Ecosystem Services for Planning Impacts Assessment on Urban Settlement Development

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Abstract. At global level, land-use changes induced by urban growth processes are considered to be one of the most relevant threats to the conservation of natural habitats, their biodiversity and capacity to provide ecosystem services for human well-being. While in the academic field there is a growing interest in the methodological framework of ecosystem services, in the practice of urban and territorial planning there is a need for new methods and tools to support the assessment of planning choices' sustainability. The aim of this work is to propose a method to evaluate the effects of expansion forecasts set in the urban plan (PRG) of the Municipality of Perugia. The comparison between the state of art and the forecast scenario highlights the degradation increase especially along the interface between urban settlements and agricultural areas, and the relevant habitat quality decrease in urban green areas and in complex agricultural systems close to built-up areas. In spite of the limitations related to the subjectivity of the parameterization of input values, the approach shows potential for the assessment of urbanization processes and for supporting the evaluation of planning choices.

Keywords: Urban growth · Ecosystem services · Habitat quality

1 Introduction

Worldwide, urbanization processes are one of the greatest threats to ecosystem services' and biodiversity conservation. Different development dynamics, the speed of growth of settlements and the specificities of the several contexts lead to increased threats and pressures having negative impacts in terms of reduction and fragmentation of natural habitats [1], depleting their ability to provide ecosystem services and to constitute suitable sites for trophic resources supply and reproduction of wild animal and plant species [2].

In this perspective, it is extremely important for planners to dispose of methodologies and tools to understand and quantify the effects following the implementation of urban and territorial plans on natural systems and their capacity to provide ecosystem services

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[3]. This consideration constitutes the background to the present work, which intends to evaluate the impact due to the full implementation of expansion forecasts of Perugia's urban plan (Piano Regolatore Generale - PRG) in force.

According to Umbria Regional Law no. 31/97, the PRG is divided into a structural and an operational part, assigning to the latter the task of identifying and regulating urban planning forecasts in the methods, forms and limits established in the structural part, specifying its contents and identifying territorial transformations.

The operational part also includes the zones' delimitation, detailing their use and implementation methods in the "Technical standards for implementation" (Testo Unico Norme di Attuazione - TUNA). This identifies areas destined for the completion of building fabric and the expansion of urban aggregates.

On this basis the zoning vectorization was performed, which allowed the spatialization of threats posed by further surfaces' artificialization, increase in settlement pressure and the infrastructural development of new areas.

In particular, for the purposes of this work these threats were implemented within the InVEST Habitat Quality model [4] in order to verify how the levels of cumulative degradation and environmental quality change following the full implementation of the plan forecasts.

For this reason, two scenarios were compared using the informative layers of the Urban Atlas as a basis for land use. The first is the state of art: threats assume an increasing value according to the current urbanization density. The second is the scenario of the full implementation of the expansion forecasts: the mainly residential expansion areas (Zone C) provided within the plan replace the current urban aggregates, leading to an increase in urbanization density.

In the context of this work, the basic assumption is that habitat quality is significant for the total capacity to deliver ES and is therefore a proxy for biodiversity level [5] and overall environmental performance [6].

The paper is structured as follows. The first paragraph describes the study area, illustrating the main characteristics of settlement system of the Perugia Municipality.

The "materials and methods" section describes the preparatory phases of the layers used to simulate the effects of zoning, the datasets used, the functioning of the "Habitat Quality" software of the InVEST suite with relative input data and informative layers.

The second section of the paper concerns the discussion of the results both in terms of mapping cumulative degradation and habitat quality, and in terms of changes in ES considered for each land use class affected by urban growth.

Finally, conclusions report the most relevant highlights showing the contribution that this approach can make to the assessment of expected impacts following different plan choices.

2 Study Area

This work, within the Integrated Project LIFE IMAGINE UMBRIA (LIFE19 IPE/IT/000015) – "Integrated MAnagement and Grant Investments for the N2000 NEtwork in Umbria", focuses on the territory of the Municipality of Perugia, in central Italy, which covers approximately 450 km^2.

