UNIVERSITY OF TRENTO

Doctoral School in Civil, Environmental and Mechanical Engineering

Curriculum 4. Architecture and Planning, Landscape

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Methods and Tools for Mainstreaming Nature-based Solutions in Urban Planning

2022 - Doctoral thesis

UNIVERSITY OF TRENTO - Italy
Department of Civil, Environmental and Mechanical Engineering

Doctoral School in Civil, Environmental and Mechanical Engineering
Topic 4. Architecture and Planning, Landscape - XXXIV cycle 2019/2021

Doctoral Thesis - July 2022

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Acknowledgments

Approaching the end of this journey, many are the words that could be spent to thank all the wonderful people who accompanied me during these three (and a half) years.

Unfortunately (or luckily, for those who usually get bored reading this section) I don’t like to elaborate too much on this kind of thing. But my next few words are very heartfelt.

First of all, I would like to infinitely thank my supervisor Prof. Davide Geneletti and co-supervisor Dr. Chiara Cortinovis for the time dedicated to me and for being so professional and so friendly at the same time. Nothing in this thesis would have been possible without your constant support and high-quality inputs. If I have to attribute the merits of the work presented in this thesis, for sure I would say one-third each.

A special thank you goes to my companions of this adventure, Susana and Jarumi. First, for being friends other than colleagues. Second (not for importance), for the continuous exchange of ideas and sharing of knowledge that helped me to advance my scientific background. This is also valid for all the other PLANES members I met in Trento, from the older ones to the newcomers. Unfortunately, the hours spent together at the office (and outside) have not been so many during the last two years, but you all have contributed to making me feel part of an amazing big family and an excellent research group. I would also like to acknowledge Dr. Enzo Falzo and Prof. Sara Favargiotti from the University of Trento for their precious suggestions and comments on my research.

An important role in this adventure is to be attributed to the ReNature project and especially to all the awesome people involved that I had the pleasure to meet. A very big thank you go in particular to Mario, Judita, Marcus, Jean, Anna, Lynn, Miriam, and all the other people who participated in the various events in Malta, Dublin, and Trento. I really enjoyed your company and you all contributed to both expanding my scientific knowledge and creating good memories through insightful conversations and fun moments, better if in front of a beer or a glass of wine (sadly, this was possible only during the first half of the project). A special note goes (again) to Mario (aka, Dr. Mario Balzan from the Malta College of Arts, Science and Technology, coordinator of the ReNature Project) for his active involvement in part of my research activities and for helping me with the organization of meeting with local practitioners and the collection of relevant information from the Malta Planning Authority, which I also would like to acknowledge for sharing precious information and data.

In addition, I would like to express my gratitude to the two external reviewers of the thesis, Prof. Eugenio Morello (Politecnico di Milano) and Prof. Dr. Christine Fürst (Martin-Luther-Universität Halle-Wittenberg), for the time dedicated to review my work and for their useful comments.

Last but not least, a huge thanks goes to the people who always supported and encouraged me in my life and in my choices. My parents. My brother. My (pretty new) family: my wife Chiara and my eight-month-old daughter Nicole, two pillars for the rest of my life. As you can see, life outside the PhD gave me enormous satisfaction during these years, although has made even more challenging these last months of work. However, if I am here now, I owe them too.

Part of this work was carried out under the project ReNature (Promoting research excellence in nature-based solutions for innovation, sustainable economic growth and human wellbeing in Malta) receiving funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 809988.

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Summary

Among the various perspectives and concepts focussing on the benefits that humans gain from nature that have emerged over the past years to support decision-making in the management of natural resources, the concept of Nature-based Solutions (NbS) is the most recent. NbS can be described as actions that utilize ecosystem processes of green and blue infrastructure in order to safeguard or enhance the delivery of ecosystem services (ES). They are purposely planned and designed to address multiple urban environmental, social, and ecological challenges. Compared to other ecological concepts, such as ecological engineering, ecosystem-based approaches, and green infrastructure, the innovative elements of NbS are a strong connection to the policy dimension and decision-making of land use and spatial planning, the emphasis placed on the role of nature in addressing multiple key societal challenges for human wellbeing through the delivery of ES, and the relevance of implementation aspects, which is partly linked to the policy dimension.
However, scarce experience with ES integration in land use and spatial planning decisions and shortage of actionable ES knowledge about the benefits delivered by NbS to address the existing urban challenges, as well as lack of knowledge and experience with NbS planning and implementation instruments, are among the main gaps limiting NbS mainstreaming in urban planning.

