Università degli Studi della Basilicata

Dottorato di Ricerca in

"INGEGNERIA PER L'INNOVAZIONE E LO SVILUPPO SOSTENIBILE"

"From multiple Ecosystem Services (ES) to ES Multifunctionality: assessing territorial transformations in spatial planning"

Settore Scientifico-Disciplinare
ICAR/20

Coordinatore del Dottorato	**Dottoranda**
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Ciclo XXXIV

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Sommario

1. Introduction

Spatial planning and natural resources: a relationship to be renewed

Urban planning discipline initially arose from the need to rationalize and acquire instruments to manage the expansion of urban agglomerations (Salzano, 1998).Through decade this approach, that we consider as a process, suffered the dualism between *urbanism* and *environmentalism* generated a distorted perception of the disciplinary principles. On one side, the radicalization of environmentalism perspective that puts nature conservation before any hypothesis of territorial anthropic transformation deemed necessary to pursue socio-economic development objectives. On the other side, the adoption of human-centered socio-economic development models in which several environmental goods and services spontaneously provided by natural ecosystems were not included in “commodities”, i.e. without exchange value. This second paradigm has only recently - and partially - been questioned. A decisive factor has been the recognition and consequent increase in awareness among scientists, politicians and citizens' movements that natural resources are limited.

On the basis of these assumptions, this research work is based on the firm conviction that spatial planning is a privileged dimension in which the above factors can converge in a sustainable perspective. This consideration stimulates research questions oriented to balance the conflicting needs of conservation of natural resources, economic development and social equity. The results may contribute to reinforce the planner’s toolkit for a more effective decision-making in managing territorial development (Batty, 2013; Friedmann, 2019; Healey, 2003), defining an up to date methodological framework oriented to enhance the procedural approach in planning (Alexander & Faludi, 2016), grounded on evaluation stage (Weiss, 1972) highlighting lessons learnt and cyclic approach.

According to Archibugi (Archibugi, 1994, 2002), an initial change in this approach can be traced back to the introduction of the concept of "sustainable development" (Brundtland, 1987), understood as the continuous search for a dynamic equilibrium between available resources and development. This, according to the urban planner, marked the moment of convergence between the concept of sustainability and environmentalism.

However, more than 30 years later the Brundtland report, at global level, the planning discipline is still tackling the unsolved conflict between the anthropic systems and environmental components experimenting methodologies, normative tools and spatial analytical models for the improvement of the integration between the anthropic and environmental components (Nelson et al., 2010) through planning system. Among modern planning issues it is relevant to mention: the persistent land consumption, which is increasing in intensity and speed (Zullo et al., 2021), the consequently growing awareness of the expected impact on natural capital (Costanza & Daly, 1992), quality of life in urban environments (Blečić et al., 2018) and new challenges related to climate changes (Pasi et al., 2019; Pietrapertosa et al., 2019).

The challenge facing spatial planners is to resolve conflicts between competing demands for limited resources (Shoyama & Yamagata, 2014) while ensuring adherence to the three principles of rational planning (Las Casas & Scorza, 2016a): fair access for people to opportunities and services, efficiency use of natural resources

(Gómez-Baggethun & Barton, 2013a) and sustainability (R. De Groot, 2006; Dendoncker et al., 2013; Selman, 2009).

The effective handling of these challenges is undermined by the lack of full integration of the environmental components management in the traditional planning system, which, according to the author, can be ascribed to three main weaknesses:

- the first weakness concerns the rigidly prescriptive of “zoning” (Cortinovis & Geneletti, 2020). It is based on verifying the suitability of the territory for a specific function and it leads to an a-priori design of the plan aimed at "conforming" development projects and actions to the pre-established strategy (Janin Rivolin, 2008). This aspect, object of criticism by an extensive scientific literature that puts it in opposition to an alternative approach based on the concept of *performance* (Baker et al., 2006; Faludi, 2000b; Frew et al., 2016; Geneletti et al., 2017; Haller, 2014), has generated criticalities and inefficiencies (Scorza, Saganeiti, Pilogallo, & Murgante, 2020). This lack of flexibility depends from the rapidity with which the community needs evolve, making the traditional plan “vintage” and inadequate (Romano et al., 2018).
- an additional weakness of the traditional planning system is the overlapping policies and responsibilities at different territorial government levels (Nolte et al., 2010) that are often reflected in cross-scale political contradictions (Apostolopoulou et al., 2012) linked to a range of sectoral policies (Winkel et al., 2015) and a top-down governance gap (L. C. Stringer & Paavola, 2013). As highlighted by the authors (Scorza, Pilogallo, Saganeiti, & Murgante, 2020a; Scorza et al., 2021), this fragmentation affects long-term strategies related to the sustainable development goals (United Nations, 2015), the mitigation and adaptation measures to climate changes (Lovell & Taylor, 2013; Pachauri et al., 2015; Pramova et al., 2012), the conservation of biodiversity (Balletto et al., 2020; IPBES, 2019) and natural resources (Bongaarts, 2019; Primmer & Furman, 2012).
- the third weakness concerns the failure of traditional planning in promoting the quality of territorial transformations beyond minimum thresholds depending on technical and sectorial rules. This criticality manifests itself both at urban scale and at territorial scale. For instance, if we refer to the urban context, the assessment of transformations related to urban development including environmental components pursues, in the Italian practice, the traditional approach related to the concept of "urban standard". These are nothing more than minimum thresholds that regulate the availability of services and facilities for each inhabitant, regardless of the assessment of the effective improvement of citizens' well-being (Colavitti et al., 2020; Graça et al., 2018). In the scientific literature, several authors advocate overcoming this approach, highlighting the opportunity to explicitly refer the real needs of citizens generating specific demands for services and urban functions depending on the specific context (Cortinovis & Geneletti, 2020; Gobattoni et al., 2017; Ronchi et al., 2020).

At the territorial scale, the fundamental normative framework for the evaluation of territorial transformations is the Environmental Impact Assessment (EIA). It consists of a coherence check with the binding framework foreseen for the territory in which the project is inserted, and in the consequent agreement/disagreement on the impacts that the project exerts on each component of environmental matrix. The effectiveness of this procedure, already weak in a context where there is no effective process of involvement and participation of decision-makers and stakeholders (R. De Groot, 2006), is further undermined by the absence of adequate monitoring systems of territorial transformations capable of providing a comprehensive and integrated view of the expected effects at several scales (Scorza, Saganeiti, Pilogallo, & Murgante, 2020). During the research program, these topics were analyzed in several works (L. Saganeiti et al., 2019; Lucia Saganeiti et al., 2018; Lucia Saganeiti, Pilogallo, et al., 2020; Scorza, Saganeiti, Pilogallo, & Murgante, 2020).

Ecosystem Services: a framework for reformulating the human-nature relationship

The term "Ecosystem Services" first popped up in the scientific literature in 1983 in an article published by Ehrlich and Mooney (Ehrlich & Mooney, 1983) who was the first addressing the loss of "*services to humanity*", suggesting the conservation approach to these services as the only possible to guarantee a long-term well-being for human kind.

For a while, it remained bounded within ecological and biological disciplines. It is following the publication of two pioneering works in the late 1990s that ES gained much attention within the scientific debate. In 1997, the first attempt to comprehensively illustrate the multiple benefits that humans obtain from ecosystems was published by Daily et al. (Daily, 1997). In the same year, Costanza et al. (Costanza et al., 1997) made further progress by globally estimating the economic value of ES provided by all types of biomes. The same author (Costanza et al., 2014) points out that the most important contribution of the ES approach is its ability to reformulate the relationship between humans and environmental components by highlighting their role as critical components of wealth, well-being and inclusive sustainability. The resonance of this approach was such that in 2001 the United Nations within the United Nations Environmental Programme (UNEP) launched the Millennium Ecosystem Assessment (MA) (Millennium Ecosystem Assessment, 2005) with the aim of illustrating the state of the art of ecosystems and providing a scientific basis for the definition of actions needed to improve the conservation and sustainable use of Natural Capital (C. Finlayson, 2018). Although the ES framework today is gaining relevance in the international policy agenda (Geneletti, Cortinovis, Zardo, & Esmail, 2020), crossing the boundaries of ecological and biological disciplines and directly communicating with decision-makers (Carpenter et al., 2006), it still represents an emerging research topic for planning disciplines.

In spatial planning and land use management, ES constitutes an integrated and robust analytical framework as it is directly related to land use patterns and their changes over time, to the spatial distribution of different spatial components (both natural and anthropic) as well as to the implementation of land use plans and policies (Ronchi, 2018) producing two levels of contributions: informative and methodological.

The first refers to the possibility of measuring and spatializing the services that ecosystems provide for citizens' well-being. This implies the possibility to improve the knowledge infrastructure that supports the planning process in its different phases. The spatially explicit assessment of ES can take place ex-ante and provide the elements for deepening the knowledge framework and spatializing the demands emerging from the territory in terms of specific ES (Bolund, Permar & Hunham, 1999). For example, in the urban context it is possible to map areas where there is an unsatisfied demand for recreational services (Giedych et al., 2017; Graça et al., 2018), for local temperature regulation (a service linked to the growing topic of heat islands) (Elliot et al., 2020; Sabrina Lai et al., 2020), or for the absorption of noise and atmospheric pollutants along routes with heavy vehicle traffic (Blum, 2017; De Carvalho & Szlafsztein, 2019). Instead, in the case of ex-post evaluation, ES offer an effective infrastructure for monitoring the actual benefits deriving from the implementation of the planned actions.

In addition, we include in this contribution the communicative capacity of this approach towards non-expert stakeholders and decision-makers, which is expressed both by acting as an interface between science and decision-makers (Gustafsson et al., 2020; Perrings et al., 2011), and by contributing to increasing the transparency of the plan process (Karrasch et al., 2014; Schröter et al., 2018).

The methodological contribution, instead, refers to support the elaboration and benchmarking of alternative development/transformation scenarios, making quantitatively and spatially explicit the impacts of planned actions on the wider territorial values system (environmental, social, cultural, etc). This reinforces the capacity of rational decision-makers to take “better” decisions (Owens, 2005; Sanderson, 2002; Scorza et al., 2019; Weiss, 1979) by structuring a context-based assessment framework (Gee & Burkhard, 2010; Potschin & Haines-Young, 2013a), tailored to the features of the territorial system’s structure. This dimension becomes even more important when the territorial transformation drivers act in a different scale than the one where impacts become measurable (Scorza, Pilogallo, Saganeiti, Murgante, et al., 2020b).

From Ecosystem Services to ES Multifunctionality: an innovative approach to meet specific demands for nature-based services

For ES multifunctionality we intend the opportunity offered by the ES approach to consider “the joint supply of multiple Ecosystem Services (ES)” (Mastrangelo et al., 2014; Stürck & Verburg, 2017), i.e. the natural capacity of ecosystems to deliver for humans manifold benefits (Hansen & Pauleit, 2014).

This concept derives from disciplinary fields related to ecology (Byrnes et al., 2014) that, for example, were aimed at explicating the high ecological value of territories characterized by a variety of habitats and living species (Lovell & Johnston, 2009). It was successively adopted in conservation planning where, for the purposes of biodiversity conservation and enhancement, was applied as a criteria to define priority areas to be protected (Cimon-Morin & Poulin, 2018; García-Llorente et al., 2018; Y.-P. P. Lin et al., 2017; Vaz et al., 2021). In contrast to monofunctional “grey” infrastructures, the European Commission furtherly declined its meaning within the “Green Infrastructure-Enhancing Europe’s Natural Capital” Strategy (European Environment Agency, 2013) where GI are defined and specifically designed to “deliver *a wide range* of ES”. In this specific application domain, ES multifunctionality has been applied at different spatial scales from the urban to the territorial one (Arcidiacono et al., 2016; Cannas et al., 2018b; D. La Rosa & Privitera, 2013; Sabrina Lai et al., 2018a; Ronchi et al., 2020; Zhang & Muñoz Ramírez, 2019). Whereas initially it constitutes a value in itself (from the perspective of providing as many of *whatever* ES as possible), aiming at meeting as many demands and valuing co-benefits as much as possible (Hansen & Pauleit, 2014).

Recently, the interest in spatial and urban planning disciplines toward the ES multifunctionality approach also increased (Artmann, 2014; Dendoncker et al., 2013; Hansen et al., 2015; Primmer & Furman, 2012). This is due to several factors. Firstly, some authors point it as a useful tool to operationalize the concepts of efficient use of natural resources' use efficiency (Gómez-Baggethun & Barton, 2013a) and sustainability (R. De Groot, 2006; Dendoncker et al., 2013; Selman, 2009), included among the founding principles of planning (Las Casas & Scorza, 2016a). Secondly, considering several goods and benefits simultaneously, means pursuing several environmental, social, cultural and economic objectives and addressing different potentially conflicting demands in both urban planning and spatial governance. This directly relates to the complexity of socio-ecological systems (Gómez-Baggethun & Barton, 2013b; Murray-Rust et al., 2011) that characterize human settlements: the capacity to supply multiple ES results in perceived benefits, for example in terms of human health, social cohesion and in the diversification of rural economic opportunities (Fagerholm et al., 2020; Lafortezza et al., 2013; Tzoulas et al., 2007). Finally, different authors (Galler et al., 2016a; Uthes et al., 2010) argue that pursuing ES multifunctionality as an objective, makes it possible to increase the efficiency of efforts - including economic ones - to protect the various environmental components. Galler et al (Galler et al., 2015b) for example, show that the economic efficiency of the measures financed by the European Agricultural Fund for Rural Development (EAFRD) can be increased by adopting an integrated approach.

In compliance with Juntti et al (Juntti et al., 2021) who consider the ES multifunctionality to be representative of the citizens' perceived quality of life in urban environment, we acknowledge that ES multifunctionality has a strong communicative potential, providing a cross-cutting and comprehensive assessment of the overall performance of the environmental components. This can be implemented as a tool for increasing awareness of sustainability issues among non-experts or as an element of comparison between territorial units in the light of spatial arrangements (e.g. land use pattern, territorial fragmentation, degree of anthropization, land use intensity) which in turn are the expression of different territorial policies.

Although there is no unambiguous definition of ES multifunctionality in the literature (Mastrangelo et al., 2014) and there is also a lack of agreement on which ES should be delivered by territorial components in order to be considered "multifunctional" (Stürck & Verburg, 2017), this approach promises to be able to confer several added values to the plan process.

Research questions and thesis objective

The preceding paragraphs are useful to place the PhD course within a broader framework of research in the disciplinary field of spatial planning.

On the one hand, there is a need for more effective integration of environmental issues within the planning processes. The pursuit of this objective can be traced back to three weaknesses identified within the traditional planning system. On the other hand, there is the ES methodological framework within which the ES multifunctionality approach is promising in providing methodological support to overcome the limitations arising from the weaknesses outlined above.

In the light of these premises, the research program was structured around one main question:

How can the ES multifunctionality approach contribute to renew the planning system placing environmental components as services providers whose availability represents a pre-condition for any sustainable development strategy?

Therefore, the general objective is to deepen the ES multifunctionality concept, generalizing a framework methodology supporting the planning process.

The research was therefore divided into several steps. An extensive analysis of scientific bibliography was carried out in order to explore conceptualizations, computational methods and applications of ES multifunctionality to selected case studies in order to demonstrate potentials and shortcomings.

An extensive part of the research work dealt more specifically with the computational aspects of assessing and mapping the ES. In the following chapter we define the choice of computational software used for the case studies applications. Among available options the InVEST suite of models (NatCap, 2020). Offered several advantages: it is available in open-source format, which allow the replicability of the elaborations and favors the spreading of these models; additionally it is based on available datasets and information layers including land use patterns and sector-specific disciplinary layers; it is a spatially explicit model, a fundamental feature for the application of those models in the planning practice.

Outline of dissertation

The thesis structure follows the *"three papers"* format, which generally consists of a collection of articles recently published in (or submitted for publication to) international peer-review journals.

Specifically, this thesis consists of an introductory chapter that places the research agenda within the broader disciplinary framework, five chapters that constitute the main body of the thesis and a final chapter that describes the major findings and outlines the future perspectives of the research.

The main contents of each chapter are described below.

Chapter 2

This chapter proposes a critical review of the ES multifunctionality in the urban and spatial planners' perspective. The main purposes are to explore the topic of ES multifunctionality proposing a classification of approaches present in a wide selection of scientific literature, and to highlight possible contributions for the effective integration of environmental components within planning processes.

The review is structured in two-step. The first one is based on "three decision domains" and classifies the works on the basis of the respective "research questions" that we link to the three elements of weakness of the traditional planning system mentioned in the previous paragraphs. The second step is founded on three sets of criteria (the criteria for selecting the ES, the method and scale for assessing multifunctionality, the explicit reference or not to specific beneficiaries and stakeholders) considered relevant in the planning practice.

This chapter is based on the article:

Pilogallo, A., & Scorza, F. (2022). Ecosystem Services Multifunctionality: an operative review from urban planners' perspective. *Progress in Planning*. [Under review]

Chapter 3

This chapter has the purpose of illustrating the main computation methods of the ES subsequently implemented in the further case studies. In particular, for each of the modules used, we illustrate the assumptions, input data and sources of information related to the different biophysical tables required by the software. All the elaborations are developed at the national scale and constitute an original result contributing to extend the national spatial knowledge infrastructure.

This chapter is based on the article:

Pilogallo, A., & Scorza, F. (2021). Mapping regulation ecosystem services (ReMES) specialization in Italy. *Journal of Urban Planning and Development.* https://doi.org/10.1061/(ASCE)UP.1943-5444.0000801

Chapter 4

In Chapter 4 we deliver an original "Cities ranking" applying ES multifunctionality approach based on the Multiple Ecosystem Services Landscape Index (MESLI) formulated by (Rodríguez-Loinaz et al., 2015b).

This ranking include all the Italian Provinces and is compared with the most well-known rankings yearly published in Italy by relevant agencies. We highlight hoe ES-based ranking produce an alternative classification of Italian territories describing a different perspective in assessing the quality of life.

This chapter is based on the article:

Pilogallo, A., Scorza, F., & Murgante, B. (2022). Ecosystem Services based Cities Ranking in Italy: committing decision makers toward sustainable planning. *Land Use Policy.* [Submitted]

Chapter 5

Chapter 5 is a further application of the ES multifunctionality approach conducted at the national scale. The purpose is to provide an interpretive framework of the land use dynamics that occurred in the period 2000-2018 based on three different indices of ES multifunctionality. The results show that the settlement dynamics and the territorial transformations occurred, produced a different effect on the three indices highlighting that their joint interpretation can support the definition of ES multifunctionality conservation strategies.

This chapter is based on the article:

Pilogallo, A., Scorza, F. (2022). Ecosystem Services Multifunctionality: an analytical framework to support sustainable spatial planning in Italy. *Sustainability.* [Under revision]

Finally, in order to give a comprehensive picture of the whole research program it is relevant to point out that the selected papers organized in this thesis give evidence of the innovation perspective that ES approach may bring in planning theory and practice placing the environmental components as key factors of the planning process. It represents a way to overcome the pure conservation principle expressing a passive role of natural and environmental territorial features to an active dimension of services providers whose availability represents a pre-condition for any sustainable development strategy. It is also a way to provide new tools and new answers to the unsolved conflict between anthropic and natural systems. Furthermore we demonstrated the operational transferability of the results in the current practice from the Environmental Impact Assessment processes to the effective contribution of ES multifunctionality assessment in Decision Making including scenario analysis. Finally, multifunctionality index strongly support communication in planning process according to the potential to synthetize a complex technical information set in easy-to-use map for stakeholders and non-expert actors of the process.

Furthermore, the chapters included in this thesis comes from a selection of a wider papers list published during the Ph.D. course representing on going applications of ES framework on several relevant planning emerging themes. In particular relevant applications regards:

- Land take and territorial fragmentation (Lucia Saganeiti et al., 2018; Lucia Saganeiti, Pilogallo, et al., 2020; Scorza, Saganeiti, Pilogallo, & Murgante, 2020)
- Ex-post impact assessment of Renewable Energy Plants settlement (Scorza, Pilogallo, Saganeiti, Murgante, et al., 2020b)
- Territorial tourism attractiveness evaluation (Angela Pilogallo et al., 2018; Scorza et al., 2019)
- Habitat Quality compared with territorial transformation in inland areas (Muzzillo et al., 2021; Impact of Renewable Energy Installations on Habitat Quality, 2020; Nolè et al., 2020, 2021)
- Monetizing ES in regional territorial context (A. Pilogallo et al., 2020)
- Conflicts between natural conservation policies and remediation plan for polluted industrial sites (Scorza, Pilogallo, Saganeiti, & Murgante, 2020a; Scorza et al., 2021)
- Assessment of the impacts of Land Use Changes on ES Control of Erosion Rates (Angela Pilogallo et al., 2020)
- Carbon Stock VS Renewable Energy Plants un-planned settlement (Arianna Mazzariello et al., 2018)
- Ecosystem Services, human health and territorial management (Murgante et al., 2022; Murgante, Murgante, et al., 2021)

All the references of the above mentioned papers, not included as chapters in this thesis, are included in the list of publications attached.

2. Ecosystem Services Multifunctionality: an operative review from urban planners' perspective

Abstract

Ecosystem Services (ES) thinking is emerging as a robust methodological framework, capable of enriching the planning knowledge system by effectively explicating environmental performances and supporting the assessment of impacts expected as a result of land-use policy implementations and spatial transformations. In particular, here we focus on ES multifunctionality, i.e. the opportunity offered by the ES approach to consider several goods and benefits simultaneously, thus jointly pursuing several environmental, social, cultural and economic objectives and addressing different potentially conflicting demands in both urban planning and spatial governance.

Because of the high degree of complexity of ES multifunctionality, due to the properties of simultaneity and interactivity between several ES, its integration into planning processes is still challenging.

This work proposes a review of a selection of scholarly papers with the twofold aim of: highlighting the contributions that ES multifunctionality approach can provide with respect to some of the weaknesses of the traditional planning system; deriving considerations regarding the ES selection, the specification of beneficiaries and the methods used with the aim to finalize the applications of ES multifunctionality to planning processes.

The conclusions report the support that the ES approach can provide in addressing critical issues in the traditional planning system, improving the efficiency and transparency of the decision-making process and encouraging the involvement of multiple types of stakeholders.

Keywords: Ecosystem Services (ES), ES Multifunctionality, Planning processes

Introduction

Ecosystem Services (ES) thinking is emerging as a robust methodological framework, capable of enriching the planning knowledge system by effectively explaining environmental performance and supporting the assessment of impacts expected as a result of land use policies implementations and territorial transformations (Angela Pilogallo & Scorza, 2021a). Recently, the interest in planning discipline toward the ES multifunctionality approach also increased (Artmann, 2014; Dendoncker et al., 2013; Hansen et al., 2015; Primmer & Furman, 2012) mainly because it is able to effectively implement the concepts of natural resources' use efficiency (Gómez-Baggethun & Barton, 2013a) and sustainability (R. De Groot, 2006; Dendoncker et al., 2013; Selman, 2009).

The purpose of this paper is to explore the topic of ES multifunctionality, defined as *"the joint supply of multiple Ecosystem Services (ES)"* (Mastrangelo et al., 2014; Stürck & Verburg, 2017), proposing a classification of approaches present in a wide selection of recent bibliography related to the domain of urban and spatial planning (Bretagnolle et al., 1998; Gatzweiler et al., 2020; Lobo et al., 2020) aimed at highlighting possible contributions for the effective integration of environmental components within planning processes.

The persistent increase of land take and urbanization, the growing awareness of their consequences on Natural Capital and the new challenges related to climate change, call indeed for reflection on the degree and modalities of integration between the planning system and environmental components (Nelson et al., 2010). Spatial planners are increasingly asked to solve conflicts between competing demands for limited resources (Shoyama & Yamagata, 2014) but in addressing these issues, the traditional planning system showed three main weaknesses: rigidity, fragmentation and un-effective evaluation. The first concerns the rigid approach pursued, focused on verifying the suitability of the territory for a specific function rather than providing an integrated and comprehensive vision of the human-territory system. The second refers to the fragmentation of plans and planning responsibilities due to both the multi-level hierarchical system and the sectoral plans' archipelago. This fragmentation makes it difficult to assess the convergence degree of planning instruments with respect to emerging shared objectives connected to natural resources conservation (Bongaarts, 2019; Primmer & Furman, 2012), mitigation and adaptation to climate change (Lovell & Taylor, 2013; Pachauri et al., 2015; Pramova et al., 2012), inclusive citizenship (*New Urban Agenda*, 2016), renewable energy supply (International Renewable Energy Agency, 2019), sustainable development goals (United Nations, 2015). Finally, the third weakness concerns the capacity of the plan to assess its performance in terms of objective achievement, effective use of resources, the quality of territorial transformations. It reflects the pillars of the methodologies of procedural approach in planning widely described by (Alexander & Faludi, 2016; Weiss, 1972) defining the evaluation stage as a fundamental input for effective circular approach in planning: the lessons learned from the ending planning/programming period becomes drivers to inform and improve the next planning season in a circular process (Figure 1).

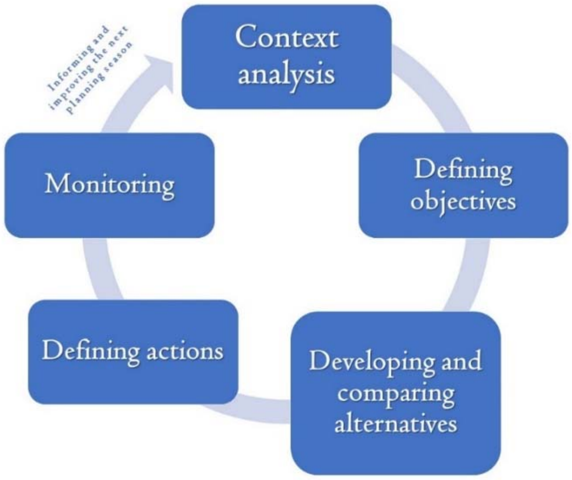

Figure 1 Circular planning process

If we refer to the specific issue of integration between the assessment of transformations linked to urban development and environmental components, the approach envisaged by the Italian planning system is still linked to the concept of 'standards'. Transformations can take place within the strict zoning and the parameters set by the urban planning instrument. The availability of services – including green areas - is instead regulated by minimum thresholds for each inhabitant (i.e. urban standards). In this regard, there is a general effort (Gobattoni et al., 2017; Ronchi et al., 2020) to overcome this approach in practice and pursue a perspective fully focused on the improvement of citizens' well-being by the means of ES framework (Colavitti et al., 2020; Graça et al., 2018).

We have to point out that, on the territorial scale, a key reference for territorial transformations assessment is the Environmental Impact Assessment (EIA), widely managed by competent authorities as an agree/disagree check on qualitative impacts of the project on some reference environmental components/values. It is even weaker in a context where an effective process of involvement of the relevant decision-makers and stakeholders is not realized. Additionally, the effectiveness of this process is further undermined by the absence of monitoring systems that support an effective and transparent decision-making process (Scorza, Saganeiti, Pilogallo, & Murgante, 2020).

Our position is that the concept of multifunctionality, belonging to the methodological framework of ES, is worthy to be explored as a suitable dimension to address the previous planning traditional system's weaknesses (Angela Pilogallo et al., 2020; Scorza, Pilogallo, Saganeiti, Murgante, et al., 2020a; Scorza, Pilogallo, Saganeiti, & Murgante, 2020a). In fact, ES multifunctionality allows a performative approach to evaluation processes explicating several aspects of the complex human-territory system and contributing to the construction of a knowledge system that prevails over the limits linked to the fragmentation of sectoral plans and the mosaic of authorities responsible for land management. The adoption of a ES multifunctionality approach does not impact on the rigidity of the planning system as it depends on a rigid regulatory framework. Nevertheless, it offers the decision-maker an innovative knowledge infrastructure to appropriately relate the planning instruments to the development strategy.

The literature review shows that the topic of ES multifunctionality is increasingly recurrent in planning disciplines (Hölting, Beckmann, et al., 2019) but the wide variety of conceptualizations and approaches (Mastrangelo et al., 2014) risk undermining its potentials in decision-making processes.

For this reason, we propose a literature review on ES multifunctionality according to the following structure: in the first session, we define our two-step review framework. The first step is based on the three "Domains of Decisions" (DD), defined as decision-making contexts where the ES multifunctionality approach can provide added value. We defined the Strategic DD, the Integration DD and the Transformations DD. The second step concerns the analysis of the ES applied in in the selected literature, the method and the scale for assessing ES multifunctionality and the more or less explicit reference to the "beneficiaries" of the goods and services delivered by ecosystems.

In the second session, we report the most relevant results of the papers classified according to the first review step. For each DD we discuss the aims pursued and the approaches used by authors highlighting salient features, strengths and weaknesses that bring a significant contribution to the integration of ES multifunctionality in planning processes.

In the third session we discuss the results of the second step of review, highlighting relevant considerations about the trend in selecting ES to integrate in the multifunctionality assessment and the most common methods used to assess and represent the multifunctionality. Further remarks concern the identification and evaluation of beneficiaries; this allows us to verify to what extent elaborations and analyses for the evaluation of multifunctionality are consistent with a plan process that responds to a specific instance.

Finally, we derive conclusions about the existing gap between scientific production and planning system and propose some highlights that could set the path for future research aimed at implement ES multifunctionality in practice.

Our framework

The ES multifunctionality approach is finding increasing applications in the planning discipline (Hölting, Beckmann, et al., 2019) because, despite the critical nature of the planning process which makes challenging the interpretation of technical and sectoral contents, it allows an integrated and comprehensive overview of complex dynamics.

The capacity to supply multiple ES results in perceived benefits, for example, in relation to human health, social cohesion and in the diversification of rural economic opportunities (Fagerholm et al., 2020; Lafortezza et al., 2013; Tzoulas et al., 2007). Following a social-ecological perspective (Hansen & Pauleit, 2014), the measure of territorial ES multifunctionality supports a comparison between different territorial units and produces a strong communicative representation allowing citizens to perceive ES multifunctionality as a proxy of the quality of life perceived in their living area.

The ES multifunctionality derives from disciplinary fields related to ecology (Byrnes et al., 2014) that, for example in studies conducted at landscape scale, were aimed at explicating a value related to the variety of habitats present and the abundance and richness of the number of living species (Lovell & Johnston, 2009). A consequent progression was the use of ES multifunctionality assessment for the purpose of biodiversity conservation and the designation of areas to be protected (Cimon-Morin & Poulin, 2018; García-Llorente et al., 2018; Y.-P. P. Lin et al., 2017; Vaz et al., 2021).

In applications more closely related to the discipline of urban and spatial planning, ES multifunctionality has become one of the design criteria of Green Infrastructure (GI), from the urban to the territorial scale (Arcidiacono et al., 2016; D. La Rosa & Privitera, 2013; Ronchi et al., 2020; Zhang & Muñoz Ramírez, 2019). Even regarding this specific application sector, an evolution in the GI designation approach can be observed: GI is no longer the infrastructure that delivers as many ES as possible, but the one that *leveraging co-benefits* tries to cope with as many instances as possible (Hansen & Pauleit, 2014). In other words multifunctionality is no longer a value its own but, in the planning perspective, it becomes a value when it satisfies multiple demands, multiple needs that emerge from a previous context analysis. In this sense, for example, (Meerow & Newell, 2017) propose a design methodology based on a spatial multi-criteria evaluation in order to maximize citizens' expectations in terms of ES supplied by GI.

This premise is useful to better define the purpose of this work, which is not to deepen the topic of ES multifunctionality, but to draw useful indications and insights for the purpose of its integration within the planning processes. Therefore, with the final aim to contribute to tackle the challenge of a more effective integration between environmental components and the traditional planning system, we structured our two-step review framework (Figure 2): the first is based on three Domains of Decisions (DD); the second consider ES assessed, method and scale of assessment, the presence of stated beneficiaries.

We defined Domains of Decisions as decision-making contexts where the ES multifunctionality approach can contribute to meet a specific urban planning demand. In light of this, we considered the Strategic DD, the Integration DD and the Transformations DD.

The first is the Strategic DD, where the strategy is formulated and the objectives of spatial development in a long-term perspective are outlined. It is oriented towards facilitating understanding of socio-economic and environmental complex dynamics related to the land use pattern, and the search for actions and solutions through continuous interaction between the different players involved in territorial management. It also provides keys to interpretate territorial dynamics that can facilitate the balance between development needs, environmental performance and social well-being.

The second is the Integration DD, aimed at illustrating methodologies and approaches useful to overcome the fragmentation of sectoral plans or to measure to which extent a local action can contribute to pursuits of policy objectives defined at a larger scale. Jointly considering multiple ES, in fact, allows to assess the coherence between several sectoral plans or between plans implemented at different spatial scales, with the ultimate goal of finding the best possible synergy or, in some cases, the solution corresponding to the least trade-off.

The third is the Transformation DD, oriented to the evaluation of territorial transformations and able to provide a measure of their effects in terms of change in environmental performances. For example, this DD includes proposals for urbanization compensatory mechanisms based on the concept of ES multifunctionality (Calzolari et al., 2020; Cortinovis & Geneletti, 2020), evaluations of the environmental impact of projects (Angela Pilogallo et al., 2019; Scorza, Pilogallo, Saganeiti, Murgante, et al., 2020a), assessment of the effects of urban growth dynamics (González-García et al., 2020a).

The second step of our review framework is founded on three sets of criteria. One concerns the ES considered in each work. In particular, in addition to the number and the class of belonging according to the various classification schemes, the motivation of the choice of the analyzed papers was deepened. This aspect is aimed at bringing out how much the assessment of multifunctionality is integrated within a planning process and therefore to what extent it derives from a context analysis or a previous assessment of territorial instances. In some cases, in fact, the evaluation of multifunctionality comes after a participatory process that sees the active involvement of stakeholders (R. De Groot, 2006; Guerry et al., 2012); in others, it derives from a purely scientific approach (Meerow & Newell, 2017; Remme et al., 2014) or from the data availability (Blumstein & Thompson, 2015; Leh et al., 2013). In many cases, the choices are not argued at all (De Vreese et al., 2016; Lawler et al., 2014; Nelson et al., 2010).

A second set of criteria concerns the explicit consideration of ES beneficiaries. As highlighted by (Wolff et al., 2015), the set of ES beneficiaries is quite varied as it depends on a kind of demand that can be aimed at (1) risk reduction, (2) preferences and values, (3) direct use or (4) consumption of goods and services. As part of this work, we therefore took note of whether there was an exact definition of beneficiaries in the evaluation for the various ES considered and whether the authors proposed criteria for their quantification as well. In planning perspective, in fact, it is not enough for a service to be delivered. For the purposes of a real contribution to community, it is indeed indispensable that the service be accessible and that it responds to a real need (Cimon-Morin & Poulin, 2018) or have a strong social relevance (Fagerholm et al., 2020; Potschin & Haines-Young, 2013b).

Since we share the position of (Stürck & Verburg, 2017) about the importance of selecting the scale and method of assessment based on the research question, the third set of criteria summarizes the methods used to assess multifunctionality, specifying the assessment scale and whether or not mapping was performed. For the purpose of supporting planning process, it is in fact relevant to highlight how much the results of each research project maintain a spatial distributed dimension.

According to our review framework, we classified the methods used to assess multifunctionality in: simple assessing of multiple ES, aggregate indices, trade-off analysis, ES bundles.

By aggregate indices we mean those aimed at expressing in an overall and integrated way a single value of ES multifunctionality. These indices may have been formulated by the authors based on their own specific objectives/needs or be the result of spatial aggregation, weighted (e.g. (Nin et al., 2016)) or not (e.g. (Zhang & Muñoz Ramírez, 2019)).

Trade-offs analysis are to be intended as the investigation of the mutual relationships between various ES and the assessment of their variations under different scenarios resulting, for example, from changes in land use (e.g. (Zarrineh et al., 2018)), implementation of specific policies (e.g. (Albert et al., 2016)), or project implementation (e.g. (Intralawan et al., 2018)).

Finally, we refer to *bundles* as "*set of associated ES that repeatedly appear together across time or space*" (Raudsepp-Hearne et al., 2010), affected by the same change drivers or processes (Staiano et al., 2021) and thus varying toward the same direction.

As pointed out by several authors (García-Nieto et al., 2013; Palomo et al., 2013), for the purposes of implementing the ES methodological framework in planning and decision-making processes, the issue of the assessment scale is tricky. One of the main reasons for this is that there is often a mismatch between the urban or suburban scale at which spatial transformations take place and are actually regulated, and the scale at which the effects of these transformations are experienced in terms of the provision of ecosystem services. The second reason lies in the availability of data at such a fine scale (González-García et al., 2020a; Kandziora et al., 2013) and in the scalability of the models to be used (Blumstein & Thompson, 2015), intended as the ability to ensure the same result accuracy for each assessment scale.

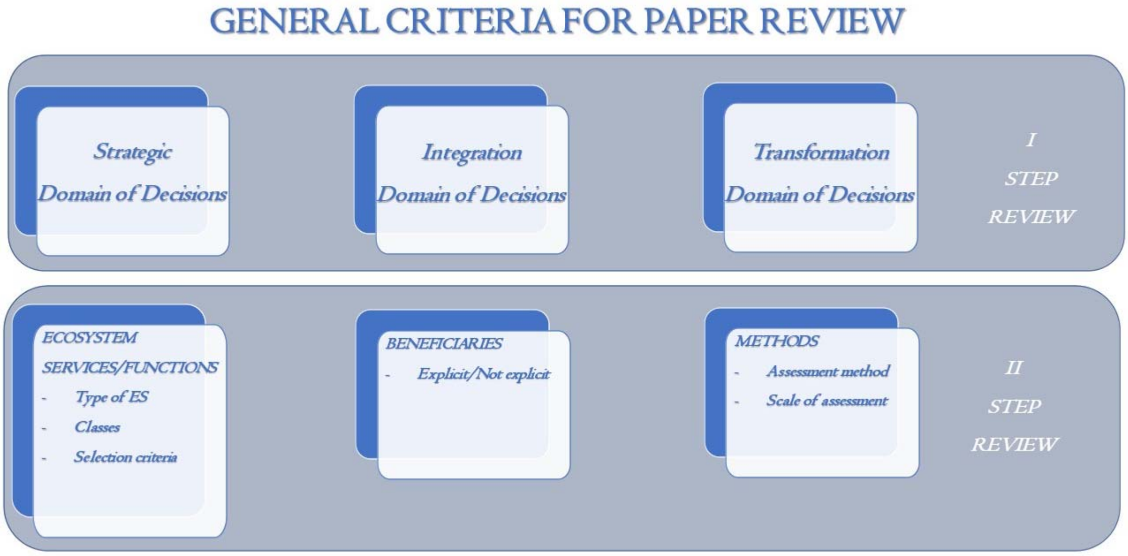

Figure 2 Two-steps review framework

I Step review

The Strategic DD

This DD concerns the strategic definition of the framework of urban-environmental/regional-environmental sustainability in order to identify policies of intervention and objectives to pursue in in the concerted planning of individual transformation actions. In order to set the objectives of spatial development in a long-term perspective, it is aimed at an interpretation of the territorial structure from which emerge the identification of needs and the actions required to meet them.