Over the last decade, the demographic trend has been more or less constant, with a resident population of around 165 000 000 inhabitants at 31/12/2020 [7].

The overall settlement system is characterized by four main macro-components.

The first is represented by the historic nucleus which, despite its most significant expansion towards the Genna valley, has preserved the characteristics of the compact settlement.

The second macro-component is made up of the system of secondary centers located beyond the Genna valley, which are characterized by considerable complexity due to the overlapping and intertwining of urban and rural structures and functions.

The urban centers along the Tiber valley, which constitute the third macro-component, have different specificities. They are in fact urban aggregates that have developed quite compactly around pre-existing historical settlements.

Finally, the last component is diffuse urbanization consisting of small residential and productive areas set in a disorderly and fragmented way in the rural and natural landscape.

The negative impacts on habitats and ecosystems of high fragmented aggregates and the poor socio-economic efficiency of low-density settlements [8, 9] have led the Umbria Region to search for settlement planning and design models oriented to favor settlement aggregation and preserve the significant landscape heritage [10].

As it emerges from the contribution published in the ISPRA report in 2021 [11], the region of Umbria and the province of Perugia in particular, have an index of settlement dispersion (urban sprinkling) equal to 0.66 (in a range of values between 0 and 1 where 0 indicates dispersed settlement and 1 compact settlement).

In order to obtain an overall picture in terms of the effects of urbanization on natural systems and to avoid the “island effect” linked to the assessment of habitat quality, the elaborations were carried out at a supra-municipal scale including the municipalities of Passignano sul Trasimeno, Magione, Corciano, Panicale, Piegaro, Marsciano, Deruta, Torgiano, Bettona, Bastia Umbra and Valfabbrica. For all of them, the informative layers of the Urban Atlas were available.

3 Materials and Methods

The aim of this work is to compare the impacts due to the full implementation of Perugia’s urban plan with those due to the distribution of the existing settlement system in terms of habitat quality.

To this end, the methodology is essentially structured in two successive steps: the construction of a synthesis vector layer showing the zoning of the municipal territory of Perugia according to what foreseen in the PRG; the execution of the "Habitat Quality" model with reference to the two phases before and after the implementation of Zone C and therefore the increase in building and housing density.

3.1 Dataset Building: The PRG Mosaic

The PRG mosaic is a product of the Life SUN project (ref) developed in order to have a strategic vision on the territorial transformation forecasts. In fact, the mosaic of PRG

forecasts is a procedure of elaboration and standardization of the urban planning tools in force on the territory of the Umbria Region. PRG mosaic has been defined by Fiorini et al. [12] as PTM - Planning Tool Mosaic. A PTM contains the summary of the contents of individual municipal planning tools, using a unified legend obtained from the interpretation of the zone assignments indicated in the source documents. In this way, the zoning of n plans that flow together into PTMs are welded into a single layer accompanied by a single database. Of course, it would also be possible to prepare a simply spatial PTM, maintaining the original synoptic items of the individual plans, but this would compromise the searchability of the device relative to the macroscopic effect deriving from the summary of the indications of the individual municipalities [12]. The standardization procedures of the General Regulatory Plans in the PTM:

- the coding of the graphics and symbolisms to be used to identify the homogeneous zones, the restricted areas, and the land use destinations through the creation of a standard legend;
- defining technical and informatics characteristics of the documentation through the organization and naming of the folders and files;
- defining characteristics of the basic cartography formats to be used for the works.

A strategic level assessment tool was critical to moving forward with the proposed analyses.

3.2 Habitat Quality

Although the result is not immediately convertible into a bio-physical quantity, Habitat Quality (HQ) is recognized as a useful tool for investigating the spatial heterogeneity of the impact of urbanization on ecosystems [1].

The HQ model belongs to the InVEST software suite and it assumes that areas with greater habitat quality grade is characterized by higher biodiversity and relevant environmental values [13]. Its implementation produces two maps: habitat degradation (D_{xj}) and quality (Q_{xj}).