The overall aim of the thesis is to develop and test methods and tools to advance the mainstreaming of NbS in urban planning processes and instruments by unveiling i) ES science contributions and open issues associated with the integration of ES in spatial planning, ii) the support that ES spatial assessment approaches can offer to the planning of NbS that maximise the benefits to residents, and iii) the available options to promote NbS in urban plans through the use of specific policy instruments. Accordingly, the thesis is structured around three objectives.

The first objective is to analyse practical case studies from the scientific literature that successfully integrated ES knowledge in spatial planning

processes. It aims to reveal in which ways ES science has been already used to support planning decisions and to shape planning instruments and regulations, the open issues still associated with the integration of ES in spatial planning, and the potential to promote NbS.
To this aim, a systematic literature review was carried out in order to map scientific publications addressing the use of ES in spatial planning and to analyse case studies where ES knowledge has been integrated into real-life processes and instruments. Findings revealed that case studies with policy relevant applications of ES are very few, confirming the mismatch between ES science and its use in practice. The main advantages of introducing ES knowledge in spatial planning processes that emerged from the real-life case studies are: i) a broader inclusion of relevant issues to address during the planning process (e.g., existing urban challenges), ii) a synthesizing perspective to interpret multiple data and information (e.g., for assessing baseline conditions and policy scenarios), and iii) an effective involvement of stakeholders with a higher degree of participation and environmental awareness. This can contribute to legitimate decisions dealing with more sustainable spatial allocation of uses and management options (e.g., ES maps used as a basis for producing formal zoning schemes). Overall, the integration of ES knowledge into spatial planning processes has been shown to possibly favour nature-based projects. However, there is still a gap in the typology of ES information currently used in spatial planning processes and instruments, namely the use of ES supply assessments only, without considering the socio-economic demand for ES, which is particularly useful in supporting planning decisions that include NbS.

The second objective of the research is to develop and test a planning approach to select and allocate NbS in the city. The approach aims at addressing urban challenges by maximizing the benefits that citizens gain from NbS implementation. Hence, it is based on the mapping and assessment of ES demand as fundamental information to support planning decisions.
The approach was applied in the case study area of Valletta (Malta) to allocate NbS on the ground within the potential NbS sites identified. It combines the spatially-explicit assessment of the demand for five key ES (runoff regulation, microclimate regulation, air purification, noise reduction, and (nature-based) recreation) with performance scores reflecting the capacity to supply the analysed ES of eleven NbS types.

Based on this combination, in each site the NbS type that best meets the demand profile of the site is identified, together with the level of priority for NbS implementation, allowing the identification of the sites where NbS implementation should be prioritized because characterised by higher demand levels for multiple ES.
The proposed approach can be used to inform planning decisions aimed at prioritizing both the locations and the specific typologies of NbS in order to deliver the most demanded ES across urban areas, thus responding to the main goal of addressing the existing urban challenges while maximizing the ecosystem's benefits to citizens taking advantage of their multifunctionality. It can be used and adapted to support a variety of planning decisions dealing with the prioritization and/or spatial allocation of NbS, being particularly suitable to support the development of performance-based planning approaches aimed at integrating NbS within urban transformation projects through the definition of ES-based scoring systems and requirements.

The third objective of the research is to investigate what specific policy instruments are available and suitable for promoting the implementation of different typologies of NbS in urban plans.
An overview of the different policy instruments that can be used in urban plans to promote the implementation of NbS was provided according to the literature, including regulatory, other command and control instruments (i.e., design-based instruments and land acquisition programmes), as well as incentive-based (i.e., including financial and non-financial incentives) and information-based instruments that are mostly applied on a voluntary basis. The suitability of each instrument to different typologies of NbS – classified based on based on the possible permitted transformations by the plan and management intensity of interventions – was then analysed.
The findings were summarized in a matrix showing what instruments can be used to promote the implementation of each type of NbS, thus providing the knowledge base to support practitioners in their identification and selection according to the different NbS they seek to promote. They show that to each typology of NbS, it always corresponds more than one possible instrument, providing alternative options and allowing combinations of instruments of the same category or pertaining to different categories (e.g., regulatory and incentive-based). This is especially important considering that a mix of different

policy instruments is considered necessary for the long-term stability and scaling up of NbS projects, as well as for advancing policy shift from grey to green.
The proposed matrix was then applied to analyse the two urban plans in force in the case study area of Valletta, revealing which instruments are currently deployed and which are not, thus identifying missing opportunities that could be further exploited for promoting NbS implementation, for example in the light of the urban plan's policy revision.