Key element of the strategic domain is the sharing of objectives and the building of a consensus-based strategy. For this reason, its role is also to facilitate the understanding of socio-economic and environmental dynamics in order to identify shared strategies for a proper balance between development needs, environmental performance and social welfare, regardless of the spatial scale of evaluation. The papers assigned to this DD are summarized in Table 1.

With reference to a planning process, therefore, this DD includes work that provides a context analysis that expresses the potential of the territory also in terms of multifunctionality, work aimed at defining strategic objectives, and work that uses multifunctionality as one of the criteria for developing and comparing plan alternatives.

As part of context analysis, one of most easy-to-use methods for assessing and mapping ES multifunctionality by an aggregate index was proposed in 2009 by Burkhard et al. (Burkhard et al., 2009) with the specific intent to foster the sustainable use of services provided by natural ecosystems by *providing an integrative information layer*. Based on a matrix that assigns to each land use class of the Corine Land Cover a provisioning capacity for each ES considered, this approach is useful to communicate even to non-experts the potential expressed at the territorial level in terms of benefits provided by natural ecosystems. In this sense, this approach is configured as an awareness raising tool and a method to rapidly rank the territorial units, easily identifying areas in which to prioritize conservation measures or carry out interventions for regeneration. Based on the same approach, Bolund et al. (Bolund, Permar & Hunham, 1999) suggest formulating urban growth strategies that value the provision of ES that contribute to the quality of both urban spaces and the citizens' life.

In order to help build a shared systemic vision, Soderman et al. (Soderman et al., 2012) develop a set of ES-based indicators to inform planners, administrators and local stakeholders about the sustainability of urban development strategies and planning choices. With the same aims of supporting a debate in participatory planning processes and mainstreaming the sustainability thinking into decision-making processes, (Grêt-Regamey, Altwegg, et al., 2017) propose a web-based spatial decision support tool able to dynamically perform multi-criteria analysis thus ensuring both integrating different preferences and maintaining an high transparency (Malczewski, 2006). The tool, designed to support the definition of developments areas at regional and municipal level, highlighted its potential in analyzing land use changes and urban settlement growth under the lens of ecological and socio-economic aspects. With the same aim, Cerreta et al. 2020 (Cerreta et al., 2020a) proposed a 3D representation of Urban Ecosystem Services as a spatial decision support system aimed at highlighting the mutual relationships between man and environment, at improving the visualization of the spatial relationships of service allocation and at modeling urban structure-function relationships.

An additional strategic dimension is that of linking ES framework to UN Sustainable Development Goals (SDGS) (United Nations, 2015). This is closely related to the concept of multifunctionality because one or more ES contribute to the pursuit of each SDG, and making these relationships explicit is essential for planning synergistic and cost-effective measures (Costanza et al., 2016; Wood et al., 2018; Yin et al., 2021). In this perspective, some authors performed long-term scenario analyses in order to compare management choices for a marine protected area (Ward et al., 2018) or to assess synergies and trade-offs between SDGs and their targets under future LULC changes (J. Xu et al., 2021).

Context analysis and identification of potential critical issues in some work takes advantage of the concept of multifunctionality to assess current and future trends in land use change (e.g. (Stürck & Verburg, 2017) and the effects of implementing different environmental policies among administrative units. For example, Chen et al. (W. Chen et al., 2019) investigated by means of a spatial regression the variation in the spatial distribution of multifunctionality with respect to significant variables of land use changes, in turn influenced by the protection and conservation policies in force in each of the Chinese counties.

Still at the stage of in-depth context analysis, Queiroz et al 2015 (Queiroz et al., 2015) declined multifunctionality in terms of diversity of ES provided and identified bundles over which to formulate effective territorial policies that could potentially benefit from ES synergies.

Also belonging to this domain are works that, as part of a planning process, are placed in later stages such as defining strategic goals and developing and comparing different alternatives.

For example, the strategic dimension underlying the choice of the most suitable approach for the evaluation of multifunctionality at the landscape scale is well explained by Mastrangelo (Mastrangelo et al., 2014), who illustrate the differences between two opposite land use patterns, namely land-sparing and land-sharing. The authors pointed out that a territorial policy oriented to pursuit objectives of global relevance (e.g. habitat protection, carbon sequestration) should favor land-sparing. Within this pattern, the distribution of land uses reflects specialization in the provision of a specific function, i.e., a particular ES. In turn, if priorities are to be placed on the well-being of local communities (Baró et al., 2017; Peña et al., 2018) and increasing resilience, for example against natural hazards, land policy should encourage land-sharing. With the same multifunctionality measured at the landscape scale, such spatial arrangement is finalized to distribute as uniformly as possible the provision of all the ES considered. Not to define a strategy, but in order to comparing alternative scenarios, this approach was used by several author both in urban context, for example to evaluate urban growth dynamics (Collas et al., 2017), or at a wider scale to assess land use management strategy (Zarrineh et al., 2018) also by a participatory approach (Martínez-Sastre et al., 2017).

Table 1 - Papers assigned to Strategic DD indicating assessment scale

Paper	Scale of assessment	Paper	Scale of assessment
(Albert et al., 2016)	Spatial scale	(Y.-P. P. Lin et al., 2017)	Spatial scale
(Allan et al., 2015)	Spatial scale	(Lovell & Taylor, 2013)	Municipal
(Andersson-Sköld et al., 2018)	Local	(Madureira & Andresen, 2014)	Municipal
(Arcidiacono et al., 2016)	Regional	(Martínez-Sastre et al., 2017)	Spatial scale
(Asadolahi et al., 2018)	Spatial scale	(Meerow & Newell, 2017)	Multiscale
(Baró et al., 2017)	Multiscale	(Nelson et al., 2010)	Multiscale
(Blumstein & Thompson, 2015)	Multiscale	(Nikodinoska et al., 2018)	Municipal
(Bolund et al., 1999)	Municipal	(Pan et al., 2013)	Spatial scale
(Burkhard et al., 2009)	Spatial scale	(Peña et al., 2018)	Spatial scale
(Cannas et al., 2018c)	Regional	(Plieninger et al., 2013)	Spatial scale
(Cerreta et al., 2020a)	Regional	(Queiroz et al., 2015)	Multiscale
(W. Chen et al., 2019)	National	(R. De Groot, 2006)	Spatial scale
(Collas et al., 2017)	Municipal	(Raudsepp-Hearne et al., 2010)	Regional
(De Vreese et al., 2016)	Spatial scale	(Remme et al., 2014)	Multiscale
(Fagerholm et al., 2020)	Spatial scale	(Rodríguez-Loinaz et al., 2015a)	Multiscale
(Frank et al., 2014)	Regional	(Ronchi et al., 2020)	Municipal
(Fürst et al., 2010)	Spatial scale	(Schirpke et al., 2019)	Spatial scale
(García-Llorente et al., 2018)	Spatial scale	(Shoyama & Yamagata, 2014)	Spatial scale
(Geneletti, 2013a)	Regional	(Soderman et al., 2012)	Multiscale
(Grêt-Regamey, Altwegg, et al., 2017)	Spatial scale	(Stürck & Verburg, 2017)	Multiscale
(Guerry et al., 2012)	Spatial scale	(Sun et al., 2017)	Multiscale
(Hu, Zhang, & Ke, 2018)	Municipal	(Wang et al., 2019)	Multiscale
(Jiang, 2018)	National	(Ward et al., 2018)	Spatial scale

(Juntti et al., 2021)	Local	(X. Chen et al., 2017)	Spatial scale
(Lawler et al., 2014)	Supranational	(J. Xu et al., 2021)	Spatial scale
(Leh et al., 2013)	National	(Y.-P. Lin et al., 2017)	Spatial scale
(Lester et al., 2013)	Spatial scale	(Zarandian et al., 2017)	Spatial scale
(Li et al., 2018)	Spatial scale	(Zarrineh et al., 2018)	Spatial scale

The Integration DD

Although the value of multifunctionality is widely recognized, the assessment of mutual interactions among multiple ES is not sufficiently integrated within regional and urban plans (Bennett et al., 2009). One dimension in which the evaluation of multifunctionality could add value is the Integration DD. In fact, many authors point out the criticalities linked to the fragmentation of sectoral plans and difficulties in verifying the coherence among the environmental objectives of plans hierarchically placed at different levels (Rozas-Vásquez et al., 2018).

Regarding the complexity of the integration between environmental targets and the hierarchical organization of planning system (González-García et al., 2020a), common to many countries (Rozas-Vásquez et al., 2018), there is a demand for multiscale approaches capable of transferring objectives of global interest to local scale (Schröter et al., 2005), where most land-use decisions are made (García-Nieto et al., 2013; Palomo et al., 2013). According to Kandziora et al. (Kandziora et al., 2013), this issue is challenging for several reasons: the lack of accurate and spatially explicit data, the intensity of effort needed and the high time consumption required.

Since, however, the successful integration of the ES framework depends on its potential adaptability to urban planning tools, several authors have seized the multifunctionality approach as an opportunity to combine local instances, the main object of fine-scale planning, with global objectives. Paper assigned to this DD are summarized in Table 2.

(Vaz et al., 2021), for example, perform scenario analyses to verify the convergence of zoning and constraints set within the urban planning tool with the objectives of the EU Biodiversity Strategy for 2030. Their stated purpose is to directly involve local administrators in pursuing the protection and restoration of the areas richest in biodiversity by means of the urban planning tool. A further example comes from (Cimon-Morin & Poulin, 2018) who propose an approach to integrate wetland conservation objectives, also evaluated in terms of economic resources needed, within the decision-making process in urban areas and referring to the zoning provided by the urban planning instrument.

Instead, the mismatch between the ES supply and demand scales is the core of the work of (Kleemann et al., 2020), aimed at proposing a methodology for evaluating ES flows that benefit a country but are provided elsewhere. Their ultimate goal is to support the development of governance models capable of overcoming administrative boundaries with a view to global sustainability.

The other dimension of this DD concerns the fragmentation of sectoral plans that several authors indicate as a potential source of conflicts in land management measures (Cortinovis & Geneletti, 2018; Scorza, Pilogallo, Saganeiti, & Murgante, 2020a; Tao et al., 2018) and a cause of waste of public resources due to the low efficiency of actions implemented disorganically (Bateman et al., 2013; Uthes et al., 2010).

Many of works addressing this issue, deal with the need to balance demands that if not well managed, can result in significant trade-offs. This often relates to what (Shen et al., 2020) call "the food-environment dilemma", i.e. the increasing demand for agricultural productivity that should not be pursued at the expense of environmental quality (Nelson et al., 2010).

Galler et al (Galler et al., 2015b) discuss the same topic related to the fragmentation of measures financed by the European Agricultural Fund for Rural Development (EAFRD). They show that the efficiency of these measures can be increased by adopting an integrated approach that simultaneously considers the objectives related to the individual environmental components (water, soil, climate change mitigation, biodiversity). In other words, their findings reaffirm the potential of multifunctionality assessment as a basic layer on which to develop sectoral management plans that collectively improve overall ecological benefits and improve the efficiency of public spending.

(Uthes et al., 2010) show in fact that pursuing a multifunctionality objective rather than individual goals aimed at increasing only one ecosystem function, can produce a relatively better result for the same amount of money spent. As stated by (Galler et al., 2016b), "*assessing multifunctionality leads to higher effectiveness and efficiency in offering ES*".

We consider afferent to this DD also the work of (Manea et al., 2019) that uses the ES framework and the assessment of multifunctionality to overcome the fragmentation of the competent authorities in the management of the Adriatic Sea with the aim of identifying priority areas for conservation.

Table 2 - Papers assigned to Integration DD indicating assessment scale

Paper	Scale of assessment	Paper	Scale of assessment
(Cimon-Morin & Poulin, 2018)	Multiscale	(Shen et al., 2020)	Spatial scale
(Galler et al., 2015b)	Regional	(Uthes et al., 2010)	Spatial scale
(Kleemann et al., 2020)	Supranational	(Vaz et al., 2021)	Municipal
(Manea et al., 2019)	Spatial scale	(Villoslada et al., 2018)	Spatial scale

The Transformation DD

This DD addresses the use of the concept of multifunctionality in the land transformation assessment process (Table 3). By spatial transformation we mean changes in land use due to spatial dynamics, such as urban growth, or the implementation of projects capable of having an effect in terms of changing the provision of some ES. For this reason the assessment scale is also varied, ranging from the local scale to the urban or even territorial scale. In the context of a planning process, these assessments can be performed ex-ante and be aimed both at comparing different alternative scenarios and at assessing suitable environmental compensation measures. Alternatively, the ES methodological framework and the multifunctionality evaluation can support and complement environmental impact assessment (EIA) procedures.

Related to an-ante evaluation phase, is the work proposed by Calzolari et al. 2020 (Calzolari et al., 2020) and aimed at make the concept of multifunctionality fully operational in the context of urban planning. In particular they illustrate a methodology to map the quality of urban soils, formerly assess the impact of urban transformation and support the definition of compensating measures. Similarly, Cortinovis et al. (Cortinovis & Geneletti, 2020) shape a mechanisms to assess the impacts of the transformations envisioned by the urban plan following a benefit-oriented perspective. In particular, they assign to each transformation a level of performance depending from how much ES supply should be provided, and a type of performance depending from what ES demand should be prioritized. In contrast to the first work, however, this second compensation mechanism explicitly considers and measures ES beneficiaries, weighing the demand for each ES proportionally to them.

Still at the urban scale, (Zhang & Muñoz Ramírez, 2019) propose a method for mapping multifunctionality basing on a spatial non weighted aggregation and using as reference an ES matrix that scores the capacity for each land use class to provide every ES considered. The holistic approach to design a urban GI is novel because it does not consider only green areas but extends mapping and assessment of ES to the whole municipal area. On the basis of these it also provides useful measures to drive future urban transformations. Based on the current level of ES provision, the authors make in fact a classification ("ecosystem service barren area" (ESBA); "ecosystem service obstructed area" (ESOA); "ecosystem service provision area" (ESPA)) and define for each of them a set of planning goals (e.g. maintain the existing high-quality green spaces; protect cultural services; increase green areas; regenerate the vacant lots; ecological restoration measures) in order to provide a quantitative approach to foster sustainable development of urban settlement.

Also at the spatial scale, several authors propose approaches to integrate the assessment of the effects of land use change in terms of the multiple ES provided: (Nin et al., 2016) pursues the path of comparing different scenarios, whereas Gonzalez-Garcia (González-García et al., 2020a) performed an ex-post transformation processes' assessment along an urban-rural gradient in the Madrid region. Othoniel et al. (Othoniel et al., 2019) formulate a cause-effect chain to describe land-use impacts and calculate mid-point and end-point characterization factors in the context of a life cycle assessment (LCA).

Table 3 - Papers assigned to Transformation DD indicating assessment scale

Paper	Scale of assessment	Paper	Scale of assessment
(Calzolari et al., 2020)	Municipal	(Jackson et al., 2013)	Spatial scale
(Chang et al., 2017)	Local	(Karjalainen et al., 2013)	Spatial scale

(Cortinovis & Geneletti, 2020)	Municipal	(Mandle et al., 2016)	Spatial scale
(González-García et al., 2020a)	Multiscale	(Nin et al., 2016)	Spatial scale
(Graça et al., 2018)	Multiscale	(Othoniel et al., 2019)	Multiscale
(Haase et al., 2012a)	Multiscale	(Scorza, Pilogallo, Saganeiti, Murgante, et al., 2020a)	Municipal
(Hashimoto et al., 2019)	Regional	(Staiano et al., 2021)	Spatial scale
(Intralawan et al., 2018)	Spatial scale	(Zhang & Muñoz Ramírez, 2019)	Municipal
(J. C. S. Rosa & Sánchez, 2016)	Spatial scale		

With regard to traditional EIA procedures, several authors point out critical issues. Some (Landsberg et al., 2013; J. C. S. Rosa & Sánchez, 2016) argue that current procedures fail to capture the impacts resulting from interactions between different components of environmental matrix, and only investigate the project-single-component relationship. Others (Honrado et al., 2013; Mindell et al., 2008; Slootweg et al., 2003) complain of a lack of consideration for social impacts and how changes in biophysical ES provision influence citizens' well-being. Finally, Scorza et al. (Scorza, Saganeiti, Pilogallo, & Murgante, 2020) highlight that its effectiveness is furtherly undermined by the lack of monitoring systems, thus ending up being ineffective in supporting transparent decision-making (Fisher et al., 2009).

Seeking to fill these gaps, the literature analysis shows that integrating the ES framework with the EIA process can be aimed either at bringing scientific support or at giving the whole process a more comprehensive approach, including social assessments. In the first case, the use of ES serves to fill a gap in terms of cumulative impacts resulting from the complex dynamics underlying the ecosystems' multifunctionality. To this end Scorza et al. (Scorza, Pilogallo, Saganeiti, Murgante, et al., 2020a) proposed a methodology aimed at characterizing the cumulative impact of renewable energy settlements throughout a procedure implemented on the specific territorial system and based on four ES selected because considered to be most significant for the study area.

In the second case, the aim is to integrate the social component into the evaluation. (J. C. S. Rosa & Sánchez, 2016), for example, formulated a methodology resulting in an impact assessment directly proportional to the vulnerability of beneficiaries, considered as a combination of: intensity of service use (daily, weekly or less); dependence on the service; relative importance of the service to affected beneficiaries.

Jackson et al. (Jackson et al., 2013) refer specifically to "ES negotiation" illustrating a GIS framework (namely *Polyscape*) designed to promote cross-sectoral evaluation and to encourage the active involvement of multiple stakeholder groups.

II Step review

This session illustrates the results obtained following the second step of our review framework, founded on three sets of criteria as described in Figure 2. For each of the papers analyzed, the results are shown in the Table 4.

Table 4 – Results obtained following the II step of the review

Paper	Ecosystem Services/Functions	Beneficiaries	Methods	Scale of assessment
(Albert et al., 2016)	Food production, Carbon storage, Landscape aesthetics, Biodiversity	Not explicit	Simple assessing multiple ES, Trade-offs analysis	Spatial scale
(Allan et al., 2015)	Aboveground productivity, Forage quality, Carbon sequestration, Belowground productivity, Root decom- position, Nitrification rate, Phosphorus retention, Mycorrhization, Soil aggregation, Pest control, Pathogen regulation, Pollination, Aesthetic appeal, Cultural/conservation value	Not explicit	Aggregate indexes	Spatial scale
(Andersson-Sköld et al., 2018)	Success of urban vegetation, Local climate regulation, Air quality regulation, Noise reduction, Water regulation, Recreation and mental and physical health, Aesthetic appreciation and inspiration for culture, art and design	Not explicit	Aggregate indexes	Local
(Arcidiacono et al., 2016)	Habitat quality, Recreation and tourism	Not explicit	Aggregate indexes	Regional
(Asadolahi et al., 2018)	Soil retention, Food production, Habitat quality	Not explicit	Trade-offs analysis	Spatial scale
(Baró et al., 2017)	Food provision, Global climate regulation; Air purification, Erosion control, Outdoor recreation	Not explicit	Simple assessing multiple ES, Bundles	Multiscale
(Blumstein & Thompson, 2015)	Carbon stock and storage, Water yield, Impervious surfaces, Water quality, Timber harvesting, Outdoor recreation, Habitat quality	Not explicit	Simple assessing multiple ES, Trade-offs analysis	Multiscale
(Bolund et al., 1999)	Air filtration, Microclimate regulation, Noise reduction, Rainwater drainage, Sewage treatment, Recreational and cultural values	Not explicit	Simple assessing multiple ES	Municipal
(Burkhard et al., 2009)	Abiotic heterogeneity, Biodiversity, Biotic waterflows, Metabolic efficiency, Exergy capture (radiation), Reduction of nutrients loss, Storage capacity, Crops, Livestock, Fodder, Capture fisheries, Aquaculture, Wild foods, Timber, Wood fuel, Energy, Biochemicals, Freshwaters, Local climate	Not Explicit	Aggregate indexes	Spatial scale

	regulation, Global climate regulation, Flood protection, Groundwater recharge, Air quality regulation, Erosion regulation, Nutrient regulation, Water purification, Pollination, Recreation and aesthetic values, Intrinsic value of biodiversity			
(Calzolari et al., 2020)	Soil biodiversity, Buffer capacity, Carbon storage, Agricultural production, Water regulation, Water storage	Not Explicit	Simple assessing multiple ES, aggregate indexes	Municipal
(Cannas et al., 2018c)	Four values (conservation value, natural value, recreation value and anthropic heritage) that represent many functions (biodiversity conservation, supply of ecosystem services, recreation, identity building) performed by the landscape	Not explicit	Simple assessing multiple ES, aggregate indexes	Regional
(Cerreta et al., 2020a)	Environmental protection area, Waterbody, Forest, Land without current use, Waterway, Railway, Road, Airport, Port, Bus/underground stop, Mineral extraction site, Habitation density, Waste disposal, Tourism facility, Cultural site, Place of worship, Sport and leisure, Green urban area, Attraction place, Attractive landscape feature	Not explicit	Aggregate indexes	Regional
(Chang et al., 2017)	Microclimate regulation, Noise mitigation, Cultural services provided by green spaces	Not explicit	Simple assessing multiple ES, Aggregate indexes	Local
(W. Chen et al., 2019)	Food, Raw materials, Gas regulation, Climate regulation, Water supply, Waste treatment, Soil formation and retention, Biodiversity protection, Recreation and culture	Not Explicit	Aggregate indexes	National
(Cimon-Morin & Poulin, 2018)	Carbon storage, Existence value of rare and threatened species, Cooling islands, Potential for ornithological activities, Surface runoff management, Aesthetics, Recharge of groundwater, Potential for recreational activities, Water flow mitigation	Explicit	Aggregate indexes	Multiscale
(Collas et al., 2017)	Biodiversity, Carbon sequestration	Explicit	Simple assessing multiple ES	Municipal
(Cortinovis & Geneletti, 2020)	Food provision, Runoff mitigation, Air purification, Noise mitigation, Recreation, Habitat provision, Microclimate regulation (cooling)	Explicit	Simple assessing multiple ES, aggregate indexes	Municipal
(De Vreese et al., 2016)	Aesthetical experiences, Education, Historical landscape, Recreation, Research opportunities, Sense of place, Therapeutic recovery, Berry picking, Employment agriculture, Employment nature and landscape management, Food production, Growing regional products, Wood production, Air purification, Carbon sequestration, Climate regulation, Erosion control, Flood protection, Habitat provision, Local species, Noise protection, Pollination, Water purification, Social relations, Hunting, Creating a good place to live, Motorized recreation, Spiritual experiences, Biofuel production, Employment in recreation, Real estate, Regulating pests and diseases	Not explicit	Aggregate indexes, Trade-offs analysis	Spatial scale

(Fagerholm et al., 2020)	Well-being items	Explicit	Simple assessing multiple ES, Aggregate indexes	Spatial scale
(Frank et al., 2014)	Ecological integrity, Provision of food and fibre, Provision of biomass, Soil erosion protection, Drought-risk regulation, Flood regulation, Landscape aesthetics	Not explicit	Trade-offs analysis	Regional
(Fürst et al., 2010)	Human health and well-being (water and air quality), Economic wealth (income and provision of working places), Aesthetic value (intensity of recreation and tourism activities), Ecological functioning (richness in species and structures), Bio-resource provision (provision of biomass and food), Climate change mitigation (ability to mitigate the risk of drought, erosion and flooding)	Not explicit	Trade-offs analysis	Spatial scale
(Galler et al., 2015b)	Erosion prevention, Water quality conservation, Climate change mitigation, Safeguarding biodiversity	Not explicit	Simple assessing multiple ES, Trade-offs analysis	Regional
(García-Llorente et al., 2018)	Food from agriculture, Livestock, Fishing/shell fishing, Freshwater, Clean energy, Timber, Air quality, Climate regulation, Habitat for species, Water regulation, Erosion control, Soil fertility, Invasive alien species prevention, Existence values, Tranquility and relaxation, Environmental education, Scientific knowledge, Recreational hunting, Nature tourism, Aesthetic values, Local identity	Not explicit	Simple assessing of multiple ES, Trade-offs analysis	Spatial scale
(Geneletti, 2013a)	Water purification, Soil conservation, Habitat provision, Carbon sequestration, Timber production	Not explicit	Simple assessing multiple ES, Trade-offs analysis	Regional
(González-García et al., 2020a)	Water provision, Climate regulation, Outdoor recreation	Not explicit	Simple assessing multiple ES	Multiscale
(Graça et al., 2018)	Climate regulation, Water flow regulation, Air purification	Not Explicit	Simple assessing multiple ES, Aggregate indexes	Multiscale
(Grêt-Regamey, Altwegg, et al., 2017)	Food production, Groundwater recharge, Drinking water production, Ecological connectivity, Public recreation spaces, Quiet recreation areas, Quiet residential areas	Not Explicit	Aggregate indexes, Trade-offs analysis	Spatial scale
(Guerry et al., 2012)	Habitat quality, Water quality, Number of recreational float homes, Spatial extent of recreational kayaking, Value of shellfish aquaculture harvest	Not explicit	Simple assessing multiple ES, Trade-offs analysis	Spatial scale
(Haase et al., 2012a)	Local climate regulation, Recreation potential, Biodiversity potential, Food supply, Carbon mitigation	Not Explicit	Simple assessing multiple ES, Aggregate indexes, Trade-offs analysis	Multiscale
(Hashimoto et al., 2019)	Food production, Disaster prevention, Recreation	Explicit	Simple assessing multiple ES	Regional
(Hu, Zhang, & Ke, 2018)	Gas regulation, Climate regulation, Disturbance regulation, Water regulation, Water supply, Erosion control, Soil formation, Nutrient cycling, Waste treatment, Pollination, Biological control, Habitat/refugia, Food production, Raw	Not Explicit	Aggregate indexes	Municipal

	materials, Genetic resources, Recreation, Cultural			
(Intralawan et al., 2018)	Aquaculture, Reservoir fisheries, Irrigated agricultural production, Capture fisheries, Wetlands, Social and cultural cost, Sediment/nutrients loading, Recession rice, Flood damage mitigation, Mitigation of salinity, Losses in bank erosion, Navigation	Not Explicit	Simple assessing multiple ES, Aggregate indexes, Trade-offs analysis	Spatial scale
(J. C. S. Rosa & Sánchez, 2016)	Crops, Livestock, Capture fisheries, Aquiculture, Wood, Biomass fuel, Freshwater, Regulation of water timing and flows, Water purification, Waste treatment, Educational and inspirational values	Explicit	Simple assessing multiple ES	Spatial scale
(Jackson et al., 2013)	Flood mitigation, Erosion/sediment delivery risk, Habitat connectivity, Carbon sequestration, Agricultural productivity	Not explicit	Simple assessing multiple ES, Trade-offs analysis	Spatial scale
(Jiang, 2018)	Cultural, Recreation, Habitat/refugia, Biological control, Pollination, Waste treatment, Nutrient cycling, Soil formation, Erosion control, Water regulation, Disturbance regulation, Climate regulation, Gas regulation, Genetic resources, Water supply, Raw materials, Food production	Not explicit	Aggregate indexes	National
(Juntti et al., 2021)	Food (fruits and vegetables), Food (fish), Drinking water, Ornamental vegetation, Wood and fiber, Natural medicines, Energy production, Mineral raw materials, Regulating Erosion control, Flood control, Storm water runoff mitigation, Water quality enhancement, Water cycle, Air purification/air quality regulation, C sequestration/storage, Temperature regulation, Noise reduction, Supporting, Transport of water, sediments, chemicals by water, Geological subtract for crops and buildings, Storage capacity for water, humidity, Soil formation, Biodiversity support, Nutrient cycling, Aesthetic value, Recreation and cognitive development, Educational opportunities	Not Explicit	Simple assessing multiple ES	Local
(Karjalainen et al., 2013)	Commercial harvest, Subsistence harvest, Personal use, Water quality, Habitat formation, Nutrient cycling, Sediment turnover, Aquatic/terrestrial food weds, Recreational values, Tourism opportunities, Attractive landscapes features, Regional/local identity	Not explicit	Aggregate indexes	Spatial scale
(Kleemann et al., 2020)	Cocoa trade, pest control by migratory birds, Transboundary flood regulation, Information flows from giant pandas at the Berlin Zoo	Not Explicit	Simple assessing multiple ES	Supranational
(Lawler et al., 2014)	Carbon storage, Food production, Timber production, Amphibians, Influential species, Game species, At-risk birds	Not explicit	Simple assessing multiple ES, Trade-offs analysis	Supranational

(Leh et al., 2013)	Water yield, Nutrient retention (N and P), Sediment retention, Carbon storage, Biodiversity	Not explicit	Aggregate indexes	National
(Lester et al., 2013)	Fishery yield, Biomass preservation, Wave energy, Viewscape value	Not explicit	Trade-offs analysis	Spatial scale
(Li et al., 2018)	Food supply, Water supply, Material supply, Climate regulation, Air quality regulation, Wastewater treatment, Regulation of water flow, Erosion protection, Soil fertility maintenance, Biodiversity, Aesthetic landscape	Not explicit	Simple assessing multiple ES, Aggregate indexes	Spatial scale
(Y.-P. P. Lin et al., 2017)	Water yield, Sediment retention, Phosphorus retention, Nitrogen retention, Carbon sequestration, Habitat quality, Aesthetic, cultural, economic, historic, intrinsic, learning cultural value	Not explicit	Simple assessing multiple ES	Spatial scale
(Lovell & Taylor, 2013)	Plant Biodiversity, Production, Microclimate control, Soil Infiltration, Carbon sequestration, Visual Quality, Physical Activity, Social Capital	Not explicit	Aggregate indexes	Municipal
(Madureira & Andresen, 2014)	Local temperature regulation, ESs supplied by urban green areas	Not explicit	Simple assessing multiple ES	Municipal
(Mandle et al., 2016)	Sediment retention, Nutrient retention, Carbon sequestration	Explicit	Simple assessing multiple ES,	Spatial scale
(Manea et al., 2019)	Primary production, Nutrient cycling, Biodiversity maintenance, Habitat provisioning	Not explicit	Simple assessing multiple ES, Aggregate indexes	Spatial scale
(Martínez-Sastre et al., 2017)	Livestock production, Agriculture production, Erosion control, Provision of habitat, Pollination; Traditional ecological and local knowledge	Not explicit	Simple assessing multiple ES, Aggregate Indexes, Trade-offs analysis	Spatial scale
(Meerow & Newell, 2017)	Stormwater management, Social vulnerability, Green space; Air quality, Urban heat island amelioration, Landscape connectivity	Not explicit	Simple assessing multiple ES, Trade-offs analysis, Aggregate indexes	Multiscale
(Nelson et al., 2010)	Carbon storage, Water availability, Crop production, Habitat for species	Not explicit	Trade-offs analysis	Multiscale
(Nikodinoska et al., 2018)	Saw logs, pulpwood, and fuelwood by conifer, broadleaved, and mixed forests and nature reserves, Firewood, Meat from game, Mushrooms, Wild berries, Water supply, CO2 sequestration in above and below ground tree biomass, CO2 sequestration in litter, Nitrogen retention, Phosphorus retention, Hunting activities, Recreational values, Crop production, Fodder & forage, Energy crops, Horticultural products, Honey production, Pest regulation, CO2 sequestration in semi-natural grasslands, Landscape value (arable land), Landscape value (semi-natural grasslands), Food from urban agriculture, Compost biomass, CO2 sequestration, Aesthetic benefits of urban parks for residents	Not explicit	Aggregate indexes	Municipal

(Nin et al., 2016)	Flood prevention, Erosion control, Prevention of eutrophication, Prevention of exotic plants invasion, Bushmeat production	Not explicit	Aggregate indexes	Spatial scale
(Othoniel et al., 2019)	Pollination, Food production, Livestock production, Carbon sequestration, Climate regulation	Not explicit	Simple assessing multiple ES	Multiscale
(Pan et al., 2013)	Grain provisioning, Meat provisioning, Water conservation, Soil retention	Not explicit	Aggregate indexes, Trade-offs analysis	Spatial scale
(Peña et al., 2018)	Food production, Timber production, Habitat maintenance, Air purification, Carbon storage, Waterflow regulation, Recreation, Aesthetic quality	Not explicit	Aggregate indexes, Trade-offs analysis, Bundles	Spatial scale
(Plieninger et al., 2013)	Spiritual services, Educational values, Inspiration, Aesthetic values, Social relations, Sense of place, Cultural heritage values, Recreation and ecotourism (walking, dog walking, horse riding, swimming, gathering wild foods, angling, hunting,)	Not explicit	Aggregate indexes, Trade-offs analysis, Bundles	Spatial scale
(Queiroz et al., 2015)	Wheat production, Cattle, Pig production, Sheep, Forest products, Crop pollination, N retention, P retention, Standing water quality, Running water quality, Moose hunting, Outdoor recreation, Summer cottages, Horseback riding, Cross-country skiing, Biodiversity	Not explicit	Simple assessing multiple ES, Aggregate indexes, Trade-offs analysis, Bundles	Multiscale
(R. De Groot, 2006)	Water quality, Water supply, Biological control, Habitat function, Aesthetic information, Cultural-historical value, Recreation and eco-tourism production, Forestry/fire wood collection, Fishing/fish ponds, Hunting	Not explicit	Trade-offs analysis	Spatial scale
(Raudsepp-Hearne et al., 2010)	Crops, Pork, Drinking water, Maple syrup, Deer hunting, Tourism, Nature appreciation, Summer cottages, Forest recreation, Carbon sequestration, Soil phosphorus retention, Soil organic matter	Not explicit	Simple assessing multiple ES, Aggregate indexes, Trade-offs analysis, Bundles	Regional
(Remme et al., 2014)	Hunting, Drinking water extraction, Crop production, Fodder production, Air quality regulation, Forest carbon sequestration, Recreational cycling	Not explicit	Simple assessing multiple ES, Aggregate indexes	Multiscale
(Rodríguez-Loinaz et al., 2015a)	Food, Raw materials, Freshwater, Global climate regulation, Maintenance of soil fertility, Local climate regulation, Water flow regulation, Water purification, Erosion prevention, Tourism, Biodiversity	Not explicit	Aggregate indexes	Multiscale
(Ronchi et al., 2020)	Habitat quality, Carbon sequestration, Water yield, Sediment retention, Soil erosion, Cultural heritage	Not explicit	Aggregate indexes	Municipal
(Schirpke et al., 2019)	Drinking water, Grassland biomass, fuel wood, Filtration of surface water, Protection against natural hazards, Carbon sequestration, Outdoor recreation, Symbolic plants and animals	Not Explicit	Simple assessing multiple ES, Trade-offs analysis, Bundles	Spatial scale

(Scorza, Pilogallo, Saganeiti, Murgante, et al., 2020a)	Carbon Storage and Sequestration, Crop pollination, Crop production, Habitat Quality	Not explicit	Aggregate indexes	Municipal
(Shen et al., 2020)	Food production, Sil conservation, Carbon sequestration, Biodiversity protection, Flood mitigation, Recreation service	Not explicit	Simple assessing multiple ES, Aggregate indexes, Trade-offs analysis, Bundles	Spatial scale
(Shoyama & Yamagata, 2014)	Habitat quality index, Carbon sequestration, Timber production, Water yield.	Not explicit	Simple assessing multiple ES, Trade-offs analysis	Spatial scale
(Soderman et al., 2012)	Timber products, Food, Fresh water, Regulation of microclimate, Gas cycles, Carbon sequestration and storage, Habitat provision, Air pollution purification, Noise cushioning, Rain water absorption, Water infiltration, Pollination, Nutrient content, Recreation, Psycho-physical and social health benefits, Science education, research, and teaching	Not Explicit	Simple assessing multiple ES	Multiscale
(Staiano et al., 2021)	Groundwater recharge, Evapotranspiration, Avian richness, Soil Organic Carbon	Not Explicit	Aggregate indexes	Spatial scale
(Stürck & Verburg, 2017)	Crop production, Raw material, Climate regulation, Flood regulation, Pollination, Erosion control, Nature-based tourism, Wild food, Residential function, Habitat connectivity, Agro-biodiversity, Megafauna habitat	Not explicit	Aggregate indexes	Multiscale
(Sun et al., 2017)	Climate regulation, Water supply, Water purification, Soil conservation, Biodiversity protection, Recreation opportunity, Food production	Not explicit	Simple assessment multiple ES, Aggregate indexes, Trade-offs analysis	Multiscale
(Uthes et al., 2010)	Soil quality, Water quality, Maintenance or enhancement of biodiversity, Maintenance or enhancement of the cultural landscape	Not explicit	Aggregate indexes, Trade-offs analysis	Spatial scale
(Vaz et al., 2021)	Timber and wood, Cattle and fodder, Energy supply, Medicines and genetic materials, Cultivated food, Water supply, Wild food, Biological control and pollination, Carbon regulation, Wildfire prevention, Soil regulation and maintenance, Local climate regulation, Water quality maintenance, Habitat maintenance, Natural heritage, Aesthetics and recreation, Cultural identity, Knowledge systems	Not explicit	Aggregate indexes	Municipal
(Villoslada et al., 2018)	Cultivated crops yield, Reared animals and their outputs, Fodder, Biomass-based energy sources, Herbs for medicine, Bio-remediation, Filtration/storage/accumulation, Control of (water) erosion rates, Pollination and seed dispersal, Maintaining habitats, Weathering processes/ soil fertility, Chemical condition of freshwaters, Global climate regulation, Physical and experiential interactions, Educational, Cultural heritage, Aesthetics	Not explicit	Aggregate indexes, Bundles	Spatial scale
(Wang et al., 2019)	Food production, Carbon sequestration and oxygen production, Water conservation, Soil retention	Not explicit	Simple assessing multiple ES	Multiscale

(Ward et al., 2018)	Recreational fishing, Small scale fishing, Large scale fishing, Illegal fishing	Not Explicit	Simple assessing multiple ES	Spatial scale
(X. Chen et al., 2017)	Aquatic products, Water, Floods, Water quality, Recreation and tourism, Scientific research, Environmental education, Biodiversity	Explicit	Aggregate indexes	Spatial scale
(J. Xu et al., 2021)	Crop production, Livestock numbers, Carbon stock	Not explicit	Trade-offs analysis	Spatial scale
(Y.-P. Lin et al., 2017)	Habitat quality, Carbon storage, Water yield, Soil retention, Nutrient retention	Not explicit	Simple assessing multiple ES, Aggregate indexes, Trade-offs analysis	Spatial scale
(Zarandian et al., 2017)	Habitat provision, Carbon storage and sequestration, Water balance and supply	Not explicit	Simple assessing multiple ES, Trade-offs analysis	Spatial scale
(Zarrineh et al., 2018)	Water quantity regulations, Water quality regulation, Erosion regulation, Food provision, Climate regulation	Not Explicit	Trade-offs analysis	Spatial scale
(Zhang & Muñoz Ramírez, 2019)	Local climate regulation, Global climate regualation, Gas regulation, Disturbance prevention, Natural hazard mitigation, Air quality regulation, Water regulation, Water purification, Groundwater recharge, Soil retention, Soil formation, Nutrient regulation, Pollination, Waste treatment/disposal, Erosion protection, Biological control, Disease regulation, Food, Water, Raw materials, Genetic resources, Medicinal resources, Ornamental resources, Habitation, Nursery, Identity, Aesthetic, Recreation, Cultural and artistic, History and religion, Science and education, Tourism	Not Explicit	Aggregate indexes	Municipal

Ecosystem services/functions

There is large variation in the number of ES considered within the scholarly papers analyzed, depending on the scope of the work, the approach followed by the authors and the method used to assess ES. For example Madureira et al. (Madureira & Andresen, 2014), in proposing a methodology for designing a green infrastructure to serve the city of Porto, carry out a context analysis that leads them to define a priority scale of benefits expected by citizens. This leads to prioritizing of local temperature regulation as a strategy to satisfy an existing demand and to promote long-term actions to mitigate the effects of climate change. Although there is an explicit reference to multifunctionality, there is no evaluation of further ES: the second design criterion aims to foster population proximity to different categories of public urban green spaces, able to provide several components of dwellers' well-being. On the other hand, with the same aim of supporting a green infrastructure in Barcelona, Zhang et al.' (Zhang & Muñoz Ramírez, 2019) approach is based on "supply capacity", an indicator of "abundance" as defined by (Hölting, Jacobs, et al., 2019). The ES covered in this case are 32; they are assessed on the basis of a matrix modelled after (Burkhard et al., 2009, 2012).

