The utilization of ecosystem services mapping in land use planning: the experience of LIFE SAM4CP project

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The utilization of ecosystem services mapping in land use planning: the experience of LIFE SAM4CP project

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Abstract

Ecosystem Service assessment requires better integration of the information that supports land use decisions. Nevertheless, the interpretation of maps and their utilisation to address sustainability during the land use planning process remains critical, especially at a local scale. In this study, a Geographic Information System- Based approach is presented to transform an Ecosystem Service biophysical multipart analysis into a composite parcel-scale indicator, mainly using Esri ArcGIS (version 10.5) functions, and particularly: (i) the Weighted Overlay, (ii) Hotspot Analysis and (iii) Aggregation of Polygons. This methodology has been used experimentally in three municipalities of the metropolitan city of Turin (Italy) during the LIFE SAM4CP project. The study aims to demonstrate how the operationalisation of Ecosystem Service assessment in planning aided Local Administrations in defining land use planning priorities, such as the identificationof land take control strategies and the definition of Urban Growth Boundaries.

Abbreviations: LIFE SAM4CP: Soil Administration Models For Community Profit (visit < seurld>http://www.sam4cp.eu/en/</seurld>); DIST: Interuniversity Department of Regional and Urban Studies and Planning, Politecnico di Torino. DIST is a partner of the LIFE research concerning ES mapping activities. The research group includes the scientific coordinator Prof. Carlo Alberto Barbieri and collaborators Prof. Angioletta Voghera, Prof. Giuseppe Cinà, Prof. Carolina Giaimo, and the technical staff, Francesco Fiermonte, Gabriella Negrini Costanzo Mercugliano, and Marcella Guy

Keywords

Ecosystem services; mapping; land use planning; decision-making; science-policy

1. *Introduction*

The land use plan is the final product of a long-term interaction between technical, political, and civil needs that are considered during a decision-making process; here intended as the arena of a complex negotiation between stakeholders (Kaczorowska *et al.* 2016; Wilkinson *et al.* 2013). During this interaction, the consultation of mapsand technical documents is crucial to creating awareness of spatial problems and their territorial distribution. Recently, the Ecosystem Service (ES) approach rose to attention and became pivotal to addressing sustainability in the land use planning process. Nonetheless, it remains a weak approach if there is not an operational integration of the vast quantity of information that frames the assessment to support effective land use planning (Cortinovis and Geneletti 2018; Salata, Ronchi, and Ghirardelli 2016; Meerow and Newell 2017). However, while the ES operational and methodological approach is widely recognised, the practical utilisation of biophysical maps to aid the definition of parcel-based functional zoning is not codified by shared experiences. ESs (Costanza *et al.* 1997) are often cited in planning documents as indexes to determine the impact of urban transformations on the environment and landscape, which eventually affects society with a monetary quantification. However, it is quite difficult to find a common analytical ES assessment that generates practical implementation at the parcel-based level, such as the functional zoning that regulates spatial development.

Open access ES mapping tools are now freely available for many uses with different proposals to a vast majority of technical and non-technical people. This utilisation is innovative and contributes to closing the gap separating the theoretical knowledge of ES from its translation into plans and projects. Whereas land use planning dealswith space, it is only the evidence of a 'spatial' distribution of ES values that matchesthe needs of planners and their capacity to interpret and define territorial strategies, connections, regulations, and parcel-based zones to regulate land use. While the mapping activity makes the value of Natural Capital explicit and understandable, the interpretation of maps, biophysical indicators, and their synthetic utilization (Favretto *et al.* 2016; Rikalovic, Cosic, and Lazarevic 2014; Guarini, Battisti, and Chiovitti 2018) remains less explored, especially at the local scale (Kaczorowska *et al.* 2016; Lopes*et al.* 2015; Woodruff and BenDor 2016). Few examples of plans explicitly use a common ES framework (Wilkinson *et al.* 2013; Hansen *et al.* 2015), where the resultingES maps support land use planning, as they assist in identifying the multifunctionalkey areas of green infrastructure and in examining the provision potential of variousES (Dick *et al.* 2018).

Multilayered analysis of ES is used to design planning tools. Green infrastructures, along with other environmental planning tools such as Urban Growth Boundaries, Net Environmental Benefit analysis, and costs for development, represent an advanced approach to regulating urban expansion, limiting the land take, and increasing sustainability in urban areas. The methods mentioned above support the different application measures for re-development and become crucial in practical planning procedures (BenDor *et al.* 2017; Dearing *et al.* 2015; Gomez-Baggethun and Barton 2012).

Recently, the design of parcel-level composite indexes (Dizdaroglu and Yigitcanlar 2016) has become a key issue relevant to developing urban policies aimed at incorporating ES assessment, increasing the well-being and health of citizens (Salmond *et al.* 2016; Meisner, Gjorgjev, and Tozija 2015; Frumkin 2002). Composite indexes support the spatial development of sustainable policies, achieving a long-term benefit for people by connecting environmental values with cultural, aesthetic, furtive, and urban values (Meisner, Gjorgjev, and Tozija 2015; Pulighe, Fava, and Lupia 2016; Mononen*et al.* 2016).

Nonetheless, communicability of technical maps and documents remains a critical issue. Even if the ES approach is widely discussed on the scientific and academicstage its operationalisation at the community level is less practiced (Zulian *et al.* 2018; Dick *et al.* 2018), and if planners are not able to represent synergies or tradeoffs in a spatial and simplistic way (Meerow and Newell 2017; Lin *et al.* 2018; Turkelboom*et al.* 2015) the utilization of the scientific assessment is weak. In the work of Martinez-Harms *et al.* (2015) the degree to which ES assessments have addressed management decisions has been evaluated, and results indicate that only 3% of studies documented how the research has been used for effective land use decision-support (Martinez-Harms *et al.* 2015). This problem is widely acknowledged in planning communities, since the operationalisation of ES is discussed by environmental engineers, soil scientists, hydrologist, ecologists, botanists, but less so by territorial planners.

In this view, the higher the quantity of scientific and low-communicable data, the lower the possibility of bringing together community and political agreement. Often, increasing the scientific soundness of the ES, analytical data is not the right way to discuss sustainability during planning decisions if there is not a framework to make it usable and communicable.

Mapping the trade-off, or synergies, among ESs is not enough to deliver comprehensible information to policymakers. ES data may not be available to make informed decisions about how to structure local regulations (Rose *et al.* 2014). Limitations include the synthesis of multi-service analysis of ES to be understandable to policymakers, stakeholders, or users, and enable them to evaluate the policy options to establish land use alternatives (BenDor *et al.* 2017; Smith *et al.* 2017; Salata *et al.* 2014).