Habitat degradation (D_{xj}) represent the cumulative impact depending on several threats. According to the following formula, it is a function of both habitat sensitivity (S_{jr}) and threats characteristics, i.e. the weight w_r and the impact i_{rxy} of the threat r in cell x originating in y and distant d_{xy}:

$$D_{xj} = \sum_r \sum_y \left(\frac{w_r}{\sum_r w_r} \right) r_y i_{rxy} \beta_x S_{jr}$$

where β_x (varying from 0 to 1) is the accessibility degree of grid cell x.

Habitat sensitivity (S_{jr}) ranges from 0 to 1 and represents the intensity to which the habitat type is affected by each threat: higher values mean that the habitat type is heavily degraded by threats [14].

The HQ is instead dependent from the suitability of each Land Use class to provide adequate conditions for biodiversity persistence (H_j) [15] and from the degradation level (D_{xj}):

$$Q_{xj} = H_j\left(1 - \left(\frac{D_{xj}^z}{D_{xj}^z + k^z}\right)\right)$$

where z and k are numeric constant parameters.

On the basis of these brief model descriptions, it can be stated that the key aspects affecting the execution of HQ model are basically three: the definition of threats, the assignment of habitat suitability and the compilation of the sensitivity matrix.

The definition of threats depends on the purpose of the work: some authors [5, 15, 16] use the model in order to maximize the efforts of long-term biodiversity conservation policies and therefore consider agricultural lands and imperviousness soils to be among the threats. Others [18, 19] use the model to assess the relationships between the loss of ecosystem services and factors representative of socio-economic development, such as population and gross domestic product (GDP). In works and case studies strictly related to urban and spatial planning, it is common to attribute threats only to anthropic territorial components such as infrastructures, urban aggregates, production areas, extraction sites and landfills [19, 20].

As can be seen from Table 1, this is the approach chosen for this work as well. The highly detailed format of the Urban Atlas also allowed for the differentiation of threats posed by urban areas on the basis of building density. In particular, three types of urban areas were considered, characterized by increasing values of both weight and distance of impact of threat. The first type (Urban Areas 1) includes isolated structures, construction sites and discontinuous very low density urban fabric. Urban Areas 2 comprises low and medium density urban areas; the third (Urban Areas 3) consists of dense and continuous urban aggregates.

Table 1. The threats factors and related parameters.

Threat	Max_Dist	Weight	Decay
Urban Areas 1	0.6	0.75	Exponential
Urban Areas 2	1.0	0.80	Exponential
Urban Areas 3	1.5	0.85	Exponential
Industrial areas	1.0	0.90	Exponential
Dump	1.0	0.80	Exponential
Road networks	0.6	0.75	Exponential
Railways	0.75	0.60	Exponential

Concerning the habitat suitability (H_j), the highest values were assigned to the land use classes corresponding to wetlands and freshwaters, forests and herbaceous vegetation associations; intermediate values were assigned to the semi-natural classes (including

arable land, permanent crops, pastures, complex and mixed cultivation patterns) in which the presence of herbaceous, tree and shrub vegetation is relevant, but the impact of anthropic activities is not negligible.

Table 2. Habitat suitability and sensitivity matrix.

Land Use class	Habitat suitability	Urban Areas 1	Urban Areas 2	Urban Areas 3	Industrial areas	Dump	Road networks	Railways
Continuous urban fabric	0.1	0.22	0.24	0.25	0.58	0.51	0.47	0.41
Disc. dense urban fabric	0.15	0.25	0.28	0.32	0.59	0.53	0.48	0.43
Disc. medium density urban fabric	0.20	0.31	0.34	0.37	0.58	0.54	0.49	0.45
Disc. low density urban fabric	0.25	0.36	0.39	0.42	0.61	0.56	0.52	0.47
Disc. very low density urban fabric	0.30	0.42	0.45	0.48	0.62	0.57	0.56	0.48
Isolated structures	0.35	0.35	0.36	0.37	0.38	0.37	0.35	0.34
Industrial, commercial, public, military and private units	0.1	0.30	0.34	0.38	0.56	0.54	0.54	0.49
Fast transit roads and associated land	0.1	0.28	0.34	0.38	0.54	0.53	0.53	0.52
Other roads and associated land	0.15	0.37	0.40	0.43	0.52	0.50	0.52	0.51
Railways and associated land	0.15	0.38	0.41	0.44	0.54	0.51	0.53	0.52