The class most represented is that of Regulating Services, often neglected in current decision-making processes (Cortinovis & Geneletti, 2019) although *fundamentally underpinning the integrity of the biosphere, human safety and the provision of most other ES* (Sutherland et al., 2018).

This probably responds to a growing research demand for the development of methodologies, approaches and methods able to integrate them into planning processes, to overcome the complexity of their assessment and to legitimize plan choices formulated in order to enhance them (Langemeyer et al., 2016; McPhearson et al., 2014). In addition, there is an urgent need to examine some specific Regulating ES as well as the dynamics of climate regulation (both globally (e.g. (Baró et al., 2017)) and locally (e.g. (Bolund et al., 1999; Haase et al., 2012a)) and the mitigation of natural hazards (e.g. (Hashimoto et al., 2019; Ronchi et al., 2020; Schirpke et al., 2019)) exacerbated by climate change.

For the purpose of effective integration into a plan process and to reinforce any recommendations or policy implications that may be present in the paper, it is important that the choice of ES is justified.

Often this selection follows a purely academic approach, drawing on previous scientific literature relating to the same study area (e.g. (Frank et al., 2014; Martínez-Sastre et al., 2017)), perhaps according to the availability of data and time series (e.g. ((X. Chen et al., 2017)). The availability of datasets and information layers is a limitation pointed out by several authors (Lovell & Taylor, 2013; Shen et al., 2020), especially when there is an awareness of making a non-exhaustive assessment (e.g. (Nin et al., 2016)). The selection of ES often takes place on the basis of specific evaluations by the authors (e.g. (Albert et al., 2016; Bolund & Hunhammar, 1999; Cerreta et al., 2020a; Haase et al., 2012a)), only sometimes well argued with respect to the criteria used (e.g. (González-García et al., 2020a; Othoniel et al., 2019; Queiroz et al., 2015)). This is also the kind of works that uses matrix methods based on land use categories to interpret the concept of multifunctionality as a synonym for abundance (e.g. (Villoslada et al., 2018)). In some cases, the context analysis and needs/problems identification phases of the plan process were carried out preliminary to the work and were conducted by directly involving and interviewing stakeholders (e.g. (R. De Groot, 2006; Guerry et al., 2012; Zarandian et al., 2017)). Only in a few cases the selection of ES is the result of a choice made by planners (e.g. (Fürst et al., 2010)) or policy makers (e.g. (Remme et al., 2014)), or derives from the analysis of already implemented plans and programs (e.g. (Galler et al., 2015b; Geneletti, n.d.; Uthes et al., 2010)).

A number of authors have commented on the need for an appropriate context-based selection of ES. In fact, although the term "multifunctionality" generally has a positive meaning, it must be explored in detail because the joint provision of multiple ES can also lead to disservices that, in specific contexts, must be properly taken into account (Gómez-Baggethun & Barton, 2013a). Some authors suggest, for example, the opportunity to investigate the link between air quality and the presence of trees (Setälä et al., 2013) depending on some factors such as the occurrence of heat islands (Calfapietra et al., 2013) or the settlement morphology (Vos et al., 2013). Graça et al. (Graça et al., 2018) provide interesting insights into the design and management of urban green areas by explicating the relationship between ecosystem multifunctionality and the disservices delivered by tree-planted areas. More pragmatically, Bolund (Bolund & Hunhammar, 1999) asserts that often the most effective solutions to local problems in an urban environment must be sought locally through a thoughtful choice of ES that can actually help address that specific demand.

Beneficiaries

In the perspectives of spatial planning and territorial governance, the ES methodological framework constitutes as an added value as it reformulates the relationship between environmental components and humans. Costanza et al. (Costanza et al., 2014) stated that approaching ES highlights the role of natural resources as *critical components of inclusive wealth, well-being and sustainability*. Thus, while contributing to pursuit sustainable development goals, the ES approach is not really the same as a sustainability assessment. In this regard, Gomez-Baggethun et al. (Gómez-Baggethun et al., 2010) clarify: sustainability is conservation-oriented; the ES approach, by highlighting human needs met by ecosystems, is instead aimed at striking a balance between 'use' and 'conservation' of Natural Capital.

This remark presupposes that the evaluation of ES is not an end in itself but derives from the estimation of a demand and, therefore, from the evaluation of the beneficiaries of those goods and services. (Cimon-Morin & Poulin, 2018) reinforce this view by adding that ES bring a contribution to human well-being if: ES are provided, the benefits are accessible, at least a part of the existing demand for that service is satisfied.

Although within the plan processes, context analysis and needs assessment phases include the services endowments' evaluation and mapping, this is not yet an established practice for ES.

Some authors (Mandle et al., 2016; J. C. S. Rosa & Sánchez, 2015) identify this as one of the main reasons why the ES framework is struggling to be fully integrated into planning and EIA procedures.

These considerations prompted us to investigate whether and how the studies analyzed considered and estimated ES beneficiaries. Differences emerge in the way beneficiaries are operationally defined within the work. Some authors (Collas et al., 2017; Hashimoto et al., 2019) consider ES beneficiaries all the resident population while others (X. Chen et al., 2017; Cortinovis & Geneletti, 2020), on the basis of what theorized by Wolff et al. (Wolff et al., 2015), consider a range of type of beneficiaries depending on the specific ES considered. For example, both citizens and farms benefit from the "water supply", while buildings that would otherwise have been flooded are beneficiaries of "flood regulation".

Other considerations arise regarding the role of beneficiaries in planning processes or EIA procedures. For example, the work of Fagerholm et al. (Fagerholm et al., 2020), is part of a wide pilot survey aimed at highlighting differences in citizens' perceptions of 13 rural and peri-urban sites in Europe. The implications of the work, according to the authors, lie in providing support for the integration of top-down global policies and a bottom-up, place-based assessment of the values that link citizens' well-being to biodiversity and ecosystem conservation issues.

Hashimoto et al. (Hashimoto et al., 2019) integrate the evaluation of beneficiaries into a methodology aimed at supporting rational and efficient choices in financing and managing urban allotment gardens.

Finally, several authors use the beneficiaries' assessment to perform a context-based evaluation of territorial/urban transformations and expected impacts, and to propose targeted mitigation or compensation measures in the perspective of improving or at least preserving the well-being of affected beneficiaries (Landsberg et al., 2013).

(J. C. S. Rosa & Sánchez, 2016) develop the impact assessment for an iron ore mining area based on the ES approach where the role of beneficiaries is decisive in prioritizing ES in order to then determine the study area delimitation, and in weighing the significance of each impact. Significance is function of magnitude and vulnerability, where this latter makes explicit the specific link between the beneficiaries and the service analyzed in terms of intensity of use, level of dependence, relative importance.

In the same vein, Mandle et al. (Mandle et al., 2016) design a software to develop environmental mitigation and compensation measures that provide benefits in a more equitable and transparent way integrating within the several input, information data on beneficiaries who may be impacted by changes in ES supply. An "out of kind" compensation mechanism is also proposed by Cortinovis et al. (Cortinovis & Geneletti, 2020) who propose offset interventions in urban areas to meet the needs of local population weighted on the basis of stated criteria to select beneficiaries in according to the specific ES considered.

Special mention should be made of papers which, often as part of a participatory process, identify and involve different groups of stakeholders in the assessment of multifunctionality. Intending for stakeholders "*individuals who affect or are affected by certain decisions and actions*" (Freeman, 2010), they are considered as expressing different perceptions of well-being and needs related to diverse ES (Martínez-Sastre et al., 2017). They include some kind of beneficiaries, for example representative of organized users (R. De Groot, 2006; Martínez-Sastre et al., 2017), public administrations (Martínez-Sastre et al., 2017), governmental organizations and ministries (R. De Groot, 2006; Meerow & Newell, 2017), biodiversity and environmental conservation group (Martínez-Sastre et al., 2017), community development organizations (Meerow & Newell, 2017).

Also with reference to the criteria for the choice of stakeholders, while some authors intended to make the audience as varied as possible (R. De Groot, 2006; Martínez-Sastre et al., 2017; Sun et al., 2017), possibly considering that the needs expressed could change over time (Soderman et al., 2012), others opted for a choice based on the expertise gained in the intervention area (e.g. (Meerow & Newell, 2017)).

As pointed out by Intralawan et al. (Intralawan et al., 2018), opening up the decision-making or co-planning process to stakeholders aims to raise awareness and promote dialogue by providing useful insights in order to achieve a more balanced development with objectives of economic efficiency, social justice and ecological sustainability.

Methods

The literature review shows that the methods used to assess multifunctionality essentially fall into 4 types: the simple assessing and comparing of multiple ES, the use of aggregate indexes, the trade-off analysis and the characterization of ES bundles.

Although the hotspot approach provides a valid representation of the joint supply of multiple ES (Calzolari et al., 2020), for the purposes of this classification we considered hotspot analysis as a representation technique rather than an analysis method specifically aimed at assessing multifunctionality. The reasons for this choice is that it is a type of analysis that can be carried out on a single variable, which is the intensity of an ES or the result of an aggregation method performed to assess the multifunctionality. For example, Calzolari et al. (Calzolari et al., 2020) use it to represent the result of unweighted spatial aggregation of the number of ES exceeding the 75th percentile of the magnitude distribution. In contrast, Wang et al. (Wang et al., 2019) use the method of "simple assessing multiple ES" and perform hotspot analysis using the Getis-Ord Gi* index for each ES considered, so defining areas where investigate the relationship between ES delivery intensity and urbanization dynamics (expressed in terms of population density, GDP density, developed land proportion). In order to make explicit the link between the services provided by ecosystems and the socio-economic well-being of the local population, Shoyama et al. (Shoyama & Yamagata, 2014) carry out scenario analyses evaluated by comparing the changes undergone by each ES. They make this choice by explaining that it is functional to highlight ES variations that constitute a necessary condition to support productive and economic activities specific particularly relevant for the study area (e.g. habitats quality and the presence of wild and mature ecosystems is the basis of most tourism-related activities).

The adoption of an aggregated multifunctionality index is a useful method to effectively represent a synthesis of complex dynamics and to communicate the value of environmental components to non-experts stakeholders and decision-maker. For example, Jiang (Jiang, 2018) argues that the representation of the Ecosystem Services Value (ESV) can serve as a tool for communicating the importance of ES and for raising public awareness towards sustainability issues; Rodriguez-Loinaz et al. (Rodríguez-Loinaz et al., 2015a) formulate instead the Multiple Ecosystem Services Landscape Index (MESLI) based on the proximity-to-target methodology that allows to represent the assessment of current ES provision compared to a representative performance benchmark, such as a policy goal.

Following applications have shown the potential of MESLI in comparing environmental performance between different territorial units (Angela Pilogallo et al., 2021), in discerning cold-spots and hotspots of multiple ES (Shen et al., 2020) and in accurately depicting the level of change in multifunctionality (Stürck & Verburg, 2017).

Some of those proposed (e.g. the Ecosystems Services Change Index (ESCI) and the Ecosystems Services Status Index (ESSI) as described by (Leh et al., 2013)) can be useful to detect a trend over time and thus can contribute to a monitoring system in which the information is part of a broader evaluation framework showing what/where/why there have been changes in ES provision.

Other authors, do not make proposals for new indexes but transfer to the ES approach some indices deriving from the discipline of ecology. According to Holting et al. (Hölting, Jacobs, et al., 2019), these are classified as indices of abundance (Rodríguez-Loinaz et al., 2015a), richness (De Vreese et al., 2016; Manea et al., 2019; Plieninger et al., 2013) and diversity (Queiroz et al., 2015; Stürck & Verburg, 2017) and applied to the ES assessment to highlight the many dimensions of multifunctionality.

Many aggregate indices are calculated from remotely sensed data and, as highlighted by several authors (R. S. de Groot et al., 2010a; Haines-Young & Potschin, 2012), they are relevant for ecosystem processes and functions located at different steps of the ES cascade. An example is the Ecosystem Services Supply Index (ESSI) (Paruelo et al., 2016) that, as highlighted by (Staiano et al., 2021), can support several steps of planning processes, from the assessment of environmental functionality to the monitoring of the effectiveness of a territorial policy.

Finally, the spatial aggregation of ES integrated within participatory processes, is performed by some authors (Karjalainen et al., 2013; Meerow & Newell, 2017; Plieninger et al., 2013) considering the weight of each ES as the result of a multi-criteria analysis or an analytical hierarchy process (AHP) in which the different stakeholders directly participate.

Regarding the use of aggregate indices, there is no lack of doubts and criticism. Manning et al. (Manning et al., 2018a) for example states that a single value could not be meaningful and (Hansen & Pauleit, 2014) add that using an aggregate index as a measure of whether or not a target is met, could lead to neglecting ES that, although contributing little to the index, are essential to ecosystem well-being. Completely different is the position expressed by (Raudsepp-Hearne et al., 2010) who, in their case study, consider that only ES above a certain threshold are to be considered as effective benefits.

A further way of looking at multifunctionality is to represent trade-offs, i.e. the mutual interactions existing between different ES considered as a result of a policy/intervention designed to support the provision of a specific ES (Frank et al., 2014) or a change in the land use pattern (including scenario analysis as in (Asadolahi et al., 2018; Guerry et al., 2012; Zarandian et al., 2017)) that generates variable effects on different ES. The knowledge and representation of the interrelations between ES fosters the implementation of the ES approach in society and in the decision-making process (Haines-Young & Potschin, 2010) and supports the assessment of whether it is viable, resource- and cost-efficient to support the provision of one ES compared to a possible relevant and costly decline of another ES (Bastian et al., 2012) . Moreover, since the enhancement of one ES can improve the supply of others, effective management of synergies can be a key component of any spatial development strategy aimed at increasing human well-being (Haase et al., 2012a).

This evaluation can be carried out in pairs (as in (Haase et al., 2012a)) or by considering multiple ES jointly provided (as in (Martínez-Sastre et al., 2017; Zarrineh et al., 2018)); it can be represented graphically (as in (Galler et al., 2016b; Lester et al., 2013)) or mapped in a spatially distributed way (as in (Haase et al., 2012a)). This type of approach is adopted in order to define measures aimed at generating specific synergies (perhaps resulting from the evaluation of preferences expressed by beneficiaries and stakeholders as in (Meerow & Newell, 2017)), limiting undesirable effects (e.g. in (Peña et al., 2018)) or increasing the effectiveness of multiple objectives rather than singular ES-targeted measures (e.g. (Frank et al., 2014; Galler et al., 2015b; Uthes et al., 2010)).

Oriented towards exploiting synergies between multiple ES is the method based on "*bundles*", defined as "*set of associated ES that repeatedly appear together across time or space*" (Raudsepp-Hearne et al., 2010) affected by the same change drivers or processes (Staiano et al., 2021) and thus varying toward the same direction. Several works focus on ES *bundles* in order to characterize the territorial features in terms of provided ES and therefore to evaluate the effects of management decisions (e.g. in grassland-related management as in (Villoslada et al., 2018)) or to propose measures/policies that can benefit from the already occurring mutual interactions. ES bundles corresponds in fact to geographically clustered portions of land where appropriately designed measures can have desired effects on multiple ES (Queiroz et al., 2015; Shen et al., 2020). Raudsepp-Hearne et al. (Raudsepp-Hearne et al., 2010), moreover, suggest that the characteristics of these interactions could be influenced by social as much as ecological factors, contributing to reinforce the vision of the ES approach as a means of pursuing transdisciplinary objectives (Ahern et al., 2014a; Lobo et al., 2020). This approach was applied in the work of Schirpke et al. (Schirpke et al., 2019) who, after defining bundles, used random forest analysis to explain their spatial distribution in relation to socio-ecological factors such as population density, tourism activities/farm/enterprise density, landscape diversity, and land use pattern.

Finally, Barò et al. (Baró et al., 2017) use the bundle method to make a comparative analysis of the existing mismatch in supply and demand along an urban-rural gradient. Its aim is to provide a methodological contribution to the definition of urban development strategies more oriented towards multifunctionality.

The methods described were either used on their own or as part of multistep methodologies structured by the authors in order to pursue the intended objective.

With regard to the scales used to assess ES, some authors preferred scales corresponding to administrative boundaries, others made an assessment on the basis of the extent of the project, while others preferred to investigate an area functional to the purpose of the work.

For this reason, the work scales have been divided into:

- Municipal, Regional, National, Supranational/Global scales for works carried out by administrative units;
- Local scale and Spatial scale for work carried out not considering administrative limits and referring respectively to a finer or larger scale than the municipal scale;
- Multiscale if the elaborations refer to a study area that includes multiple territorial assessment units.

The first type includes work carried out at a spatial scale that corresponds to an administrative boundary and consequently to a specific spatial planning instrument. Some examples are the works of Ronchi et al. (Ronchi et al., 2020) at the municipal scale, Cerreta et al. (Cerreta et al., 2020a) covering the metropolitan area of Naples, Arcidiacono et al. (Arcidiacono et al., 2016) and Cannas et al. (Cannas et al., 2018c) carried out at the scale of European NUTS2 areas, or Chen et al. (W. Chen et al., 2019) covering the entire national territory.

In these cases, the reference to planning/programming tools is explicit and very often mentioned in the scope of work. For example, Ronchi et al. (Ronchi et al., 2020) describe a methodology to support the shift of the urban planning instrument towards a more performance-oriented approach to green areas. With reference to the Italian planning system and the regional norm (Lombardy Regional Law n°12/2005), GI design based on the ES approach is a strategy for guiding sustainable urban development and enhancing benefits for citizens, and constitutes a central focus of both SEA and the Urban Plan. More specifically, the SEA fosters the concept of ES provision, outlines ES assessment criteria and monitors the environmental impacts of urban transformation; while the municipal plan incorporates ES provision and GI strategies into the regulatory planning framework addressing the relationships between ES provision, GI and Nature Based Solutions.

In the same line, Galler et al. (Galler et al., 2015b) focus on Verden County (Germany) as study area by comparing scenarios involving the implementation of different agri-environmental measures financed by different programmes (e.g. German Federal Water Act). Also in this case, the choice of the study area is linked to the need for comparison in terms of cost efficiency and monitoring of the objectives achieved against those stated in the programme instrument.

At the local suburban scale, work is aimed at investigating specific characteristics of certain contexts in order to better orient urban planning instruments. For example, Chang et al. (Chang et al., 2017) focus on urban-edge gradients in order to perform a cost-benefit analysis of maintaining or expanding green spaces to support sustainable urban development. Juntti et al. (Juntti et al., 2021), on the other hand, work at the scale of three peri-urban settlements to characterize the services and disservices of urban green areas in a context-specific way directly exploring human-nature interactions.

Similarly, several authors have assessed multifunctionality at the most appropriate scale (here defined "spatial scale") to capture significant aspects or impacts of transformation dynamics and land-use change. In this case, there is no explicit reference to specific planning/land-use instruments. The planning process can take advantage of the results of these works to deepen the knowledge of specific urbanization processes (as in (Wang et al., 2019)), to investigate the link between ES and perceived wellbeing (as in (Fagerholm et al., 2020)), to analyze trade-offs between various land use alternatives and environmental values (as in (R. De Groot, 2006)).

Finally, many authors adopt a multiscale approach in order to overcome the complexity of hierarchical planning systems (Rozas-Vásquez et al., 2018) and interface with decision-making actors at several levels without renouncing integration with the municipal level (González-García et al., 2020a), which is the one that actually regulates territorial transformations (Cortinovis & Geneletti, 2018).

An example is the work of Queiroz et al. (Queiroz et al., 2015) which analyses and maps multifunctionality in terms of ES bundles for the entire Norrstrom drainage basin but considering the municipality as the reference territorial unit. The choice is motivated by the authors: the municipal is the smallest scale of governance in Sweden; it constitutes an intermediate scale capable of capturing variations in ES of both global and regional relevance, as well as locally delivered. Along the same lines, Rodriguez-Loinaz et al. (Rodríguez-Loinaz et al., 2015a) are interested in evaluating ES at the landscape scale but discretizing the assessment at the municipal scale, that is where synergies and trade-offs occur and are measurable.

The influence of the assessment scale on the overall result is precisely the focus of the work of Sturk et al. (Stürck & Verburg, 2017) who investigate the pattern of ES multifunctionality across Europe by considering several different scales (six differently-sized square moving windows, river catchment, NUT2, NUT3) as a function of the pattern of land use change.

Finally, the last aspect of the review framework aimed to investigate whether and how the assessment of ES multifunctionality was spatialized and mapped.

Most of the reviewed works include a spatial representation of multifunctionality, which can take the form of mapping individual ES (as in (Albert et al., 2016), (Zarandian et al., 2017)) or aggregated indices (as in (Zhang & Muñoz Ramírez, 2019),(W. Chen et al., 2019)), visualizing areas where synergies and trade-offs occur (as in (Haase et al., 2012a)), or locating land use or spatial units characterized by specific bundles (as in (Baró et al., 2017)).

From the perspective of planning and territorial governance, the spatial representation of ES and multifunctionality makes it possible to highlight how they are spatially distributed, while also making it possible to consider potentially related social, ecological and geographical factors (Raudsepp-Hearne et al., 2010). This aspect is so important that some authors (e.g. (Queiroz et al., 2015)), adopt a multistep methodology and map each of the results obtained.

Among those that do not map ES multifunctionality, works assessing ES and multifunctionality in monetary terms prevail. An example of this is the work of Ward et al. (Ward et al., 2018) who monetize the value of multiple ES in order to support the definition of a local development strategy that can boost social equity, stimulate long-term economic growth and support ecological sustainability. A purely quantitative approach is also adopted by Zarrineh et al. (Zarrineh et al., 2018) who address the issue of land use conflicts by comparing different land management scenarios through a trade-offs analysis.

Discussion

For the purposes of this review, a total of 81 scientific papers belonging to different disciplinary fields were considered, although the focus was on issues related to spatial planning and territorial governance.

Most of those belonging to the fields of Ecology and Natural Sciences have been classified within the Strategic DD as aiming to improve understanding of the dynamics linking ES with land use patterns (as (Allan et al., 2015; Asadolahi et al., 2018; Blumstein & Thompson, 2015; Stürck & Verburg, 2017)) and to deepen the relationships between ES measured in biophysical terms and their perceived value to beneficiaries and stakeholders (as (De Vreese et al., 2016; García-Llorente et al., 2018)).

Works published in journals related to ecological disciplines focus on processes rather than administrative limits and tend to include a significant number of ES in the assessment of multifunctionality, very often also representative of habitat quality, biodiversity and supporting ES in general.

More varied are the papers that pursue a more cross-cutting approach to environmental and sustainability issues. They use the ES framework and the topic of multifunctionality with a more pragmatic approach, often aimed at being *practically applicable in the routine planning processes* (Andersson-Sköld et al., 2018) and providing recommendations and insights for management strategies (as (Galler et al., 2015b; Hu, Zhang, Ke, et al., 2018; Peña et al., 2018)) and methodological tools (as (Cannas et al., 2018c)).

The assessment scales favored by this disciplines are what we have termed 'spatial scale' and 'multiscale'. The reason for this is to be found in the disciplines' perspective, which gives priority to ecological-functional dynamics, putting administrative and management limits on the second place. Many of these authors use aggregate indices derived from ecology and the biological sciences and transferred to the ES framework to represent the many facets of multifunctionality. An example is the work of Sturk et al. (De Vreese et al., 2016; Stürck & Verburg, 2017) who compare indices of abundance, richness, diversity.

About a quarter of the reviewed papers come specifically from journals of urban and regional planning and land use policies. In many of these papers, the approach to multifunctionality ES is declined in a specific way with respect to the disciplinary field, for example by providing regulations coherent with the planning instruments in force (as (Geneletti, 2013a; Vaz et al., 2021)), by integrating the assessment of ES with the existing regulatory frameworks for landscape protection (as (Arcidiacono et al., 2016)) or by suggesting methodological approach to foster the implementation of green infrastructure and nature based solutions (as (Madureira & Andresen, 2014; Meerow & Newell, 2017; Ronchi et al., 2020)).

Most of these works focus on scales of work that coincide with administrative boundaries. Aggregate indices and trade-offs analysis are also frequently used since being recognized as having a great potential to inform decision-makers about the consequences of plan choices.

Conclusions

Referring to the three founding principles of planning (equity, efficiency and conservation of resources), we recognize the ES approach as having great potential for reformulating the relationship between human beings and the several environmental components by providing keys of interpretation and analytical tools (Costanza et al., 2014).

In this paper we focus on ES multifunctionality, i.e. the opportunity offered by the ES approach to consider multiple goods and benefits simultaneously, thus jointly pursuing multiple planning objectives. Although the ES multifunctionality has been recognized as a means of achieving a range of environmental, social, cultural and economic goals and to address several potentially conflicting demands (Madureira & Andresen, 2014) its integration into planning processes is challenging both for scholar and practioners of urban planning. We have to affirm that ES multifunctionality show an high degree of complexity due to the properties of *simultaneity and interactivity* (Selman, 2009) between the several ES. This affects the computational procedures and makes difficult the results interpretation.

This literature review (I step) is based on three DD: the Strategic DD is the decision-making context impacted by the rigidity, to be intended as the not taking into account the interactions between environmental and socio-economic spheres when defining strategic long-term development goals. Works in this category aim to provide a greater understanding about the sustainability of development strategies and planning choices, supporting the debate in participatory planning processes and mainstreaming the sustainability thinking into decision-making processes by illustrating integrative information layer. Some of them address the tricky issue of searching for a balance between development needs, environmental performance and social welfare, also defining framework to interrelate the ES framework to UN Sustainable Development Goals (SDGS).

The second DD is the Integration DD. In this DD we collected works where the ES multifunctionality constituted an approach able to overcome the limits linked to the fragmentation of sectoral plans and the breakdown of planning multi-level responsibilities. Several authors, in fact, recognized the sectoral fragmentation as a potential source of conflicts in land management measures so they applied the ES multifunctionality approach to foster the efficiency of public spending by proposing multi-objective measures and to improve overall environmental benefits. On the other hand, several author showed the ES multifunctionality potential in illustrating the coherence between local actions and global objectives contributing to find the best synergy or to minimize trade-offs.

The Transformation DD collects a series of literature contributions in which authors have approached ES multifunctionality as a dimension to structure a process of assessing transformations and monitoring system performance during implementation stage. The transformations that take place in the urban context have a local impact on the relationship between the built environment and green areas and concern the processes of urban expansion, modifying the services provided along the city-nature interface. Works addressing these issues are essentially aimed at integrating such assessments into the regulatory framework of urban planning instruments, for example by proposing innovative environmental compensation mechanisms. Other works focus on the transformations occurring at territorial level and explore the contributions that the ES multifunctionality approach can offer to the EIA process.

All work was subsequently re-examined (II step review) on the basis of further aspects considered significant for the integration of ES multifunctionality into planning processes.

The types of ES considered are useful to understand if there are specific issues that benefit from the multifunctionality approach. While in fact in the strategic DD the variability of ES is very wide, in the integration DD there are some themes more recurrent than others. They often involve the "conflict" between exploitation and conservation of resources (e.g. the "the food-environment dilemma" formulated by Shen et al., (2020) or the implementation of management policies aimed at enhancing synergies between ES. In these applications, the role of multifunctionality emerges as a dimension where targets traditionally pursued within sectoral plans converge.

The criteria for the selection of the ES included in the elaboration and the explication of the beneficiaries/stakeholders involved provide information on the degree of transparency of the process. In fact, the choice of the ES can be an important moment of participation and debate, on which to build the consensus also extended to non-experts. It becomes a tool to provide decision-makers with elements of legitimization for policies and measures. In the same way, declaring the beneficiaries of the plan choices contributes to reinforcing the choices themselves, as it makes explicit the link between the demands and needs that emerge from the context analysis and the measures implemented within the plan process. Explicit assessment and various ways of 'measuring' beneficiaries also points to the principle of fair distribution of resources and multiple benefits from ecosystems - including urban ones.

Finally, the choice of computational method for the ES multifunctionality assessment is functional to the purpose of each specific application. The various methods used by the authors have different communicative and synthesis potentials: while the comparison of individual ES and the bundle analysis allows for more technical evaluations, the trade-offs and the aggregated indices are able to provide an explanatory overview for non-expert decision-makers. Aggregate indices also provide an efficient tool to compare the performance of different territorial units and to monitor the degree of achievement of any set environmental target.

A final consideration concerns the assessment scale. On the one hand, it is known that for several ES there is a mismatch between the extent of the area to which it is delivered and the scale at which its benefits are appreciated. On the other hand, in the perspective of planning practice there is the need to refer to a scale that corresponds to a specific planning level/authority.

On the basis of those critical findings, we affirm that Ecosystem Services (ES) thinking represents a robust methodological framework, in explaining environmental performance and supporting the impacts assessment of land use policies implementations and territorial transformations (Angela Pilogallo & Scorza, 2021a).

Future research will apply analytical ES multifunctionality indexes to assess how land use changes affected three main dimensions of ES multifunctionality following the conceptualization of Holting et al. (Hölting, Jacobs, et al., 2019): abundance, diversity, richness. We in fact consider assessing multifunctionality - as the joint provision of multiple ES - an innovative and integrated way to study the effects of different land use patterns, considering the further territorial feature linked to the fragmentation of anthropic components (Romano, Zullo, et al., 2017; L. Saganeiti et al., 2018; Lucia Saganeiti, Mustafà, et al., 2020), and the multiple components of human well-being (Queiroz et al., 2015; Rodríguez-Loinaz et al., 2015a). A better understanding of the spatial distribution of ES multifunctionality, considering its different dimensions, could help predict where and how specific governance policies or territorial transformations might affect ES supply and consequently the ability of ecosystems to cope with multiple human needs.

3. Mapping regulation ecosystem services (ReMES) specialization in Italy

Abstract

Today, the land use planning system shows structural weakness from an informative perspective depending on the capacity to develop rapidly and accurately territorial knowledge as Decision Support System (DSS). The capacity to effectively manage territorial transformations in a sustainability perspective results inadequate, especially under the pressure of rapid changes involving social, environmental and economic dimensions. We recognize the Ecosystem Services (ES) Approach as a robust framework (Scorza, Pilogallo, Saganeiti, Murgante, et al., 2020a) to contribute to the renewal of the planning system by introducing spatially explicit knowledge both of the actual environmental performances and of the expected impacts related to land use policies and territorial transformations. In this paper we address the class of Regulation and Maintenance Ecosystem Services (ReMES) that has a relevant influence on the environment's suitability to contribute to human well-being and to relate the local anthropic transformations to the larger scale where ES are provided and the impacts are tangible. The aim of this work is to propose a methodology to build a territorial knowledge infrastructure by mapping a relevant set of ReMES in Italy and identifying specialization sub-regions, to be intended as areas of high provision of one or more ReMES.

The results, interpretable as a measure of territorial performances, represent a cross-cutting informative layer and a tool to support the comparison between different planning scenarios comprehensive of both environmental protection issues and socio-economic development strategies.

Keywords: Ecosystem Services, Regulation and Maintenance Ecosystem Services (ReMES), territorial specialization, territorial transformations

Introduction

The environmental, social, and economic changes, evolved so rapidly in recent decades, revealed some limitations in traditional approaches of planning processes as well as in the governance of land transformations. The land use planning system is indeed experiencing a structural weakness from both a regulatory and informative perspectives. The first aspect concerns the lack of flexibility of conventional zoning and prescriptive models applied in urban and regional plans. A relevant debate on Performance Based Planning was collected by Pelorosso, La Rosa and Gobattoni in Sustainable Cities and Society 2020 (Sustainable Cities and Society | Performance-based urban planning to generate sustainable solutions for cities | ScienceDirect.com by Elsevier available at: *https://www.sciencedirect.com/journal/sustainable-cities-and-society/special-issue/10B4NMF57P4* accessed July 2021). The role of ES as a tool for promoting performance based approach in planning practices gained importance in that scientific debate. Additionally, the articulation of responsibilities among planning authorities operating at different administrative levels is a critical issue in plans elaboration and in the management of governance processes. The second component deals with the availability of territorial data infrastructures able to support decision-makers in managing territorial development, jointly considering all the three dimensions of sustainability (environmental, social and economic) (Pacione, 2003) and human well-being (Groenewegen et al., 2006; Martín-López et al., 2017). Today, if we focus on the planning process, it emerges that a comprehensive and integrated approach (Kopperoinen et al., 2014) is still required. The demand for effective tools to support policy design throughout territorial analysis and the assessment of alternative development scenarios (Cerreta et al., 2020b; Grêt-Regamey, Altwegg, et al., 2017) still remains unsolved.

We join this debate re-affirming the Faludi's position (Faludi, 2000a) about the "*ultimate goal of spatial planning"*: strategic planning processes should be assessed not so much in the light of tangible outcomes obtained, but on the basis of how much they improve the decision-makers' knowledge about current and future issues of urban and territorial contexts where the plan will be implemented.

Defined the Ecosystem Services (ES) Approach as the methodological framework based on the assessment and mapping of multiple services supplied by ecosystems for human well-being, we recognize that it is a mature and robust framework (Albert et al., 2016; Comino et al., 2014) for territorial analysis, showing high potential in adding value to the traditional planning process by explicating trade-offs as a consequence of land use transformations (Haase et al., 2012b; Howe et al., 2014; Spyra et al., 2020), explaining complex dynamics (Bagstad et al., 2013; Elliot et al., 2019) also through spatial explicit assessments and facilitating communication and joint implementation among relevant stakeholders (Albert et al., 2016) involved in the different levels of governance.

Although the ES concept has been extensively investigated as a research topic, the added value of ES approach for planning practice remains a hotly debated topic (D. La Rosa, 2019a), with many questions still opened about how to pursue a better integration of the ES mapping and assessment into planning processes (R. S. de Groot et al., 2010a; Hauck et al., 2016). The state of the art related to integration of ES approach into planning is rather fragmented. It seems to find more space in complementary procedures than in the core elaboration of the plan especially within the Italian context: it is the case, for example, of Strategic Environmental Assessment procedures (SEA) (Geneletti, 2012; Sabrina; Lai, 2016). On the urban scale, a recent research conducted by La Rosa (D. La Rosa, 2019a), showed that the inclusion of ES in municipal planning tools is very limited. According to this review the percentage of cases where the ES concept has an weight on urban planning choices: just about 8% of analyzed plans explicitly consider the ES assessment; of these, only six plans rely on ES maps and spatial analysis (e.g., hotspots). At a broader planning level, we report the case of the Lombardy Region which took the opportunity of the revision process of the Regional Landscape Plan (PPR) to map the Habitat Quality indicator *as a proxy of the ecological state of the Region* (Salata, Ronchi, et al., 2017a) and to support the Green regional infrastructure (Arcidiacono & Ronchi, 2021).

In this work, we consider the Regulation and Maintenance Ecosystem Services (ReMES), defined by the Common International Classification of Ecosystem Services (CICES) (Roy Haines-Young & Potschin, 2018a) as "*all the ways in which living organisms can mediate or moderate the ambient environment that affects* *human health, safety or comfort, together with abiotic equivalents*” because, although not directly consumed, they have a strong influence on the ability of the environment to contribute to the quality of human life. We found the ReMES relevant in the process of measuring the three dimensions of sustainability in planning phase and in land use transformation processes since they contribute to relate local changes and anthropic transformations to the wider scale of the ES supply where impacts becomes tangible.

Among the ReMES and according to the classification CICES 5.1 (Haines-Young & Potschin-Young, 2018), we chose the following classes:

- Regulation of chemical composition of atmosphere;
- Pollination;
- Maintaining nursery populations and habitats;
- Control of erosion rates;
- Regulation of the chemical condition of freshwaters.

As they all belong to the Division of “Regulation of physical, chemical, biological conditions”, they are significant of ecosystems quality relative to a specific date (Maes et al., 2014; Maes & Barbosa, 2015): the year 2018, that for the purpose of this study represents our baseline. Focusing on several components of the environmental matrix (soil, water, biodiversity, atmosphere), they represent key elements useful in building a comprehensive picture of current environmental conditions, to be intended as a reference baseline for assessing environmental performance (i.e. the ability of ecosystems to supply ES). The concept of baseline is useful in planning processes because it is the element of comparison on the basis of which to evaluate environmental transformations, alternative development scenarios, the effects resulting from the implementation of specific territorial policies (e.g. nature conservation, agricultural policies, forest management, management of semi-natural environments in peri-urban areas, expansion of human settlements, etc.). Furthermore, the evaluation framework they compose is cross-cutting with respect to territorial components that traditionally constitute the subject of several sectoral plans (e.g. the water management plan, the forest management plan or the reforestation plan, the reclamation plan, the management plan for protected areas). The issue of fragmentation of sectoral policies and plans is at the center of a disciplinary debate (Scorza, Pilogallo, Saganeiti, & Murgante, 2020a) since the need for a more integrated and comprehensive evaluation framework emerges.

