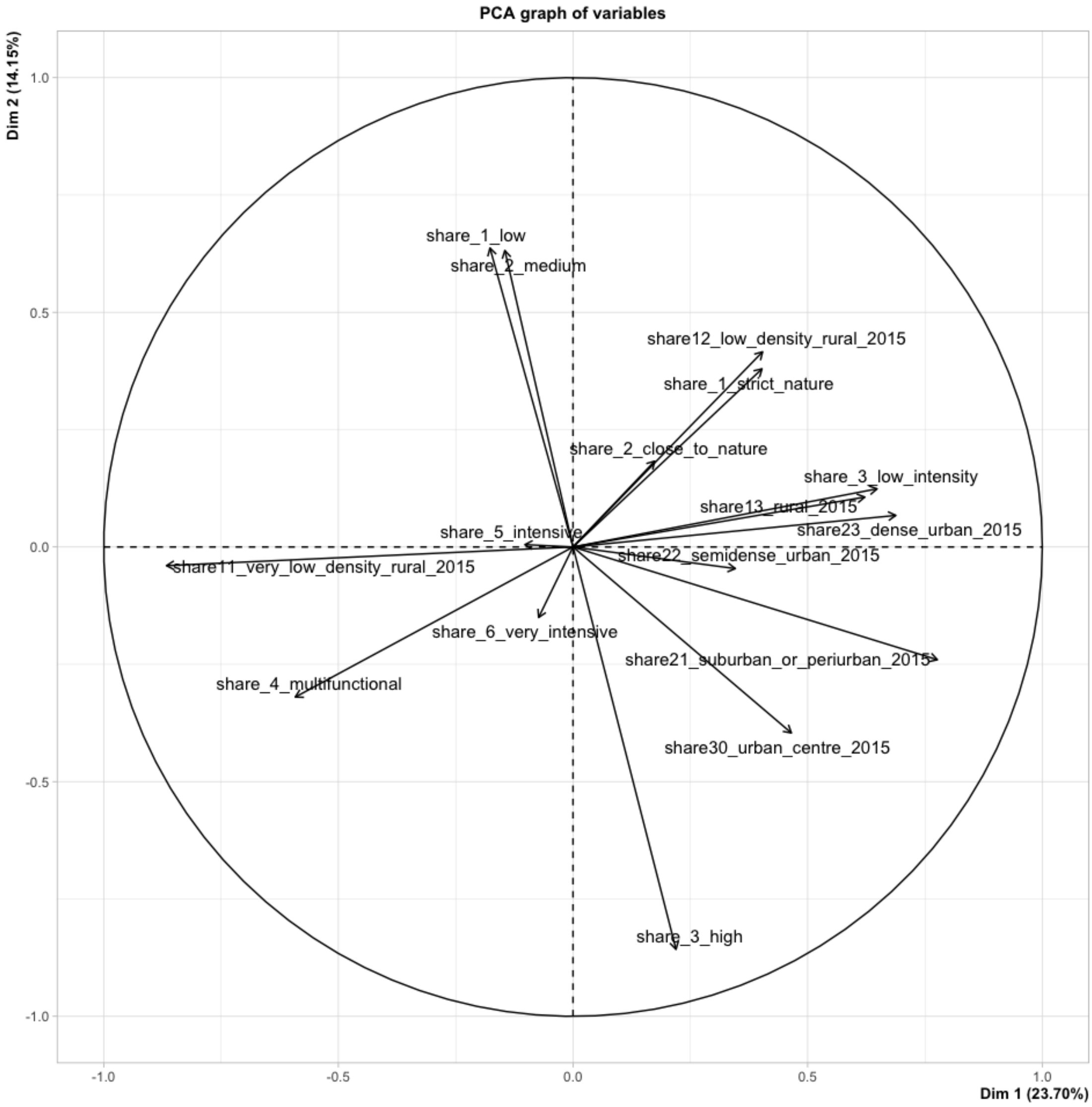


Table A6 3. Eigen Values *on environmental variables related to trends*.

PC	eigenvalue	percentage.of.variance	cumulative.percentage.of.variance
comp 1	3.79	23.70	23.70
comp 2	2.26	14.15	37.85
comp 3	2.12	13.26	51.12
comp 4	1.63	10.17	61.29

comp 5	1.33	8.30	69.59
comp 6	1.29	8.08	77.67
comp 7	0.92	5.74	83.41
comp 8	0.82	5.10	88.50
comp 9	0.64	3.99	92.49
comp 10	0.55	3.43	95.93
comp 11	0.32	1.98	97.90
comp 12	0.25	1.56	99.47
comp 13	0.09	0.53	100.00
comp 14	0.00	0.00	100.00
comp 15	0.00	0.00	100.00
comp 16	0.00	0.00	100.00

We will **keep the status variables separated**, no simple patterns comes out from PCA.