In this study, insights into a methodological framework developed to support the local land use decision-making process, are presented. Land use planners are gradually gaining technical knowledge about the tools to operationalise ESs in planning; nonetheless, in most cases, ESs are used to prompt the discussion around the value of green areas in a general way, instead of using mapping as an instrumental tool to deliver parcel-based functional zoning at the local scale.

1.1. *The multifunctional character of ecosystem services assessment*

ES assessment requires indicators that may entail the spatial relationship in a highresolution scale, which can only be addressed with sophisticated mapping models. Software such as InVEST (Integrated Valuation of Ecosystem Services and Tradeoffs), AIRES (Artificial Intelligence for Ecosystem Services), or LUCI (Land Utilization and Capability Indicator), among others, support the mapping activity and the possibility of including a geographical and site-specific ES evaluation into the decision-making process. The spatial-explicit approach requires technical skill, a sound knowledge of the mapping processes, and a vast collection of quantitative and qualitative input data (Nelson *et al.* 2011).

Notably, the utilization of ES mapping software implies a certain amount of modeling uncertainties and mistakes, such as those related to reliability, rather than their sensitivity to different inputs, or their combination in algorithms with pre-set values that remain obscure to the vast majority of users (Rosenthal *et al.* 2015; Salata *et al.* 2017;De Sy *et al.* 2013). For these reasons, part of the existing bibliography discourages the direct use of ES maps for parcel-based land use planning purposes (Jetten, Govers,and Hessel 2003; Muñoz-Carpena, Zajac, and Kuo 2007; van Griensven *et al.* 2006), while others state that ES maps should not be used for land use prescriptions (at least without a field campaign of expert validation; Nelson *et al.* 2011), notwithstandingthat real progress in the paradigm of environmental planning would be achieved in the near future if only pioneering approaches and newer tools were utilized (and in doing so accepting uncertainties but limiting their effects). In this view, just the integration of a holistic view of ES can overcome the extraordinarily detailed and partial approach that comes from different disciplines. Such an approach aids the decision-making process of land use planning, since land use planning is contradistinguished by a plural and interdisciplinary view of ESs.

The concept of multifunctionality represents an advancement of the traditional landscape ecology approach which has been applied to ecological processes (Potschin and Haines-Young 2013; Partidario and Gomes 2013; Bennett and Mulongoy 2006), and environmental imbalances (Surya 2016; Dearing *et al.* 2015). Multifunctional ES assessment is designed to emphasise the different benefits (combining supporting, regulation, provisioning and cultural ecosystems) that Natural Capital can play in increasing citizens' quality of life, including immaterial benefits derived from the aesthetic values of urban green areas (Pulighe, Fava, and Lupia 2016).

Multifunctional ES assessment is at the base of sustainable land use planning (Rosenthal *et al.* 2015; Mononen *et al.* 2016) and it is the result of a composite index score (Partidario and Gomes 2013; Wilkinson *et al.* 2013), that supports land use suitability analysis (Turkelboom *et al.* 2015; Salata *et al.* 2014; Schroter *et al.* 2015) achieving a better environmental quality in land use transformations.

Combining different ES indicators and mapping the aggregated indices allows simplification of the information for planning (Hansen *et al.* 2015; Artmann 2014; Langemeyer *et al.* 2016), since the spatial knowledge of ES distribution in a detailed parcel-level manner helps to quickly find the elements where different kinds of services are provided (Partidario and Gomes 2013; Haines-Young and Potschin 2013). The challenge is to find out where, and how, multiple ecosystem services may be well balanced in achieving an overall increase in ecosystem performance (Metz and Weigel 2010). Generally, ES provision displays an asymmetrical relationship among the single functions, and it is, therefore, better to optimise across all services than to pursue a separate ES maximisation. (Escobedo *et al.* 2015; Zang *et al.* 2011).

This paper presents the operational ES evaluation and utilisation experienced during a European funded project LIFE SAM4CP, aimed at introducing, at the practical stage, the ES evaluation to generate sustainable land use plans and projects. The research activity has been supported by the Interuniversity Department of Regionaland Urban Studies and Planning (DIST), where some innovations in urban planning procedures were tested. Notably, the research activity has been focused on the practical utilisation of spatial ES assessments (e.g. biophysical maps) as input data to create an overlay structure of final values. Although it has been excluded, the demand side andthe weighting factor in the provisioning capacity from this study, it is acknowledgedthat there is an essential measure in identifying elements to support land use planningin the future (Kopperoinen, Itkonen, and Niemela2014).

The experience presented here shows how to include in the ES assessments the utilisation of different mapping outputs to establish a final multilayered indicator (Arcidiacono, Ronchi, and Salata 2016; Bottalico *et al.* 2016; Lovell and Taylor 2013; European Environment Agency 2014). The methodology aims to integrate different geostatistical procedures; given an ES spatial assessment made by InVEST (ver. 3.3.3; Rosenthal *et al.* 2015) a set of biophysical outputs at the local scale was obtained and used to set a geospatial ESRI ArcGIS (ver. 10.5) analysis. ES maps were used to overlay every single value and generate a spatial analysis of a composite ES delivering capacity distribution at parcel-level. The final result is the product of a geostatistical process that transforms biophysical multipart data into a network design, mainly usingthe Weighted Overlay, the Hotspot Analysis and the Aggregation of Polygons. Therefore, this study does not perform a technical 'mapping' assessment of ESs,testing the sensitivity of an input to output variation (Salata *et al.* 2017), assuming, as a precondition, that the outcomes (maps of several ESs) of the abovementioned research LIFE SAM4CP served to aid the re-design of parcel-based land use zoning.This study:

1. presents the development of a new methodology for assessing multifunctional ESs based on existing mapping outcomes;
2. examines how multifunctional ES maps contribute to defining local policies against land take, facilitating re-use and maximising the ecological benefit.

This approach followed the research activity aimed at demonstrating how to support the explicit incorporation of ESs into practical urban planning activities (Arcidiacono, Ronchi, and Salata 2016; Pulighe, Fava, and Lupia 2016; Grêt-Regamey *et al.* 2017), and, precisely, it follows the trajectory designed by McHarg in his book Design with Nature, (1969), which provided a pioneering example of how specific ecological indicators and maps should be created, represented, and employed to support land use decisions at different scales. Such an approach has been applied in thelast thirty years and has recently been integrated into what has been explicitly called "the ES framework" (Albert *et al.* 2016; Nin *et al.* 2016).