We thus consider the ES selected relevant for both land use planning and landscape management since they depend on the conditions of ecosystem but also from the spatial pattern resulting from the integration of both natural and anthropic components land use

The choice of year 2018 as temporal base line reference for the analysis discussed in this paper depends on the availability of the most recent CORINE land cover data.

The aim of this work is to build territorial knowledge by mapping a relevant set of ES in Italy at national scale applying a reproducible approach to evaluate the spatial supply of ReMES as a cross-cutting informative layer useful in different planning processes, from the urban (Cortinovis & Geneletti, 2020; Geneletti, Cortinovis, Zardo, & Adem Esmail, 2020; Yong et al., 2010) to the territorial scale (Baró et al., 2017; Jaligot & Chenal, 2019; Tammi et al., 2017).

The primary implementation perspective of this work is to support the assessment of alternative development scenarios in an ex-ante stage of the planning process and to monitor the results following the implementation of territorial development policies (Scorza, Pilogallo, Saganeiti, & Murgante, 2020a). The relevance of such activities may be intended also as an argument of the current national policy development debate in Italy, oriented to tackle the post-pandemic recovery issues. In fact, investments programming and the choices underlying the allocation of limited resources cannot disregard an integrated assessment capable of capturing synergistic effects or tradeoffs in terms of impacts on multiple spheres of human well-being and, more specifically, on the provision of ReMES.

In the following section, we address the issue of mapping ReMES considering the Italian national territory as our study area. For each ES included in the selected ReMES classes, we present the definition in accordance with the CICES classification, we specify the characterizing aspects for the planning issues, we expose the method/model of assessment and we show the maps that constitute the basic informative layers, essential for the next step: the identification of areas of specialization.

In the discussion paragraph, we show how the evaluation of hotspots may be intended as a measure of territorial specialization: areas in which the provision of one or more ES defines an indicator useful to compare different territorial performances.

Finally, the conclusions highlight the contribution that a data infrastructure based on ReMES mapping provides to the assessment of local specializations.

Mapping ReMES

According to the purposes of this work, five ES were selected in relation to their significance for the assessment of the current status of ecosystems in Italy and their ability to provide long-term regulating services.

The five ReMES selected (Table 1), according to the CICES classification, relate to groups of ES that address different components of the environmental matrix: ‘Carbon stock and Carbon Dioxide Uptake’ are related to *Atmospheric Composition and Condition*; ‘Control of erosion rates’ is specifically related to the soil and its capability to regulate extreme events; ‘Pollination’ and ‘Habitat Quality and Degradation’ refers to the biotic components with respect to the lifecycle maintenance and habitat protection; ‘Regulation of freshwaters’ quality’ refers to *Water conditions*.

To assess each ES, we relied on experimental equations based on the use of remotely sensed data and the INtegrated Valuation of Ecosystem Services Tool (INVEST) suite (Isely et al., 2010a), a set of spatial-explicit models particularly useful to involve stakeholders and decision-makers into evaluating those ES not belonging to traditional markets (Isely et al., 2010b). In fact, this suite was developed with the aim of supporting decision makers in assessing trade-offs associated with different policy options or spatial transformations while also offering the opportunity to identify areas where investments in ES can improve human well-being and ecosystem conservation, and help mitigate the effects of climate change (Hoyer & Chang, 2014; Mokondoko et al., 2018). It also proves to be a useful tool for multiple purposes in both urban and regional planning, including biophysical assessments and mapping (Ahern et al., 2014b; González-García et al., 2020b), monetary evaluations (Gómez-Baggethun & Barton, 2013b; Prager et al., 2012), scenario analysis of land use changes (Geneletti, 2013b; Polasky et al., 2011).

The basic spatial information layer necessary for the use of InVEST tools and in the interpretation of the results obtained is the "land use map". For this purpose, we used the CORINE Land Cover (year 2018) made available as part of the Copernicus program for all EU Member States with a classification divided into 44 classes organized into three hierarchical levels. The potential of this inventory lies in the standardization of the methodology that allows the comparison between different territorial units (Bielecka & Jenerowicz, 2019), and the continuity of acquisition that allows the monitoring of land use change dynamics (Cieślak et al., 2020) and provides the basis for the implementation of predictive models (Martellozzo et al., 2018).

Table 5 - Summary of the indicator, method, and unit of measure for each ES considered

Section	*Class*	*Indicators*	*Method*	*Unit*
Regulation & Maintenance Ecosystem Services (ReMES)	Regulation of chemical composition of atmosphere	Carbon stock	InVEST model	t/Ha
	Pollination	Pollination Abundance	InVEST model	Index (dimensionless)
		Pollination Supply	InVEST model	Index (dimensionless)
	Maintaining nursery populations and habitats	Habitat Quality	InVEST model	Index (dimensionless)
		Habitat Degradation	InVEST model	Index (dimensionless)
	Control of erosion rates	Erosion Rates	InVEST model	t/Ha
	Regulation of the chemical condition of freshwaters	Effective nutrients retention	InVEST model	Index (dimensionless)

The results are maps representing the spatial distribution of the provisioning intensity for each ES, coupled with some basic statistics.

For each ES required additional inputs are described in the following sections.

As highlighted from several authors (Burkhard et al., 2018; Paulin et al., 2020; Yang et al., 2019), mapping is the first step to analyze the relations between multiple ES and to support the design of win-win solutions in both land use management and territorial planning.

In this work, the comparison between the several single-ReMES maps makes it possible to identify the areas within the Italian national context that are specialized in the provision of Regulating ES.

2.1 Carbon Storage

The quantification of Carbon stock constitutes an informative layer relevant for the design of regional and national public policies linked to climate change adaptation and mitigation strategies. Furthermore, it also defines a baseline for the assessment of policies implementation on the basis of land use changes detection. Also in light of this important role in planning and land management processes, the recent classification of the CICES v.5.1 (Haines-Young & Potschin-Young, 2018; Roy Haines-Young & Potschin, 2018a), while considering it as an ecosystem function (Maes et al., 2012), suggests to use its assessment as a proxy of the regulatory effect that the ecosystem provides with respect to all atmospheric components that affect the environmental quality (Chaabouni & Saidi, 2017).

Concerning the analytical frameworks, we may affirm that in the scientific literature a multitude of methods are described (Chapin et al., 2006; Grêt-Regamey, Sirén, et al., 2017; Martnez-Harms & Balvanera, 2012; Sabine et al., 2013; Seppelt et al., 2011); in the present work we considered the Carbon stock strictly related to the land use pattern (Paquit, 2017). This study applied InVEST Carbon Storage and Sequestration Model to map the spatial pattern of carbon stock (extending previous case study applications (A. Mazzariello et al., 2018)), using information depending on the Land Use/Land Cover class (Gasparini et al., 2013; Haase et al., 2012b; Sharp et al., 2015; P. Smith et al., 1997; Pete Smith et al., 1997). The result is a raster map that represents the total value of carbon expressed in t/ha. Such value results from the aggregation of contributes from four different tanks: i) Aboveground biomass, which includes long-term carbon source actually stored in foliage and wood; ii) Belowground biomass, consisting of the root systems; iii) Soil organic carbon (SOC) stored in the top-soil, i.e. its mineral layer soil; iv) Dead organic matter, corresponding to the dry biomass and the litter on the soil surface.

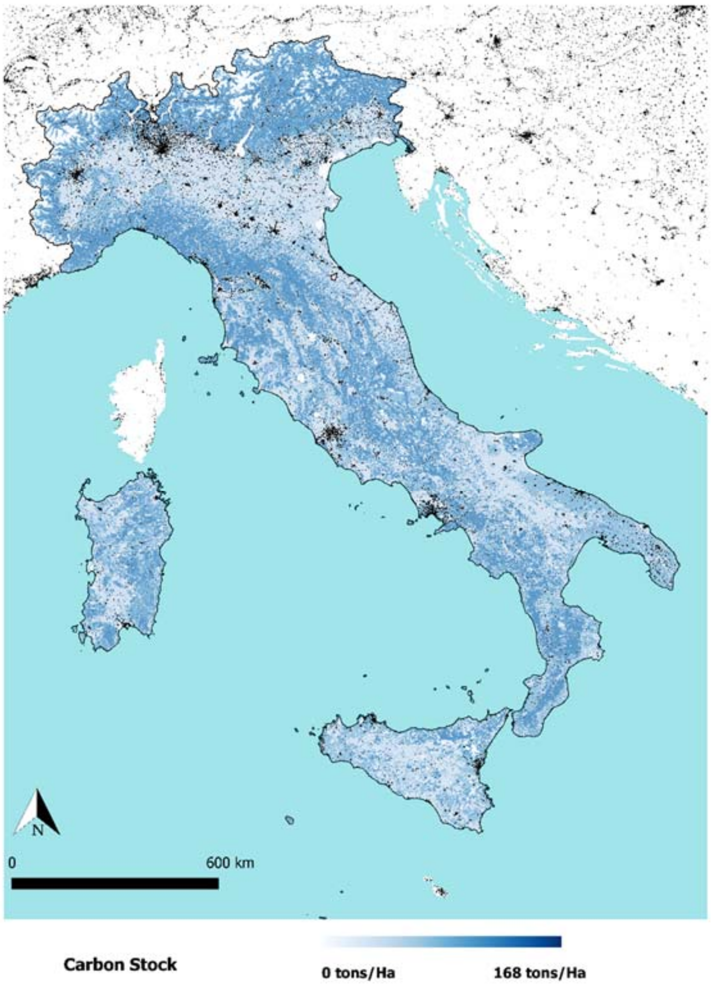

Figure 3 – Map of Carbon stock

The processing results (Figure 3) have the same resolution as the land use map (pixel size of 100x100 m). The distribution of values, due to the nature of the implemented model, is composed of discrete values ranging from 0 t/ha for “urbanized areas” (CLC class “1. Artificial surfaces”) to maximum values of 168 t/ha for “forests” (CLC class “3.1. Forests”).

The average value is 96 t/ha and is representative of land use classes consisting of “pastures” and “natural grassland” (CLC classes “2.3.1. Pastures” and “3.2.1. Natural grassland”).

Although the model simplifies the biophysical assessment of ES by considering the spatial distribution of land cover classes only, we consider this model suitable for large-scale assessments using specific data for the study area (i.e. for Italy the National Inventory of Forests and Forest Carbon Sinks (Gasparini et al., 2013)). The implementation of this model at more detailed scales depends on the availability of datasets as well as of updated land use maps.

Crop pollination

The pollination by wild insects is an important ReMES with high natural and economic value and with fundamental importance for human well-being. Not only the protection of biodiversity but also agricultural productivity are closely related to this ES. About the 75% of the global crops used as human food, depends in fact from the pollinating insects (Klein et al., 2007) and, consequently, from the supporting ecosystems (Maes et al., 2012). A specific objective of preserving and restoring this ES thus arises due to fact that pollination has been identified as directly contributing to food security (SDG2) and biodiversity (SDG15) (Dangles & Casas, 2019) even if some authors carried out study to define crosscutting indirect effects on further SDGs (Patel et al., 2021).

Actually, there is an explicit policy demand for the protection of the pollinators habitats. To this purpose the EU Biodiversity strategy (European Commission, 2011) asks the Member States to map this ReMES and assess its economic value.

InVEST Crop pollination tool was used to map the aptitude in hosting pollinating species. This is based on the territorial availability of suitable nesting grounds and food considered as appropriate environmental conditions. Input data consist in information about the potential availability of nesting sites and floral resources, relevant for the presence of food sources for pollinators, besides with the flight range and the seasonality of the pollinating species (Nelson et al., 2018).

The model uses expert estimations about nesting and floral resources according to land use classes (Davis et al., 2017) to deliver two maps for pollinating species (we considered the species “wild bees” proposed by the model): the "pollinator supply" map describe the availability of pollinator considering both accessibility to food resources and usability of nesting sites; the “pollinator abundance" map represents the potential presence of pollinators per area parcel and it is relevant to assess the area where pollination services are delivered.

Data on floral availability and nesting suitability for each Land Use Class derives from literature dataset (Zulian et al., 2013) as well as information about flight range and seasonality of pollinator species (Lonsdorf et al., 2009).

The resolution of the two maps is the same of the Corine Land Use Map equal to a pixel size of 100 m.

Both values of supply and abundance vary between 0 and 1 and are significant of a probability of observation. Our results return a maximum value of 0.99 for abundance and 0.94 for supply with a mean value equal to 0.30 for both of them. The spatial distribution depends not only on the land cover class but also on the pattern of land uses.

As can be seen from Figure 4, the areas of the national territory in which the pollination service is provided with a greater intensity correspond to "forestlands" (CLC class "3.1. Forests") and vegetated areas in which the herbaceous and shrub covers are intermixed (CLC class "3.2. Shrubs and/or herbaceous vegetation association"). In particular, the pollinator supply (Figure 4) distribution assumes its maximum value in correspondence of "transitional woodland shrub" (CLC class "3.2.4. Transitional woodland shrubs"), "forests" (CLC class "3.1. Forests") and "sparsely vegetated areas" (CLC class "3.3.3. Sparsely vegetated areas").

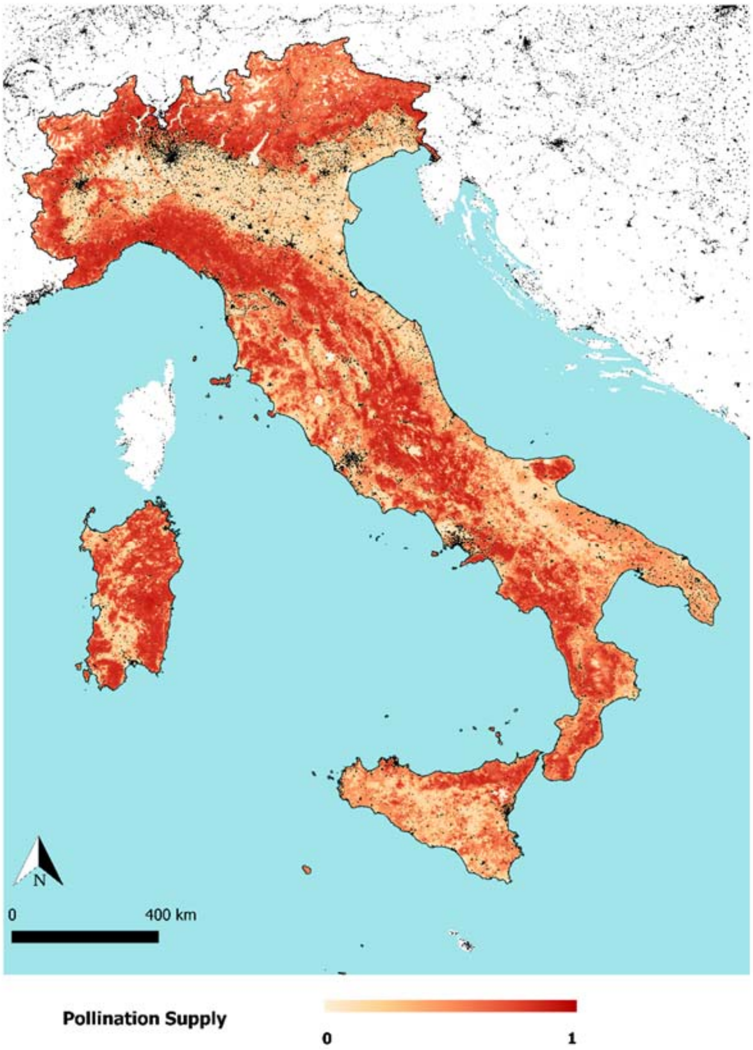

Figure 4 – Map of Pollination Supply

On the other hand, the pollination abundance (Figure 5) is relevant in those areas where the regulating services are delivered and its intensity reaches the maximum where extensive "natural grasslands" (CLC class "3.2.1. Natural grassland") are prevalent and the minimum values in the areas mainly occupied by "non-irrigated arable land" (CLC class "2.1.1. Non-irrigated arable land").

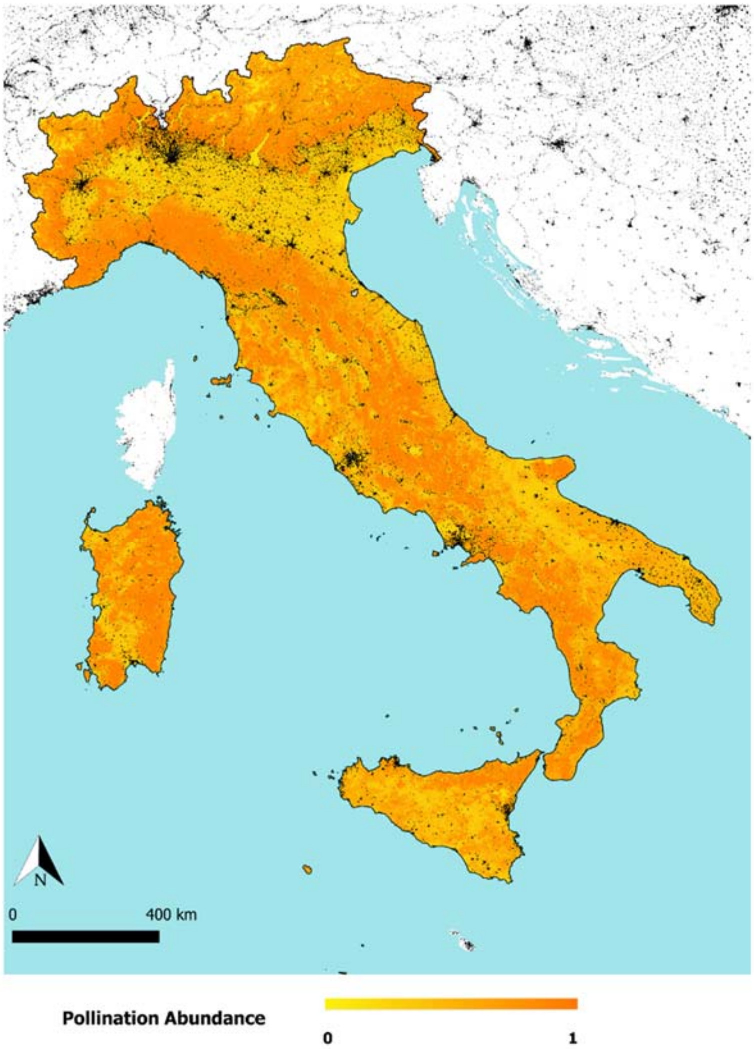

Figure 5 – Map of Pollination Abundance

Habitat quality and degradation

We place the assessment of “Habitat quality and degradation” in the class “Maintaining nursery populations and habitats” as defined by CICES. The proper interpretation of “Habitat quality and degradation” is the core of a current scientific debate and the literature lacks an univocal interpretation (Liquete et al., 2016) and the classification systems provide different definitions (Nolè et al., 2021). The Economics of Ecosystems and Biodiversity (TEEB) (*TEEB Report*, 2015) for example, considering it to be everything an animal or plant species needs to survive, included this ES among the "Habitat or supporting services”.

It is not the purpose of this paper to address the topic related to the semantics of this ES and the related difference with ecosystems function (Cardinale, 2011; Isbell et al., 2011; Mace et al., 2012). Instead, we operatively confirm the interpretation of the CICES and evaluate a map representing the “habitats quality” as a proxy for the suitability of a specific place to host natural species. This result may express a relevant support in orienting development scenarios towards the protection of biodiversity and the conservation of areas where the anthropic pressure is still negligible (Impact of Renewable Energy Installations on Habitat Quality, 2020).

We used InVEST 'Habitat Quality and Degradation' (Nelson et al., 2018) tool that combines information on habitat suitability (assigned to each land use class) and several concurrent threats for the environmental quality and biodiversity. The model allows to geographically represent alterations in the habitat quality and so evaluate interactions between natural environment and anthropic activities. The model produces two different maps: "habitat degradation" significant of the cumulative effects of anthropic threats that implies an incremental level of degradation; "habitat quality", ranging from 0 (low habitat quality) to 1 (high habitat quality) and resulting from the combination of the cumulative impacts deriving from all the threats and the habitat suitability assigned by the user.

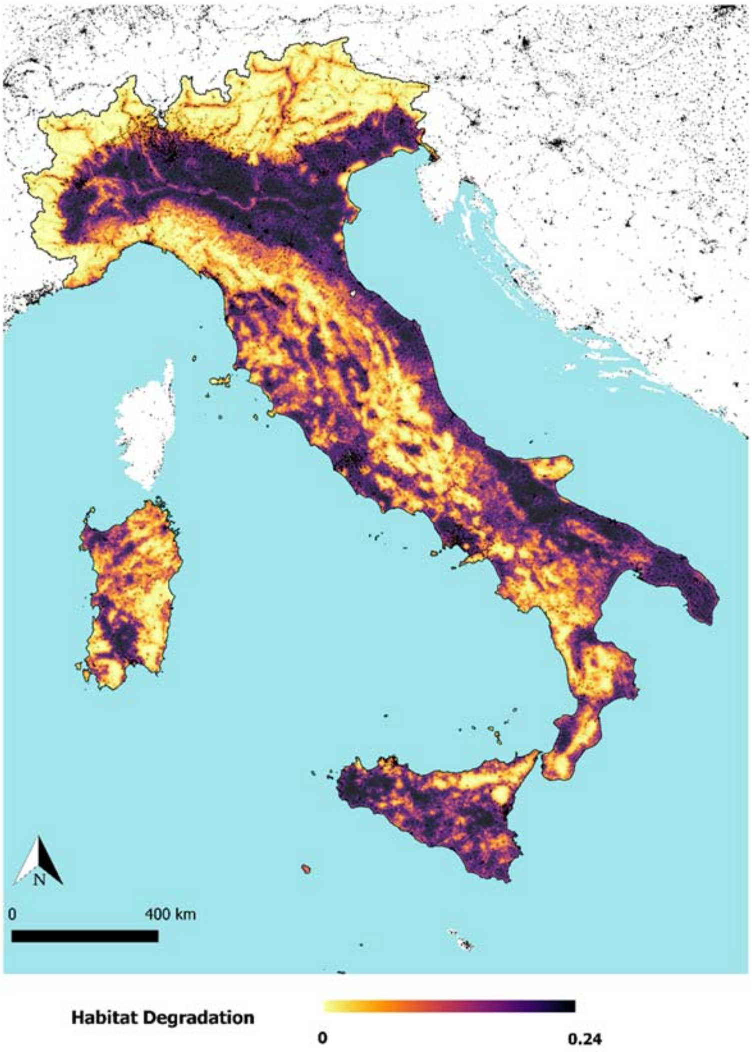

Figure 6 – Map of Habitat Degradation

Data needed are: (1) land use map (2) threats table that including their weight (in a range between 0 and 1) and the influence radius where the threat generates an impact (expressed in km); (3) a binary raster map for each of the considered threats; (4) the sensitivity matrix where a sensitivity value is expressed according to an expert appraisal for all the threats considered and for each of the land use classes present throughout the study area. Required values were assigned on the basis of datasets from previous works of the same authors for both the threats characterization and the sensitivity matrix (Impact of Renewable Energy Installations on Habitat

Quality, 2020; Nolè et al., 2020; Angela Pilogallo et al., 2019; Scorza, Pilogallo, Saganeiti, & Murgante, 2020a; Scorza, Pilogallo, Saganeiti, Murgante, et al., 2020b) .

The model requires that both threats and habitat are represented by well-defined geometric objects and assumes that threats are additive and their effects are not sensitive to patch size or habitats' connectivity (Scorza et al. 2020a).

The InVEST Habitat Degradation module enables the representation of the cumulative effects of several threats with varying degrees of intensity, depending on their weight and distance from the source. This means that values distribution is useful for comparing areas where the overall impact of threats is greater than in less urbanized areas or further away from anthropic sources of pressure. In our case, the degradation results (Figure 6) varies between 0 and 0.24, with the lowest values corresponding to the tops of the major mountain chains and the highest values with the most urbanized areas and corresponding to the largest metropolitan cities.

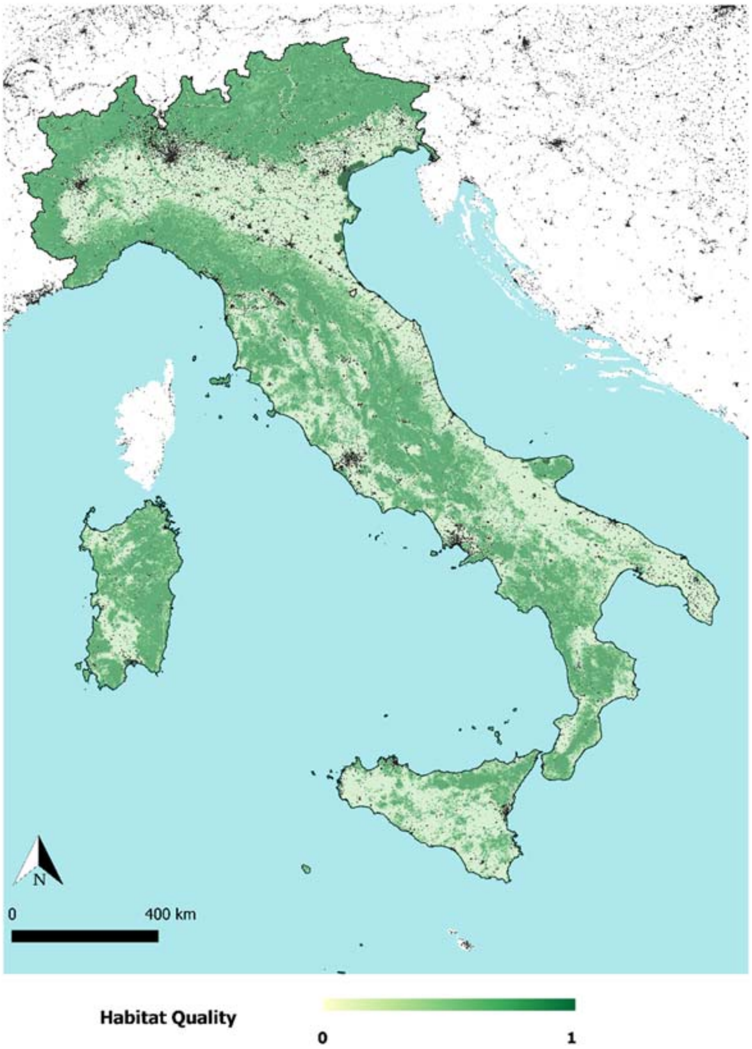

Figure 7 – Map of Habitat Quality

Habitat Quality (Figure 7Figure 7) ranges between 0.09 and 1, with a mean value of about 0.54. The lowest values correspond to the major urban centers and metropolitan areas, especially where the infrastructures network is very branched.

The values closest to one are observed in correspondence of wetlands (CLC class "4. Wetlands") close to the coast, to which a very high naturalness value was assigned, and in the wooded areas (CLC class "3.1. Forests") along the Alps and in the central part of the Apennine chain, where the distance from the sources of impact is relevant.

Control of erosion rates

Soil is the main provider of ES (Kibblewhite et al., 2008), it is essential for agricultural production and plays a key role in carbon cycle regulation (L. Stringer, 2008) and biodiversity preservation (Pascual et al., 2015; Udawatta et al., 2017).

There is a general agreement about the need to preserve soil functionality in order to pursue sustainable development strategies (Keesstra et al., 2016; Angela Pilogallo et al., 2020).

The interest of planning in mapping soil ES lies in the possibility of abandoning the dichotomous approach of soil consumption (permeable soil vs. sealed soil) and expressing the effect of land transformations in terms of gradual loss of soil multifunctionality.

We used Sediment Delivery Ratio (SDR) InVEST module (*Sediment Delivery Ratio — InVEST 3.6.0 documentation*, n.d.), a spatially-explicit tool able to model erosive phenomena and to represent the spatial variability of fertile soil loss, also considering non-linear responses to land use changes (Perrine Hamel et al., 2015). By implementing the Revised Universal Soil Loss Equation (RUSLE) (K. G. Renard et al., 1991), in fact, it allows the spatially-explicit representation of annual average soil loss amount expressed in tons/ha/yr.

Data required for running the model are: (1) the Land Use Map; (2) a biophysical table summarizing the values of the crop management (C) and support practice (P) parameters assigned to each Land Use Class; (3) the Digital Elevation Model (DEM); (4-5) two raster dataset representing the rainfall erosivity (R) and the soil erodibility (K) indexes.

The "crop management factor" (C) represents the capability of land use cover to limit the rainfall impact and consequently to mitigate the soil erosion and the runoff (S. Lee, 2004). It depends from several variables such as soil moisture, land use cover roughness and vegetation density. Its value ranges from 0 for non-erodible surface and 1 representing the non-vegetated bare land (K. Renard et al., 1997). In the InVEST SDR module we used the dataset developed by Panagos et al. (Panagos, Borrelli, Meusburger, Alewell, et al., 2015).

The support practice (P) is relevant for the implementation of agricultural management practices supporting the mitigation of erosive phenomena, such as fields contouring, terracing and strip cropping (Foster & Highfill, 1983; Karydas et al., 2009). We adopted reference datasets available in the literature (Panagos, Borrelli, Meusburger, van der Zanden, et al., 2015).

Concerning the "rainfall erosivity" (R), it is an estimation of the rainfall energy (Panagos, Ballabio, Borrelli, Meusburger, et al., 2015a) expressed in [MJ mm $ha^{-1} \cdot hr^{-1}$] and representing the rain potential capacity to cause soil erosion (Ekern, 1954). Since it depends from the total kinetic energy, the duration and the intensity of a rainfall (Wischmeier & Smith, 1978), its assessment is tricky and time-consuming (Diodato, 2004). For this reason, we used available dataset with 1 km resolution and based on the Rainfall Erosivity Database on the European Scale (REDES) which comes from a monitoring system including more than 1500 precipitation stations in all the Member States and Switzerland, with high temporal resolutions (Panagos, Ballabio, Borrelli, Meusburger, et al., 2015b).

The "soil erodibility factor" (K) is expressed in $Mg \cdot h \cdot MJ^{-1} \cdot mm^{-1}$, as it assesses the susceptibility of soil particles to be detached and transported by rainfalls and runoff (Wischmeier & Smith, 1978). It depends from several phenomena such as the splash effect during the intensive events, the intensity of runoff, the topsoil infiltration capability and the transportability of sediments (K. Renard et al., 1997; K. G. Renard et al., 1991). A reliable site-specific assessment requires the evaluation of several variables such as the soil structure (Pintaldi et al., 2018), the granulometry (Loch & Rosewell, 1992), the permeability (Lucia Saganeiti et al., 2019), and different further quantities that vary over time, such as the water content in the topsoil.

The JRC's European Soil Data Centre (ESDAC) provided the raster K-factor dataset (Panagos et al., 2014) for the entire European territory with 1 km resolution.

The result of this elaboration is a map (Figure 8) representing the phenomenon of soil loss due to erosive phenomena. In terms of ES, the highest value of soil loss characterize the areas of minimum provisioning, vice versa those areas where the soil loss is very low are the places where this ES reaches the maximum capacity.

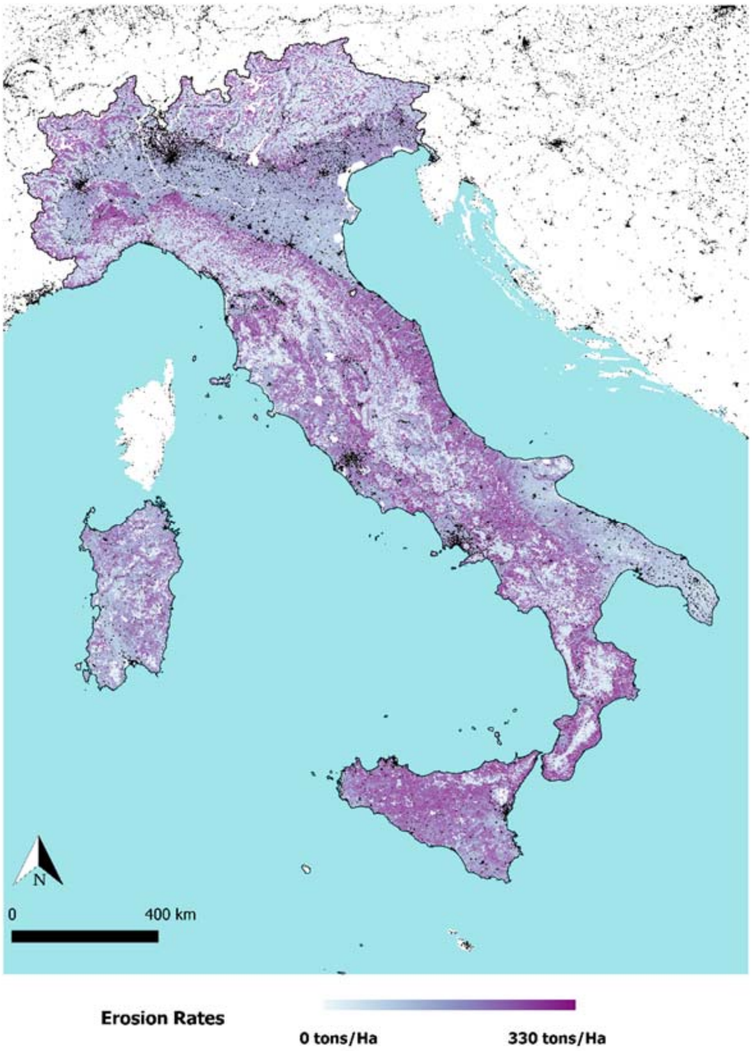

Figure 8 – Map of Erosion rate

For reasons essentially related to the morphology of the territory, the largest hotspot of this ReMES is constituted by the Po Valley where, despite practicing a type of intensive agriculture characterized by the prevalence of arable land, the very small slopes limit the production and subsequent removal of soil sediments. The quantity of soil loss, which for the Italian territory ranges between 0 and 330 tons/ha per year, does not exceed 5 tons/ha in this area. Also a large part of the territory of the Apulia Region can be considered a hotspot of this ReMES as the medium-high values of erodibility are compensated by smooth slopes and very low values of rainfall erosivity.

The distribution of the values of this ReMES follows a trend characterized by a rapid decrease of the soil loss value. With a very wide range of variability, in fact, the average is about 8.6 tons/ha and about 90% of the entire national territory has a value not exceeding 23 t/ha.

Regulation of freshwaters' quality

Assessing and mapping the Regulation of freshwaters' quality as ReMES is useful to interpret the spatial interaction between three main land uses components: land uses that constitute a potential source of diffuse pollution (e.g. agricultural uses); land use classes potentially able to mitigate contamination through filtering actions (e.g. areas covered by riparian vegetation); and natural water bodies. Spatially defining source and filtration areas allows, for example, to design new ecological compensations for urban transformations according to the desired increase in retention in order to improve surface water quality (Salata, Garnero, et al., 2017).

The model applied is the InVEST Nutrient Delivery Ratio module that represents the movement of an amount of pollutants (Nitrogen and Phosphorus) by computing a mass balance (per-pixel nutrient load) combined with information on the territorial morphology. This tool can simulate the nutrient loads considering both the components transported through surface and subsurface flows. Since modeling subsurface flow is optional, we choose to model surface flow only.

Input data required are: (1) The land use map; (2) the Digital elevation model (DEM) of the study area; (3) the nutrient runoff proxy that is a raster representing the capacity to transport nutrient downstream. In this work, as suggested by the authors, we used the annual precipitation dataset; (4) the watersheds layer in vector format; (5) a biophysical table containing the nutrient loading (Nitrogen and Phosphorus), expressed in kilograms per hectare per year, and the maximum retention efficiency for each land use class ranging from 0 (poor efficiency) to 1 (maximum efficiency).

Since the model outputs show a high sensitivity to inputs (P Hamel & Guswa, 2014) the selection of data sources represents a critical issue. In our case we chose for the biophysical table the data collected by Salata et al. (Salata, Garnero, et al., 2017) related to some Italian study areas.

Among the outputs of the model, we considered the layer called "effective nutrients retention" (Figure 9) as the most relevant output for the purposes of this work. It estimates the filtering power of each territorial unit. Such result is as a function of land use classes and the runoff pattern depending on territorial morphology.

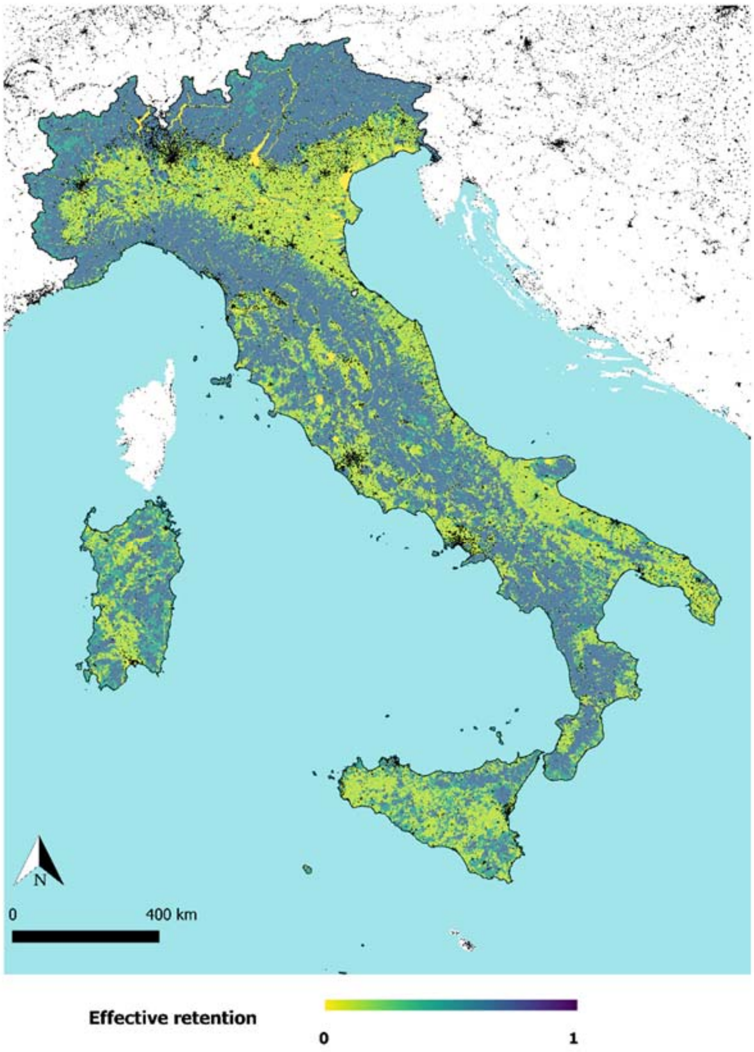

Figure 9 – Map of Effective Retention

The value of Effective Retention varies between 0 and 1. In our application it is 0, in correspondence with watercourses, and goes up to 0.8 where vegetated areas are located in proximity to watercourses. The average value, equal to about 0.58, does not correspond to a specific land use class.