We **group variables on degree of urbanisation** into 3 classes (sprawl, intermediate, dense)

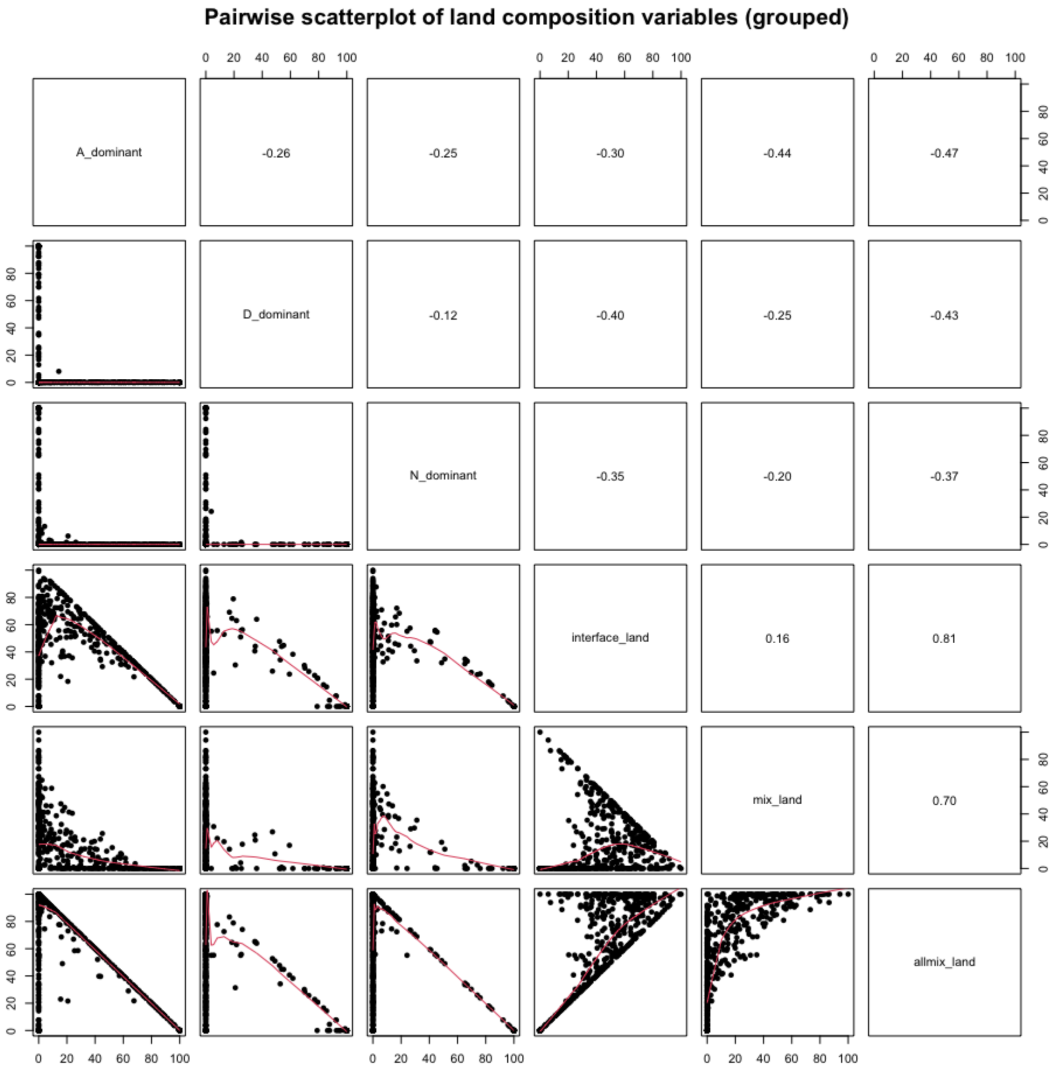
```
urbandegree.df <- envlevel2_merged.df %>%
  dplyr::select(share11_very_low_density_rural_2015,
share12_low_density_rural_2015, share13_rural_2015,
share21_suburban_or_periurban_2015, share22_semidense_urban_2015,
share23_dense_urban_2015, share30_urban_centre_2015) %>%
  replace(is.na(.), 0) %>%
  mutate(sprawl_urban = share11_very_low_density_rural_2015 +
share12_low_density_rural_2015 + share13_rural_2015) %>%
  mutate(intermediate_urban = share21_suburban_or_periurban_2015 +
share22_semidense_urban_2015) %>%
  mutate(dense_urban = share23_dense_urban_2015 + share30_urban_centre_2015
)

## add new variables to full table
envlevel2_merged.df <- cbind(envlevel2_merged.df,
urbandegree.df[,c("sprawl_urban","intermediate_urban","dense_urban")])
```

And data on land composition at the FUA level are summarized, with pop density and FUA size => land configuration types (from *Land_configuration_France.csv*)