Recently, an operational utilisation of InVEST following this principle has been discussed by Butsic *et al.* (2017), and a similar multi-layered analysis for multifunctional GI has been mentioned by Butsic *et al.* (2017), and Meerow and Newell (2017). In both cases, a GIS-based multi-criteria model provides an inclusive and replicable approach for land use planning so that it maximises the overall ES value for a particular landscape (Yang *et al.* 2018; Yang *et al.* 2017). Focusing their analysis in a multi-layered ecosystem service analysis, both approaches demonstrate how to identify specific high priority hotspots through the spatial overlay of different maps.

2. *Materials and methods*

2.1. *The case study area*

The research project developed by DIST was part of a joint National partnership project that aimed to develop specific recommendations for the land use plan design atthe local scale in the Piedmont Region (North-west of Italy). The mapping activity was applied in a study area which comprises three municipalities of the metropolitancity of Turin (see Figure 1), due to the need to cover a broad spectrum of the morphological conditions of the metropolitan territory. Scattered medium and small towns surround the metropolitan city of Turin, along with villages and countryside that form the sub-urban area giving an urban-rural continuum. The rural environment is a mosaic of small natural and semi-natural patches alongside rivers and a rugged environment, while the agricultural plain valley, which covers the most significant portion of the territory, is dominated by croplands. The three case studies belong to different socio-morphological characterisations.

Settimo Torinese is a neighbouring city of Turin in the highest urbanised axes that connect the city to Milan. It spans 3,328 ha and is made up of 55% urban areas (including urban public gardens and parks), while less than 42% is agricultural land. It is characterised by extended industrial peripheral suburbs with poor landscape/environmental surrounds due to the high fragmentation of the residual rural system which has been threatened by the built-up expansion during the 1970 s. The primary planning target is to reconvert a significant part of the industrial area, which is affected by abandonment, partial utilisation, and soil contamination.

None is a city of the flat and low valley of Turin which belongs to a rural-metropolitan territory that underwent considerable industrial expansion and is now suffering an economic crisis in trying to reconvert its built-up industrial stock that overestimates its productive capacity. It spans 2,464 ha with 21% urban areas (including urban green) and more than 80% agricultural areas, with a high rural characterization.

Chieri is a city in the hilly and rural part of the metropolitan context with a high scenic landscape and an excellent natural environment. It spans 5,416 ha, and less than 20% of its territory is covered by urban areas (including urban public gardens and parks), with 73% covered by agricultural land. Chieri is the only example where the natural areas cover more than 6% of the territory. It represents a rural context with the strong presence of natural or agroforestry uses. The Public Administration was involved in a reduction of building rights permissions for a planned industrial expansion that, in the last 20 years, remained unbuilt due to the low demand for new industrial sites.

Overall, the three study cases cover an area that spans more than 11,776 ha (see Table 1), which represents about 0.46% of the metropolitan territory. In these municipalities, the SAM4CP project provided an ES mapping to support the Local administrations during the decision-making phase to renew the in-force land use plan, achieving better sustainability.

Table 1. Land use composition in the study area.

	Chieri		None		Settimo Torinese	
Land Use	ha	(%)	ha	(%)	ha	(%)
urban areas	995.22	18.37	374.57	15.20	1,499.40	45.05
green urban areas	92.89	1.72	33.84	1.37	318.83	9.58
agricultural land	3,995.96	73.77	1,974.33	80.12	1,384.32	41.59
natural and semi-natural	332.40	6.14	81.33	3.30	126.09	3.79
total	5,416.47	100.00	2,464.08	100.00	3,328.64	100.00

2.2. *Mapping and data collection*

The ES mapping activity included the following models: Habitat Quality, Carbon Sequestration, Water Yield, Sediment Delivery Model, Nutrient Delivery Model, and Crop Pollination. Additionally, the Crop Production map was autonomously created by the users because the InVEST model was not yet completed at that time (2015) and the lack of input data limited the utilisation of the available 'demo' version at thatdate. This ES has been computed as the market value of specific crop production associated with the land uses. The Crop Production map was necessary to achieve a comprehensive set of ES types achieving a multiple ES assessment as required by theresearch target.

Data requirements and the sources of information used as inputs in the InVEST modules were discussed with the Superior Institute for Environmental Protection and Research (ISPRA, Italy) adapting national catalogues of data or inputting local data when available. The primary inputs are listed in Table 2. All models use the Land Cover Piemonte raster as the base map (Land Use Land Cover) with a graphical resolution of 1:10,000 and a pixel dimension of 5 m cells covering the entire territory of the Metropolitan City of Turin. The land use classes follow the standard categorisation of Corine Land Cover. In the municipal area of Settimo Torinese, None and Chieri, the Land Use base map has been refined, adding the fourth level of legend detail and usinga scale of representation of 1:2,000. Such detail was justified by the need to obtain a parcel-level assessment usable to design the land use zones at the local scale (thus the pixel dimension of each ES map fits with the cadaster limits) in the case of study.

Once models were prepared, the distribution of outputs was checked to identify discordance with the local situation, focusing on unpredicted values. A test of sensitivity has only been applied to the Nutrient Retention model, because the interaction of the land use map with the Digital Elevation terrain Model was initially problematic. In that model, the distribution of nutrients along the landscape was scattered and discontinuous evidentiating was a problem in the final generation of the output; thus an expert evaluation of model reliability was then necessary (Salata *et al.* 2017).

Table 2. Major input data for InVEST models.

Carbon Sequestration	Input data were based on the Italian National Inventory of Forests and Carbon Pools (INFC). Notably, for each kind of land use the quantity of organic carbon stored in the soil, in the litter and in the above and below ground vegetated biomass has been defined.
Water Yield	Root restricting layer depth: the Land Capability Classification took soil depth data with a scale of representation of 1:50,000. Precipitation: data were collected from the regional department for environmental protection (ARPA Piemonte. http://www.arpa.piemonte.it/rischinaturali/tematismi/clima/confronti-storici/precipitazioni/introduzione.html) Plant Available Water Content: data comes from the SPAW Model for Agricultural Field and Pond Hydrologic Simulation" "Soil Water Characteristic Estimates by Texture and Organic Matter for Hydrologic Solutions". To obtain the specific data required by the SPAW Model the original land capability map was integrated with additional soil texture information provided by The Regional Institute for Plant and Environment (IPLA) at the reference scale of 1:250,000. Average Annual Reference Evapotranspiration: values for each watershed were collected from the regional department for environmental protection (watershed boundary dataset) http://www.