Discussion

The unsolved balance between natural ecosystems and anthropic structures is a driving factor of continuous processes that determined the current scenario. The management of such process is the core of planning practices. Today the sustainability attribute has to bring effective solutions according to the relevant global objective frameworks and is demanded to generate new planning instances in the three dimensions of sustainability: environmental, economic, social.

What is new?

the possibility to measure differences or unbalances between different areas by the means of ES. The previous maps express their potential in terms of enriching territorial knowledge for a better support in rational planning processes (Las Casas & Scorza, 2016b);

the availability of a new metric to assess ex-ante planning choices or relevant investments programs (i.e. national infrastructures, agricultural policies, water management);

an operative tool to understand the relations between natural areas protection policies and the anthropic system which determine potential threats for ecosystems;

the measure of specialization in ReMES provisioning.

This work thus proposes a methodology to favor the explicit use of the ES concept in the planning processes with the ultimate goal of improving the overall territorial sustainability and make the decision-making process more transparent with respect to the impacts expected as a result of the implementation of the plan choices.

The selected ReMES includes five ES classes taking into account different environmental matrix: atmosphere, water, soil, natural habitat and biodiversity.

The results obtained in term of mapping ReMES constitute an heterogeneous set of characteristics for Italian ecosystemic sub-regions mainly depending on land use transformation processes. The applied models generate meaningful spatial appraisal for the selected ES at national scale and contributes to overcome the traditional approach and proposing a data infrastructure that allows performative evaluations in relation to the territorial capacity to deliver ES. The same information are less appropriate for technical elaboration at regional and sub-regional scale due to the need of site-specific surveys for input parameters.

The discussion of the main research results are based on the identification of territorial hotspots for each ES and identifying cumulative effects through spatial overlaying in the perspective of assessing multifunctionality in ES provisioning.

The hotspots identification is based on the selection of territorial areas characterized by the highest range for each ES estimation. The results highlight the areas that play a relevant role in the provision of ReMES, in other words “sub-regions of specialization” for each ES provisioning. In this case specialization doesn’t mean that only a single ES is present in a specific area but the fact that one ES show a relevant magnitude of the provisioning effect according to specific site characteristics.

In the following Figure 10 the specialization maps for all ReMES classes are proposed.

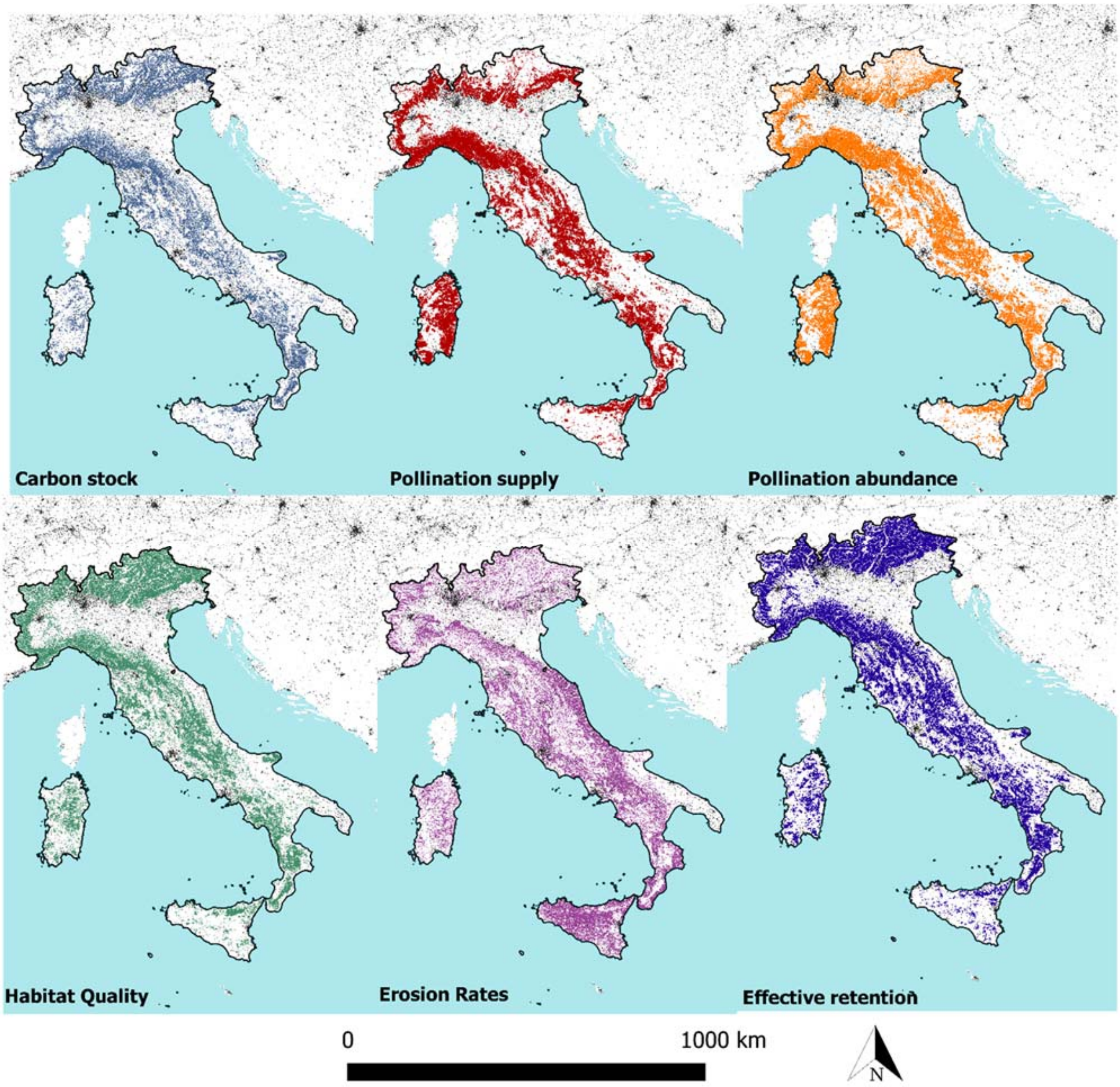

Figure 10 – Sub-regions of specialization for ReMES provision

Some comprehensive pictures arose, for example the relevance of woods and forests in northern Italy, along the Alps and along the Apennines Chain. Here, the value of carbon stored ranges from 168 tons/ha for the areas covered by forests, to 125 tons/ha for the areas where moors, shrubs and sclerophyllous vegetation are present. Those areas hold a considerable extension and are characterized by an evident continuity along the whole country. It is recognizable as the "green backbone" in terms of habitat quality and pollination functions. This is a precondition to reinforce biodiversity conservation objectives. Similar considerations regards the eastern part of the Sardinia Region where the widespread presence of forests and agro-forestry, the considerable extension of moors and natural grasslands, and the low degree of urbanization make it specialized in ReMES supply. This result confirms what highlighted by Cannas et al. (Cannas et al., 2018c) about the high natural value of this part of the Region and its important role within the regional Green Infrastructure.

In the case of the Sicily Region it is possible to identify an area specialized in the provision of regulatory services, confirming what found by Signorello about the distribution of habitat naturalness (Signorello et al., 2018). In fact, the north-eastern area, especially at the highest altitudes, assumes average high values for all the ReMES considered: habitat degradation lower than 0.01; pollination abundance and supply on average not lower than 0.6; freshwaters' quality regulation reaching the maximum value of 0.8; wide areas where carbon stock assumes values higher than 100 t/ha.

The degradation map highlights the areas of the national territory where the anthropic pressure is very high due to the prevalence of anthropic surfaces, a dense network of transport infrastructures and a prevalence of intensive agricultural activities. The largest degraded areas coincide with the Po Valley, which is one of the largest productive areas of Italy (Romano & Zullo, 2015), and with the territory of the Apulia Region. Further areas characterized by a high degradation degree are present along the Tyrrhenian coast, in the Campania Region and in Calabria Region. In the other smaller high-degraded areas determinant is the presence of wide arable lands. This is the case of the Southern part of the Sardinia Region, the central area of the Sicily Region and an area between the Basilicata and the Apulia Regions (Ladisa et al., 2012; Serio et al., 2018).

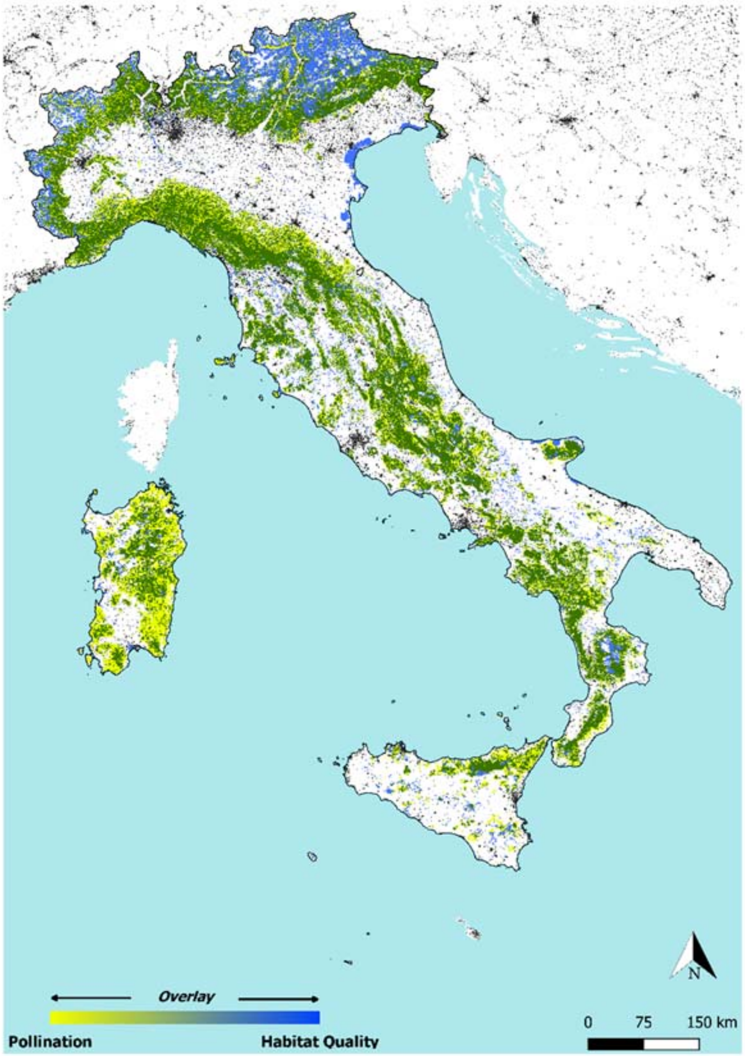

Figure 11 – Overlay between Pollination and Habitat Quality ES

Concerning the freshwaters' quality ReMES, this assessment becomes particularly relevant in contexts such as the Po Valley where the anthropic pressure due to agricultural activities is significant as connected with the use of severe amounts of nutrients (Battini et al., 2016; Perego et al., 2012).

The pollination abundance does not cover those national areas characterized by structured agricultural uses. This is a critical consideration that should be deepened in order to address actual territorial demand and supply. The objective of pollination abundance maximization may radically change the current environmental protection policies including sustainable agricultural practices, affecting market values deriving from responsible agricultural practices (Ellis et al., 2020; Saunders, 2018). Pollination is essential for agricultural productivity (Porto et al., 2020), and the definition of new ecotonal areas that ensure the sufficient presence of suitable sites for nesting and foraging pollinators may reinforce the provisioning capacity (Pisanty & Mandelik, 2015).

The overlap between pollination services and habitat quality specialization area (Figure 11) is meaningful of high naturalness degree of the territory and low anthropic pressures, identifying spatial complementarity (Eeraerts et al., 2019) between these two ReMES.

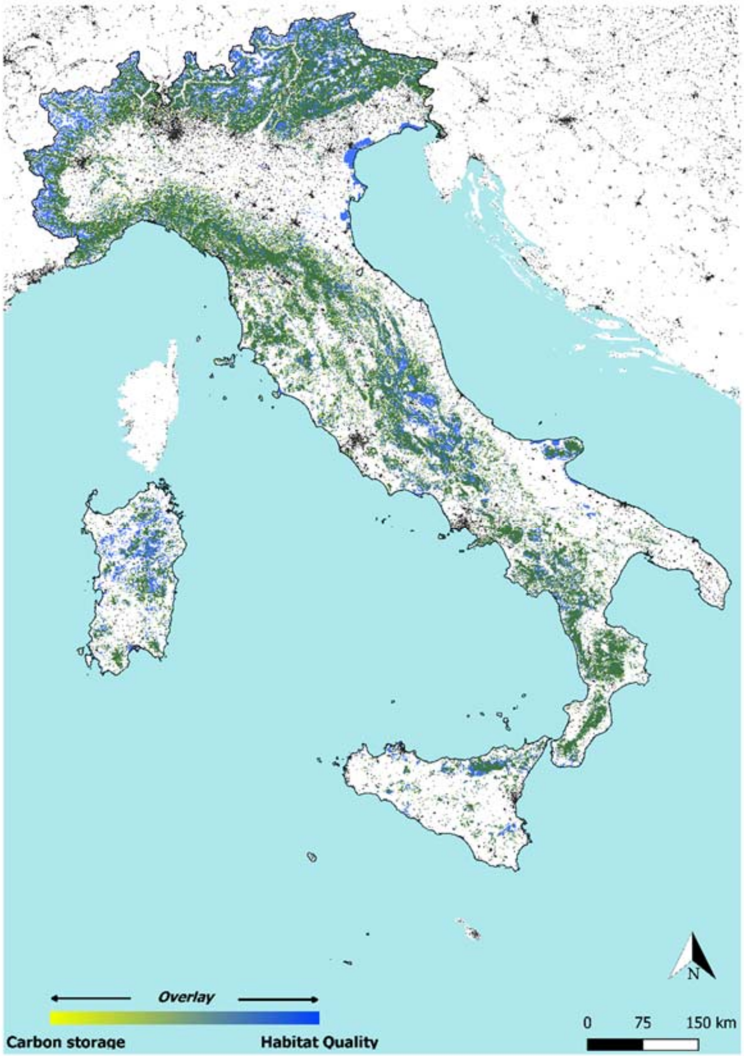

Figure 12 - Overlay between the Carbon Stock and Habitat Quality ES

The high level of habitat quality is directly linked to the presence of wooded areas, meadows and pastures, and peak areas in which, despite the presence of human settlements, the cumulative effect of threats doesn't compromise their naturalness. Mapping lands of high ES supply is preliminary to the establishment of the areas of significant natural value to be protected and/or restored (Salata, Ronchi, et al., 2017b) and is a necessary step in the integration of the ES approach within the legislative frameworks.

This high ecosystems' functionality is also reflected in the capacity to store carbon (Figure 12), highlighting areas where specific management policies can promote and increase the level of synergy between these ES (Haase et al., 2012a; Karimi et al., 2021).

The carbon storage assessment is effective for accounting land use change processes in the perspective of assessing the performances of a relevant part of the country in addressing global challenges related to mitigation and adaptation to climate change (Keskitalo et al., 2015) and thus supporting an aware prioritization in the decision making process (Duarte et al., 2016). This type of assessment, as already pointed out by other authors (He et al., 2016; Lyu et al., 2019; Q. Xu et al., 2019), also allows to evaluate the sustainability connected to different urbanization scenarios.

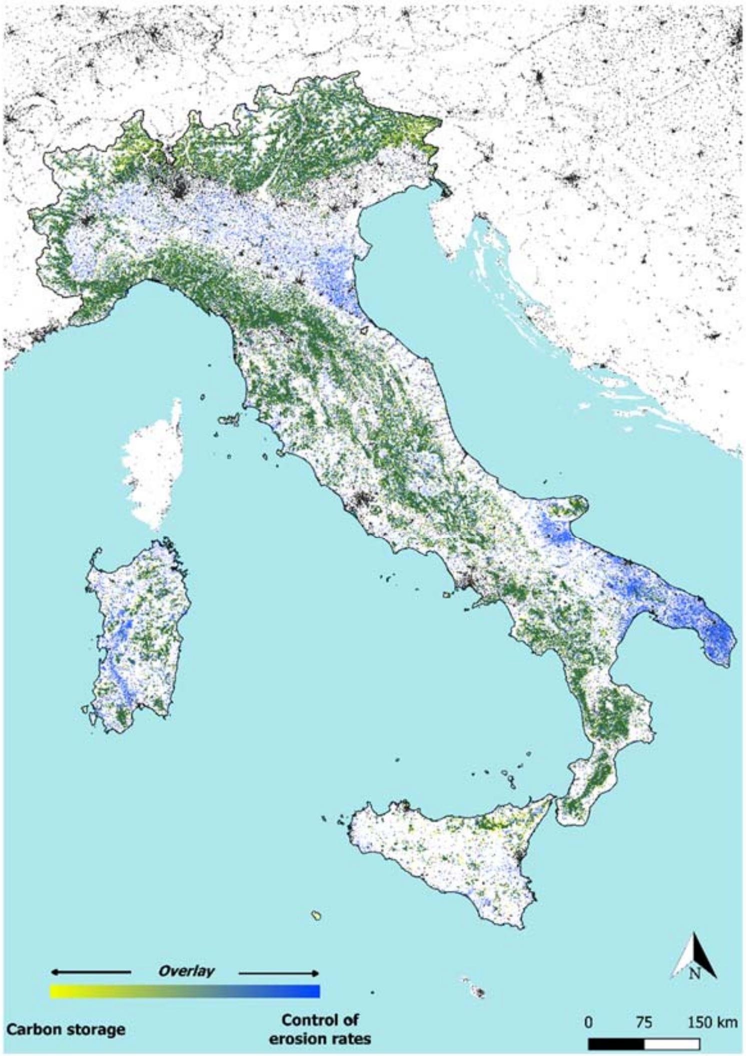

Figure 13 – Overlay between Carbon stock and Control of erosion rates ES

Finally, Figure 13 shows the overlay between areas specialized in Carbon Storage and Regulating erosion rates. This shows how more holistic management policies (Borrelli et al., 2018) of wooded land in the inner areas of the Apennine Chain, could help to facilitate the management of processes related to erosive phenomena, hydrogeological risk and management of solid sediments produced and transported by the hydrographic network.

This consideration expresses a contribution of integration between different levels of sectoral planning, including: forest management, hydrogeological hazard management and water management but, more generally, they are part of the existing debate on the management of natural resources, ES and the complex issue of soil consumption (Lucia Saganeiti, Mustafà, et al., 2020). From a normative perspective, in fact, we have to point out that the piecemeal legislative approach (L. Stringer, 2008) is far from realize an integration of development objectives connected with ES provisioning capacity of natural and semi natural ecosystem. As highlighted by several authors (Hartmann & Spit, 2015; Sabrina Lai et al., 2021), planning should be the dimension in which sectoral policies achieve integration, developing capacities to produce synergies and reduce trade-offs as well as improving the well-being of the communities that benefit from the ES provided. An integrated evaluation framework is still un-available and, often, the sectoral decision-making processes regarding land use and management (Jónsson & Davídsdóttir, 2016) produces conflicting priorities. The authors, in this regard, believe that the ES approach can be a valuable tool in bridging this gap and providing effective support to decision making or policy design processes to be more comprehensive and integrated.

Conclusions

The Italian land use planning system, critically defined as "*orthodox and technocratic*" in recent researches (Pelorosso, 2020), showed structural weaknesses in governing territorial transformations according to sustainable principles, lacking in flexibility (Moroni & Cozzolino, 2019; Pelorosso et al., 2017). Such considerations, widely shared by scholars and practitioners may undermine the effectiveness of ongoing policy of huge public investments for recovery and resilience.

The dualism between "protection of natural resources" and "anthropic development" (mainly linked to the socio-economic factors) brings planning to elicit a territorial conflict between those who receive a constraints in land use practices and those who can get advantages from the use of natural resources (Gómez-Baggethun, 2017). The ES perspective gives planners a way to balance such conflict on the basis of mutual benefits linked to protection policies and development ones (Yu et al., 2010). Of course it includes compensation measures that can be defined on the basis of the ES territorial appraisal to which this study contributes with ReMES mapping.

Thus, the ES approach can provide an effective contribution to the request of structural renewal for the actual planning system through a substantial enhancement of the knowledge building process. ES thinking holds the potential of making explicit complex dynamics between natural functions and anthropic land uses currently not fully integrated within the plan evaluation process.

In the context of Italian planning, there are attempts, at various levels of governance, to integrate the ES approach into the decision-making and planning processes. However, these are spontaneous and isolated initiatives, lacking of organicity and that cannot be placed within a more unified frame of reference.

In order to tackle future challenges in compliance with sustainability principles, decision makers require comprehensive synthesis of ES provisioning in order to build effective planning scenario in which the environmental protection is coupled with socio-economic development issues (Dittrich et al., 2017) balancing land use management (Schmidt et al., 2019) towards a clear identification of strategic development objectives. Our results highlight the informative contribution that the mapping activity provides to the assessment of territorial specializations in the ReMES delivery. Mapping the spatial distribution of territorial specializations measured in terms of ReMES provisioning is useful to define territorial complementarity among provisioning areas and beneficiaries ones. It is also useful in supporting the definition of measures supplementary to those strictly related to the designation of protected areas and oriented to the assess the eligibility of different areas for the identification of green infrastructures (Breed et al., 2014; Sabrina Lai et al., 2018b; Ronchi et al., 2020; Zoppi, 2020) or as elements of a wider ecological network (De Montis, Ganciu, Cabras, Bardi, & Mulas, 2019; De Montis, Ganciu, Cabras, Bardi, Peddio, et al., 2019).

This is particularly relevant for the category of ReMES because the area of service supply does not match the size of the territories that benefit from it.

Specific limitations of this work regard the accuracy and the possibility of updating the results depends on the land use map used. As far as the Italian territory is concerned, there are annually published land use maps with even higher resolution than the CORINE land use map. However, the use of CORINE ensures the replicability of the work in other European contexts and the comparison between the ongoing spatial dynamics and the consequent effects on the provision of ES.

Another limitation is connected to the implemented models strongly dependent on the availability of datasets and information layers for which a periodic and systematic update is desirable. This is the case, for example, of the rainfall erosivity layer that depends on the characteristics of the intensity of expected rainfall.

Further development of the research regards two relevant directions: the multifunctionality assessment in ES provisioning oriented to compare territorial performances in term of ES availability, protection, restoration, etc.; the effort in assessing the beneficiaries of ES in a relevant way compared with instances of participatory planning and the selection of key actors involved in the process at different scales. Differently, the identification of beneficiaries may be intended as groups of citizens (territorial users/consumers) taking advantages form a single or multiple ES provisioning.

The novelty of this work basically regards two dimensions: the first concern with the lack of ES estimation at national scale for Italian territory. Some specific studies comes from the national Natural Capital Committee (CCN) (*Quarto Rapporto sullo Stato del Capitale Naturale in Italia (2021) | Ministero della Transizione Ecologica*, 2021), but the proposed methodology allows a better replicability of the approach and is tuned with CORINE data availability, following the COPERNICUS Programme (*Homepage | Copernicus*, 2021) development in detailed territorial data provisioning. Through our research we made available a relevant set of ES maps for future applications and research. The second dimension of research novelty regards the ES multifunctionality assessment. This is an original result based on the previous outcomes and demonstrate how this data could be used in order to express comprehensive territorial appraisal. Furthermore it is a way to deliver a meaningful synthetic map as DSS paving the way to an effective integration of ES in planning practices.

4. Ecosystem Services based Cities Ranking in Italy: committing decision makers toward sustainable planning

Abstract

Multidimensional integrated indicators became extremely popular as a way to rank territorial units and compare them in terms of performance in environmental transformation, socio-economic development and quality of life. Recognizing the Ecosystem Services (ES) framework as a tool to drive urban and territorial development toward sustainability, in this paper we take up the challenge of transdisciplinary by proposing a "Cities Ranking" based on the concept of ES multifunctionality. Our aim is to contribute to provide a public debate argument enhancing the importance of ES value and driving a demand for sustainability in the territorial governance processes.

Although the scientific community is not unanimous in considering the "Cities ranking" a robust tool, they are recognized as having great potential in terms of communication capacity and as an awareness raising tool.

Basing on a spatially explicit assessment of a relevant set of ES, we mapped the Multiple Ecosystem Services Landscape Index (MESLI). Through the spatial aggregation of the results, we obtained an ecosystem-multifunctionality ranking of the Italian Provinces. This was compared with the major Italian Cities Rankings, demonstrating how the Ranking tool brings to heterogeneous results with relevant differences in assessing territorial features. The conclusions highlight how ES framework represents a new field for Urban Science as a way to operationalize transdisciplinary approach providing quantitative territorial knowledge enriching the sustainability thinking.

Keywords: Cities ranking, Ecosystem Services, Ecosystem multifunctionality, MESLI, performance

Introduction

"Ranking": we care! We leave in an era in which decision making is strongly driven by unstructured knowledge framework or polls. This is representative of the crisis for technical and/or scientific advice in decision making (Faludi, 1986, 1987; McLoughlin, 1969), in favor of rapid consensus building often represented by populisms. It is also a practical basis to produce some kind of hierarchically organized lists from 'best' to 'worst' that helps in urban management to set operational priorities.

Among unstructured knowledge framework we consider "Cities Ranking" as an heterogeneous system of indicators, accounted for different purposes, accompanied with a strong communication potential toward several target groups, influencing local urban policies and global investments.

Over those evidences we also affirm the potential of Cities Ranking to contribute in awareness raising of citizens in front of generalized topic like: sustainable development, resilience, wellbeing, quality of life, environmental quality.

Acuto et al. (Acuto et al., 2021) identified general research questions concerning the weight of Cities Rankings starting from the evidence of how those rankings are soaring in popularity in media reports and became part of everyday practitioner arguments in consulting activities in favor of municipal governments. Sustainability assessment in urban policies becomes in many cases a benchmark exercise where ranking cities is a way to legitimate a government decision or the success of an urban policy. This may be recognized as a tendency and according to Mc Manus (McManus, 2012) it encourages ranking cities through an extensive use of sustainability indexes in comparative urban sustainability studies.

The primacy of cities in planning development and the consequent amount of resources invested on cities represent the actual "mainstream global urbanism". Even if it persistently fails to deliver on its promise of prosperity for all (Sheppard et al., 2013), it still grounds current policies connecting the "smart city" approach with "post-pandemic" and "recovery" claims.

In this global competition process, cities have to pay attention to each other (Da Cunha et al., 2012) and consequently tools like "Cities Rankings" get more importance in urban management and strategic planning. Consequently good urban management practices or good strategic planning are those that allow a city to climb the leaderboard. Those arguments frequently enrich decision makers speeches and goes in the common people debate influencing citizens behaviors and people choices.

Additionally, the primacy of primary cities (the biggest, the richest, the more sustainable), identified as best practices, inspired urban models and scholars in identifying laws and structures ensuring city effectiveness (i.e. sustainable city effect) in a scientific debate where the position of those who deprecates the effort in development large scale urban models (D. B. Lee, 1973) were contraposed to those who invested in modelling cities (Batty, 1997, 2006, 2013; Harris, 1994; Klosterman, 1994) from the rank-size rule.

Against those who were opposed to the simplification of complex reality through the use of indicators to simplify complex phenomena (Bettencourt et al., 2010) and present it in a communicable form (PARKER, 1995) the opposite instance is both a domain for practitioners and politicians but also for scholars who place their complex urban and territorial modelling in an applied perspective.

Our position is intending transdisciplinary as part of a "science-policy interface" that, crossing disciplinary boundaries (Lobo et al., 2020), provides an opportunity to achieve significant progress in integrating the value of ecosystems into governance processes resulting from the synergy of different perspectives and contributions (researcher, policymakers, practitioners, stakeholders). In this direction the role of "interactive communication" appears to be more relevant than specific disciplinary knowledge and indicators that covers complex analysis proposing a synthetic (even undisclosed) meaning may be more effective than detailed descriptions based on structured technical background.

If Ecosystem Services (ES), as a transdisciplinary framework, represent a tool to drive urban and territorial development toward sustainability (BenDor et al., 2017), an ES City Ranking may represents an expressive way to better place this thesis in the political debate achieving priority in the political agenda and building trust among citizens. We furthermore consider an ES Cities Ranking as a tool to enhance the involvement of varied stakeholders in a co-producing knowledge process in order to support decision-making and policies design. We place those arguments in the stream proposed by De Groot et al. (R. S. de Groot et al., 2010b) in terms of challenges regarding the inclusion of ES in integrative landscape planning and decision-making according to the concept of "interactive communication tools".

We acknowledge that the ES approach is gaining an ever-increasing role in policy and legislative frameworks (mostly at the national and supra-national level), however we agree with some authors (Bouwma et al., 2018; Grizzetti et al., 2016; Kistenkas & Bouwma, 2018; McKinley et al., 2018) highlighting the lack of fully explicit use of ES assessments within the planning and the decision-making processes. A further consideration also concerns the inappropriate use of the ES approach to justify an accounting of benefits to humans, without more appropriately considering the scarcity of ecosystem resources and the high rate at which humans are consuming them (Hesslerová et al., 2021).

To this end, in our opinion, research markedly oriented to transdisciplinary, can contribute as a tool for public awareness raising and participation. While maintaining a high attention to the debate on whether ES should be considered as "boundary objects" (Abson et al., 2014; Ainscough et al., 2019; Steger et al., 2018; Turnhout, 2009), stimulating public debate is the first step in paving the way for a bottom-up definition of territorial governance policies and strategies in which environmental performances and ES multifunctionality are properly regarded.

In this paper we consider the main Italian Cities Rankings compared with the one we developed on the basis of ES perspectives and analytics, demonstrating once again (Chapman & Pike, 1992) how those applications bring to heterogeneous results with relevant differences in assessing single city features. Thus, we consider ranking development not as a purely "scientific" approach to measure complex urban dynamics but we recognize its effective communicative mainstream capacity to drive and influence current practices in urban management, involving people towards a transdisciplinary interpretation of local condition, committing individuals, stakeholders and decision makers toward applied sustainability.

The paper is structured as follows: the next chapter illustrates and describes the main Italian City rankings selected to compare the performances of territorial units according to specific analytical purposes, explicitly disclosed by the proponents (mainly national press agencies) of each ranking. After categorizing the scope of each indicator, the assessment scale and the macro sectors of data sources, we describe the methodology and the analytical stages applied to deliver the multifunctionality ES index: the MESLI. The result is a new territorial ranking we compared with previous indicators in the discussion section. Conclusions regard considerations about our ES-based ranking for improving urban planning practices contributing to rebuild our paradigm of how nature matters to people. ES ranking is proposed as a transdisciplinary concept useful in the short term to stimulate public debate on prioritizing ES integration in mainstream policies; in the medium term to integrate of ES values into governance of green deal transition; in the long term to achieve sustainability in term of performance of natural and semi-natural systems against anthropic use of environment, thus contributing to the development of urban sustainability sciences.

Italian City Rankings

Yearly, a number of rankings are published ordering the territorial units according to different multidimensional criteria. They are placed transversally with respect to several aspects of urban quality, ranging from the provision of services to the availability of infrastructure, from the assessment of wealth to environmental performance, from the dynamism of the world of labor to the perception of personal safety, from demographic trends to the variety of cultural opportunities available. Their purpose is comparing different territorial contexts in order to identify elements of competitiveness or criticality, and to provide useful insights for the definition of place-based policies, the design of local development strategies or the effectiveness evaluation of measures implemented in specific sectors.

The purpose of these classifications is to order territorial units on the basis of an index that expresses both a measure of the livability of a place and the performance of administrative capacity. These rankings were developed in the socio-economic context; however over the years the concept of quality of life has significantly evolved, moving from a purely economic measure to a multidimensional assessment.

We identify two criteria for comparing the several rankings proposed at the national level: a categorization based on the relevant features that each rank considers to assess the "quality of life"; the territorial scale at which the rankings are drawn up.

In Italy. the oldest nationwide rankings included only variables related to the income and the economic well-being of the population. Today, they consider the well-being as a multifaceted concept ranging from economic wealth to the services provision, from the environmental quality to demographic trends, from the assessment of criminality to the availability of recreational experiences.

This classifications pursue the aim of identifying the components that contributing to the quality of life and are to be intended as a tool for comparing different territories rather than to deepen the meaning of quality of life. To this first category belong the rankings drawn up by *Italia Oggi* and *Il Sole 24 Ore*, two important economic mastheads.

Equally well-established over the years is the ranking compiled by *Legambiente*, a non-profit environmental organization, which annually draws up a list of Italian provincial capitals on the basis of the degree of sustainability and environmental performance. Its purpose is to assess the extent to which the urban ecosystem is evolving in the direction outlined by the Sustainable Development Goals (SDGs) and, therefore, to evaluate the effectiveness of prescriptions and actions implemented by public administrations. For these reasons, we included the *Legambiente*'s ranking in the “Sustainability and environmental performance” category.

To these official and regularly published national rankings, we added a third category: the policy-derived rank related to the National Strategy for Inner Areas (SNAI). SNAI represents a national policy of development and territorial cohesion aimed at tackling the marginalization and demographic decline occurring in inland areas. Its goal is to develop place-based multi-level governance models by adopting an integrated approach capable of addressing locally identified critical issues and enhancing natural and cultural heritage. To this end, SNAI classifies the national territory on the basis of accessibility to three main kind of services: education, health, mobility. The strategy classifies all the Italian municipalities basing on their role in providing these services. There are five classes identified: “ultra-remote”, “remote”, “intermediate”, “beltway municipalities” and “poles”. In order to obtain a ranking based on this classification, we calculated an indicator for each Province equal to the ratio between “remote” and “ultra-remote” areas and the overall extent of the provincial territory.

With regard to the second criterion we used for classifying the rankings considered, it concerns the territorial scale at which the evaluation is carried out. In particular, *Italia Oggi* and *Il Sole 24 Ore* rankings are computed on a provincial scale which corresponds to NUTS level 3 (Figure 14) according to Eurostat; the Urban Ecosystem performance index is assessed at the urban scale for the Provincial capitals; the SNAI-derived index is assessed at the municipal scale.

In order to facilitate the comparison of rankings, we considered the Provinces as the territorial units of reference.. For this reason, the *Italia Oggi* and *Il Sole 24 Ore* rankings were considered as originally provided; the *Legambiente* ranking was considered as representative of the entire provincial territory.

Table 6 - Summary of the main characteristics of the rankings considered

Authors	**Index**	**Link**	**Categories**	**Territorial Scale**	**Macro-Sectors considered in the cumulative indicator**
ITALIA OGGI	Quality of life	https://www.italiaoggi.it/qualita-vita	Multidimensional derived from a socio-economic category	Provincial	• Business and labour • Environment • Social security • Education, training and human capital • Population • Income and wealth • Crimes and security • Health system • Leisure
Legambiente	Urban ecosystem	https://ecosistemi.legambiente.it/il-progetto/	Sustainability and environmental performance	Urban	• Air • Water • Waste • Mobility • Urban environment • Energy
Il SOLE 24ORE	Quality of life	https://lab24.ilsole24ore.com/qualita-della-vita/	Multidimensional derived from a socio-economic category	Provincial	• Wealth and spending • Business and labour • Demographics and society • Environment and services • Justice and security • Culture and Leisure
National Strategy for Inner Areas (SNAI)	Remoteness index	https://www.agenziacoesione.gov.it/strategia-nazionale-aree-interne/	Policy-derived	Municipal	-

The *Sole 24 Ore*'s ranking is the most long-standing in Italy: in 2019 its 30° edition was published. Its stated purpose is to measure "the performance of the population, businesses and public institutions". In order to capture more aspects related to the perception of the quality of life, on the occasion of its 30° anniversary, the number of indicators overall considered was increased from 42 to 90 still divided into the traditional six thematic macro-categories: Wealth and spending, Business and labour, Demographics and society, Environment and services, Justice and security, and Leisure.

The first group, “Wealth and Spending”, considers average salary and pension values and describes the real estate market. To these were added households' debt values, loan payments and the risk rate of financing credit. “Business and labour” illustrates the dynamism of the world of work, employment/unemployment rates and exports’ value. This category was extended with the youth entrepreneurship index and the percentage of e-commerce companies. The "Demography and society" group describes the population pyramid, the composition of households and the ratio of the population over 65 with respect to residents of school age and working age. The "Environment and Services" class is rather heterogeneous as it includes indicators relating to social and health services (hospital out-migration, paediatricians per thousand inhabitants, general practitioners per thousand inhabitants, social expenditure for minors, the disabled and the elderly) and environmental parameters such as air quality, per capita water consumption and the percentage of waste separate collection. To these was added a Climate Index describing with ten sub-indicators the climatic characteristics of the territory (e.g. solar insolation, extreme events, fog, heat waves). The “Justice and security” class includes statistics on crimes committed and the efficiency of the administration of legal proceedings. The "Culture and leisure" category considers a set of indicators relevant in terms of tourist accommodation and opportunities to enjoy cultural and sports events.

The methodology considers all indicators with the same weight. For each of them, a value between 0 and 1000 is assigned to each Province. The final ranking is obtained by making an arithmetic average of the six macro-sectors classifications.