Collinearity Analyses

1. Analysis level 1

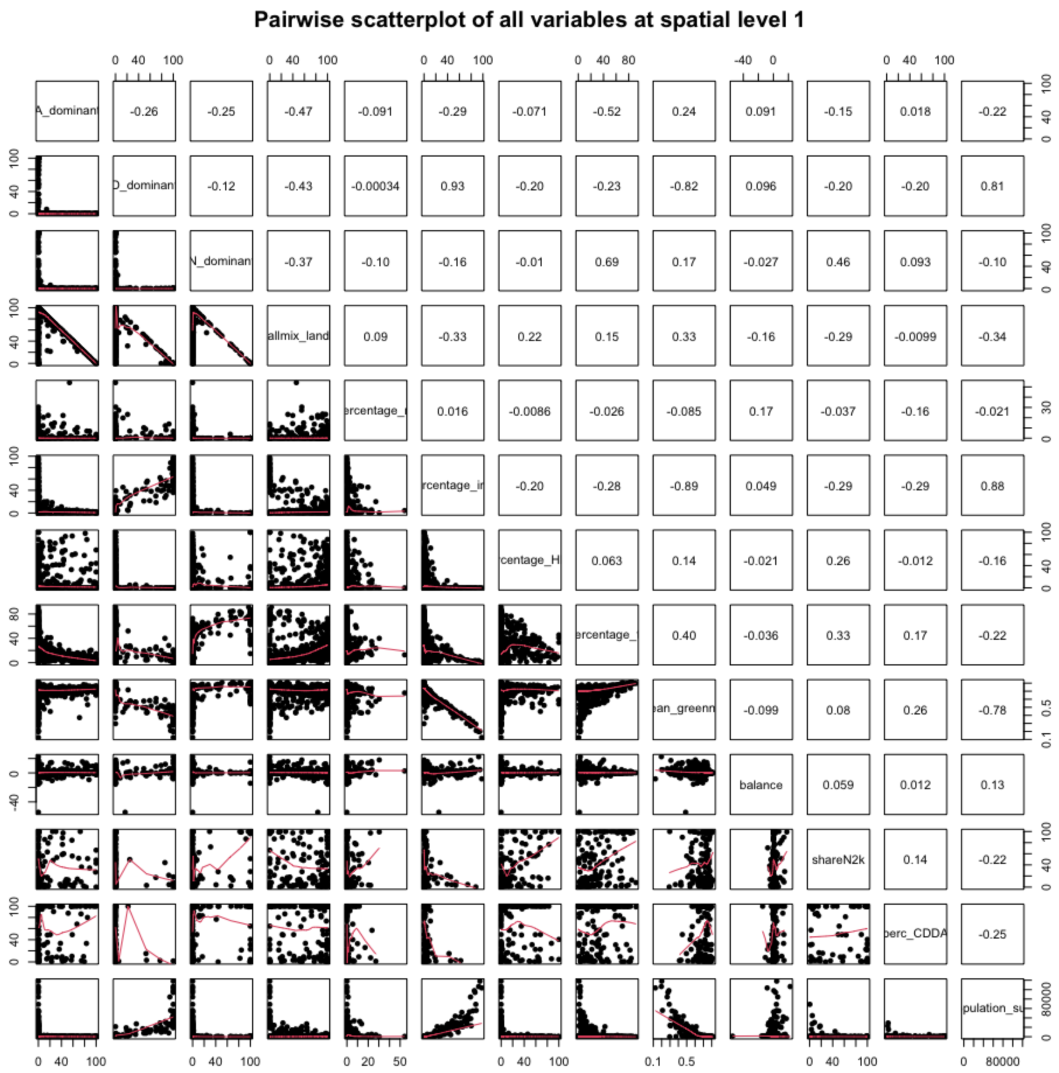
Annex 6-Figure 5: Pairwise Scatterplot with Variables on land composition



Note: allmix_land = interface + mix land classes

=> For now, we will keep only the three *_dominant* classes and allmix_land

Annex 6-Figure 6: Pairwise Scatterplot with all selected variables at level 1



VIF analysis on all select variables

Table A6 4. *vif all variables - level 1*

PC	Variables	VIF
1	A_dominant	15.51
2	D_dominant	61.49
3	N_dominant	25.49
4	allmix_land	27.52
5	percentage_rp	1.19

6	percentage_imp	19.90
7	percentage_HNV	1.89
8	percentage_tc	8.36
9	mean_greennes	4.91
10	balance	1.60
11	shareN2k	1.67
12	perc_CDDA	1.17
13	population_sum	113.09

vif result suggests we should remove population_sum , percentage_imp, allmix_land and percentage_tc.