	scia.isprambiente.it/Documentazione/report2006.pdf Watersheds: The biophysical values in the attributes table were taken from references collected in the InVEST user’s guide (Nelson *et al.* 2011)and supervised by ISPRA.
Nutrient Delivery Model	Average annual precipitation was calculated using the regional climatereport by ARPA The Digital Elevation Model (DEM) is a raster dataset of 10 m cellsize (scale of representation 1:10,000, the year 2005) covering the entire territory of the Region Piemonte.
Sediment Delivery Model	This model shares the vast majority of inputs with the Nutrient Delivery Model. The rainfall erosivity index (R) indexes in the attributes table were calculated using the biophysical values computed using the reference parameters collected in the InVEST user’s guide (Nelson *et al.* 2011) and supervised by ISPRA
Crop Production	Crop Production values come from the regional “standard production table” http://rica.crea.gov.it/public/it/rls_ps.php
Crop Pollination	The nesting behaviour, flight season, nesting requirements, or flight distance and were provided in the table of pollinator species or guilds. The source data comes from an independent expert evaluation conducted by ISPRA

2.3. From multipart to a composite parcel-based indicator

As introduced, the mapping activity covered different ES categories with indicatorsthat range from the tons per pixel of carbon stored in the soil, the millimetres of water evapotranspiration per pixel, the pixel contribution in kilograms of nutrients on streams, and so forth. Once maps were generated their values were analysed and interpreted by the research group during focus sessions, and each ES was measured through the quantitative sum (the quantity of a specific service delivered) and verified by a qualitative interpretation of the spatial distribution across the territory with a supervision of the distribution of the high/low performing areas and their coherence with the peculiarity of sites. The quantitative/qualitative evaluation was useful to understand how each land use configuration delivers a pre-determined amount of service. In this phase, it was evident that some ESs behaved differently: synergies were found between Habitat Quality and Carbon Sequestration, while a trade-off was recorded between Crop Production and Nutrient Retention. To facilitate the evaluation, a normalisation of absolute biophysical values has been applied to standardise units, obtaining finalvalues ranging from 0 to 1 (see Table 3). Some ESs display a similar pattern, while others do not. To some extent, the factthat areas where the pixel value of the Habitat Quality was low while, at the sametime, the pixel value of the Sediment Delivery was high, or where the pixel value of the Carbon Sequestration was flat, while the pixel value of the Habitat Quality was high, remains mostly obscure to the majority of stakeholders, even those with a strong environmental background. Also, if the literature already talks about trade-offs and synergies among ESs (Crossman *et al.* 2013) it is not easy to explain such an issue to a broad and non-academic public. It has to be considered that the research was not designed to address the maximisation of a specific ES, but rather to demonstrate how the revision of the land use plan provides an increase in the overall value of ESs in the territory. To achieve this objective, a synthetic quantification and representation of the various ES values in a single indicator was necessary to employ the maps for practical utilisation and explain the results. It could be tempting to use biodiversity as a proxy of ES provision, but species richness and other ESs have shown poor correlation on separate study (Naidoo *et al.* 2008); this is particularly true in urban areas where the quality of green areas is mostly influenced by other attributes, rather than pure biodiversity.

Therefore, a parcel-level composite index score has been tested during the research activity.

Table 3. Ecosystem Service average normalised value in the selected Municipalities.

	Habitat quality	Carbon sequestration	Water yield	Nutrient delivery ratio	Sediment delivery ratio	Crop production	Crop pollination
Catchment area	0.375	0.206	0.145	0.456	0.471	0.375	0.428

2.3.1. **Aggregation**

Given the SAM4CP research constraints defined by the project (seven selected ES biophysical maps for three study areas), a first step was composed by an arithmetic aggregation procedure. The ArcGIS function that has been employed to obtain a parcel-level composite index is the Weighted Overlay tool. This tool sums the value of various raster maps, multiplying each layer for a weighted score (any positive or negative decimalvalue defined by the user). The tool adds different integer cell values together to produce a single final output raster. The aggregation was employed with two preconditions:

- summoned by the same weight of importance as summoned each pixel; thus all values are of equal importance in this procedure. For this study, none of the actions concerned an expert opinion analysis aimed at defining criteria for weighting the selected ESs;
- a normalisation was employed to all biophysical values before the sum to remove imbalances between different units.

The formula that generates the total sum of values is as follows:

$$\mathrm{VALTOT} \sum_{n=1}^{7} (\text{pixel normalized value})*(-1)$$

where:

VALTOT is the output of the weighted overlay function; pixel normalised value is the single ES map's pixel normalised value generated by InVEST or by users; (–1) represents a conversion from positive to negative values applied for the Sediment Delivery Retention and Nutrient Delivery Retention layers, since these models represent not the quantity of retention (the service) but the quantity of delivery (of nutrients and sediment in streams), thus lowering the VALTOT value when erosion or nutrient loadis present.

Table 4. VALTOT values in Settimo Torinese.

Statistics	Values
Minimum	0.050
Maximum	2.677
Mean	1.046
Standard deviation	0.475

The final grid-based composite index was edited maintaining a final cell resolutionof 5 meters.

Assigning the scores mentioned above to each ES layer, the pixels of the final VALTOT value would hypothetically range between –2 and –5. This range represents the best and the worst composite ES conditions; –2 is a theoretical pixel condition where Habitat Quality, Carbon Sequestration, Water Yield, Crop Pollination, and Crop Production are equal to 0 (no ES delivered), while the Sediment Delivery Model and the Nutrient Delivery Model are both –1 (maximum erosion and contamination). Onthe other hand, 5 is the ideal condition where the VALTOT is a pixel generated by a sum of Habitat Quality, Carbon Sequestration, Water Yield, Crop Pollination, and Crop Production equal to 1 (maximum ES delivered) while the Sediment DeliveryModel and the Nutrient Delivery Model are both 0 (no erosion and nutrient load). Table 4 and Figure 2 show the VALTOT values and their distribution in the territory of Settimo Torinese.

The output of the Weighted Overlay function aided in the comprehension on complementary ESs delivering capacity for the same pixel, therefore, reducing the number of different values and information coming from many sources and computational models into a single parcel-based representation where the original inputs are summed.