(*continued*)

Table 2. (*continued*)

Land Use class	Habitat suitability	Urban Areas 1	Urban Areas 2	Urban Areas 3	Industrial areas	Dump	Road networks	Railways
Port areas	0.1	0.39	0.42	0.45	0.55	0.52	0.54	0.53
Airports	0.1	0.39	0.42	0.45	0.55	0.52	0.54	0.53
Mineral extraction and dump sites	0.2	0.25	0.28	0.32	0.59	0.53	0.48	0.43
Construction sites	0.30	0.36	0.39	0.42	0.61	0.56	0.52	0.47
Land without current use	0.3	0.45	0.49	0.54	0.72	0.69	0.47	0.47
Green urban areas	0.5	0.71	0.73	0.75	0.81	0.59	0.75	0.68
Sports and leisure facilities	0.25	0.46	0.49	0.54	0.65	0.61	0.68	0.65
Arable land	0.6	0.68	0.71	0.74	0.81	0.79	0.67	0.65
Permanent crops	0.7	0.73	0.75	0.79	0.80	0.74	0.82	0.79
Pastures	0.7	0.77	0.79	0.82	0.87	0.86	0.88	0.86
Complex and mixed cultivation patterns	0.75	0.71	0.75	0.78	0.79	0.83	0.72	0.70
Forests	1.0	0.91	0.93	0.95	0.98	0.97	0.89	0.83
Herbaceous vegetation associations	0.9	0.86	0.89	0.92	0.93	0.88	0.84	0.54
Open spaces with little or no vegetation	0.7	0.76	0.78	0.81	0.89	0.86	0.83	0.81
Wetlands	1.0	0.85	0.88	0.96	0.96	0.91	0.90	0.87
Water	0.85	0.81	0.83	0.91	0.87	0.88	0.72	0.71

As already explained, for the purposes of this work it was not useful to differentiate between land-use classes characterized by the presence of intensive agricultural practices and more conservative ones as proposed in other works [21–24]. Finally, land-use classes related to urban areas and infrastructures were associated the lowest habitat suitability

values. Again, for urban areas, values differ on the basis of building density: lower density (Urban Areas 1) corresponds to slightly higher values than dense and compact settlements (Urban Areas 3).

The last step is to compile the sensitivity matrix (Table 2), considering the relative impact of each threat on every land use class. The criterion used for the assignment of these values reflects the assignment of habitat suitability, considering the greater impact occurring on the more vulnerable land use classes.

4 Results and Discussion

Running the model results in two maps, degradation and habitat quality, which provide different information. While habitat degradation map highlights areas where a relevant cumulative impact occurs by different threats, habitat quality also depends from the suitability, i.e. from its intrinsic environmental value. In other words, quality depends on the specific habitat characteristics and threats extent, degradation is particularly useful to evidence parts of a territory where there is a risk of natural values deterioration [5].

As can be seen from Fig. 1 related to the "State of art" scenario, the areas characterized by the greatest degradation correspond to the most densely populated areas and those with the largest industrial areas.