We run an new analysis, without these 4 variables.

```
## No variable from the 9 input variables has collinearity problem.
##
## The linear correlation coefficients ranges between:
## min correlation ( percentage_HNV ~ percentage_rp ): -0.004021491
## max correlation ( shareN2k ~ N_dominant ): 0.4913196
##
## ---------- VIFs of the remained variables --------
## Variables VIF
##1 A_dominant 1.323946
##2 D_dominant 1.482924
##3 N_dominant 1.783875
##4 percentage_rp 1.139167
##5 percentage_HNV 1.443152
##6 mean_greennes 1.664877
##7 balance 1.363678
##8 shareN2k 1.624918
##9 perc_CDDA 1.140823
```

=> no more collinearity

—

—

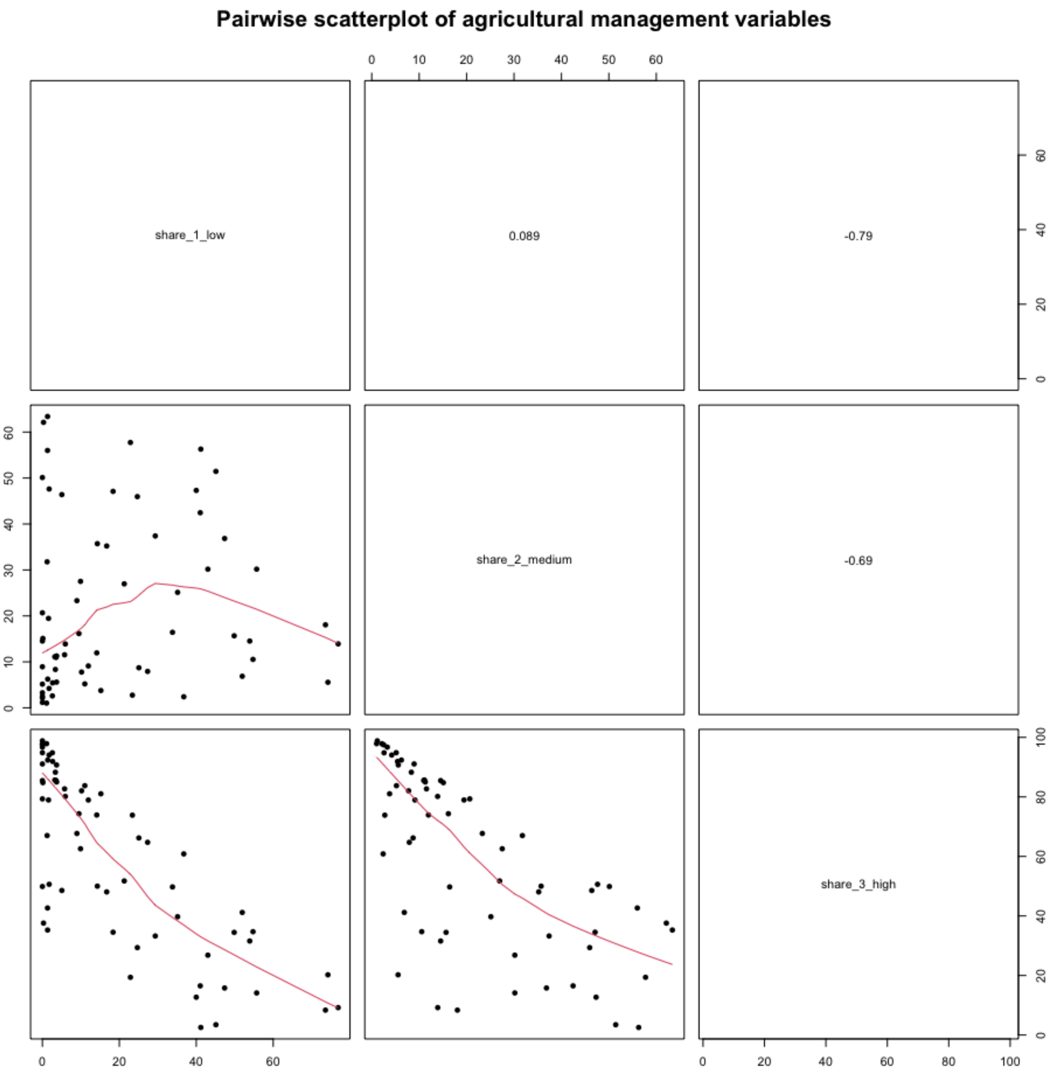
—

—

—

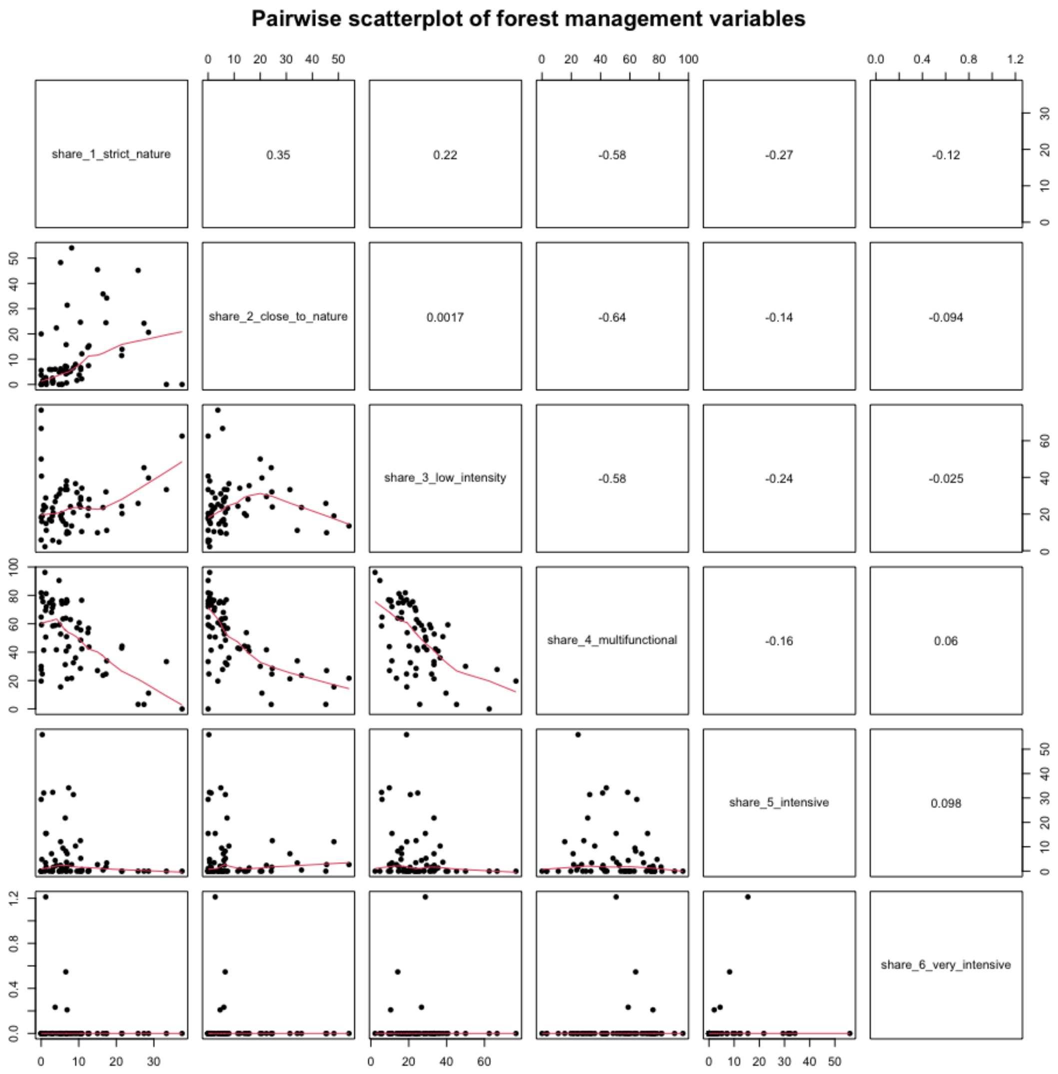
— **Analysis level 2**

— **Annex 6-Figure 7:** Pairwise scatterplot with variables on agricultural management



— We removed the higher level (*share_3_high*)

— **Annex 6-Figure 8:** Pairwise scatterplot with variables on forest management



—

—

We removed the multifunctional level (share_4_multifunctional).