The second ranking, carried out by *Italia Oggi*, pursues two objectives: to stimulate a debate on the actions to be implemented to promote the growth of welfare at the territorial level; to inform public opinion of the gap between the political guidelines adopted at the national level and the effectiveness of administrative action. For this reason, the methodology adopted over the course of the 21 editions was revised and supplemented in order to better highlight the effects of specific contingencies or following the implementation of sector policies. The structure of *Italia Oggi*'s ranking is characterized by 9 analysis dimensions (Business and Labour; Environment; Crimes and security; Social security; Education, training and human capital; Population; Health system; Leisure; Income and wealth), divided into 16 sub-dimensions and 85 indicators. The first dimension, “Business and Labour”, describes the work environment in terms of employment rates, opportunities for businesses, and the dynamism of the entrepreneurial context. The “Environment” class includes indicators about air quality, use of natural resources (water and energy), waste cycle efficiency and sustainable mobility. The “Crime and Security” group summarizes the main crime data while the “Social Security” class refers to the frequency of fatal or disabling diseases, the frequency of fatal driving accidents and the mortality trend compared to the previous five years. “Education, training and human capital” provides a summary of the population literacy level and the acquired skill bases. The “Population” dimension tracks the demographic trend whereas the “Health system” describes the equipment and infrastructure of the healthcare system. The “Leisure” dimension illustrates the provision of services in the sectors of tourism, accommodation, sport and culture. Finally, the "Income and Wealth" class refers specifically to the dimension of economic development in terms of average wages and debt, patrimonial value, real estate value and purchasing power.

Compared to the first rank published by *Il Sole 24 Ore*, *Italia Oggi* considers an additional dimension: the Social Security. The dimensions 'Environment' and 'Services' are furthermore considered separately.

The third rank, called Urban Ecosystem, is drawn up by *Legambiente* on an annual basis computing statistical data collected on a national scale by both the National Statistics Institute (ISTAT) and by questionnaires designed for municipal administrations. Its aim is to sort Italian urban areas considering the overall environmental performance. A total of 18 indicators divided into 5 macro-sectors are considered. The ranking for each indicator is compiled by linearly scaling the scores obtained by each provincial capital with respect to the city that obtained the best score. The final ranking is obtained by assigning a score of 100 to the provincial capital that achieves at the same time the highest score for all 18 indicators . For all the other cities, the raniking is calculated by a linear scaling down of the scores. The indicators considered are classified into six main macro-sectors: air, water, waste, mobility, urban environment, energy.

The first group includes "Air" quality indicators such as the concentration of particulate matter and ozone. The second group, "Water", considers data on domestic water consumption, dispersion in the distribution system, purification capacity and water scarcity. The "Waste" macro-sector includes indicators significant of both the quantity of waste produced and the efficiency of the collection and treatment system (e.g. the percentage of sorted waste out of the total municipal waste produced; the percentage of inhabitants of the municipality served by home collection). The "Mobility" dimension contains indicators describing the efficiency of the public transport system, transport network safety and active mobility but also the attitude of citizens to car-sharing and bike-sharing. The "Urban environment" cluster illustrates the characteristics of urban green areas (e.g. number of trees per 100 inhabitants and usable green areas in urban areas expressed in m^2/inhabitant). The last macro-sector finally proposes a ranking based on the energy supply from renewable sources.

As previously mentioned, the last considered rank was derived by the National Strategy for Inner Areas. It stems from the need to address problems of marginalization that affects the less accessible areas of the Italian territory. Since the post-World War II, in fact, a large part of the national territory underwent phenomena as: a) depopulation and demographic ageing; b) reduction in employment and in the degree of land use; c) quantitative and qualitative reduction in local supply of public, private and collective services. This marginalization process, however, did not affect the inland areas uniformly: some experienced projects such as landfills, caves or large renewable energy plants that did not generate significant benefits for local communities. Others, on the other hand, developed projects to enhance environmental, cultural and landscape resources or successfully experimented forms of cooperation among municipalities for the production of some basic services. The identification of the inner areas thus starts from a polycentric interpretation of the national territory, characterized by a network of municipalities or aggregations of municipalities (service supply centers) around which areas with different levels of spatial remoteness are distributed.

This classification, therefore, does not derive from demands related to a comparative assessment of the quality of life of different territories. However, we interpret the level of territorial remoteness from the service supply centers as a measure of the quality of life of citizens and their level of social inclusion. The concept of remoteness thus reflects the lack of availability and poor accessibility of services. However, it is also relevant to the lack of governance skills of some local communities in triggering virtuous processes capable of limiting the effect of disadvantage conditions.. On the basis of the time required to reach the service centers, inner areas have been classified into intermediate (20'<t<40'), remote (40'<t<75') and ultra-remote (t>75').

Code	Province	Code	Province	Code	Province	Code	Province	Code	Province	Code	Province	Code	Province
1	Torino	17	Brescia	33	Piacenza	49	Livorno	65	Salerno	81	Trapani	97	Lecco
2	Vercelli	18	Pavia	34	Parma	50	Pisa	66	L'Aquila	82	Palermo	98	Lodi
3	Novara	19	Cremona	35	Reggio nell'Emilia	51	Arezzo	67	Teramo	83	Messina	99	Rimini
4	Cuneo	20	Mantova	36	Modena	52	Siena	68	Pescara	84	Agrigento	100	Prato
5	Asti	21	Bolzano	37	Bologna	53	Grosseto	69	Chieti	85	Caltanissetta	101	Crotone
6	Alessandria	22	Trento	38	Ferrara	54	Perugia	70	Campobasso	86	Enna	102	Vibo Valentia
7	Aosta	23	Verona	39	Ravenna	55	Terni	71	Foggia	87	Catania	103	Verbano-Cusio-Ossola
8	Imperia	24	Vicenza	40	Forlì-Cesena	56	Viterbo	72	Bari	88	Ragusa	108	Monza e della Brianza
9	Savona	25	Belluno	41	Pesaro e Urbino	57	Rieti	73	Taranto	89	Siracusa	109	Fermo
10	Genova	26	Treviso	42	Ancona	58	Roma	74	Brindisi	90	Sassari	110	Barletta-Andria-Trani
11	La Spezia	27	Venezia	43	Macerata	59	Latina	75	Lecce	91	Nuoro	111	Sud Sardegna
12	Varese	28	Padova	44	Ascoli Piceno	60	Frosinone	76	Potenza	92	Cagliari		
13	Como	29	Rovigo	45	Massa Carrara	61	Caserta	77	Matera	93	Pordenone		
14	Sondrio	30	Udine	46	Lucca	62	Benevento	78	Cosenza	94	Isernia		
15	Milano	31	Gorizia	47	Pistoia	63	Napoli	79	Catanzaro	95	Oristano		
16	Bergamo	32	Trieste	48	Firenze	64	Avellino	80	Reggio di Calabria	96	Biella		

N

0 75 150 225 km

Figure 14 – Italian Provinces and territorial districts

Multifunctionality in ES assessment

In the ES perspective, the concept of “multifunctionality” has a broad definition that refers to the joint supply of multiple services, functions and benefits. Its role, the importance of its assessment and how it should be interpreted, depends on the context, on the assessment scale and on the method of evaluation.

For example, agricultural multifunctionality has to be intended as the ability of agro-ecosystems to deliver multiple benefits: food and fiber production as ES provisioning, regulating ES (including, for example, carbon sequestration and freshwaters’ quality regulation) and cultural ES (e.g., preserving the rural landscape’s identitary characteristics) (Wilson, 2007).

From the planning perspective, assessing ES multifunctionality is an integrated approach to investigate land uses patterns and the interaction between ecosystems and the anthropic components in terms of multiple human benefits derived from nature (Queiroz et al., 2015). Thus, ES multifunctionality does not constitutes a planning aim in itself but provides an effective support in evaluating plan choices because:

allows to compare cost-efficient VS spatial-efficient scenarios (Galler et al., 2015a);

expresses an efficiency measure in terms of multiple supplied functions per territorial unit (Ahern, 2011);

provides a cross-cutting and comprehensive assessment of the overall performance of the environmental components that constitute the objects of different sectoral policies.

If we refer to multifunctionality in terms of a synthetic index expressing the capacity to *simultaneously* provide several ES, the degree of multifunctionality depends on different spatial arrangements of ES considered (Mastrangelo et al., 2014) and their mutual interactions (synergies or trade-offs). The information deriving from multifunctionality assessment in planning processes are multiple, depending on the choice of the assessment scale and the methods used for the estimation, and the identification of potential beneficiaries. For this reason, such conceptual framework found several applications in planning practices where ES multifunctionality was applied for different scopes. As part of Green Infrastructures Planning and Management, ES multifunctionality represents a spatial criteria together with “ecological connectivity” and “biodiversity conservation” (Cannas et al., 2018b). This approach regards both the urban (Madureira & Andresen, 2014; Meerow & Newell, 2017; Zhang & Muñoz Ramírez, 2019) and the wider regional scale (Cannas et al., 2018a; García et al., 2020).

Concerning planning processes at the municipal scale, the experience by Salata et al. (Salata et al., 2020) refers to “address sustainability” issues in parcel-based land use regulation by means of a multifunctional index. Specifically, as part of the LIFE SAM4CP project (*Sam4cp - EN - Life project - Soil administration model for community profit*, n.d.), three municipal administrations were involved in a participatory process aimed at defining land management strategies and identifying urban growth boundaries through an aggregated index of multiple ES.

Lastly, the concept of multifunctionality is mentioned in the Municipal Plan of the City of Pordenone (Italy) where is implemented a mechanism to compensate the impacts of territorial transformations with mitigation actions and enhancement of ES (D. La Rosa, 2019b).

In this work, we consider the ES multifunctionality as a measure of potential benefits that are provided to society and representing an ensemble of contributions to human well-being that people derive from the natural structures and processes (Alcamo et al., 2003), i.e. the ES. As already pointed out by Juntti et al. (Juntti et al., 2021), ES are already perceived as related to quality of life and well-being in the urban environment. The capacity to supply multiple ES results in perceived benefits, for example, in relation to human health, social cohesion and in the diversification of rural economic opportunities (Fagerholm et al., 2020; Lafortezza et al., 2013; Tzoulas et al., 2007). Following a social-ecological perspective (Hansen & Pauleit, 2014), the measure of territorial ES multifunctionality supports a comparison between different territorial units and produces a strong communicative representation allowing citizens to perceive ES multifunctionality as a proxy of the quality of life perceived in their living area. Therefore we selected a meaningful indicator for ES multifunctionality considered fairly consistent on various spatial scales (Stürck & Verburg, 2017): the Multiple ES Landscape Index (MESLI).

MESLI is a synthetic index based on the sum of the standardized ES indicators (Shen et al., 2020). Its applicability regards policy making oriented to achieve sustainability performance targets, in our case we adopt it in order to include in a comprehensive picture multiple accurate estimation of single ES development at national scale. Through MESLI we derived a territorial measure referred to the Provincial administrative borders through which we arrange a ranking for Italian territory. In the following section the analytical process is described.

Materials and methods

The Multiple ES Landscape Index (MESLI)

The MESLI index is a synthetic indicator relevant for the joint supply of several ES and significant of the environmental performances of different ecosystems (Manning et al., 2018b). It is thus both representative of the number of ES provided and their intensity (Rodríguez-Loinaz et al., 2015b).

Because ES biophysical assessment implies the comparison among non-comparable quantities, synthetic indices involve normalization of the dataset for each ES considered.

The MESLI index was calculated according to the formula (1):

$$\sum_{i=1}^{n} \frac{Observed\ value_i - Low\ performance\ benchmark_i}{Target - \ Low\ performance\ benchmark_i} \qquad (1)$$

for ES providing a positive contribution to the territorial performance, and according to the formula (2)

$$\sum_{i=1}^{n} \frac{Low\ performance\ benchmark_i - Observed\ value_i}{Low\ performance\ benchmark_i - \ Target} \qquad (2)$$

if the biophysical value constitutes a measure of the failure to provide that ES.

According to the MESLI, all the ES layers were normalized in a 0-1 scale following the “proximity-to-target” methodology where 0 value corresponds to the lowest performance benchmark and the value 1 is significant of ES target fulfillment as defined in a policy goal, biological thresholds or by expert evaluation. When the ES are instead not characterized by well-defined target and low-performance benchmark and further specific data are not provided, the minimum (equal to 0) and the maximum (equal to 1) values were assigned to the minimum and the maximum biophysical assets assumed by the ES considering a time series.

In our case, for each of the ES considered, the following table summarizes the belonging section and class according to the CICES v5.1 classification (Roy Haines-Young & Potschin, 2018b) and the references used as target and low performance benchmark. For details on the methodologies and datasets used, we refer to previous work by the same authors (Angela Pilogallo et al., 2019, 2020; Angela Pilogallo & Scorza, 2021a; Scorza, Pilogallo, Saganeiti, & Murgante, 2020b; Scorza, Pilogallo, Saganeiti, Murgante, et al., 2020a).

Table 1 - List of selected ES with their indicators and low and high performance benchmarks (Min. t. s., Max. t. s.: minimum and maximum value in entire time series data).

Section	Class	Indicators	Methodology	Unit	Low performance benchmarks	Target
Regulation & Maintenance	*Regulation of chemical composition of atmosphere*	Carbon stock	InVEST model	Shades/Ha	0	Max t.s.
		CO_2 Uptake	Equation by Clark et al. 2001 [25,26]	$g/m^2/yr$	Min t.s.	Max t.s.
	Pollination	Pollination Abundance	InVEST model	Index (dimensionless)	0	1
		Pollination Supply	InVEST model	Index (dimensionless)	0	1
	Maintaining nursery populations and habitats	Habitat Quality	InVEST model	Index (dimensionless)	0	1
		Habitat Degradation	InVEST model	Index (dimensionless)	0	Max t.s.
	Control of erosion rates	Erosion Rates	InVEST model	Shades/Ha	0	Max t.s.
	Regulation of the chemical condition of freshwaters	Effective nutrients retention	InVEST model	Index (dimensionless)	0	1
Provisioning	*Cultivated terrestrial plants grown for nutritional purposes*	Crop production	InVEST model	q/Ha	0	Max t.s.
	Ground (and subsurface) water for drinking	Water Yield	Equation by Budyko (Marlatt et al., 1975)	mm/yr/Ha	0	Max t.s.

By its own definition the MESLI index calculated for *n* ES, ranges between 0 and *n*: the higher the value, the more the system performs well in terms of multifunctionality.

For all the considered ES, equation (1) was used except for the “Erosion Rates”. Its biophysical value is indeed proportional to the rate of erosive phenomena and the loss of fertile soil so the second equation was computed. The methodology provides a spatially continuous distribution of the MESLI index, resulting in a raster that keeps the resolution of the Corine Land Cover (100 m). As can be seen in **Errore. L'origine riferimento non è stata trovata.**Figure 15, the MESLI ranges between 0.6 and 5.8. The highest values are spatially distributed in the North-Eastern territorial district and along the Apennine Chain reliefs. High values are also observed in the Province of Foggia, in the Province of Messina, in the north-eastern area of the Sicily Region and in the eastern area of the Sardinia Island. On the other hand, the areas that express a lesser ecosystem multifunctionality correspond to the Po Valley, especially in the north side of the river, and a large portion of the territory of the Sicily Region.

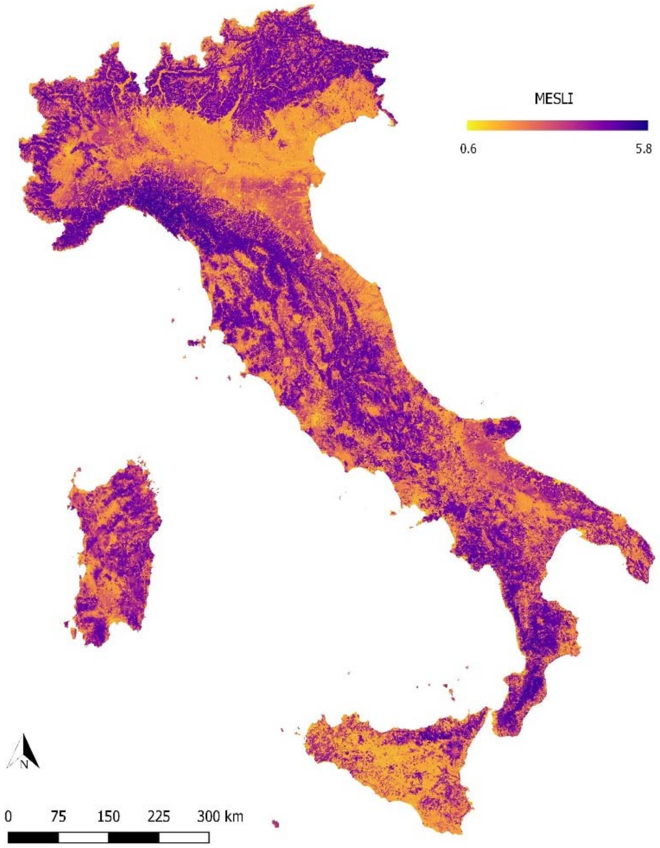

Figure 15 - Spatial distribution of the MESLI Index across the Italian territory

In order to carry out a comparison between the territorial performance measured with the MESLI and those emerging from the rankings, the data were aggregated considering the administrative boundaries of the Italian provinces, considered as the reference territorial unit. In the GIS environment, through zonal statistics analysis, the mean value of the data distribution was assigned to each province.

As can be seen from Figure 16, a rather varied representation of the Italian territory emerges and no relevant correspondence arises with the belonging of the Provinces to specific territorial districts. Very low average values spatially aggregate in the Provinces of the northern part of the Po Valley and in most of the Provinces of the Sicily Region. On the other hand, the value of the Apennine areas emerges, with average values of ecosystem multifunctionality that vary from high to very high, with a few exceptions in the provinces of Central-Southern Italy.

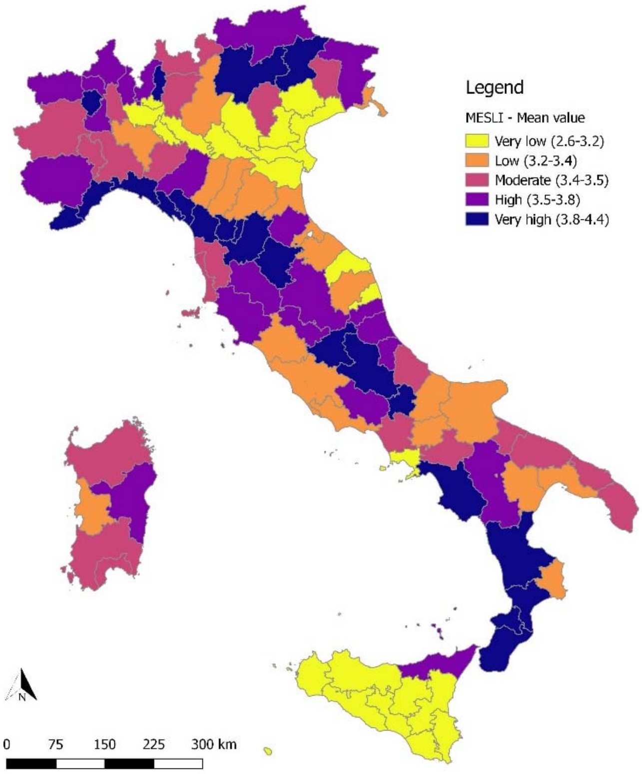

Figure 16 – MESLI mean value per Province

Based on the average values, we then assigned to each province the order number within the ranking representative of ecosystem multifunctionality (Table 7).

Table 7 - Ranking of the Italian Provinces representative of ecosystem multifunctionality

Province	Ranking	Province	Ranking	Province	Ranking
La Spezia	1	Pescara	37	Foggia	73
Massa Carrara	2	Cuneo	38	Macerata	74
Genova	3	Perugia	39	Crotone	75
Lucca	4	Teramo	40	Benevento	76
Savona	5	Vercelli	41	Matera	77
Imperia	6	Messina	42	Brescia	78
Pistoia	7	Frosinone	43	Trieste	79
Belluno	8	Torino	44	Latina	80
Arezzo	9	Piacenza	45	Ravenna	81
Rieti	10	Cagliari	46	Rimini	82
Catanzaro	11	Sud Sardegna	47	Campobasso	83
Prato	12	Sassari	48	Pavia	84
Cosenza	13	Bergamo	49	Gorizia	85
Trento	14	Sondrio	50	Siracusa	86
L'Aquila	15	Caserta	51	Catania	87
Vibo Valentia	16	Alessandria	52	Treviso	88
Firenze	17	Novara	53	Ancona	89
Reggio di Calabria	18	Livorno	54	Ferrara	90
Isernia	19	Pordenone	55	Trapani	91
Lecco	20	Chieti	56	Verona	92

Biella	21	Avellino	57	Fermo	93
Salerno	22	Bari	58	Napoli	94
Como	23	Asti	59	Ragusa	95
Forli'-Cesena	24	Barletta-Andria-Trani	60	Palermo	96
Verbano-Cusio-Ossola	25	Vicenza	61	Agrigento	97
Parma	26	Lecce	62	Enna	98
Bolzano	27	Pisa	63	Monza e della Brianza	99
Potenza	28	Brindisi	64	Lodi	100
Nuoro	29	Bologna	65	Cremona	101
Varese	30	Taranto	66	Milano	102
Udine	31	Oristano	67	Mantova	103
Terni	32	Pesaro e Urbino	68	Caltanissetta	104
Ascoli Piceno	33	Viterbo	69	Padova	105
Aosta	34	Reggio nell'Emilia	70	Rovigo	106
Grosseto	35	Roma	71	Venezia	107
Siena	36	Modena	72		

Results and discussion

As described in the previous sections, the rankings analyzed arise with different purposes and therefore consider different dimensions (or macro-sectors) for comparing performance between territorial units. Because of the importance of geographical component, we find it useful to discuss the results starting with the spatial representation.

All the rankings considered may be affected by territorial policies implemented at different scales on specific intervention sectors (i.e. mobility; transport infrastructure; etc.). Within the different classifications, the sector is described in terms of indicators that can refer to different features included in a sectorial policy. If we tackle sustainable mobility we may have: incentives provided at a national level (e.g. incentives for the increase in electric mobility, which are computed in the *Italia Oggi*'s classification>"Electric and hybrid vehicles on the total number of vehicles in circulation"), the stock of public transport at regional scale defined in the Regional Transport Plan (for example with reference to the indicator "Public transport offer" which influences the *Sole 24 Ore* Index); or at the urban scale with, the evaluation of the per capita extent of pedestrian islands (this contributes to the *Legambiente*'s index).

In order to aid comparison, the Italian provinces have been classified on the basis of their position in the selected "Cities Ranking". In the maps below (Figure **17**), the colors corresponds to three classes: "high" if a province belongs to the first 36 positions, "medium" if it is included between 37 and 72, "low" if belongs to the lower part of the distribution (from 72 to 107).

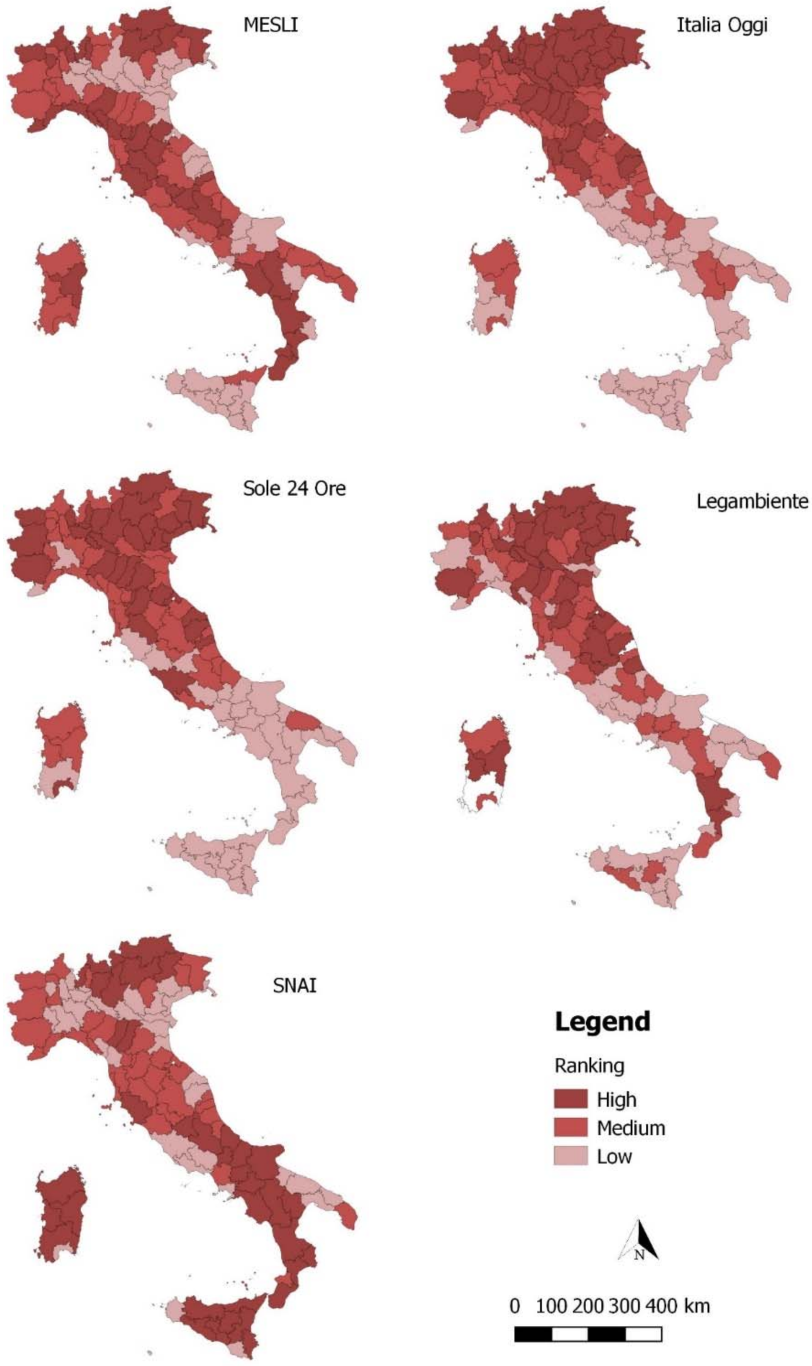

Figure 17 – Comparison between the classifications of the Italian Provinces on the basis of the considered rankings

By the comparisons between selected "Cities Ranking" it is possible to identify that some areas (the provinces in the northeastern district: Trento, Bolzano) holds high positions in all the considered rankings. These territories are characterized by a significant presence of natural and semi-natural areas that provide a high level of ecosystem multifunctionality (MESLI), but also by good systems of territorial governance that while preserving the environmental components, supported socio-economic development (*Italia Oggi* and *Sole 24 Ore*) and guaranteed accessibility to services despite the presence of remote and ultra-remote areas (SNAI).

On the other hand, some provinces of the Sicily Region (Ragusa and Trapani) hold the last positions in all the considered rankings, including the SNAI ranking that assesses the relative extent of the areas farthest from the service centers.

Further considerations arise in reference to the area corresponding to the Po Valley (Provinces of Alessandria, Varese, Novara, Pavia, Milano, Lecco, Monza e Brianza, Lodi, Cremona, Mantova, Verona, Rovigo, Padova, Ferrara, Bologna, Modena, Reggio nell' Emilia, Parma e Piacenza) characterized by a high degree of anthropization, the widespread presence of relevant productive and industrial districts and the prevailing intensive agricultural contexts.

The degree of ecosystem multifunctionality (MESLI) varies from "low", for territories overlooking the river and therefore generally more flat, to "medium" in the case of provinces that include part of the mountain areas of the northern Apennines. The *Sole 24 Ore* and *Italia Oggi*'s rankings express a level of well-being, quality of life and general development between high and medium. On the other hand, there is greater spatial variability in the *Legambiente* index, which is more affected by environmental policies implemented at the local level. Even in this area, there is not a full correspondence between the percentage of areas defined as "remote" and "ultra-remote" and ecosystem multifunctionality as measured through the MESLI.

Further reflections at the national level emerge from a comparison of the area (Figure 18) and population (Figure 19) percentages ranking "high" (dark red), "medium" (red), and "low" (light red) with respect to each classification.

On a territorial level emerges that the performances are very similar with regard to *Italia Oggi* and *Il Sole 24 Ore*. Concerning the highest class, even MESLI and *Legambiente* assign a good score to areas not much higher than the first two rankings. On the other hand, the *SNAI*-based classification is the one that assigns a higher ranking to the largest percentage of land area.

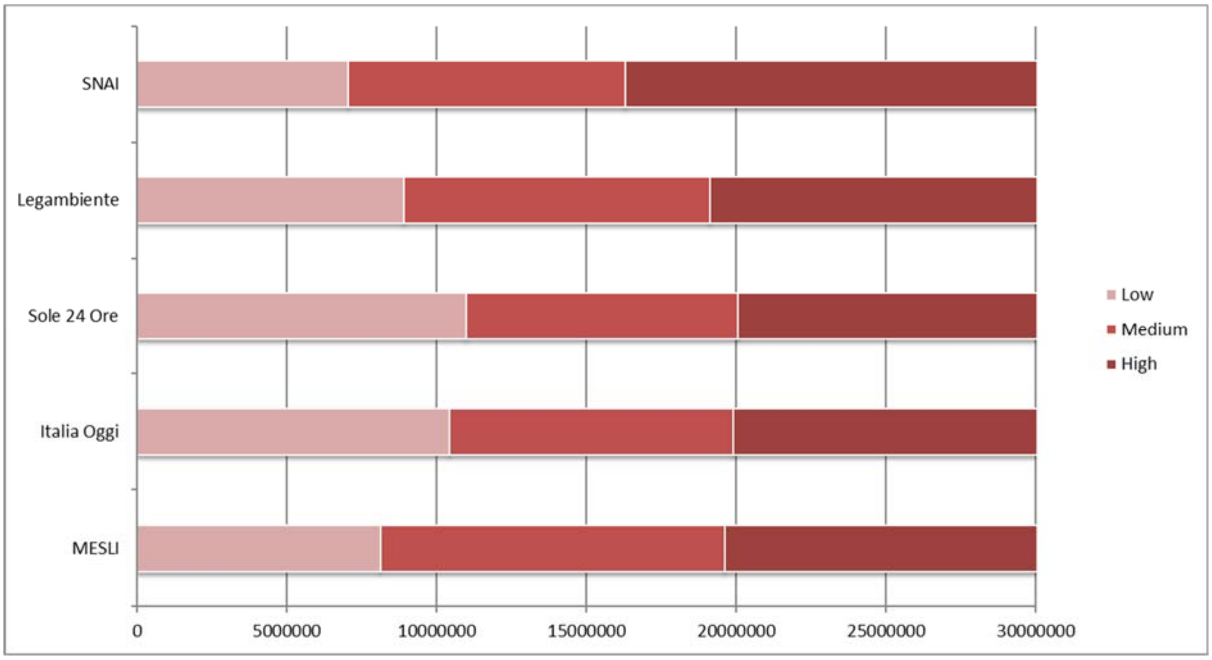

Figure 18 – Area extent included in the three classes (low, medium, high) according to all indicators considered

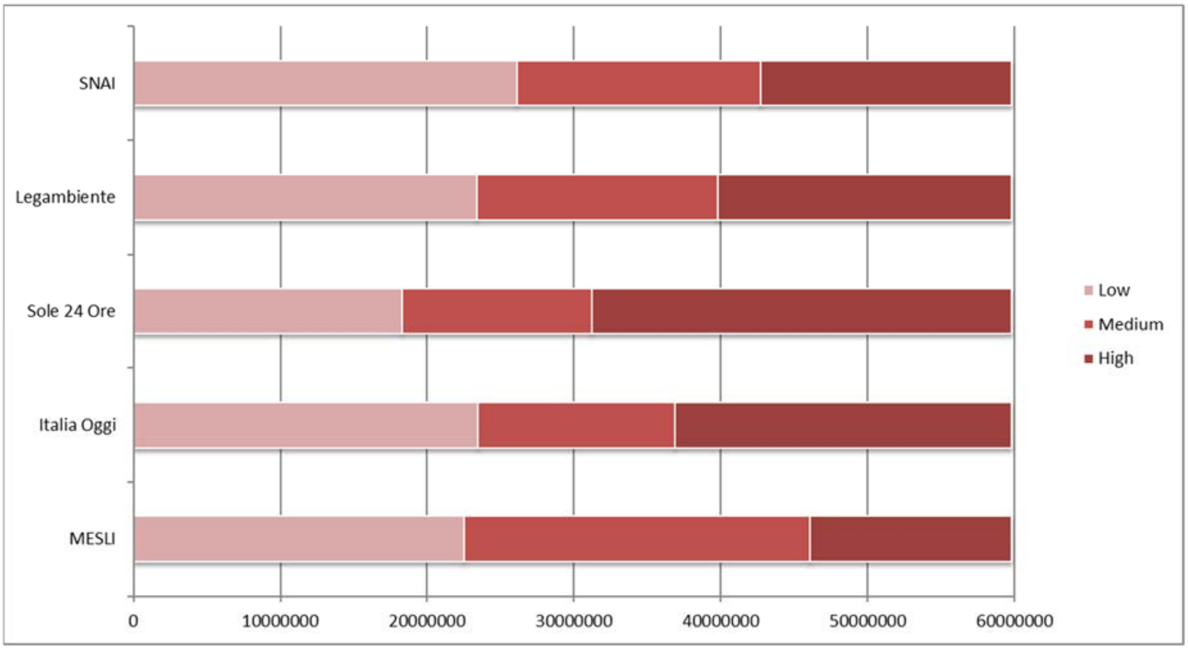

Figure 19 - Population included in the three classes (low, medium, high) according to all indicators considered

In comparison, demographic dimension (Figure 19), expresses greater variability among rankings. As can be seen in fact, MESLI is the index that rewards the least populated Provinces. About 14 million people, or 23% of the national population, reside in the Provinces in the top 36 positions. The percentages of the population classified in the intermediate range (39% of the national population) and in the low range (38% of the national population) are instead comparable.

Not very dissimilar is the division into classes according to *SNAI*. According to the percentages of remoteness and marginalization, the 44% of the population reside in territories that are in the lower part of the ranking. The percentages of the population in the middle and upper part of the ranking are comparable, being 28% and 29% respectively.

On the other hand, the *Sole 24 Ore* classification gives considerable weight to population. In fact, the best-ranked Provinces are inhabited by around 48% of the national population (over 28 million inhabitants).

The joint observation of Figure 18 and Figure 19 confirms the target of the SNAI, which is focused on territories characterized by low population density and depopulation phenomena, also due to poor accessibility to services. The "high" class according to the SNAI corresponds, with the same number of provinces, to a territory covering 46% of the national area.

A relevant way to compare territorial units ranking is to analyze the scatter distribution pair-wise with MESLI. In the following diagrams, this comparison is proposed showing also the classification of provinces per territorial districts (see colors in Figure 14). In this way it is possible to highlight how territorial differences are caught by each rank.

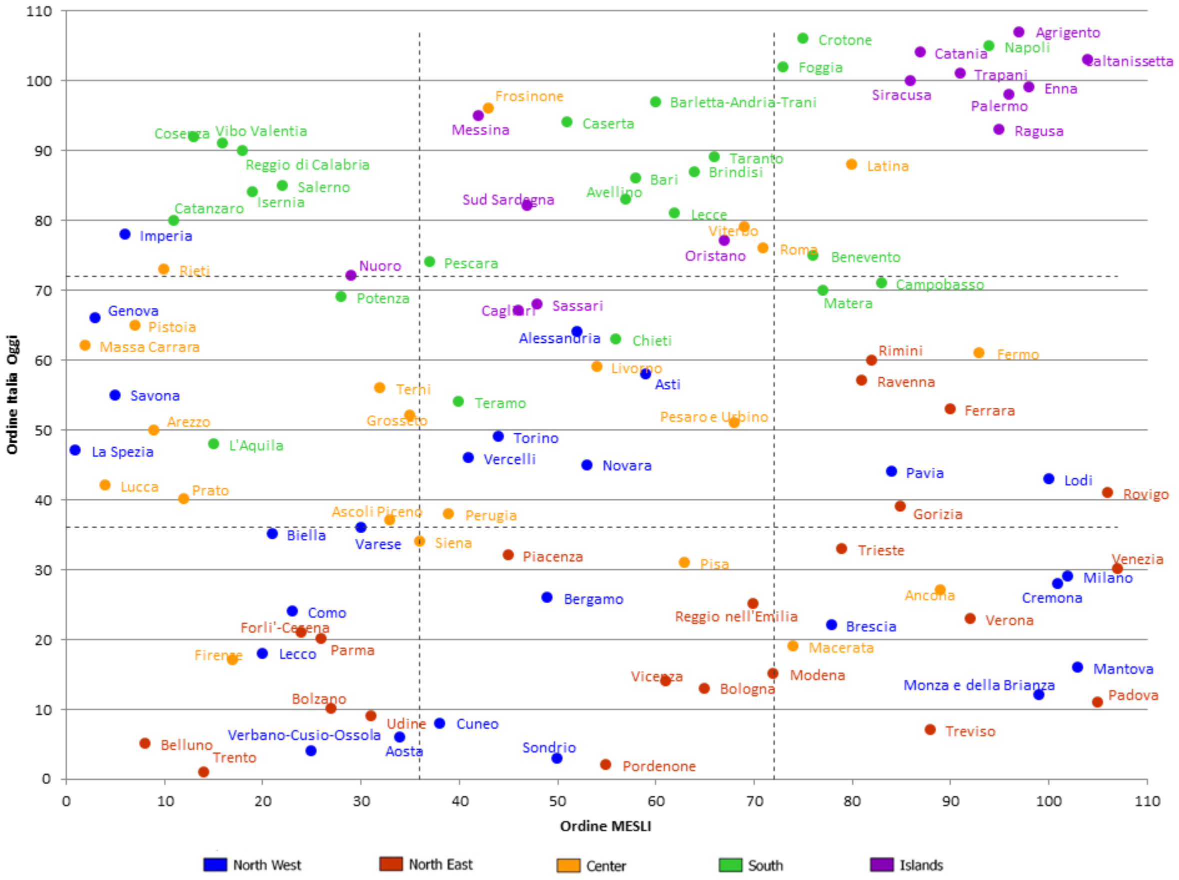

Figure 20 - Comparison between *Italia Oggi* 's and MESLI indexes

An analysis of the distribution shows that the *Italia Oggi*'s ranking, which includes an assessment of economic well-being and the prosperity of the business environment, rewards northern Italy. In fact, the top ten provinces in the ranking are Trento, Pordenone, Sondrio, Verbano-Cusio-Ossola, Belluno, Aosta, Treviso, Cuneo, Udine and Bolzano, all of which belong to the northern districts.

The average population of the provinces ranked within the top ten positions is about 405,000 inhabitants, lower than the average population of the Italian provinces equal to about 560,000 inhabitants.

The first metropolitan city in the ranking of *Italia Oggi* is Bologna (1,017,551 inhabitants) in 13rd place. So, according to this ranking, the territorial performance level is higher in medium-sized Provinces.