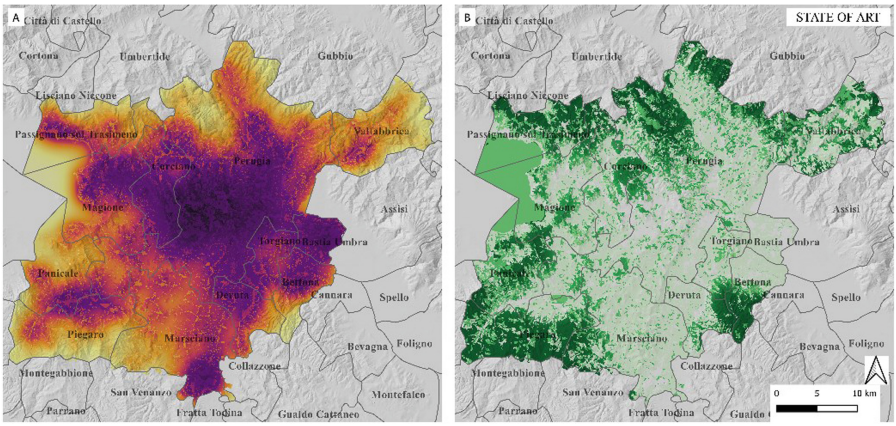

Fig. 1. Outcomes related to the "State of art" scenario: A) Habitat Degradation; B) Habitat Quality

Conversely, areas with quality values close to 1 coincide with areas that are mainly forested or characterized by the presence of herbaceous vegetation associations.

Figure 2 shows the impacts due to the full implementation of urban growth forecasts set out in the PRG. It is possible to notice an increase of areas with maximum degradation values, especially near the built-up area of Perugia. In the interface areas, at the border between urbanised urban settlements and semi-natural land use classes, an increase in the spatial continuity of most degraded areas can also be observed.

In order to facilitate the interpretation of the results and the comparison between the two scenarios, the Habitat Quality maps have been reclassified into five classes

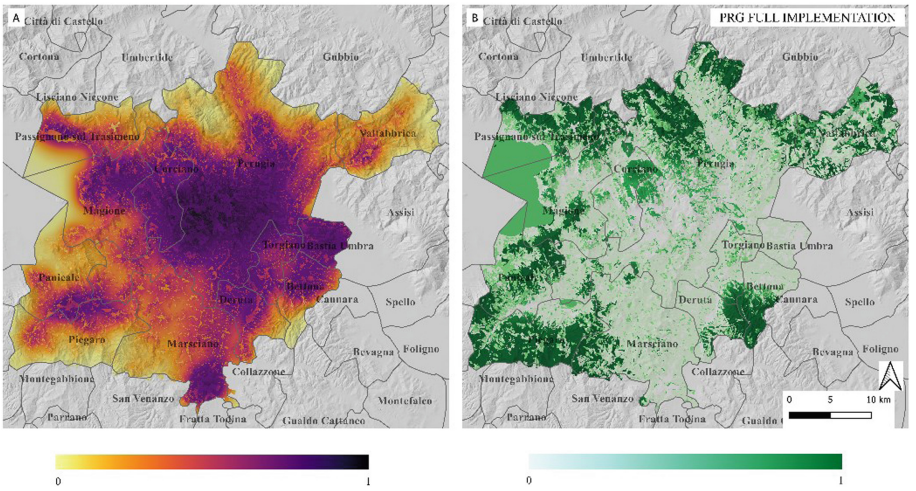

Fig. 2. Outcomes related to the "PRG Full implementation" scenario: A) Habitat Degradation; B) Habitat Quality

from "very low" to "very high". The following graph (Fig. 3) shows that in the forecast scenario areas characterized by lower quality levels increase to the detriment of all other classes.

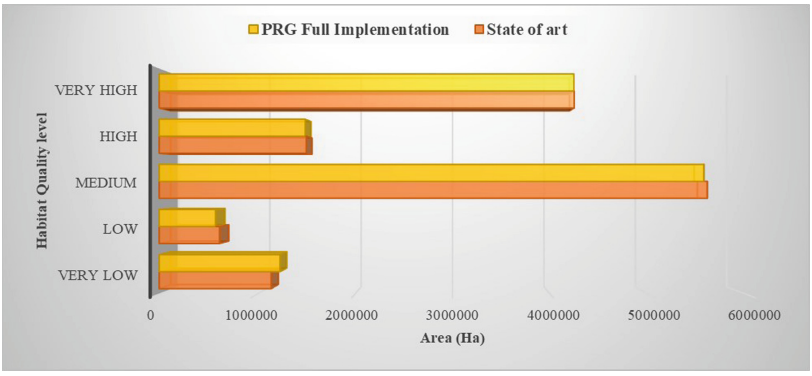

Fig. 3. Comparison between the two scenarios in terms of areas classified into five Habitat Quality levels