—

—

—

—

—

—

—

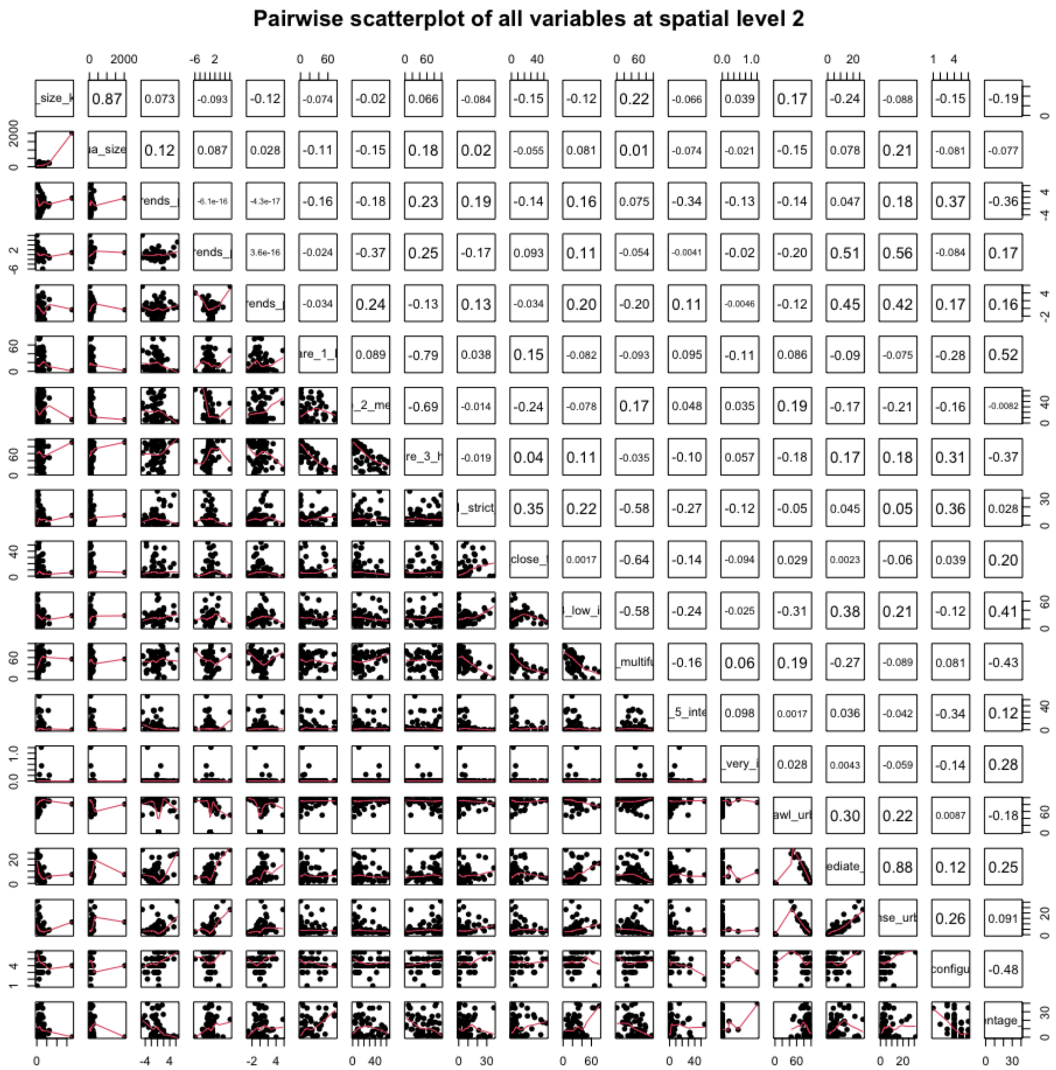
—

—

—

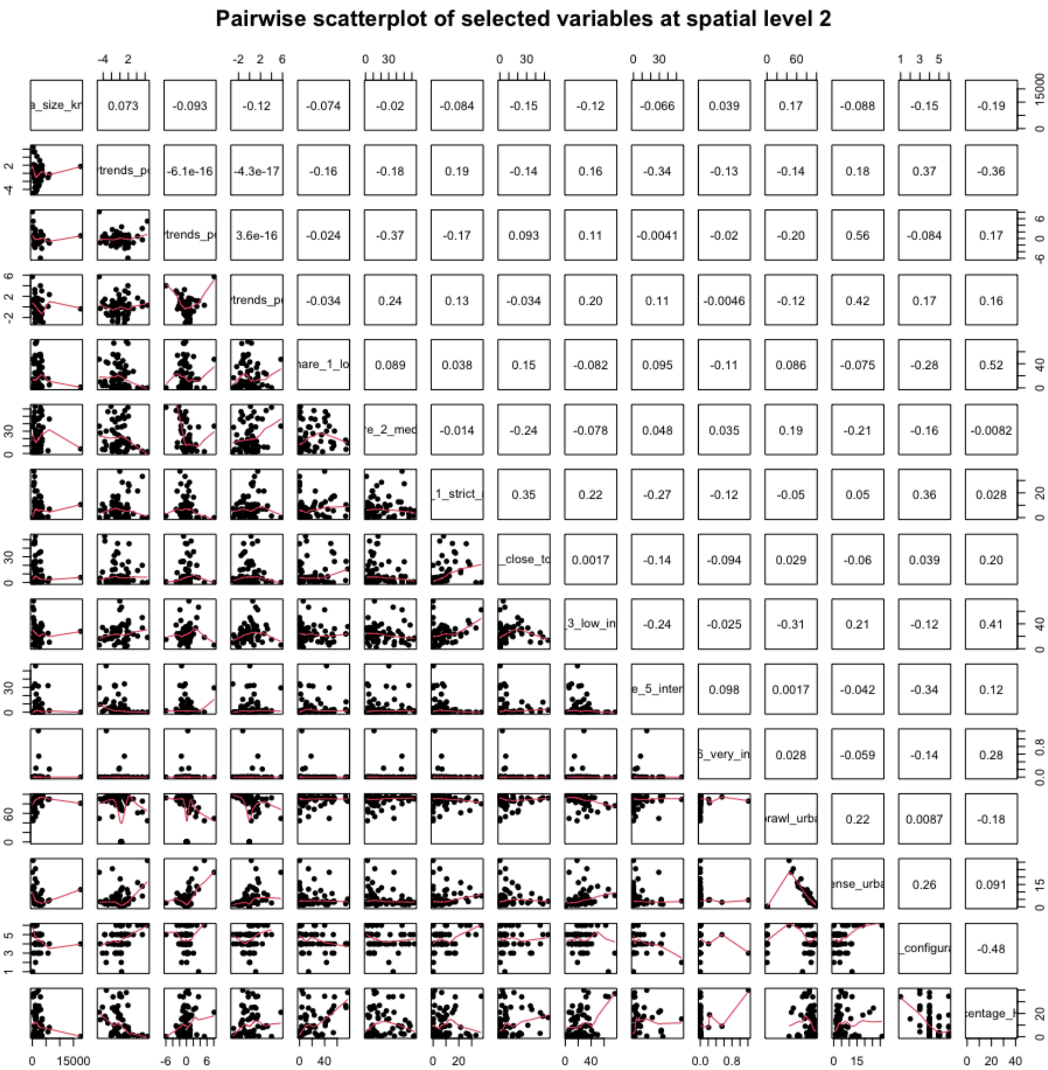
—

— **Annex 6-Figure 9:** Pairwise scatterplot with all variables



We removed corefua_size_km2, intermediate_urban, in addition to the higher level of agric management (share_3_high) and the multifunctional level of forest management (share_4_multifunctional)

Annex 6-Figure 9: Pairwise scatterplot with the selected variables



—

VIF analysis on all variables (after filter already applied based on scatterplot visualization)

```
## 3 variables from the 15 input variables have collinearity problem:
##
##        sprawl_urban        envtrends_pca2        percentage_HNV
##
## After excluding the collinear variables, the linear correlation
coefficients ranges between:
## min correlation ( share_6_very_intensive ~ envtrends_pca3 ): 0.002505547
## max correlation ( dense_urban ~ envtrends_pca1 ): 0.484109
##
## ---------- VIFs of the remained variables --------
##                                  Variables      VIF
##1                              fua_size_km2 1.165607
##2                            envtrends_pca1 1.675541
##3                            envtrends_pca3 1.556581
##4                               share_1_low 1.208718
##5                            share_2_medium 1.473922
##6                     share_1_strict_nature 1.541254
```

```
##7                          share_2_close_to_nature           1.490833
##8                                share_3_low_intensity       1.611951
##9                                       share_5_intensive    1.405622
##10                          share_6_very_intensive           1.067859
##11                                            dense_urban    1.692487
## 12      land_configuration 2.129853
```

=> VIF results suggest we should remove “sprawl_urban” (highly negatively correlated to “dense_urban”), “envtrends_pca2” and “percentage_HNV”

```
##                                                Variables            VIF
##1                                            fua_size_km2    1.165607