This thesis explores multiple aspects that need to be approached for mainstreaming NbS in urban planning processes and instruments, ranging from planning to implementation aspects, in order to offer a multifaceted view on how NbS can be planned, integrated and promoted in planning decisions. It further attempts to unveil the main connections between these aspects, summarizing them according to the two main dimensions addressed in the different thesis sections, namely the critical aspects of integrating ES knowledge to favour NbS in planning decisions and the methods and tools that can be used to support NbS mainstreaming in urban planning.
However, it necessarily offers a limited view on such a broad and evolving topic, especially since the NbS concept is relatively recent and still needs to be internalized by both science and policy. Further research should focus on assessing the transferability of the methods and findings in different planning and geographical contexts, their usability in real-world decision-making processes, and their promotion and integration into current urban planning instruments and regulations.

Chapter 1

Introduction

1.1 Conceptual framing of Nature-based Solutions

Over the past years, an increasing number of approaches have focused on the analysis of the benefits that humans gain from nature with the overall aim of supporting decision-making in natural resources management and environmental planning (Nesshöver et al., 2017; Díaz et al., 2015; MA, 2005; TEEB, 2010).
The most recent entry to this discourse is the concept of Nature-Based Solutions (NbS), which brings together well-established ecosystem-based approaches, such as Ecosystem Services (ES), green-blue infrastructure, ecological engineering, ecosystem-based management, natural capital, and urban forestry (Escobedo et al., 2019; Nesshöver et al., 2017; Nature Editorial, 2017; Raymond et al., 2017), with assessments of the social and economic benefits of resource-efficient and systemic solutions that combines technical, business, finance, governance, regulatory and social innovation (European Commission, 2015; Raymond et al., 2017). Although the NbS concept shares similarities with the abovementioned approaches, its objective towards the management of the natural resources for human well-being is quite different, indicating that such a topic has evolved over time. Compared to the other ecological concepts, NbS emphasise the value of nature to address societal challenges, the connection to policy areas – especially land use and spatial planning – and the relevance of implementation aspects (Pauleit et al., 2017; Raymond et al., 2017; Kabisch et al., 2016; Babí Almenar et al., 2021).

Among the various definitions proposed, the IUCN defined NbS as "actions to protect, sustainably manage and restore natural and modified ecosystems that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits" (Cohen-Shacham et al., 2016), while the

European Commission as “living solutions inspired by, continuously supported by and using nature, which are designed to address various societal challenges in a resource-efficient and adaptable manner and to provide simultaneously economic, social, and environmental benefits” (European Commission, 2015).
Apart from these consistent definitions, NbS can be considered as a catch-all term for all those human actions that involve the deployment, enhancement or conservation of nature with the aim to deliver desired ES (Kabisch et al., 2016; Raymond et al., 2017; Calliari et al., 2019; Croeser et al., 2021), which, unlike traditional ‘grey infrastructure’ solutions, draw on natural processes to provide multiple co-benefits (Raymond et al., 2017; Engström et al., 2018). Examples of NbS that deliver multiple co-benefits include green roofs built to mitigate flooding that may simultaneously cool down temperatures (Pianella et al., 2016), and constructed wetlands that besides providing flood risk reduction and water quality enhancement can be designed to support local biodiversity (Aronson et al., 2017). Along with environmental (co-)benefits, NbS have been shown to support social (co-)benefits, for example supporting the social capital of a neighbourhood by facilitating a sense of community and belonging between residents that is closely associated with improved mental health (Rugel et al., 2019). In order to understand their functioning and added value with respect to alternative solutions, NbS can thus be described as actions that utilize ecosystem processes of green and blue infrastructure in order to safeguard or enhance the delivery of ES, which can in turn contribute to the alleviation of societal challenges, simultaneously providing economic, human security, social/cultural, and ecological co-benefits, in spite of technical alternatives which usually simply target the challenge without providing additional benefits (Albert et al., 2019).