2.3.2. *Hotspot analysis*

The composite index was the first step in simplifying the quantity of data that the mapping ES has generated, summing up all values. Nevertheless, the range of the composite index was still difficult to interpret, since one question remained unanswered: which is the value to consider for an evaluationn of a suitable composite ecosystemic condition? To achieve a better comprehension, it was necessary to identify a threshold to define a limit of ‘good,’ ‘medium’ or ‘bad’ ecosystemic quality; otherwise the range of the first weighted sum was too broad to define when the values become relevant arbitrarily. To do so, a Hot Spot Analysis, which creates a spatial representation of the statistically significant values in the territory using their distribution, was employed for this purpose. Hot spots and cold spots are clusters of statistically relevant values that represent spatial concentrations (hot spots and cold spots) and low concentrations (no relevance). The Hot Spot Analysis has been launched using the Valtot composite index as an input variable, and the result generated a map in which the red colour identified areas where the concentration of the overall ES value is high and vice versa for the blue areas. In these selected areas, a certain number of concentrated pixels delivers a high or a low multifunctional value. The map distinguishes the significant values, while grouping in the ‘insignificant’ class all other values (3 and 3 represent significant high/low ESs values, while different values are less significant or not significant at all – value 0). The statistical significance of the output was interpreted as a relative procedure to define valuable thresholds of a composite ecosystemic quality: red areas deliver multiple ecosystem services, thus are essential for sustaining the natural condition of the city. The final map enables identification of areas where numerous ecosystem services are simultaneously delivered, and their management has great potential to foster social and ecological benefits through different measures: environmental conservation, valorisation or compensation.

2.3.3. *Aggregation of polygons*

A final step in the identification of multiple ES provisioning areas is the visualisation of corridors and connections where a certain continuity among different clusters with high values is already guaranteed (or has to be planned). From an ecological point of view, the connections between source areas of multiple ESs is fundamental to ensure the compactness and robustness of the network.

Once hot spots were identified, with a final ArcGIS procedure it was possible to isolate hot spots and to group them to frame a network for the potential identification of an existent multifunctional ecosystem service infrastructure at the local level. In this regard, two additional operations were conducted; the first concerned the selection of hot spot areas using the tool “select by attributes” to extract the hotspots and obtain a preliminary view of their distribution.

Following this, the final operation concerned the geometrical corrections to the extracted geometries applied to obtain a continuous feature from the originally separated polygons. This procedure avoids fragmentation and reduces the total number of polygons in the shape file (Figure 3) and constitutes merely a geometrical refinement of the original hotspot function. It was used to create a network of continuity in the geometrical shape of the multi-layered assessment.

The aggregation distance between different polygons has been set at 10 m. This minimum distance reduced the possibility of generating an irrational network at the urban scale and connects only patches that are close to each other. The minimum area to be retained has been set at a value close to 0, thus to also maintain small isolated patches located in the densely built-up area, while the minimum hole size of a polygon to be retained has been set 1,000 sqm, thus to avoid leapfrogged distribution inside the network.

3. *Interpretations of results and discussion*

Hereafter the results of the experimental approach are presented and briefly commented on.

3.1. *The multifunctional value of land*

Step one (the Weighted Overlay) was used to meet the need for simplifying multiple sources of information coming from different computational models that are usually discussed separately with the help of specific experts. Since the objective of the three Public Administrations involved in the research was to generally achieve a sustainable ecosystemic balance among all the ESs, this operation aided the definition of setting priorities in each case study (Borgogno-Mondino, Fabietti, and Ajmone-Marsan 2015). The overlay was used to quickly understand where the landscape provides multifunctional ESs, thus generating greater benefit for local communities, to avoid their depletion by limiting or compensating further urban transformation (Salata 2017; Artmann 2014).

The final parcel-level composite index provided a direct visualisation of multiple ES delivery, and during decision-making, phases aided the scientific knowledge-transfer of the multifunctional value of the land at the political level and to nonpractitioners.

At that stage, the multifunctional value of land has been deeply observed becauseit was evident that areas classified as artificial land cover in the original Land Use show a relevant heterogeneity of their ESs' provisioning capacity.

In Figure 4, there is a statistical distribution of the ES performance for Land Use and Land Cover macro-categories (Built-Up, Urban Green, Agricultural, Semi-Natural and Water). The scatter plot distribution shows the worst ES values are concentrated,as expected, in the built-up environment. Nevertheless, the built-up land is subject to a wide range of multiple ES delivering capacities (see Figure 2): low performances are mainly located in dense and compact sealed areas or continuous and discontinuous productive sites, or elsewhere when the interaction between many sources of threats generates a bad performance cluster; while urban residential zones show better performances due to their porosity and the presence of green unsealed gardens even showing unexpected results in terms of multifunctional quality in the low-dense areas composed of detached or semi-detached houses with unsealed private space. Urban green areas and parks display average performances that some agricultural land did not reach, and this result confirms that the ES delivering capacity of urban open space is fundamentally important, alongside the delivering capacity of rural areas, for increasing healthy conditions in local communities. This pattern is evident when looking at the plot distribution of green urban areas, which has the highest variability among the different land uses and, as introduced, the upper peak of the value distribution reaches the values of the agricultural land with the best ES delivering capacity. This simple consideration implies that proper management of urban green areas should guaranteean ES capacity similar to that of rural spaces.

Moreover, the boxplot distribution of the composite index shows that natural and semi-natural areas perform better, even with a different range of values among the different semi-natural land uses.

In an extension of this project, the representation of a parcel-level composite indexof different ESs should be integrated as a product of a weighting factor applied to the Weighted Overlay. In this experience, the sum of different biophysical values was undertaken, considering all ESs of the same weight.

3.2. ***Land take limitation, mitigation or compensation***

Step two (Hot Spot Analysis) aided in developing an easy-to-understand distribution of the ES values. Hotspot clusters are selected areas where high-value ESs are delivered. The identification of an analytical tool that picks hot spots is crucial to augment the interpretation of the analysis: indeed, once a user obtains a distribution of a composite indicator it is not easy to evaluate what is considered relevant concerning quality, and where to find its concentration. Hotspot areas are considered of ‘good’ quality, insignificant areas are considered of ‘average’ quality, and cold spot areas are considered of ‘poor’ quality. This qualitative interpretation reaches the attention of all stakeholders and increases the awareness that some areas are much more valuable than others and thus specific policies of conservation, restoration, or requalification can be considered.

Quality of soil is fundamental to provide a regulative framework to limit unsustainable urban transformations. The Regional land take regulative framework in Piedmont assumes a similar approach to the ones reported in the Guideline to Limit, Mitigate, or Compensate for Soil Sealing, and is assumed by the General Regional Plan (European Commission 2012). Indeed, the Regional Plan defines three zones: urban, transition, and greenfields. Greenfield zones are those of no-development (except for public facilities and infrastructure). Transition zones are those where the peri-urban characterisation would suggest consideration of the compatibility of urban transformations, weighing their impact on the surrounding environment and thus acting through mitigation or compensation based on their environmental effects. In urban zones, all kind of urban transformations are allowed, thus promoting re-use of brownfields and densification of the existing built-up stock where possible.