##2                                          envtrends_pca1    1.675541
##3                                          envtrends_pca3    1.556581
##4                                              share_1_low    1.208718
##5                                          share_2_medium    1.473922
##6                              share_1_strict_nature         1.541254
##7                          share_2_close_to_nature           1.490833
##8                              share_3_low_intensity         1.611951
##9                                     share_5_intensive      1.405622
##10                         share_6_very_intensive            1.067859
##11                                          dense_urban      1.692487
##12                                    land_configuration     2.129853
## No variable from the 12 input variables has collinearity problem.
##
## The linear correlation coefficients ranges between:
## min correlation ( share_6_very_intensive ~ envtrends_pca3 ):  0.002505547
## max correlation ( dense_urban ~ envtrends_pca1 ):     0.484109
##
## ---------- VIFs of the remained variables --------
##                                                Variables            VIF
##1                                            fua_size_km2    1.165607
##2                                          envtrends_pca1    1.675541
##3                                          envtrends_pca3    1.556581
##4                                              share_1_low    1.208718
##5                                          share_2_medium    1.473922
##6                              share_1_strict_nature         1.541254
##7                          share_2_close_to_nature           1.490833
##8                              share_3_low_intensity         1.611951
##9                                     share_5_intensive      1.405622
##10                         share_6_very_intensive            1.067859
##11                                          dense_urban      1.692487
##12      land_configuration 2.129853
```