Eggermont and colleagues (2015) classified NbS in three typologies by considering two dimensions: (i) the level of engineering or management applied to biodiversity and ecosystems; and (ii) the number of ES delivered and stakeholder groups targeted. In particular:

- Type 1 consists of “no or minimal intervention in ecosystems, with the objectives of maintaining or improving the delivery of a range of ES both inside and outside of these preserved ecosystems” (Eggermont et al., 2015). Solutions included in this typology are the ones that involve making better use of existing natural or protected ecosystems, such as measures to increase fish stocks in wetlands to enhance food security (Cohen-Shacham et al., 2016);

- Type 2 concerns "the definition and implementation of management approaches that develop sustainable and multifunctional ecosystems and landscapes (extensively or intensively managed), which improves the delivery of selected ES compared to what would be obtained with a more conventional intervention" (Eggermont et al., 2015). Solutions falling within this typology are based on the development of sustainable management protocols and procedures for managed or restored ecosystems, such as the re-establishment of traditional agroforestry systems based on commercial tree species to support poverty alleviation (Cohen-Shacham et al., 2016);
- Type 3 consists of "managing ecosystems in very intrusive ways or even creating new ecosystems" (Eggermont et al., 2015). Solutions included in this typology are the ones that involve the creation of new ecosystems, such as the establishment of green buildings – green walls, green roofs – or street trees to mitigate urban heat island effect and clean polluted air (Cohen-Shacham et al., 2016).

This classification, still used in more recent studies (e.g., Langemeyer and Baró, 2021), paved the way for further attempts to categorize NbS, either by further detailing the classes (e.g., Cohen-Shacham et al., 2019; 2016) or by complementing them with additional classification dimensions (e.g., Gómez Martín et al., 2020). Other alternative approaches for classifying NbS have also been proposed. These include categorizations according to the "ecosystem domain" of NbS (green, blue, hybrid domains with combinations green-blue, green-grey, blue-grey and green-blue-grey (Debele et al., 2019)) or the "dominant media" involved (land, water, built structures (Babí Almenar et al., 2021)), according to the "scale and scope" (e.g., interventions at building-scale, in public spaces, water bodies, transport infrastructures, natural areas (Dushkova and Haase, 2020)), or according to a combination of multiple criteria and hierarchical categories (e.g., Castellar et al., 2021). However, despite these efforts, a consolidated classification of NbS is still missing.

More consensus exists on key attributes of NbS, which help to define what a NbS really is and what approaches properly fit the NbS concept. Eggermont and colleagues (2015) highlight that NbS are solutions designed to address multiple goals and challenges, which are framed within adequate governance to properly tackle the issue at a larger scale than the single intervention. More recently, Albert and colleagues (2021) defined three indispensable criteria to define a solution as a NbS: (multiple) challenge-orientation, ecosystem process utilization, and practical viability (i.e. "embeddedness of NBS within governance and business models for implementation"). NbS can thus be considered as cross-sectorial solutions (Wendling et al., 2018), which serve several purposes (Haase et al., 2017) and 'emphasize multifunctionality' (Clabby, 2016; Fink, 2016). For example, when implementing a green roof or wall programme, a range of species could be selected based on their biogeography and key functional traits (Lundholm et al., 2015), in order to address the existing societal challenges (e.g., mitigation to and adaptation to climate-related hazards, biodiversity loss, improved risks to human health, etc.) by providing cooling during summer, stormwater capture, pollution abatement, increased human well-being, biodiversity enhancement, and better resilience to future hazards (Eggermont et al., 2015).

1.2 Implementing Nature-based Solutions in cities: what implications for urban planning?

In the recent years, NbS have progressively evolved from being a novel integrative concept in scholarly literature to being embedded in active investment programs provided by major international institutions to encourage their implementation in cities (Faivre et al., 2017; Croeser et al., 2021). For example, the European Union's Biodiversity Strategy for 2030 recognises the need to support measures for greening urban areas by promoting the use of NbS (European Commission, 2020).