Therefore, step two provided supporting documentation to frame the land take regulative framework during the decision-making process at the local level. To achieve this, the Hot Spot Analysis was useful in defining urban, transition, and greenfield areas where the application of urban transformation management policies was required.

3.3. *Insights from Settimo Torinese*

The utilisation in Settimo Torinese of the aggregated polygons map (Figure 3) has been used to open the technical discussion around the new land use plan and its practical application. This experimentation has been conducted answering to the specific needs of the Public Administration that asked the research group to design, in a unique layer, the distribution of the higher values of multisystemic capacity in their territory.

The map shows that from north-east to the south-west, the city is bordered by a high multifunctional ES delivering capacity provided by an agro-rural system which is composed of peri-urban agricultural fields and semi-natural zones along the Po River.The northern green border is characterised by patches of high ecosystemic value, with less continuity and a scattered distribution which includes significant green areas located inside the dense and highly sealed productive and commercial units.

Summing up the operational procedure, different ES analytical maps were used toset parcel-based functional zoning for the new land use plan in Settimo Torinese, with different operative purposes:

- the identification of a multifunctional ES classification allows the identification of areas where the land take control approach provided by the guidelines of the Regional Plan finds a prescriptive application at a local scale;
- the identification of priority areas where ecological compensation measures would be applied in the new land use plan.

As regards the application of the Regional Plan, the Hotspot Analysis (Figure 5) helped with the geometrical identification of dense (no quality), transition (average quality), and free (high quality) areas, using an overall ES condition as a proxy for setting the different land use policies: in the cold spots (low quality) re-use is always suggested, in the 'average' areas, transformations with adequate mitigation or compensation are prescribed, and finally in the hot spot areas (high quality) urban transformations are limited, if they occur at all.

In relation to ecological compensation, the creation of a single map where high multifunctional ES value was represented in a simple and straightforward matter (green layer) helped in identifying where the residual urban transformations overlap with the 'green areas' (Figure 6), and therefore some ecological compensation measures were requested in order to maintain the environmental balance. Traditionally, ecological compensation projects aim to increase continuity and contiguity of areas, achieving a better connection between the green patches displayed in the analysis.

After a while, the discussion around the introduction of ecological compensation measures with the Public Administration turned out to be used, considering an additional step to increase the sustainability of the new land use plan.

The multifunctional ES map has been used to discuss the introduction of the block of new urbanisation in open spaces with high ES quality, aiming to guarantee strong conservation of the existing ES delivering capacity. At the same time, the identification of "no-development zones" was equally used by the Public Administration to introduce prescriptive Urban Growth Boundaries. The identification of a customary "perimeter" designed to meet ES conservation with a scientific GIS methodological framework legitimated the Public Administration in monitoring future land use changes and, therefore, controlling local planning decisions. In the case of Settimo Torinese, the Public Administration shared the Urban Growth Boundaries with the

Metropolitan Authority, which served to verify, after a while, whether the local Land Use Plan achieved the target of zero land take in open areas. Finally, the boundary has been used to introduce land use taxation in open spaces with high ES quality. From this perspective, the municipality of Settimo Torinese adopted an extra fee for certain urban transformations that produce environmental impacts. Notably, the composite value of ESs in all transformation areas (greenfields and brownfields) has been used as a proxy for applying an extra environmental feed that generates an economic surplus for the Public Administration (Figure 7). These incomes were used to set compensation measures where the ES framework identifies valuable areas (e.g. new buffer zones for nutrient retention in areas where the delivery is high rather than new tree plantation in rural areas of medium or low Habitat Quality).

This utilisation of ESs for a local land taxation system has been precisely pondered and evaluated with the technical sector of the Public Administration involved in this process. It is worth mentioning that Settimo Torinese has a long tradition in negotiating public economic rents due to urban transformations, since this Municipality has been historically considered as a suitable location for industrial and productive industry. Therefore the Public Administration has been involved in a profound process of transformation during the last thirty years that gives the opportunity to negotiate with the new industrial operators' extra-incomes[1] to develop public spaces, green areas and the requalification of the peri-urban system. Settimo Torinese has been the principal municipality of the first national project on greenbelt construction called "Corona Verde" (Cassatella 2013; Borgogno-Mondino, Fabietti, and Ajmone-Marsan 2015) for its capacity to use public revenues to develop an inter-municipal project on requalification.

In this context, the LIFE SAM4CP did not increase (or decrease) the values of land taxation to avoid owners not coping with the higher taxes: imposition cannot recover all the urban rent generated by land use change; otherwise the marginal incomes for operators would not be sufficient for transforming the land (EEA 2010).

At least the application of the SAM4CP methodology to the municipality of Settimo Torinese helps to define a new scientific method to graduate land taxation according to the multifunctional value of the land and, therefore, to use the ESs as aproxy for land use regulation.

4. *Conclusions*

This paper has introduced an ES assessment approach in the local context of this study that can serve to meet the needs of other Public Administrations in addressing sustainability in planning. Despite several limitations of this study, the combined application of mapping and using multilayered analysis to support decision-making helped to increase the sustainability of decision-making processes for land use planning and increase the utilisation of ESs for their practical applications in selected case studies.

In this paper, practical experience of direct ES utilisation to design parcel-based land use regulation at the local scale is reported (Felipe-Lucia *et al.* 2015; Boerema *et al.* 2017). Such an approach combines different indicators to address a multisystemic distribution, instead of a single representation and assessment, but also has several limitations: (i) the ES selection was pre-assigned and not defined in the planning phase through stakeholder consultation, (ii) the research was not conceived to achieve a composite index, but rather to accomplish a land use plan revision and

(iii) cultural ESs were not considered in this research, thus the GI methodology presented here only partially covers the necessary ES groups (Partidario and Gomes 2013). However, even partial results were encouraging, and therefore they open opportunities for increased research activity (Smith *et al.* 2017; Schmidt *et al.* 2017; Schaubroeck 2017).

Moreover, as introduced in Section 1.1, this pioneering experience should be evaluated with some warnings in mind. First of all, the selection of ESs has a paramount value for multicriteria analysis. In this experience, the weighted overlay operation has been set using all the InVEST outputs provided by the ongoing research activity. This means that there wasn't an adequate selection and discussion on how to weight each ES type to avoid double-counting. Neither was stakeholder engagement included in this experience to define priorities among the different possible targets to achieve: increase the biodiversity, augment carbon sequestration or reduce nutrients in streams. These facts limit the possibilities for establishing an operational framework.