From the analysis of **Errore. L'origine riferimento non è stata trovata.**, it emerges that the *Italia Oggi*'s ranking has a strong geographical component: in fact, in the first positions there is a majority of provinces in Northern Italy while provinces in the South and on the Islands prevail in the last positions. This is not the case for MESLI, whose top positions are occupied by Provinces belonging to the entire national territory.

The Metropolitan Cities of Florence in the upper part of the ranking, Turin in the intermediate part, and Naples, Rome and Palermo in the lower part are also in the same position according the two classifications.

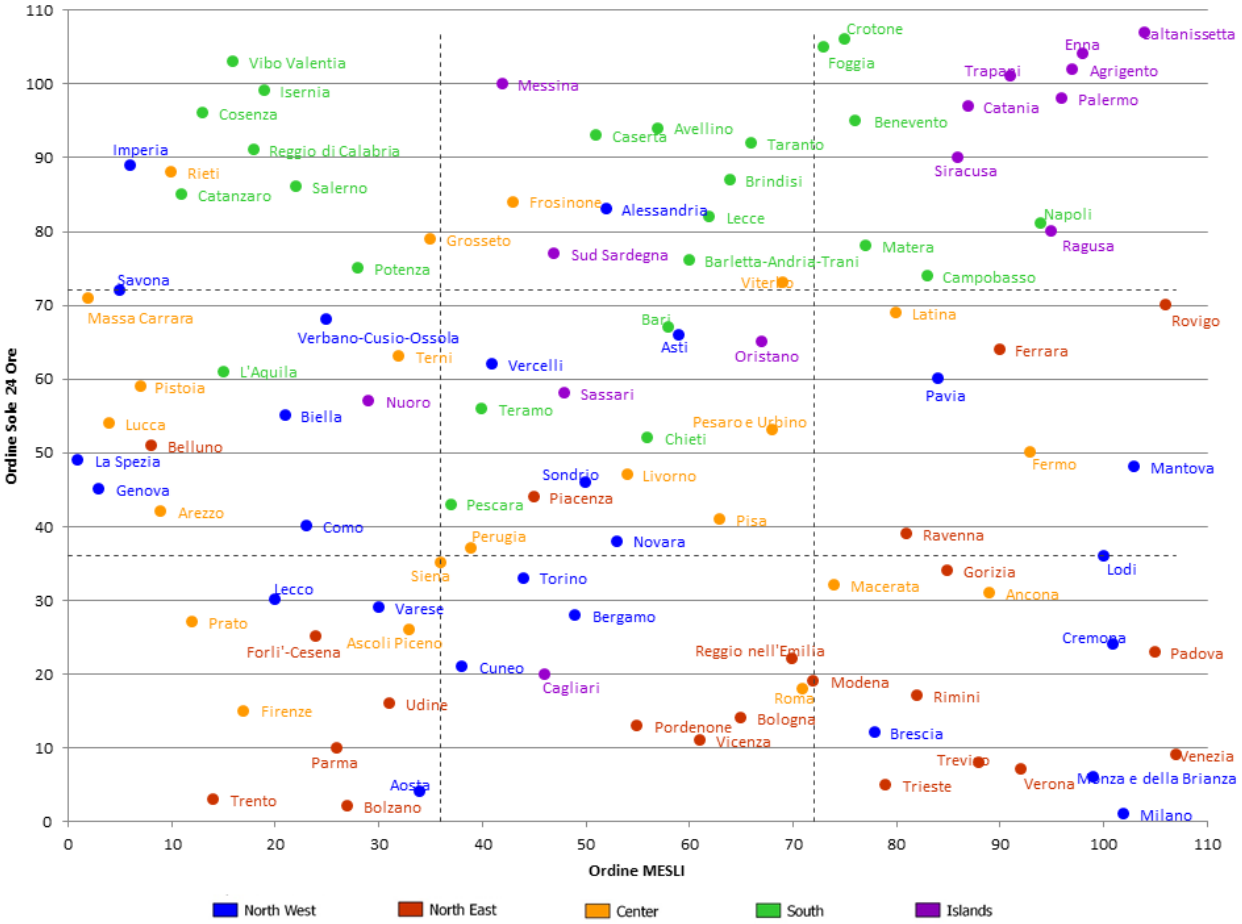

Figure 21 – Comparison between Sole 24 ore's and MESLI indexes

In the top ten positions in the *Sole 24 Ore*'s ranking, the Provinces of Northern Italy still prevail with Milano in the first place. The Province of Florence is once again first among the provinces in the center of Italy. Cagliari, in 20th place, is the first among the provinces of the Islands while we can find the first province of the district of Southern Italy almost in the middle of the ranking.

The last ten positions refer to Provinces of the Peninsular Southern Italy (Isernia, Vibo Valentia, Foggia and Crotone) and the Island of Sicily. In last place lays the Province of Caltanissetta.

With the exception of Milan, characterized by a resident population of over 3,200,000 inhabitants, the average size of the Provinces classified within the top ten places and with an average population of about 601,000 inhabitants grows, ranging from about 100,000 inhabitants of Aosta to over 920,000 inhabitants of Verona.

The geographical component of the *Sole 24 Ore* ranking is less pronounced than in the *Italia Oggi* ranking. The Provinces of the North-Eastern district still prevail in the first half and the Provinces of Southern Italy and the Islands in the second half. It is precisely the Provinces in the Sicily region that show the greatest consistency between the MESLI and *Sole 24 Ore* rankings.

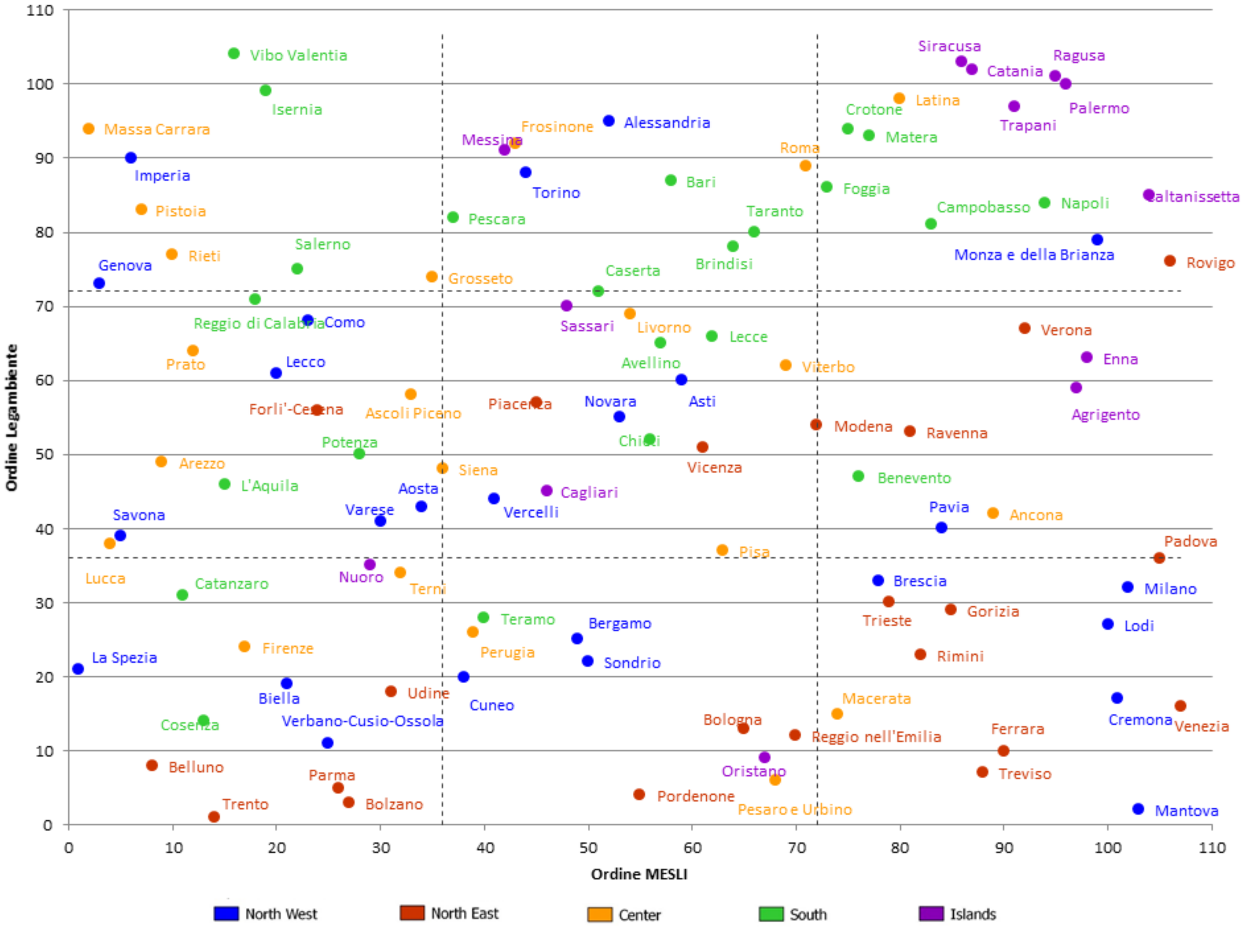

Figure 22 – Comparison between *Legambiente*'s and MESLI indexes

Legambiente's ranking rewards medium-sized cities (on average about 420,000 inhabitants) with Trento leading the ranking, followed by Provinces of the North East district, the center and the Islands.

Although the Provinces of Fermo, BAT and South Sardinia are not included in the ranking, the tendency of the Southern Provinces and Islands to occupy the lowest positions is confirmed.

The Figure 22, which represents a comparison between the *Legambiente* and MESLI rankings, shows no correspondence between the positions in the rankings and the geographical location of the Provinces. There is also no significant correspondence with regard to the population of the Provinces. For example, Florence, a metropolitan city with almost a million inhabitants, and Biella, with fewer than 200,000 inhabitants, are in the top third of both rankings.

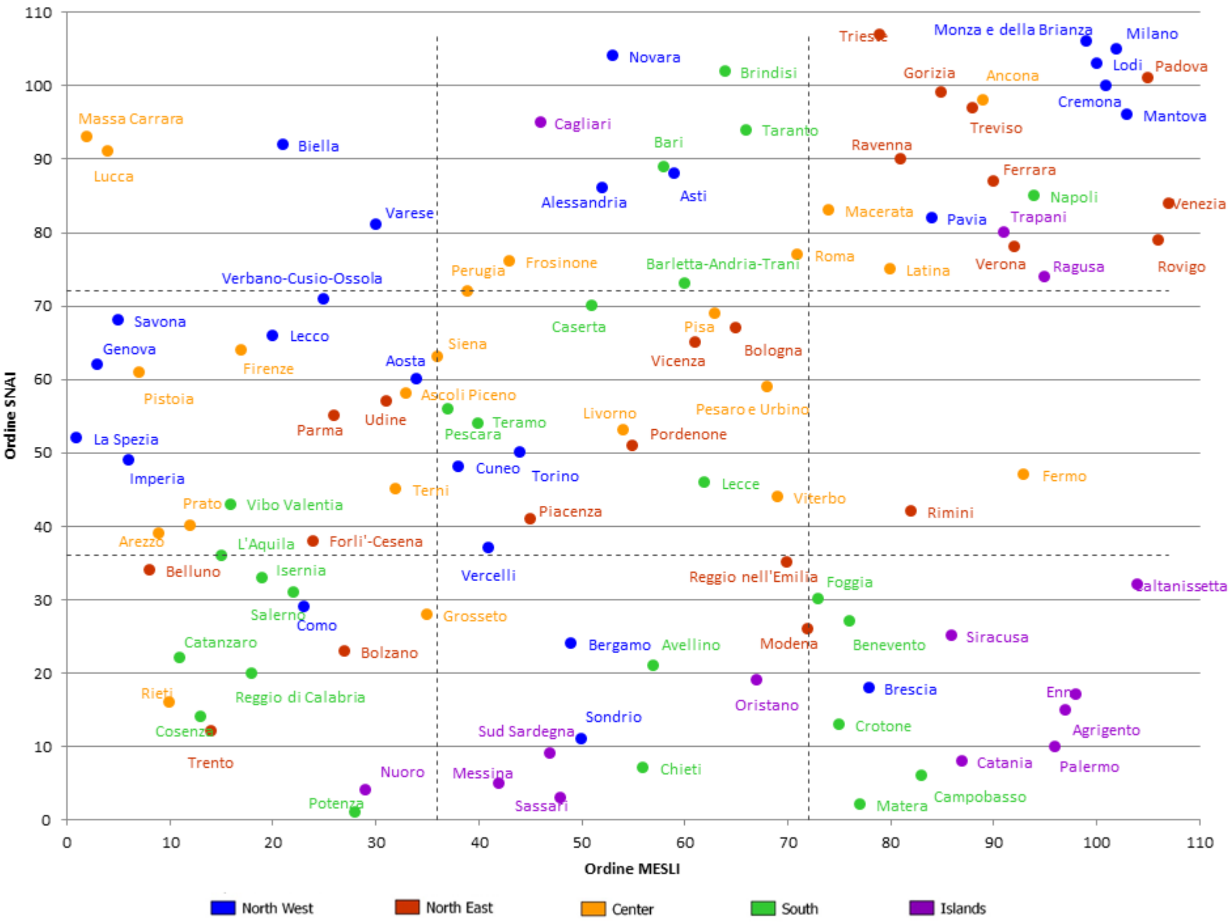

Figure 23 – Comparison between SNAI - derived and MESLI indexes

The ranking derived from the SNAI classification, overturns the previous ones and advances in the first places Provinces of the Southern district, Potenza and Matera, and of the Islands (Sassari).

In the last ten positions the Northern Provinces prevail with Trieste (N-E distribution), holding the last position. In the last three positions also Milan, the second most inhabited province in Italy.

The SNAI ranking is characterized by the presence of certain geographical matches. At the top of the ranking are indeed a large number of Provinces belonging to the North-Eastern District and most of the Provinces of Southern Italy and the Islands.

Conclusions

"Cities Ranking" constitutes a useful tool in urban and regional planning for influencing policies and investments' programs towards sustainability issues. We recognize its communication potential and its capability to act as an awareness raising tool in order to stimulate a public debate about the multiple relations between ES and well-being.

Although we share the position of Braat and de Groot (Braat & de Groot, 2012) about the need to make the ES framework fully integrated into decision-making, in the governance processes and in policy design, we affirm that their *operationalization* (Stępniewska, 2016) requires further analysis by the scientific community and greater public support in legitimizing protection and conservation policies.

We explore the hypothesis of paving the way for a bottom-up definition of ES-integrated governance processes by provoking society to recognize the ES value (Ehrlich & Pringle, 2008) and thus driving greater societal demand toward effective sustainable territorial management. Its part of transdisciplinary approach intended as a dynamic process (Siew & Döll, 2012) that contributes to the knowledge building and exchange among researcher, decision-maker and stakeholders.

Thus, pursuing this transdisciplinary approach means setting goals at different time frames:

in the short term: to enhance the policy-science interface by improving communication in order to stimulate public debate and foster co-design of policy objectives;

in the med-term: to integrate ES values into governance of green deal transition by promoting a culture of shared multi-level responsibility;

in the long term: to improve sustainability performance by integrating the ES framework into the territorial governance processes.

The proposed comparison of the different rankings analyzed highlights the multifaceted nature of the concepts of performance. Each ranking is in fact influenced primarily by the choice of macro-sectors that contribute positively or negatively to defining the concept of performance. This concept evolved over time, moving away from a strictly proportionality with the economic dimension and, progressively, assuming an multidimensional nature accounting for environmental, and social issues. This fits better with the instance to capture the concept of complexity in planning even simplified to the operational pair-wise comparisons where a territorial unit performs better than others. Through this approach the "Cities Ranking" becomes expressive of a relative performance based assessment where no information about the gaps between cities is reported, but the relative position in the rank stimulates territorial competition according to sustainability issues and involves in the debate a greater diversity of people (Tozer et al., 2020).

This evolution has, for example, led to the decision by *Il Sole 24 Ore* to integrate in the ranking the "Climate Index" that provides a way to monitor the territorial performance in relation to climate change actually perceived as one of the most important challenges of the contemporary age. This shows a growing interest even by non-experts in the themes of sustainability, the value of natural components and the integration between human and environmental components.

On the other hand, the extent to which these issues play a role in the rankings evaluation is not sufficient in orienting governance processes towards sustainability. As highlighted by Gomez (Gomez, 2017), following a Cities Ranking classification, the ambition of one city to become the best (or at least to improve its position in the ranking) may interferes with dynamics of development and competitiveness characteristics that necessarily must take account of the carrying capacity of ecosystems. It's the case of many cyclable road that often are realized in the urban context out of any mobility vision but only to account for a minimum amount of kms that influence as a key indicator the position of a city in a specific Cities Ranking classification. In other words a ingle index cannot be representative of the sustainability of a complex urban context.

In light of this, we propose an alternative ranking based on the concept of ecosystem multifunctionality and derived on the basis of a spatially explicit assessment of a relevant set of ES. The purposes are to provide a valid argument for comparing spatial units in terms of ecosystems' multifunctionality as a benchmark of territorial performance and to propose our ES Cities Ranking as a tool to reinforce the co-producing knowledge process involving several kinds of stakeholders in decision-making and policies design.

As discussed in the previous section, the MESLI ES ranking is not comparable with popular Cities Ranking in Italy. This is an expected evidence according to the fact that the input information derives from a specific assessment of eco-environmental territorial features prevailing on socio-economical ones.

It is encouraging to see that some territorial units (e.g. the Provinces of Trento and Bolzano) hold high positions both in our MESLI ES ranking and in the traditional ones. Those area may be considered as national excellences for the level of quality of life. Therefore our ecosystems-centered evaluation is consistent with those grounded on economic and social dimensions.

This allows us to propose our ES ranking as an alternative way to classify territorial units in Italy, highlighting different values and pushing ES thinking in urban and territorial management.

Some limitations of the proposed "Cities Ranking" regards: the need to extend the range of input variables in order to enrich the explanatory potential of the classification compared with urban complexity; to opportunity to better define the significative weights for each variables; to reinforce the significance of spatial relations (through proper techniques like: Spatial Autocorrelation, GWR, Hot-Spot Analysis) between areas contributing to the index measurement.

Finally we believe to support the idea (Liu et al., 2010) that the concept of multi-ecosystem performance is not in opposition to the economic and social development. It represents a complementary performance of a territorial system where the sustainability concept is applied over the three dimensions: environmental, economic and social.

5. Ecosystem Services Multifunctionality: an analytical framework to support sustainable spatial planning in Italy

Abstract

At different levels of territorial governance, there is a growing need for tools to support policy-making oriented towards sustainable planning. The Ecosystem Services (ES) methodological framework represents a structured dimension to develop tools for the assessment of environmental performances and for the evaluation of territorial transformations linked to development needs. In particular, we propose an analytical framework applied to the Italian National context based on the ES multifunctionality approach, to be intended as the opportunity to consider the joint provision of multiple ES. The methodology defines a spatial model based on three aggregate indices (abundance, diversity and richness) assessed considering the Provinces as reference territorial units. Derived from ecological disciplines, these three dimensions of ES multifunctionality describe the variability with which territorial units deliver multiple services for community well-being and support the analysis of the relationships between the anthropic components of territorial systems and the ecosystems' multifunctionality. The evaluation of how the three indices' spatial distribution varied as a result of land use changes in the period 2000-2018 allows to highlight peculiar aspects of territorial units useful to improve the knowledge framework in the perspective of sustainable planning. The results highlight its potential to sup-port decision-making processes and formulate recommendations for sustainable spatial planning.

Keywords: Ecosystem Services (ES), ES Multifunctionality, Sustainable spatial planning, Decision Support System (DSS)

Introduction

Current issues for urban studies are focused on implementing sustainable principles and addressing spatial demands related to the needs of modern society, maintaining environmental quality, protecting biodiversity and the increasingly urgent issues of climate change adaptation and mitigation (Angela Pilogallo & Scorza, 2021b).

These issues globally depend on the unsolved conflict between the anthropic systems and environmental components (Nelson et al., 2010). The need for tools to support policy-making oriented to sustainable planning arises at several levels of governance. In this regard, the Ecosystem Services (ES) approach represents a structured dimension where to develop new effective tools for the assessment of environmental performances (Angela Pilogallo & Scorza, 2021a).

More specifically, the ES multifunctionality approach (Sabrina Lai et al., 2018a; Sabrina Lai & Leone, 2017) , intended as the opportunity of computing the joint supply of multiple ES, is promising. Recently in fact, ES multifunctionality is gaining interest among planners (Artmann, 2014; Dendoncker et al., 2013; Hansen et al., 2015; Primmer & Furman, 2012) because it allows to make the three principles of rational planning (Las Casas & Scorza, 2016a) explicit and operative: equitable access to opportunities and services for people, natural resources’ use efficiency (Gómez-Baggethun & Barton, 2013a) and sustainability (R. De Groot, 2006; Dendoncker et al., 2013; Selman, 2009). It supports, in fact, a renewal in the evaluation of land use changes processes more oriented to the assessment of systemic performances than to estimate specific variable depending on territorial transformations (i.e. land take). It also contributes to the construction of an integrated knowledge system that offers the decision-maker the opportunity to relate appropriately planning tools, the different environmental components and the different strategic development alternatives.

In this respect, there is a growing body of work in the scientific literature that refers to the concept of ES multifunctionality to account synergies and trade-offs (Haase et al., 2012a; Spyra et al., 2020), to tackle the challenge of fair distribution of costs and benefits by different stakeholders (Galler et al., 2015b), to compare scenarios in a frame of rationality and efficiency (Galler et al., 2016b; Hashimoto et al., 2019), to enhance coherence between context-based measures and global instances (Baró et al., 2017; Peña et al., 2018; Scorza, Pilogallo, Saganeiti, Murgante, et al., 2020b).

The aim of this work is to provide an interpretative model of the land use change phenomena based on ES multifunctionality. As expressed by the same authors in a previous work [22, submitted], ES multifunctionality constitutes an innovative and comprehensive way to analyze and interpret different land use patterns, considering the further territorial features linked to the fragmentation of urban settlements (L. Saganeiti et al., 2018) and the multiple facets of human well-being (Queiroz et al., 2015; Rodríguez-Loinaz et al., 2015a). A deeper insight into the spatial distribution of ES multifunctionality could indeed underpin the prediction of how targeted policies or spatial transformations might affect ecosystem delivery and the following capacity of ecosystems to meet multiple human demands.

This model was applied to Italy as case study. The minimum statistical units ES multifunctionality appraisal are the Provinces, that represent the NUTS 3 EU statistical units. The input data related to the land use changes occurred in the time period considered (2000-20018) come from the CORINE Land Cover (CLC) maps, that also represent the core information layers for the spatial assessment of the ES considered. These features makes the analytical approach transferable to other UE countries in order to compare results and characterizing trends. Within the wide variety of conceptualizations and methods (Mastrangelo et al., 2014) available in the literature, we chose to express ES multifunctionality in terms integrated indices.

Aggregate indices are a useful method for effectively representing the synthesis of complex dynamics related to the capacity of ecosystems to provide multiple services useful for human well-being. They are therefore recognized as having great communicative potential, even for non-expert stakeholders and decision-makers. Several authors also highlight their role as tools for increasing public awareness of sustainability issues (Jiang, 2018) and for making an immediate comparison between different territorial units on the basis of their environmental performance (Angela Pilogallo et al., 2021).

In the context of planning practice, Staiano et al. (Staiano et al., 2021) outline that aggregate indexes can support several steps of the planning process, from the context analysis, to the comparison of development scenarios, up to the monitoring of the effectiveness of different environmental policies. Finally, other authors (Karjalainen et al., 2013; Meerow & Newell, 2017; Plieninger et al., 2013), in order to improve the degree of stakeholder involvement in participatory decision-making processes, propose an integration of multifunctionality ES and multi-criteria analysis. This makes it possible to assign a weight to the needs expressed by stakeholders, which varies according to their actual demand.

As the provision of ecosystem services depends on a mix of environmental (including land use pattern and characteristics of urbanization processes) and socio-economic (including implementation of conservation policies and management of transformation processes) factors, at the national scale we find it useful to provide a joined-up reading of transformation phenomena and consequent changes in different dimensions of ES multifunctionality, as described by Holting et al. (Hölting, Jacobs, et al., 2019). They argue that borrowing the concepts of abundance, diversity and richness from the ecological disciplines in the ES framework allows the assessment of multifunctionality across scales, differentiating the territorial units that provide ES with the greatest intensity (abundance), that contribute most to the maintenance of national multifunctionality (richness), or that provide the greatest ES variety (diversity). This contributes to a better understanding of the effects of spatial transformations and land use changes in terms of supply capacity of multiple ES (Hasan et al., 2020). Analyses related to the monitoring of land use and urbanization processes are currently limited to the perspective of increasing artificial surfaces. However, several authors highlight the importance of better characterizing these processes e.g. in terms of spatial fragmentation (Fiorini et al., 2018; Romano, Fiorini, et al., 2017; Lucia Saganeiti et al., 2018), social (Manganelli et al., 2020) and/or environmental costs (Danish et al., 2019; D. La Rosa & Pappalardo, 2020; Turkelboom et al., 2018). Extending the classification by Holting et al., this research defines a spatial model to assess these three indexes (that in our view represents the three dimensions of ES multifunctionality) deriving from ecological disciplines to characterize the ES multifunctionality of the case study area. The novelty of the research therefore lies in the integration of indices formulated in the field of ecology and the ES framework in order to obtain a synthetic spatial representation of the complex dynamics underlying ES multifunctionality, able to support sustainable planning thinking and to inform thoroughly decision-making processes concerning territorial governance.

The analysis of the spatial distribution of the three indices allows us to detect critical issues in terms of ES multifunctionality in areas characterized by a high degree of anthropization, the presence of a dense network of transport infrastructure and management models of agricultural areas marked by intense agricultural systems (Murgante et al., 2020; Murgante, Balletto, et al., 2021).

On the other hand, the role of mountain and inland areas emerges as hotspots of ES provision and presidium of multifunctionality relevant to the entire national context, confirming what found in previous work (Angela Pilogallo & Scorza, 2021a, 2021b): the role of natural area as specialized provider for multiple ES.

Furthermore, the analysis of variations allows us to differentiate the effects of urbanization processes on the three indices.

The paper is structured in four parts: the description of the study area with particular reference to the dynamics of land use change and urbanization occurred in the twenty years examined; the description of the spatial analytical model that is the ground of the analytical methodology; the discussion of the results; the conclusions that highlight the potential of the analytical framework presented to support decision-making in sustainable land use planning.

Area of study

The analytical framework of ES multifunctionality was applied to the entire Italian territory, considering NUTS3 areas as reference territorial units.

Consistent with the European context where the urban conversion rate in the period 2000-2018 was 1790 km^2/yr (Zullo et al., 2021) and according to the Italian Institute for Environmental Protection and Research (ISPRA) (Naturale, 2021), the study area is characterized by marked criticalities in terms of land take trends (Fiorini et al., 2018, 2021; Romano, Fiorini, et al., 2017), especially in peri-urban and urban areas, where artificial surfaces are increasing to the detriment of natural and semi-natural areas.

The analysis of land use changes and urbanization dynamics have been derived from the information layers made available within the Corine Land Cover (CLC), a project that started in 1985 (with the first map produced referring to 1990) and then regularly updated (2000, 2006, 2012 and 2018). The layers, available on the Copernicus project portal, are the result of land cover/land use classification from remotely sensed imagery using semi-automated procedures. The product provides a standard division into 44 classes, divided into 3 levels with the minimum mapping unit (MMU) equal to 25 ha for areal phenomena and 100 m for linear phenomena (MMW).

In order to synthesize the main changes in terms of land cover occurred between 2000 and 2018, we considered the first level of CLC.

As can be seen in Figure 24, the Artificial Surfaces (corresponding to *class 1* considering the first level of the CLC), have significantly increased (+16.33%) at the expense of Agricultural areas (*class 2*) and Forests and seminatural areas (*class 3*). This increase, equal to about 2350 Km^2, is slightly higher than the entire territorial extension of the Province of Mantua.

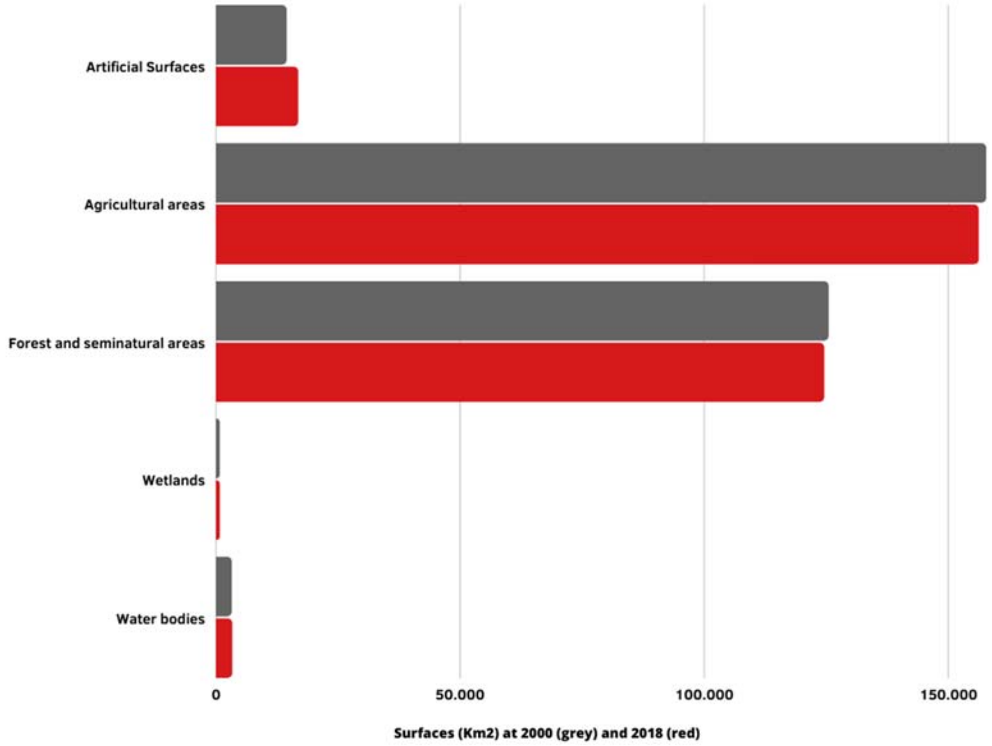

Figure 24 - Comparison between areas for each class of CLC I level referring to 2000 (grey) and 2018 (red)

Not In addition to the intensity of the phenomenon of land consumption, other critical issues concern the ways in which the processes of infrastructurization, expansion of urban settlements and transformations took place. Looking at Figure 25, which shows the increase in artificial surfaces in 2018 compared to those already existing in 2000, it is possible to recognize different dynamics.

In fact, a high rate of land conversion can be noted in the surroundings of main metropolitan areas (boxes A, B, C, E in Figure 25), which act as poles for the provision of services on territorial scale and act as drivers for new urbanization for residential and productive/commercial use.

On the other hand, urban development processes involving polycentric territorial systems are more widespread. Examples are the southern “Triveneto” (box D in Figure 25), a geographical area including the Regions of Veneto, Trentino Alto-Adige and Friuli Venezia Giulia, and the peninsular part of Apulia (box F in Figure 25), between which however there are differences in terms of population density and spatial continuity of the settlement system.

In addition to these, there are further settlement dynamics typical of low-density contexts which happen as part of the "sprinkling" process (Romano, Zullo, et al., 2017), characterized by spontaneous urban development and featured by a building density of about 0.1 building/ha and concerning also inner areas where processes of depopulation, marginalisation and land abandonment have been occurring for several years (L. Saganeiti et al., 2018; Lucia Saganeiti, Mustafà, et al., 2020). Due to its geometric/spatial characteristics, which cannot be captured by the CLC's minimum mapping units, this phenomenon is currently underestimated at European level (Science for Environment Policy, 2016).

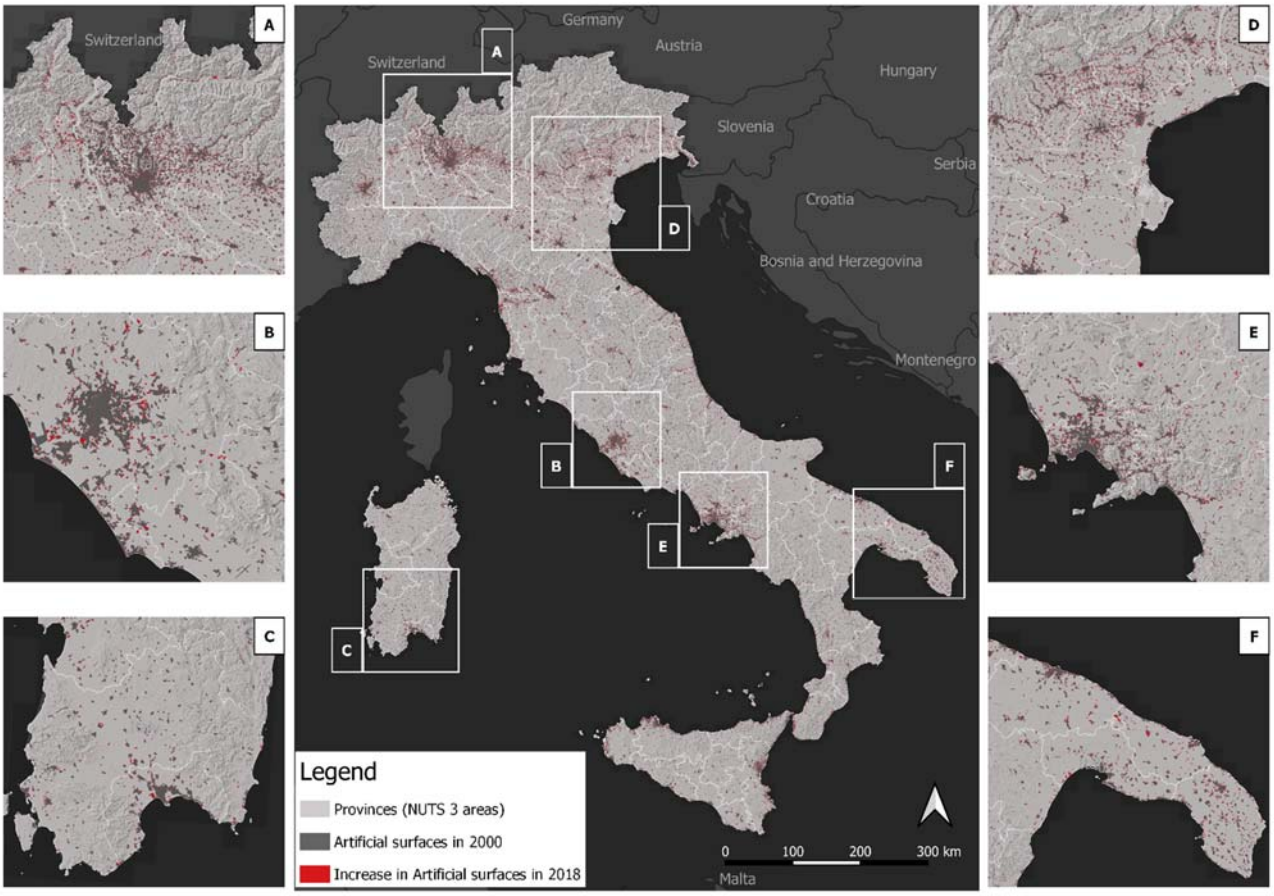

Figure 25 Increase in Artificial surfaces over the period 2000-2018

Considering that the processes of urban growth in Italy have occurred as described by Romano et al. (Romano et al., 2019; Romano, Zullo, et al., 2017; Romano & Zullo, 2014), we highlight that they are still ongoing and we also point out the lack of both an adequate monitoring system and an effective interpretative framework of the effects that these transformations exert on environmental and territorial components.

Several studies (Caldarice & Cozzolino, 2019; Palermo & Ponzini, 2012; Ponzini, 2016; Romano et al., 2018) proposed a critical review of the Italian planning system, underlining the delay in upgrading its regulatory framework in order to be effective in the governance of territorial processes and able to cope with the emerging social, technological and environmental demands related to territorial transformations.

The inefficiency of the Italian planning system in governing and monitoring these urbanization processes (Romano et al., 2018; Scorza, Saganeiti, Pilogallo, & Murgante, 2020) resulted in a distribution of the settlement system and infrastructure network that entails considerable social and environmental costs (Manganelli et al., 2020), and is difficult to manage, especially with a view to achieving zero net land take by 2050 (*The Roadmap to a Resource Efficient Europe*, n.d.). In a nutshell, this is the European Commission's ambitious objective to propose an approach to the issue of soil consumption that goes beyond the limitation of entrusting the monitoring of such a process to the single variable of the increase in artificial surface. Focusing on how natural resources could be efficiently used to provide ES for the next generations, it published guidelines for limiting, mitigating and compensating the soil sealing.

The recommended reference framework to apply to territorial transformations and land use changes is based on the impact mitigation hierarchy (Tarabon et al., 2020): negative impacts on ES and biodiversity should be avoided as far as possible; the effects that cannot be completely avoided, should be minimized by jointly considering their duration, intensity and extent. Ecosystems subject to impacts that cannot be avoided and/or minimized, should be restored with actions aimed at recovering their structure, composition or function. Finally, residual impacts should be addressed through appropriate compensation mechanisms.

In this perspective, our work propose an analytical framework based on ES multifunctionality indices aimed at interpreting the urbanizations and the land use changes dynamics described above in terms of spreading and the intensification of threats to natural ecosystems (Impact of Renewable Energy Installations on Habitat Quality, 2020) and the following depletion of ES and decrease in ES multifunctionality (Angela Pilogallo et al., 2018).

Methodology

The proposed methodology is aimed at assessing the spatial distribution of the effects of urbanization and land use change processes that occurred in the period 2000-2018 in terms of ES multifunctionality.