Cities are dealing with several societal issues and challenges arising from rapid urbanization and climate change, among others. The promotion of NbS in cities builds on the increasing evidence and experiences showing that natural resources can play an important and cost-effective role in addressing several urban challenges, such as

climate mitigation and adaptation, air pollution, human well-being, water security, food access, social cohesion, and job opportunities through enhancing the provision of urban ES (Babí Almenar et al., 2021). NbS in cities are thus believed to enhance urban resilience and sustainability by helping to address these challenges (McPhearson et al., 2015; Sarabi et al., 2022). They include green buildings (e.g., green roofs, green walls), urban green areas connected to grey infrastructure (e.g., alley and street trees, railroad bank, house gardens, green playground/school grounds), parks and (semi)natural urban green areas (including urban forests), allotments and community gardens, green indoor areas, blue areas (e.g., rivers, lakes, seacoasts, wetlands), green areas for water management (e.g., rain gardens or sustainable urban drainage systems), derelict areas (e.g., abandoned spaces with patches of wilderness) (Almassy et al., 2018).
Urban planners and municipal land managers are increasingly incorporating public needs and desires for urban green space in urban policies, planning, and revitalization projects (Gill et al., 2007; Tzoulas et al., 2007; Andersson et al., 2019). From this perspective, mainstreaming NbS in urban plans is considered a way to increase the environmental quality of urban settings and transformations, while providing a range of social and economic co-benefits (Raymond et al., 2017). In some frontrunner cities, new specific planning strategies and programs are prepared to promote scaling up NbS implementation (Lafortezza et al., 2018; Fastenrath et al., 2020).

However, the mainstreaming and scaling up of NbS in urban planning is still a serious challenge: current planning practices are mostly unable to adapt to changing needs of the cities and to capture the multiple qualities and benefits (e.g., in terms of ES supply) of green (Cortinovis and Geneletti, 2020; Ronchi et al., 2020), while the lack of knowledge of and experience with NbS limits their embedding in decision-making (Grace et al., 2021). This contributes to a significant implementation gap, which continues to exist despite the multiple advantages of NbS are widely recognised. Appropriate methods and tools that can foster the mainstreaming of NbS in urban planning are thus required. These include both methods that integrate ES knowledge (e.g., about ES supply and demand (Feurer et al., 2021)) to support NbS uptake in planning decisions, and implementation tools (such as regulations and incentives (e.g., Toxopeus and Polzin, 2021)) through which urban plans and policies can promote their scaling up.

For the former aspect, given that the “NbS concept has been developed in order to operationalize an ecosystem services approach” (Dushkova and Haase, 2020), methods and approaches integrating ES spatial assessments can provide a valuable support to facilitate the uptake of NbS in (spatial) planning decisions. In the recent years, a growing number of scientists have been involved in the assessment of (urban) ES to account for the benefits provided by ecosystems in cities or to support the design of urban green to be as effective as possible (Larondelle and Lauf, 2016). While ES mapping and assessment can be used to support policy- and decision-making to shape a variety of decisions (Posner et al., 2016), in the recent years various methods and approaches have been developed with the specific aim to support NbS-related decisions. Examples include methods and approaches to identify challenges and spatially define ES needs (e.g., Pan et al., 2021; Baker et al., 2021), to describe the impacts and/or benefits of NbS (e.g., Geneletti et al., 2022), as well as to support the prioritisation of effective NbS that address multiple challenges and maximise the supply of multiple ES (e.g., Sarabi et al., 2022; Balzan et al., 2021). In addition, the integration of ES knowledge into spatial planning processes can stimulate NbS implementation by supporting the definition of standards and policy targets or the design of regulations, incentives and compensation schemes that favour NbS projects (Barton et al., 2018; Cortinovis and Geneletti, 2018b).

As regards the implementation aspect, the promotion of NbS in cities must be aligned with existing and/or proposed planning strategies (Raymond et al., 2017), which are typically defined within urban plans together with the specific actions and related implementation tools (Cortinovis and Geneletti, 2018a). Moreover, NbS need to be incorporated within viable governance frameworks for ensuring their implementation as well as for securing their scaling up (Kabisch et al., 2017). For developing innovative ways to systematically incorporate NbS into the city’s governance instruments and regulations, which is considered one of the major contributions to the mainstreaming of NbS in cities (Raymond et al., 2017), the urban (municipal) plan appears to be one of the most appropriate planning instruments within which the policy instruments adopted to implement the plan's actions (namely, the plan's implementation tools) can be specifically developed, tailored, and systematically applied to support NbS implementation.