Nonetheless, despite the several technical (ES modeling validation) and methodological limits, these experiences served to introduce a straightforward method to simplify the way ESs are used for planning purposes in a context where the knowledge and the utilization of ESs at its practical stage is weak at all levels (Regional, Metropolitan Authorities and Local Administrations).

The operationalisation of ESs in this experience has been used to establish:

- the multifunctional ES value as a proxy of the land quality defining strategies of limitation, mitigation and compensation measures;
- the Hot Spot areas to determine the threshold of low, medium and high multifunctional delivery capacity and therefore applying the Regional Plan disposition for Urban, Transition and Greenfield identification at the local level;
- the aggregation of polygons for higher multisystemic values to define Urban Growth Boundaries and introducing land taxation to avoid land take and promote urban requalification.

All these steps constitute a unique experience in operational planning in Italy, since the paradigm of ES is at its initial stage of discussion, and far away from being operationalised in the conventional planning process.

Admittedly, this experience has been considered helpful by all Municipalities engaged in the research application. The development of this process aimed at transforming biophysical multipart analysis of ESs into a composite parcel-scale indicator has been shared with local authorities involved in the research activity; therefore ESs were understood using adequate representation and setting sustainable targets in the process of land use plan renewal.

As a minimum target of sustainability in the decision-making process, it has been demonstrated that, in all Municipalities, the territorial multifunctional value of ESs did not decrease between the present situation and the new planned scenario. The reduction of discretional interpretation of maps and the definition of possible operational ES application to aid the decision-making phase for the land use plan definition has been demonstrated here.

It is worth mentioning that the innovation of this experience is not in the technical creation of a composite ES provisioning value at parcel-based scale, since this operation does not imply any policy action. In this experience, the ES assessment has been simplistically synthesised and shared to aid the technical definition of planning priorities discussed with the offices involved in the project application. Indeed, the design of a regulative framework required an in-depth assessment of specific context-based information, such as knowledge of building rights, land properties, real estate interests, political agreement and opportunities, the legal framework and all the information that primarily supports the interaction between technical, political, and civil interests represented in a decision-making process.

One of the initial challenges of the research was to test whether ES assessment can be conceived as an operational tool to support decision-making and define land use planning regulation. The experience reported here discovered a practical solution for bridging the gap that separates the theoretical knowledge of ESs from their practical utilisation in land use instruments.

We are aware that this experience is far away from being assumed as a methodological example that can be exported to another context, but the effectiveness of the results contributes to open up a discussion on how to practically use ESs to designland use plans at parcel-based scale.

Disclosure statement

No potential conflict of interest was reported by the authors.

Note

1. The fiscal system of Local Administrations in Italy is regulated by the self-definition of parametric prices for construction or transformation of the land according to: the kind of change (new construction, restructuration, requalification, ordinary or extraordinary conservation of buildings) and the functional typology (residential, tertiary/commercial or productive/industry).

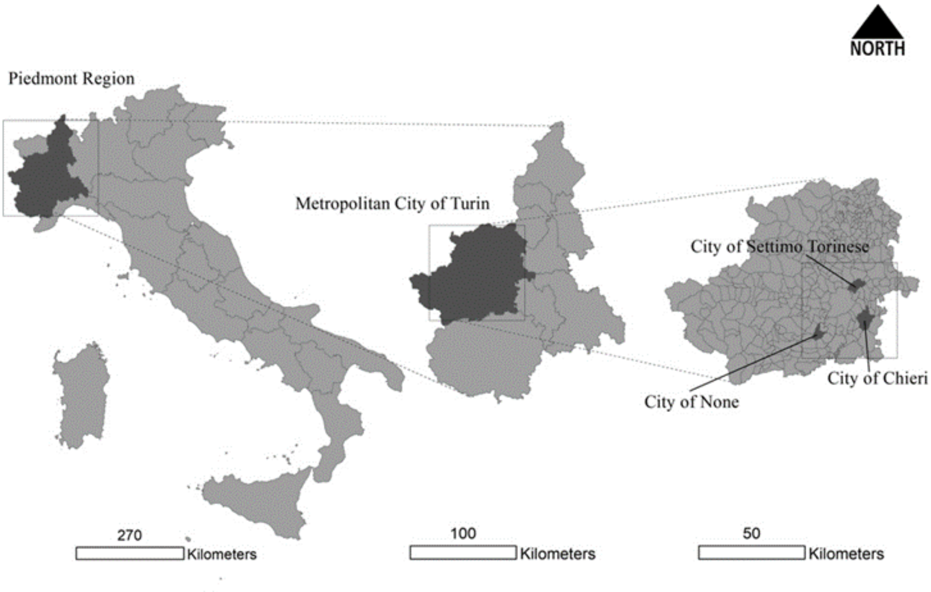

Figure 1. The case of the study area

Figure 2. Parcel-level Composite Valtot score

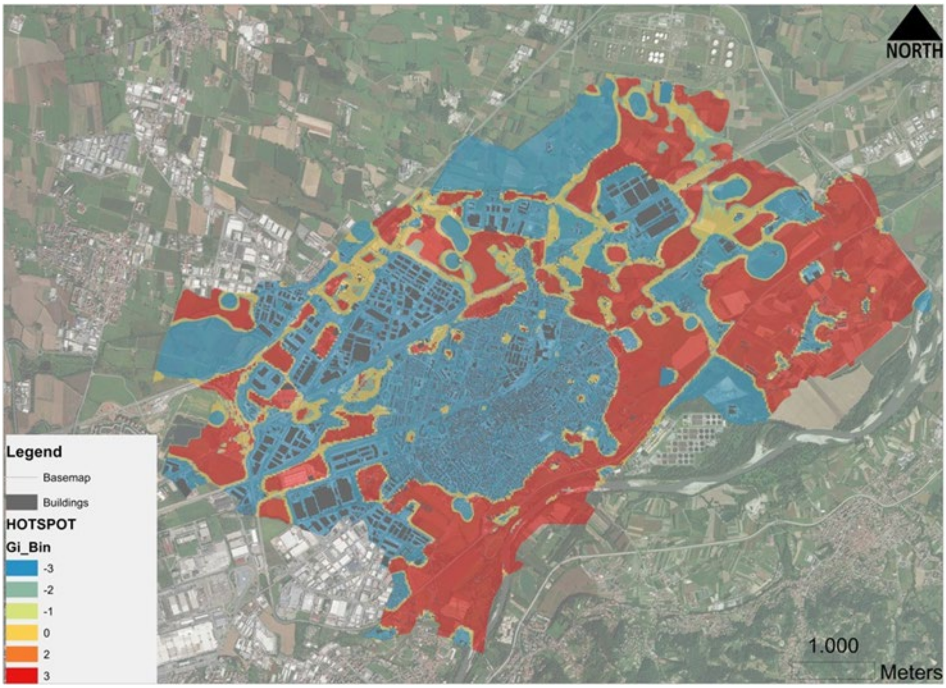

Figure 3. Hot Spot Analysis in the territory of Settimo Torinese.