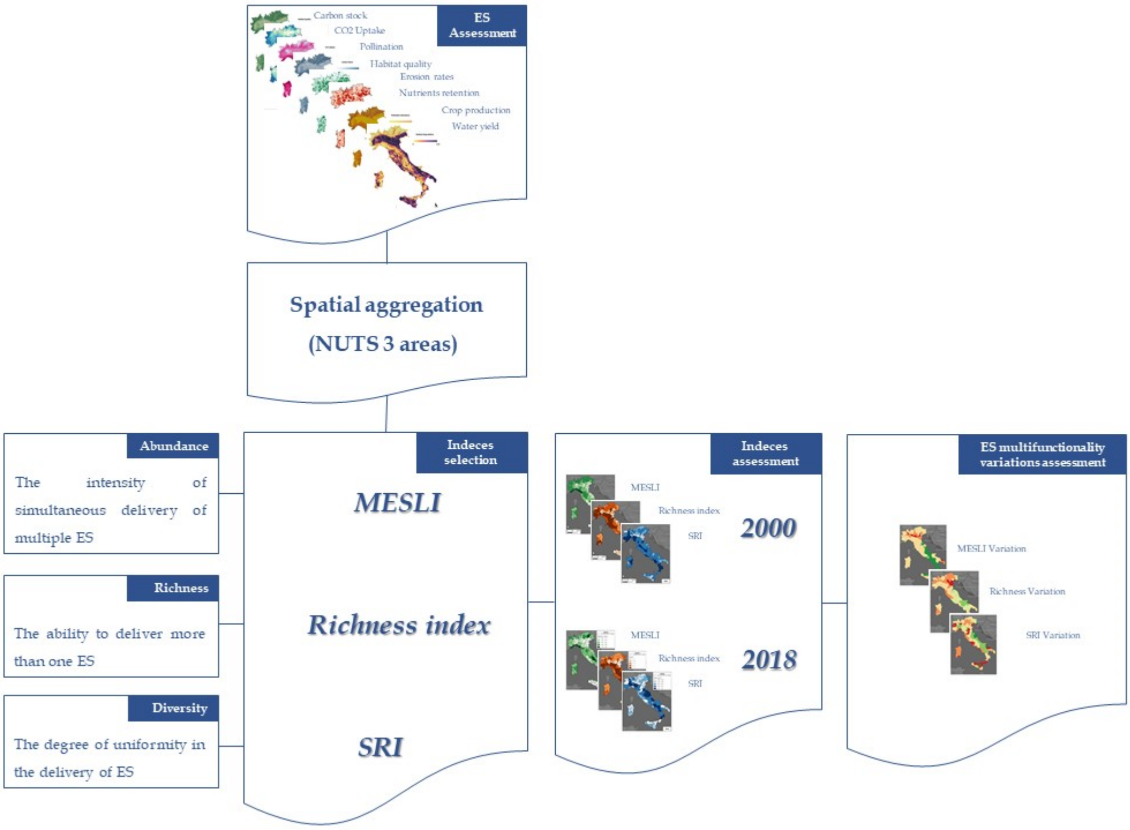

Figure 26 Methodological flow chart

Following the methodological flowchart represented in Figure 26, the first step was the selection of the ES considered most relevant to the context of the analysis and the work scale (summarized in **Table 8**), and their following assessment for the whole Italian territory.

Their assessment is essentially based on CLC land use maps and additional information layers necessary for the implementation of each of the specific models belonging to the InVEST suite. Details of the input data and models used are described in previous works by the same authors (Angela Pilogallo & Scorza, 2021a, 2021b).

Table 8 Indicators, methods and units used to quantify different ES

Class*	Indicators	Methods	Unit
Regulation of chemical composition of atmosphere	Carbon stock	InVEST	Tons/Ha
	CO2 Uptake	Eq. by Clark	g/m^2/yr
Pollination	Pollination Abundance	InVEST	Index**
Maintaining nursery populations and habitats	Habitat Quality	InVEST	Index**
Control of erosion rates	Erosion Rates	InVEST	Tons/Ha
Regulation of the chemical condition of freshwaters	Effective nutrients retention	InVEST	Index**
Cultivated terrestrial plants grown for nutritional purposes	Crop production	InVEST	q/Ha
Ground (and subsurface) water for drinking	Water Yield	Eq. by Budyko	mm/yr/Ha

*according to CICES v.5.1 (Roy Haines-Young & Potschin, 2018b); **dimensionless

In order to outline a trend of ES multifunctionality over the last decades, all the ES were assessed and mapped for the years 2000 and 2018.

The next step was the spatial aggregation of the results obtained by considering the Provinces as territorial units. To this end, we considered the average value of the distribution relative to the Province itself.

Extending the conceptualization by Holting et al. (Hölting, Jacobs, et al., 2019), we defined the three dimensions of multifunctionality (abundance, richness and diversity) and for each of them we selected an index.

Abundance represents the intensity of simultaneous delivery of multiple ES. Some work assesses abundance by considering the average (for example (Mouillot et al., 2011)) or summed values of ES (for example (Zhang & Muñoz Ramírez, 2019)) after appropriately normalizing them. In both cases, there are opportunities for misinterpretation: while the average is insensitive to the number of ES considered, the sum is very sensitive to it. In addition, the balance in the provision of different ES is not captured by these indicators and they may be inflated by the increased provision of only some ES. To address these issues, some authors (for example (Allan et al., 2015)) use thresholds to limit the number of ES considered to only those whose intensity exceed the threshold value. The limitation of this approach, however, lies in the discretion with which to define the threshold value.

In this study we assumed as abundance indicator the Multiple Ecosystem Services Landscape Index (MESLI) (Rodríguez-Loinaz et al., 2015b), considered effective in providing a comprehensive overview of environmental performances (Angela Pilogallo et al., 2021) and suitable for different assessment scales (Stürck & Verburg, 2017).

It can be considered as the ability of different ecosystems to supply multiple services simultaneously (Shen et al., 2020) and it is equal to (1):

$$MESLI = \sum_{i=1}^{n} \frac{Observed\ value_i - Low\ performance\ benchmark_i}{Target - \ Low\ performance\ benchmark_i} \qquad (1)$$

for ES providing a positive contribution to the territorial performance.

Benchmarks for low and high performance can be defined by biological thresholds, expert judgement in light of ecosystem ecology, or even policy objectives. In the absence of clear-defined thresholds, these values can be set on the basis of minimum and maximum observed considering a time-series.

In this work, all ES were assessed for the whole country for each CLC date in the period 2000-2018 (i.e. 2000, 2006, 2012, 2018). The minimum and maximum threshold values were assumed to be equal to the minimum and maximum of the resulting time series.

Richness represents the ability of an ecosystem to deliver more than one ES at the same time (Manning et al., 2018a) and it is usually calculated as the number of ES delivered in the territorial unit (Manea et al., 2019). In order to consider the intensity with which each Province (NUTS3 areas) contributes to the national multifunctionality, in this work we chose to define a threshold value and to include in the richness index only the number of ES exceeding the first quartile of the national data distribution, according to the following formula:

$$Richness = \sum\nolimits_{0}^{N} i{:}\, n_{ij} \geq Q_1(n_i)$$

where i is the number of ES ranging from 0 to N, n_{ij} is the intensity of the i-th ES at the location j and $Q_1(n_i)$ is the first quartile of the entire national data distribution for that i-th ES.

In the context of this work, the richness index allows the identification of those territorial units which, by delivering several ES simultaneously and with an intensity equal to the value of the first quartile with respect to the whole national context, constitute the main pillars of multifunctionality in Italy.

The third ES multifunctionality dimension is constituted by diversity, that combines the concepts of richness and abundance by considering the intensity of each ES' supply as proportionally to the total provision (Queiroz et al., 2015). It therefore provides information on the evenness of provision across several ES (higher values) or the dominance of a specific ES over others (lower values). For this work, we used the Simpson's reciprocal index (SRI) (Simpson, 1949), widely used as an ES multifunctionality indicator to evaluate whether ES are equally supplied or whether a few dominant ones exist (Plieninger et al., 2013).

Considering N as the total number of ES supplied and n_{ij} the intensity of the i-th ES at the location j, the SRI is calculated as:

$$SRI = \frac{1}{\Sigma \left(\frac{n_{ij}}{N}\right)^2} \qquad (2)$$

This index, originally formulated as a measure of the biodiversity (i.e. species diversity) observed in an area, has recently found useful applications within the ES methodological framework (Plieninger et al., 2013). As highlighted by Raudsepp-Hearne et al. (Raudsepp-Hearne et al., 2010), a high diversity value occurs where the trade-offs between ES are smaller and the territorial performance in terms of ES delivered is such that it satisfies a greater diversity of human demands, contributing overall to greater system resilience (McPhearson et al., 2015).

Results

The comparison of the three indices of ES multifunctionality supports the analysis of the relationships between the anthropic components of territorial systems and the capacity of ecosystems to deliver multiple ES.

As can be seen Figure 27, the overall spatial distribution of the MESLI does not change significantly. In both the years considered, in fact, the distribution of the abundance index highlights the importance of mountainous and mostly wooded areas, mainly located along the Apennine Chain and the Alps. The areas corresponding to the lowest values, coinciding with the Po Valley and central-southern part of the Apulia Region, increase in extension during the period considered. The processes of urbanization and changes in land use have therefore contributed to increasing the depletion of natural resources and the decrease in ES.

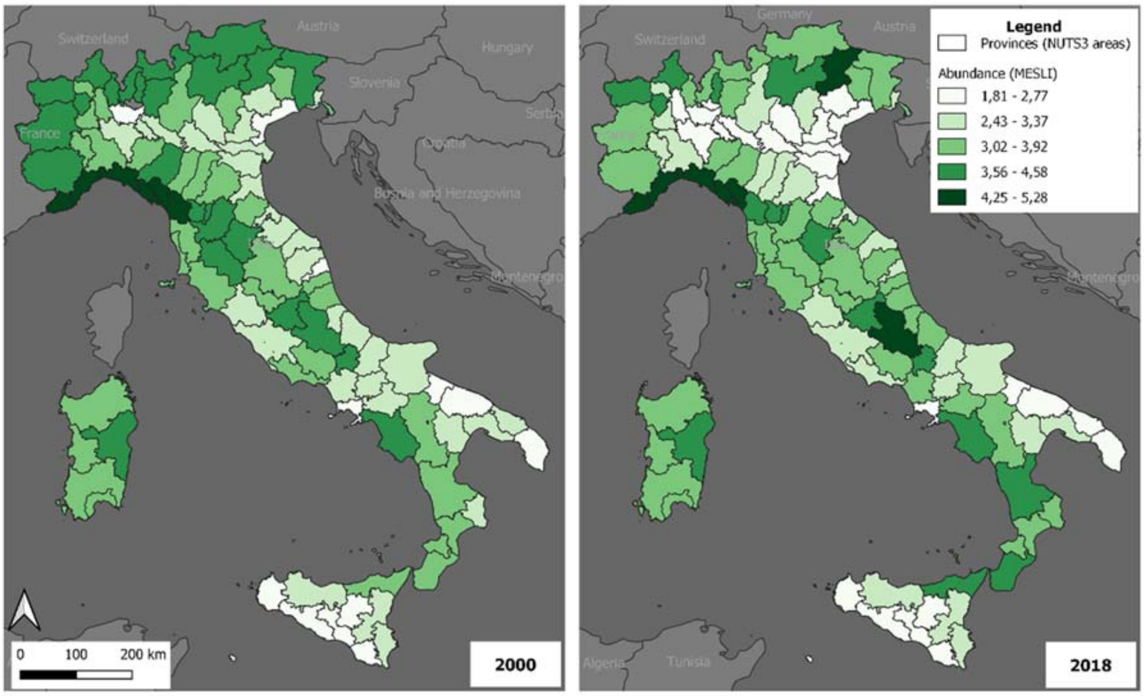

Figure 27 Comparison between the Abundance Index (MESLI) in 2000 and 2018

The territorial performance, while remaining in the lower range, does not furtherly decline in the Province of Naples and Southern Sicily.

The richness index (Figure 28) confirms what has been described by MESLI, highlighting in an even more marked way the contribution of ES in the central Apennines and in the Province of Potenza (Southern Italy). The "backbone" of the Alpine and Apennine Chains is therefore confirmed as an area of priority interest for maintaining the multifunctionality of the entire national territory. In this respect in 2018 it shows an enhancement of its spatial continuity, with increasing values in the central-southern part of the Apennines.

This is probably linked to the phenomenon of abandonment of agriculture, which is widespread in the inner areas, and the consequent process of renaturalisation of agricultural areas.

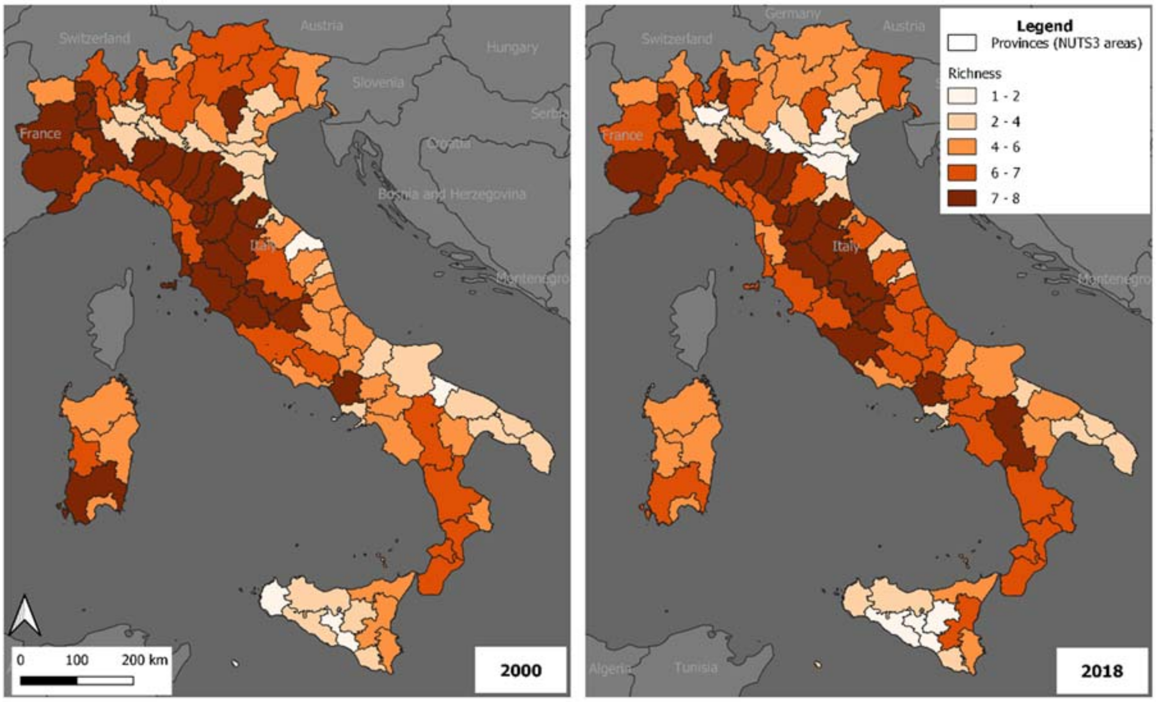

Figure 28 Comparison between the Richness Index in 2000 and 2018

The Simpson's index (Figure 29), illustrates diversity as a measure of the balance between the different ES provided. Where it takes high values, the level of delivery among individual ES is evenly distributed. Where it is lowest, a small number of ES dominate the total. This, in the Italian context, occurs in correspondence of the most densely populated Provinces or the main metropolitan areas and in areas where there is a marked presence of intensive agricultural systems. Here, in fact, the contribution of ES relating to agricultural productivity and the control of erosive processes is markedly prevalent over the overall value.

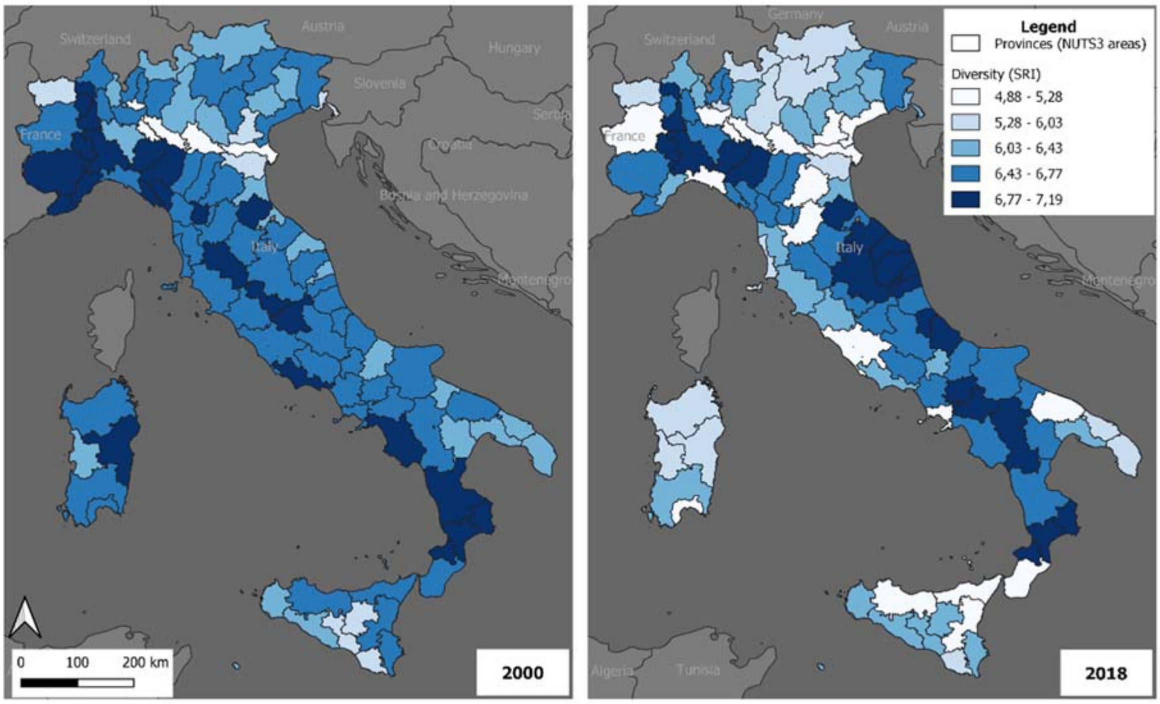

Figure 29 Comparison between the Diversity Index (SRI) in 2000 and 2018

Again, the area along the Po Valley where the lowest values are found in 2018 is larger than in 2000. Rather than land use conversion, this index shows that it is more influenced by urbanization and land consumption. Its spatial distribution, in fact, changes heterogeneously along the peninsula, decreasing in correspondence with metropolitan areas.

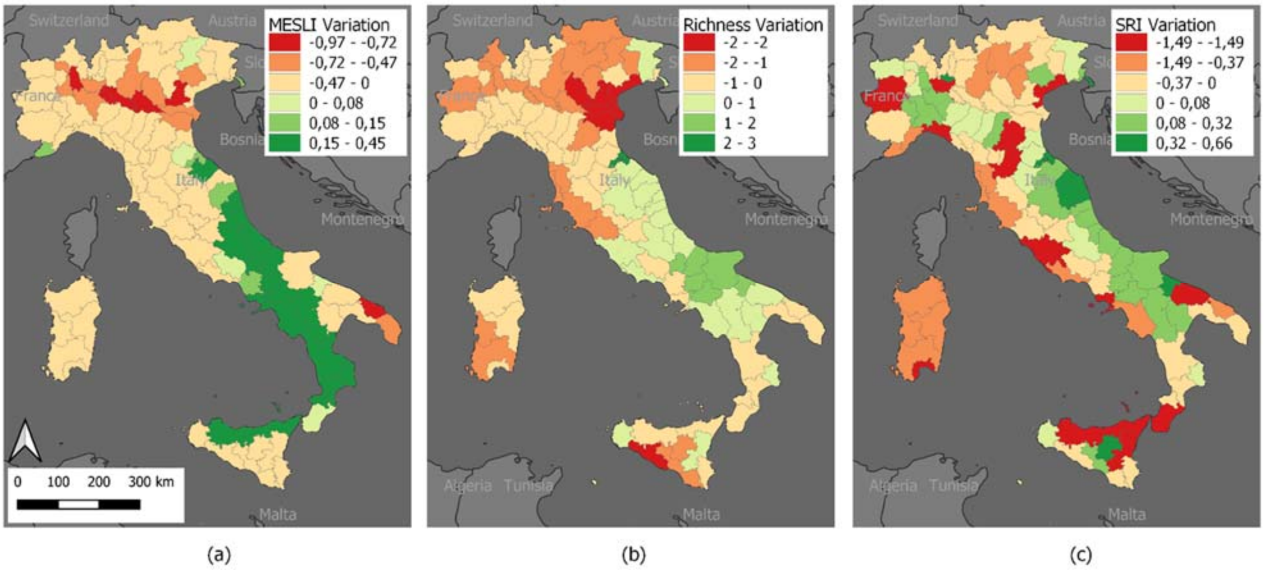

Figure 30 Variations in the three dimensions of ES Multifunctionality over the period 2000-2018: (a) Abundance (MESLI); (b) Richness; (c) Diversity (Simpson's reciprocal index)

Land use changes and new urbanization processes between 2000 and 2018 have exacerbated existing differences in the spatial distribution of ES multifunctionality. In fact, as can be seen from Figure 30**,** the indices of abundance and richness have increased along the Apennine areas of central and southern Italy. The provinces located along the Po Valley are instead characterized by a decrease in both abundance and richness, thus widening the existing ES supply gap between the most industrialized territories and the inner areas of the Apennine Chain. In contrast, the diversity index has undergone spatially more heterogeneous changes, decreasing with greater intensity along the Tyrrhenian coast and in correspondence with the main metropolitan areas.

The differences between the maps shown in Figure 30 also underline the extent to which the choice of ES multifunctionality index affects the interpretation of the results in terms of comparing the environmental performance of different territorial units.

In order to deepen the interpretation of the distributions of the indices and of their variations over time, we considered useful to report some illustrative cases that jointly show the trend of the indices with respect to the variations undergone by the ES in the same time interval.

Box A in Figure 31 refers to the Province of Naples. In this case, there is a discrepancy between the increase in MESLI and the decrease in diversity. In fact, the increment in CO_2 uptake and Habitat Quality lead to an 11.7% increase in the abundance index (from 2.23 to 2.49), even if the other 6 ES indicators decrease. However, these increases do not imply a change in richness, which remains stable at 3.

The second case refers (Figure 31, Box B) to the Province of Rome, one of the largest metropolitan cities in Italy. Compared to the national context, the abundance index is in the lower-middle class in both years considered, with a slight decrease in value (-0.6%) even though the richness index increased. Thus, although the intensity of most of ES decreased, the values in 2018 are such that they exceed the first quartile of the national distribution. Diversity also decreases as the predominance of two ES increases with respect to the distribution of supply values.

The Province of L'Aquila (Figure 31, Box C) is reported to be representative of a typically Apennine context characterized by a high degree of naturalness and a settlement system that does not compromise the ES multifunctionality of the provincial territory. For all three indices, it falls between the medium and high classes, with an upward trend over the period. The largest contributions come from increases in CO2 uptake, habitat quality and nutrients' retention capacity, which induce an increase in homogeneity between ES supply with a consequent increase in SRI (from 6.44 to 6.49).

This situation is similar to that observed in the Province of Parma (Figure 31, Box D), which, while seeing a decrease in the MESLI index (from 4.06 to 3.67) due to slight variations in several ES, shows high values of ES multifunctionality both in terms of richness and diversity. Indeed, the graph shows that in 2018 the intensity of provision among several ES is more homogeneous than in 2000.

Finally, the last two cases refer to territorial units that do not perform well in terms of ES multifunctionality: the Provinces of Caltanissetta (Figure 31, Box E) and Rovigo.

The former, located in the southern part of the Region of Sicily, shows a decreasing trend in both abundance (from 2.53 to 2.35) and richness (from 2 to 1). On the other hand, the diversity index increases (from 5.86 to 6.09) as the distribution of intensity values tends to flatten out.

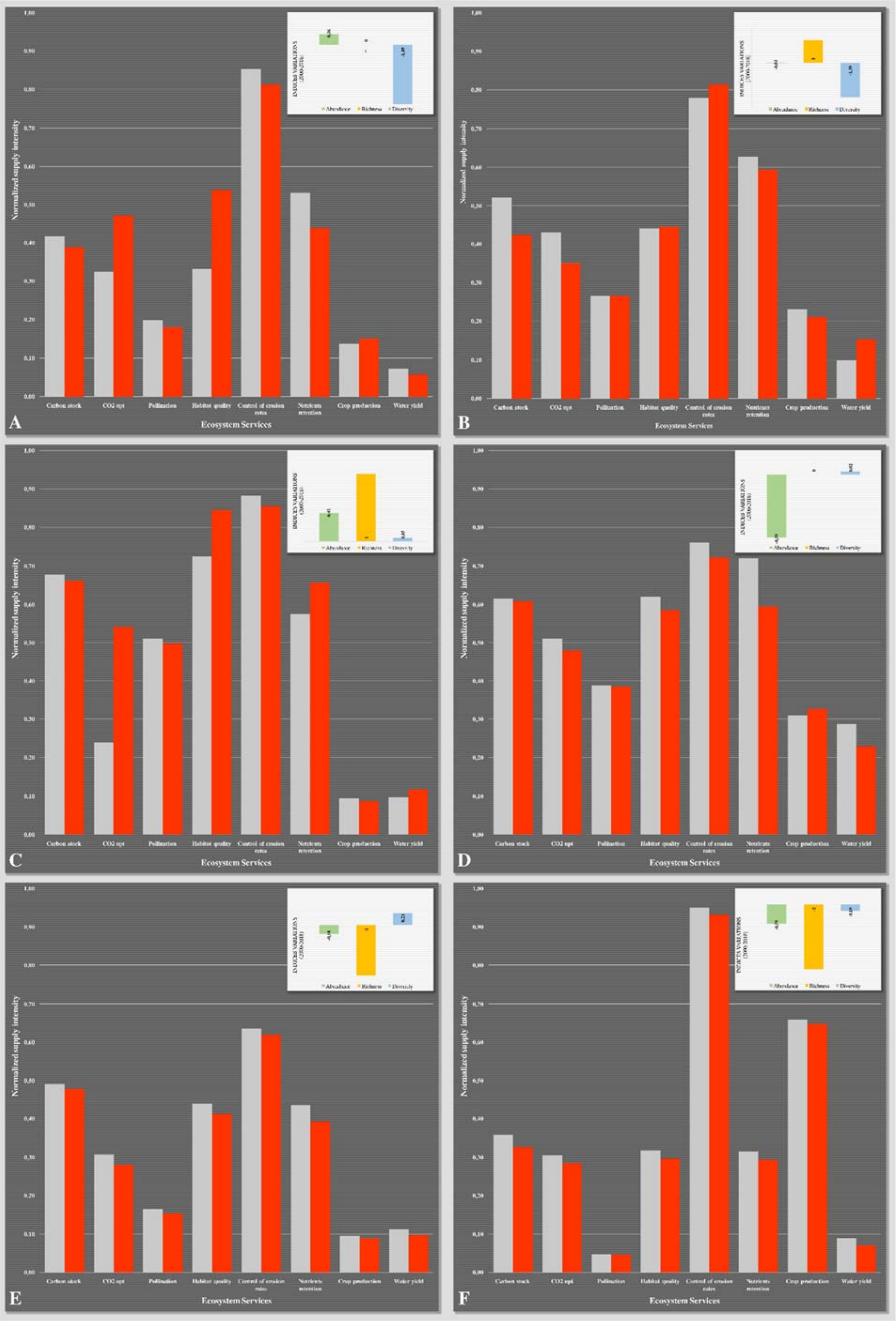

Figure 31 Variation in ES and consequent changes in ES multifunctionality indices for the Provinces of (A) Naples, (B) Rome, (C) L'Aquila, (D) Parma, (E) Caltanissetta and (F) Rovigo

The Province of Rovigo (Figure 31, Box F), on the other hand, is representative of the Po Valley area, which expresses low values of multifunctionality compared to the national context regardless of the index considered, and for all three indexes a decreasing trend over time. Both abundance and richness decrease to the lowest class. The diversity value, while diminishing, ranks the area in the lowest range as early as 2000. As can be seen from the graph, the values for ES delivery intensity is low and tends to decrease over the considered time period. The low value of the SRI index is, in fact, justified by the prevalence of ES “Control erosion rates” to which the flat morphology of the territory contributes significantly, and “Crop production”.

Conclusions

Assessing multifunctionality as the joint provision of multiple ES is considered an innovative and integrated way to study the effects of different land use patterns and the multiple components of human well-being (Queiroz et al., 2015; Rodríguez-Loinaz et al., 2015a). A better understanding of the spatial distribution of ES multifunctionality, considering its different dimensions, could help predict where and how specific governance policies or territorial transformations might affect ES supply and consequently the ability of ecosystems to cope with multiple human demands.

In this work, we propose an analytical framework based on ES abundance, richness and diversity, constituting three different dimensions of ES multifunctionality.

The results show that the same territorial transformations affect differently aspects related to the intensity of provision, the ability to contribute to overall multifunctionality ES and the degree of uniformity between the delivery of different ES.

In particular, MESLI assumes high values both if multiple ES are delivered with low intensity and if few ES are delivered with high intensity. It can therefore be considered as a tool for comparing overall environmental performance, but it does not provide an univocal interpretation of the characteristics of the human-nature system that affect the ES multifunctionality of that specific territorial unit. Its variations also seem to provide a localized picture of ES multifunctionality capable of expressing a trend over time referring to the specific unit area.

The index chosen for richness and its mean depend from the definition of the threshold to determine the ES that contribute to national multifunctionality. The threshold assumed in this work, equal to the I quartile of the global distribution, results suitable for identifying the territorial units that show greater criticality (e.g. Caltanissetta). On the other hand, it affects consistency with the index of abundance: its value is, in fact, variable both where the MESLI is high (e.g. L'Aquila) and where it is low (e.g. Rome).

The interpretation of the diversity index, which some authors identify as the most significant dimension of multifunctionality (Queiroz et al., 2015), is sufficiently variable to distinguish areas where ES provision is more uniform from those where the occurrence of trade-offs means that a small number of ES markedly prevail over others. While, in fact, high diversity can be considered an indicator of regulating ES provision (Raudsepp-Hearne et al., 2010), the second situation occurs where arises what Shen (Shen et al., 2020) calls "the food-environment dilemma", that is the prevalence of agricultural productivity under intensive practices that conflict with the maintenance of biodiversity and the provision of additional ES (e.g. Rovigo).

Our results confirm the relevance of the proposed approach in illustrating the effects of complex transformation dynamics on ES provision and in identifying strategies to reduce impacts and maximize synergies. In the literature, however, there is no unambiguous definition of multifunctionality and there is also a lack of agreement on which ES territorial components should express in order to be considered "multifunctional" (Stürck & Verburg, 2017). This constitutes a research question and a perspective towards orienting further developments. For the planning discipline, in fact, the multifunctionality approach is useful to the extent that it helps to provide support for formulating policies and actions aimed at meeting as many human needs and demands as possible (Raudsepp-Hearne et al., 2010).

Conclusions

Environmental issues are becoming more and more key aspects of political agendas at various levels of governance. With the publication of the 2030 Agenda and the corresponding Sustainable Development Goals (SDGs) (United Nations, 2015), the United Nations put the spotlight on a number of global issues concerning the relationship between humans and the environment. Furthermore, ongoing climate change and the increasingly people awareness call for an even more urgent reflection on territorial resilience, decarbonization processes and ecological transition, efficient use of natural resources and environmental justice.

To ensure that these objectives do not turn out to be "slogans" but are operationally meaningful, it is very important to move from policy to plan.

The ES framework was designed to serve as a tool to support decision-making and foster a renewed integration of environmental aspects in planning processes. Since 2005, the year of publication of the Millennium Ecosystem Assessment, which constitutes the first structured framework for the reorganization of definitions and concepts, it has been enriched with tools and models and has become a robust methodological reference for integrating ES into planning processes.

In particular, the research program aimed to explore ES multifunctionality as a promising approach to pursue this objective taking into account the several environmental, social, cultural and economic dimensions of territorial development. It was therefore structured around one main question:

How can the ES multifunctionality approach contribute to renew the planning system placing environmental components as services providers whose availability represents a pre-condition for any sustainable development strategy?

What was done . . .

The answer to the question implied first of all the need to analytically investigate the evolutionary framework of territorial transformations, land use changes and urbanization processes at different scales. The main findings emerged in the light of several topics and case studies explored during the research program and partly described in published work not included in this thesis (see for example (Scorza et al., 2021; Scorza, Pilogallo, Saganeiti, & Murgante, 2020a)).

Tentatively, we defined as " weaknesses of the traditional planning system":

- The regulatory framework lacks of flexibility. Moreover, the long delays that characterize its procedural aspects cannot keep up with the emerging territorial demands and technological innovations that are taking place all the time.
- The fragmentation of competences and responsibilities between different levels of governance and between different policy areas sometimes leads to a paradox: rather than expressing a measure of the reliability and accuracy of the spatial analyses underlying the plan choices, it leads to overlaps and spatial conflicts.

- Finally, the assessment processes of territorial transformations are not sufficiently *performative* to be able to inform the decision-making levels, and thus feed a virtuous procedural process.

An extensive critical review of the scientific literature was carried out to investigate the possible contributions that the proposed approach could offer in terms of renovation (cfr. Chapter 2). This in-depth study phase made it possible to rearrange approaches, conceptualizations and methods, but also to highlight the importance of having an adequate knowledge infrastructure.

The computation of an extensive set of ES was realized at national scale exploiting the potential of current availability of LULC maps in a significative time series. Those results contribute to the national territorial knowledge infrastructure analyzing in terms of multiple ES supply the land use patterns and their changes over time.

Assessing and mapping the ability to jointly deliver of multiple ES, made it possible to identify areas of the national territory that stand out for their high intensity ES provision and for their role in maintaining the overall national ES multifunctionality (cfr. Chapter 3).

Thus, using the Multiple Ecosystem Services Landscape Index (MESLI) multifunctionality index, we assumed ES multifunctionality as a measure of environmental performances able to rank several territorial units. This ES multifunctionality ranking was then compared with popular quality of life indices that take into account a variety of aspects (cfr. Chapter 4). The aim of the ranking was directly connected to improve planning practice, but intended to raise a debate on the importance of environmental issues in the perception and "measurement" of quality of life. In facts, sensitizing citizens and increasing their awareness can act as a driver or, at least, help to legitimize the adoption of conservation measures.

In the Chapter 5 we propose an interpretative framework based on ES multifunctionality developed to analyze land use changes occurred over the last twenty years at the national level. The three different ES multifunctionality indices used, proved to be differentially sensitive to these changes and therefore able to provide different information on the distribution and intensity of ES and their variations over time.

This kind of contribution concern what we defined "the Strategic Domain of Decisions" in Chapter 2 and consists of an in-depth understanding of how the processes of land use change and urbanization affect the delivery capacity of ES and, consequently, different dimensions of multifunctionality. This can support the definition of long-term policies aimed at regulating changes in land use patterns in order to limit losses of multifunctionality (local or global).

. . .what has to be done: future research and (possible) practical applications

The knowledge acquired within the research program and the results obtained through several case study applications, allow to confirm the initial hypothesis that the multifunctionality ES approach, developed within the ES methodological framework, can provide adequate analysis and information tools to support the plan processes.

At the strategic level, it can contribute to the construction of a knowledge framework that can be interpreted by (not necessarily experts) decision-makers as the result of complex dynamics deepened within the specific disciplines. The complex ecological and environmental processes become therefore directly connected to the territorial phenomena subject to regulation.

Our work aimed at investigating the effects of land use change confirms that this "science-policy interface" could for example support the drafting of the national Land Use Plan, also in the light of the EU targets set within the "No Net Land Take 2050". While actually the monitoring of soil consumption and land take is carried out through a computation of the increase in the amount of land consumed, the approach pursued by the EU is instead oriented towards a performative approach aimed at preserving soil functions and ES provided with a view to the overall maintenance of the multiple components of human well-being. In this strategic document, the role of the "green backbone" constituted by the Apennine Chain, which as we saw contributes in a determinant way to the national multifunctionality, could also be enhanced. In fact, these are territories affected by important phenomena of depopulation and marginalization that various policies at the national level are trying to deal with. In this regard, mechanisms of rewards, maybe inspired by the principles of Payments for Ecosystem Services, could be implemented to favor a socio-economic rebalancing between areas that constitute a hotspot of demand (such as metropolitan areas) and supply (such as inner areas).

Regarding the fragmentation of competencies due to both the hierarchical organization of planning and sectoral policies, the properties that characterize the ES multifunctionality approach: *simultaneity and interactivity* (Selman, 2009) can be used to tackle these challenges. In facts, the various applications highlight the possibility of informing different levels of decision-making through the development of scenarios that simultaneously consider the effects of different measures on spatial components and at several spatial scales. Some authors (Galler et al., 2015a; Uthes et al., 2010) also suggest that pursuing this integrated approach saves public funds and optimizes results in terms of improved environmental performance.

Finally, the integration of ES multifunctionality can improve the evaluation processes of territorial transformations by providing a more comprehensive and integrated vision of the various components of the human-territory system. ES multifunctionality demonstrates how actions implemented at local level affect the wider scales and the related ES supply capacity. Therefore, the proposed approach can support the environmental impact assessment but also the assessment of the convergence between local actions and the consequent contribution to larger scale policies.

Among promising application of the methodological framework discussed in this research work, the approach of ES multifunctionality may be also a valid support both to the definition of environmental compensation mechanisms, and to the structuring a monitoring system sensitive to the cumulative impact due to the stratification of transformation/renaturalisation processes.

Concerning the processes of evaluation of territorial transformations, a critical remark concerns the choice of ES to be included as components of ES multifunctionality. In fact as the work scale grows, the ES should be selected in such a way to capture the specificities (ES supply) of the various contexts and, at the same time, highlight their needs (ES demand).

In the applications of ES multifunctionality included in this thesis work, we also choose not to consider any cultural ES. Although these are fundamental for the quality of life and for the psycho-physical well-being of individuals and communities and can strongly influence the assessment of multifunctionality, as they generally show antagonism to provisioning ES, their assessment still remains a domain where the scientific literature fails to find unanimity. There are in fact several experimental models that propose interpretations which, however, are not perfectly suited to each domain of analysis. For this reason, we have opted to focus on ES directly related to land-use patterns, finding more relevance and less discretionality in relation to real implementations in urban and spatial planning.

The ES multifunctionality approach should, in this sense, support context analyses and eventually clarify them, not replace them. In the perspective of the rationality of planning process, there is no unique solution that fits all problems. This is even more true in the light suggested by some authors that even "nature-based solutions" in some situations can create *ecosystem disservices* (Bolund et al., 1999; Gómez-Baggethun et al., 2013; Graça et al., 2018). Especially at the local/urban scales it would be appropriate for the selection of ES to involve the beneficiaries in a participation process which could improve the transparency of the plan choices.

The criteria for identifying ES beneficiaries and the methods for estimating them remain however a gap to be faced in the further researches.

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