=> no more collinearity

Collinearity analyses

=> scatterplot could not be presented here due to figure margins too large (the plot is available in the Drive/Analyses_Outputs folder *collinearity_selectedvar_level1&2.pdf*)

```
##                                              Variables              VIF
##1                                             A_dominant   1.745894
##2                                             D_dominant   1.842205
##3                                             N_dominant   2.856469
##4                                          percentage_rp   1.681354
##5                                 percentage_HNV_level1    3.286990
##6                                          mean_greennes   3.091711
##7                                                balance   1.910437
##8                                              shareN2k    2.713186
##9                                             perc_CDDA    1.321304
##10                                         fua_size_km2    5.313585
##11                                        envtrends_pca1   5.166970
##12                                        envtrends_pca3   3.987876
##13                                           share_1_low   3.131142
##14                                        share_2_medium   4.466031
##15                              share_1_strict_nature      3.289430
##16                  share_2_close_to_nature                6.350468
##17                              share_3_low_intensity      2.684603
##18                                     share_5_intensive   3.660850
##19                         share_6_very_intensive          1.785528
##20                                           dense_urban   8.040934
##21                                   land_configuration    3.774095
##  2  variables  from  the  21  input  variables  have  collinearity  problem:
##
##                    dense_urban                    share_2_close_to_nature
##
##  After  excluding  the  collinear  variables,  the  linear  correlation
coefficients                        ranges                         between:
## min correlation ( percentage_HNV_level1 ~ percentage_rp ):  -0.004021491
##  max  correlation  (  envtrends_pca1  ~  fua_size_km2  ):    0.6175215
##
##    ----------    VIFs    of    the    remained    variables    --------
##                                             Variables              VIF
##1                                             A_dominant   1.728794
##2                                             D_dominant   1.840414
##3                                             N_dominant   2.288689
##4                                          percentage_rp   1.262138
##5                               percentage_HNV_level1      3.047304
##6                                          mean_greennes   3.043196
##7                                                balance   1.754220
##8                                              shareN2k    2.281952
##9                                             perc_CDDA    1.258049
##10                                         fua_size_km2    3.538958
##11                                        envtrends_pca1   3.485254
##12                                        envtrends_pca3   2.276801
##13                                           share_1_low   2.763205
##14                                        share_2_medium   1.858978
```

```
##15                          share_1_strict_nature            1.774537
##16                          share_3_low_intensity            2.017462
##17                                    share_5_intensive      2.125005
##18                    share_6_very_intensive                 1.594741
##19     land_configuration 2.977418
```

=> VIF results suggest we should remove *dense_urban* and *share_2_close_to_nature*

VIF output on final selection of variables :

Table A6 5. *Final selection of uncorrelated variables at level 1 & 2 after collinearity check*

PC	Variables	VIF
1	A_dominant	1.73
2	D_dominant	1.84
3	N_dominant	2.29
4	percentage_rp	1.26
5	percentage_HNV_level1	3.05
6	mean_greennes	3.04
7	balance	1.75
8	shareN2k	2.28
9	perc_CDDA	1.26
10	fua_size_km2	3.54
11	envtrends_pca1	3.49
12	envtrends_pca3	2.28
13	share_1_low	2.76
14	share_2_medium	1.86
15	share_1_strict_nature	1.77
16	share_3_low_intensity	2.02
17	share_5_intensive	2.13
18	share_6_very_intensive	1.59
19	land_configuration	2.98

GETTING IN TOUCH WITH THE EU

In person

All over the European Union there are hundreds of Europe Direct centres. You can find the address of the centre nearest you online (european-union.europa.eu/contact-eu/meet-us_en).

On the phone or in writing

Europe Direct is a service that answers your questions about the European Union. You can contact this service:

— by freephone: 00 800 6 7 8 9 10 11 (certain operators may charge for these calls),

— at the following standard number: +32 22999696,

— via the following form: european-union.europa.eu/contact-eu/write-us_en.

FINDING INFORMATION ABOUT THE EU

Online

Information about the European Union in all the official languages of the EU is available on the Europa website (european-union.europa.eu).

EU publications

You can view or order EU publications at op.europa.eu/en/publications. Multiple copies of free publications can be obtained by contacting Europe Direct or your local documentation centre (european-union.europa.eu/contact-eu/meet-us_en).

EU law and related documents

For access to legal information from the EU, including all EU law since 1951 in all the official language versions, go to EUR-Lex (eur-lex.europa.eu).

Open data from the EU

The portal data.europa.eu provides access to open datasets from the EU institutions, bodies and agencies. These can be downloaded and reused for free, for both commercial and non-commercial purposes. The portal also provides access to a wealth of datasets from European countries.

The European Commission's science and knowledge service

Joint Research Centre

JRC Mission

As the science and knowledge service of the European Commission, the Joint Research Centre's mission is to support EU policies with independent evidence throughout the whole policy cycle.

EU Science Hub
joint-research-centre.ec.europa.eu

@EU_ScienceHub

EU Science Hub - Joint Research Centre

EU Science, Research and Innovation

EU Science Hub

EU Science

Publications Office
of the European Union