Figure 4. Aggregate Polygons output in the territory of Settimo Torinese.

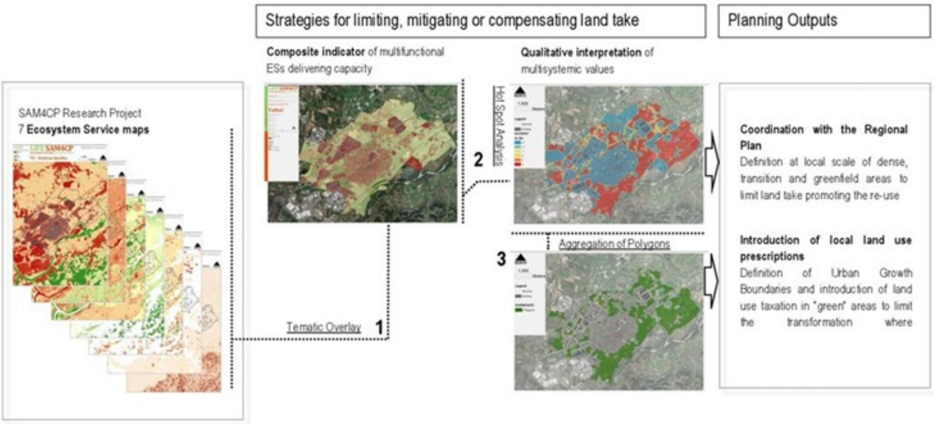

Figure 5. Analytical flowchart.

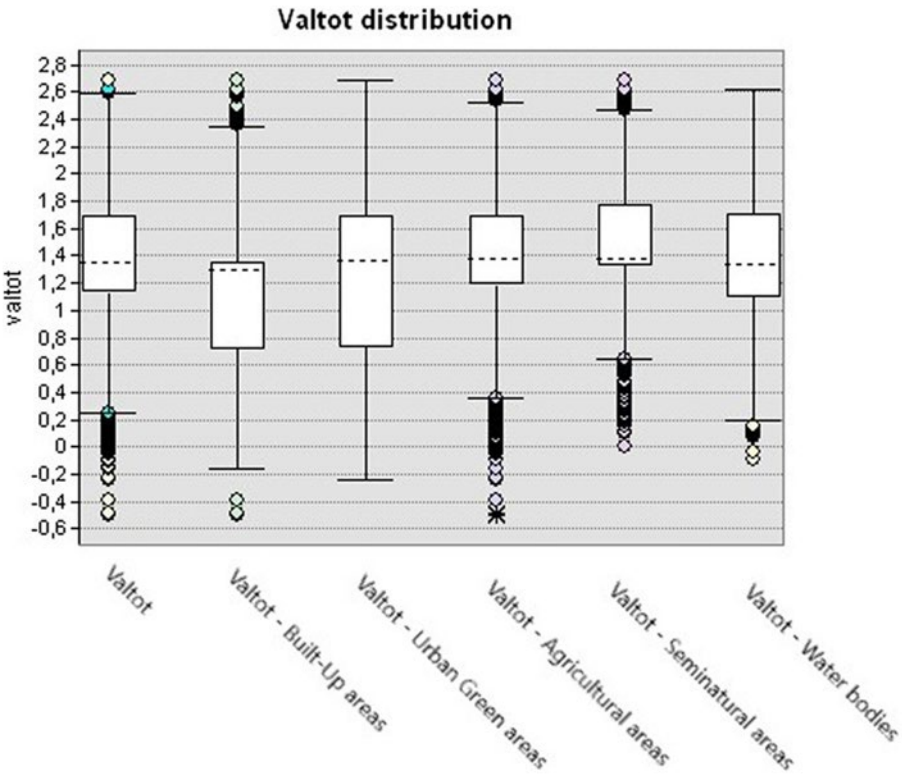

Figure 6. Boxplot of Valtot distribution. In the first column, the distribution considers all the Land Use Land Cover classes, while the other columns show the Valtot distribution for a specific Land Use Land Cover class.

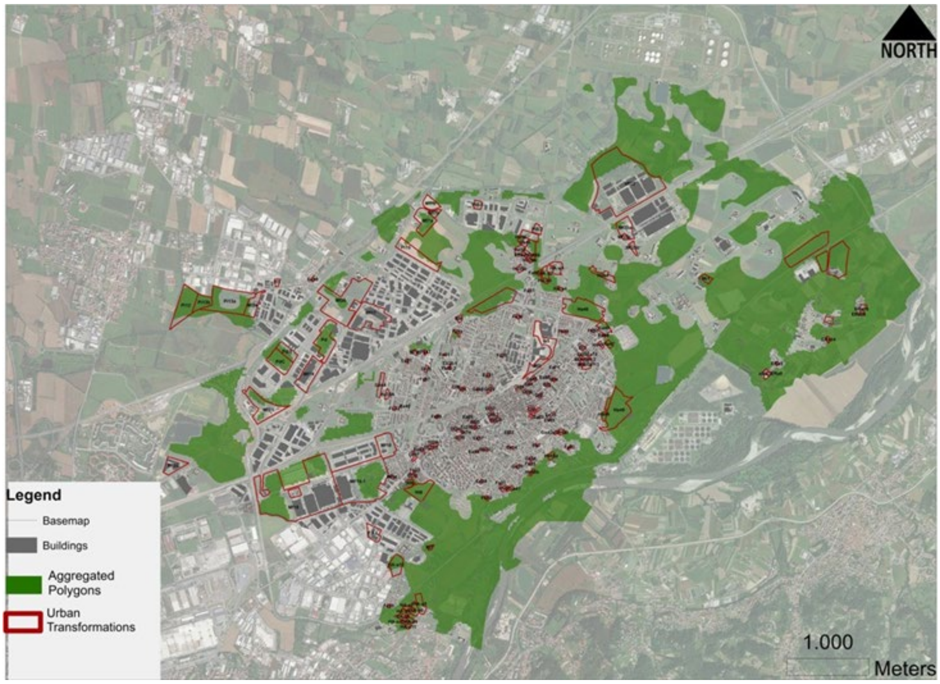

Figure 7. The ES framework overlaps with predicted urban transformations to set out strategies of limitation, mitigation, or compensation for future land use changes.

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