Further considerations can be made by assessing the habitat types most affected by the impact of urban growth. To this end, the Table 3 shows the percentage changes in both Quality and Degradation for each natural or semi-natural land use class present within the study area.

Confirming the previous highlights, the decrease in environmental value concerns almost all natural and semi-natural land use classes and especially urban green areas. The decrease in open spaces and in complex cultivation patterns is instead negligible.

Table 3. Variations in Habitat Quality and Degradation for each Land Use class

Land Use class	Habitat Quality variation (%)	Habitat Degradation variation (%)
Arable land	−0,0345%	3,09%
Permanent crops	−0,0032%	4,86%
Pastures	−0,0255%	3,82%
Complex and mixed cultivation patterns	0,0000%	23,39%
Forests	−0,0040%	3,90%
Herbaceous vegetation associations	−0,0027%	5,31%
Open spaces with little or no vegetation	0,0000%	4,68%
Green urban areas	−1,0546%	2,03%
Wetlands	−0,0013%	7,17%
Water	−0,0022%	3,05%

The changes in degradation are much more significant, particularly in complex cultivation patterns, herbaceous vegetation associations and permanent crops.

Finally, it should be also noted that changes in Quality and Degradation also concern the classes relating to surface water and wetlands, even though they are not directly affected by the spatial transformations simulated. This demonstrates that the model succeeds in capturing an increase in pressures acting on natural habitats even in the absence of land use changes.

5 Conclusions

In the last decades, conflicts between human and natural resources has intensified [25]. Globally, processes such as urbanization and land-use changes have advanced in frequency and intensity contributing to rise the impact of human disturbance on natural habitats [26] threatening long-term human well-being [27] and negatively affecting the livability of urban spaces [28–30].

In order to achieve sustainable development, there is need to comprehensively understand and assess the health of complex ecosystems [31] and to better integrate these evaluations into planning processes [32–34].

This paper proposes an innovative approach for assessing planning choices related to urban expansion processes on the basis of their influence on the capacity of ecosystems to provide ecosystem services for human well-being and biodiversity conservation.

The effort of this work is in fact to formulate a methodological proposal that allows in a spatially explicit way to quantify the impact resulting from the full implementation of expansion forecasts provided by the urban plan of the Perugia Municipality.

To this aim, impacts were assessed using the Habitat quality model which provides a proxy of overall environmental values of the territory [19], showing how increasing artificial surfaces, rising urban density and changes in the land use pattern affect the ability of ecosystems to provide appropriate conditions for biodiversity persistence.

The results show that the proposed approach provides useful insights to govern urban growth phenomena by limiting disorderly urban sprawl [35] and to explain the trade-offs between natural habitats and urbanization needs [36] by orienting planning choices towards areas where the expected impacts are lower. This constitutes an innovative aspect of this research, which operationally integrates the methodological framework of ecosystem services with urban planning, supporting an ex-ante evaluation of processes and thus fostering a more balanced combination between urban growth needs and ecosystem functionality.

Some limitations are related to the subjectivity of the parameterization of the model input values and the extent to which the assignment of these sets affects the result. One of the most important aspects to address in future research development is certainly the selection of threats, which, as pointed out in the description of method, is affected by subjectivity. In this regard, it could be useful to carry out a sensitivity analysis in order to check how much the choice of threats and their parameterization affect the resulting variations in Habitat Quality values.

Future research developments will therefore be oriented towards making more rational the values setting, so that the methodology can be replicated in other urban contexts without affecting results accuracy.

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