1.3 Objectives and structure of the thesis

The overall aim of the thesis is to develop and test methods and tools to advance the mainstreaming of NbS in urban planning processes and instruments. As introduced above, the NbS concept is characterized by several innovative elements, including a strong connection to the policy dimension and decision-making of land use and spatial planning, the emphasis placed on the role of nature in addressing multiple key societal challenges for human wellbeing through the delivery of ES, and the relevance of implementation aspects, which is partly linked to the policy dimension. However, scarce experience with ES integration in land use and spatial planning decisions and shortage of actionable ES knowledge about the benefits delivered by NbS to address the existing urban challenges (Balzan et al., 2021), as well as lack of knowledge and experience with NbS planning and implementation instruments (Grace et al., 2021), are among the main gaps limiting NbS mainstreaming in urban planning.
The thesis aims to explore these three aspects which, also due to the recent entry of the NbS concept into the science-policy interface, have not yet been thoroughly investigated. It seeks to contribute to overcoming some of the abovementioned gaps by unveiling i) ES science contributions and open issues associated with the integration of ES in spatial planning, ii) the support that ES spatial assessment approaches can offer to the planning of NbS that maximise the benefits to residents, and iii) the available options to promote NbS in urban plans through the use of specific policy instruments. Accordingly, the thesis is structured around three objectives and related research questions.

The first objective of the research is to analyse practical case studies from the scientific literature that successfully integrated ES knowledge in spatial planning processes. It aims to reveal in which ways ES science has been already used to support planning decisions and to shape planning instruments and regulations, the open issues still associated with the integration of ES in spatial planning, and the potential to promote NbS. The research questions associated with the first objective are:

- What practical support can ES science offer to guide sustainable planning decisions that foster NbS?
- What open issues have emerged from real-life case studies of spatial planning practices integrating ES?

The second objective of the research is to develop and test a planning approach to select and allocate NbS in the city. The approach aims at addressing urban challenges by maximizing the benefits that citizens gain from NbS implementation. Hence, it is based on the mapping and assessment of ES demand as fundamental information to support planning decisions. The research questions associated with the second objective are:

- What data and methods can be used to map and assess the demand for different ES in urban areas?
- How can the capacity to supply ES of different NbS types be assessed and combined with ES demand to support NbS prioritization and allocation?

The third objective of the research is to investigate what specific policy instruments are available and suitable for promoting the implementation of different typologies of NbS in urban plans. The research questions associated with the third objective are:

- What policy instruments can be used in urban plans to promote the implementation of NbS?
- What typologies of NbS can be promoted by different policy instruments?

The thesis combines different methods, including a systematic review of the literature, content analysis of urban plans, and GIS mapping and modelling, among others. Part of the research is applied to the case study area of Valletta, the capital city of Malta, within the framework of the H2020 ReNature project (https://renature-project.eu/) and in collaboration with local experts from the Malta College of Arts, Science and Technology and local stakeholders in Malta. The thesis is organized into seven chapters.

Chapter 2 aims to gather and critically analyse how ES science contributes to spatial planning practices by conducting a systematic review of the scientific literature about the use of ES in spatial planning and by analysing published case studies where ES knowledge has been integrated into real-life spatial planning processes and instruments. The rationale is that learning and feeding back from existing experiences is a fundamental step to ensure appropriate and useful support by ES science. Advantages of, and internal and external constraints to integrating ES into spatial planning processes, as well as enabling factors that boosted ES integration, are revealed on the basis of the information retrieved from the analysed case studies, together with the main open issues and shortcomings of ES knowledge use in spatial planning decisions with respect to the NbS concept.

Chapters 3 and 4 move to the empirical part of the thesis that is applied to the case study of Valletta. The selected case study is considered relevant for NbS mainstreaming that could address a number of socio-economic and environmental challenges particularly felt in Malta. These, together with the highly fragmented nature of land ownership, make it an exemplary case where NbS implementation is particularly challenging and needed. Chapter 3 describes the case study area and analyses its spatial characteristics and planning instruments with the aim to identify spatial opportunities for NbS, namely possible locations where proper conditions exist for their implementation on the ground. The potential NbS sites identified through spatial analysis are then used in Chapter 4 to test an approach to support spatial planning decisions towards effective NbS allocation and prioritization in the study area. The approach combines the mapping and assessment of the demand related to five key ES in the study area with performance scores reflecting the capacity to supply ES of different NbS that can be implemented on the ground within the potential NbS sites identified. It supports both the identification of priority locations and the selection of the specific NbS that should be implemented in order to maximise the benefits to residents by providing the best balance between the supply of multiple ES demanded in each site.

Chapter 5 moves from the selection of priority locations and typologies of NbS to the tools for their implementation. In particular, it provides an overview of the different typologies of policy instruments that can be used to promote NbS implementation in urban plans and proposes a matrix to guide the identification of suitable instruments for different typologies of NbS. The proposed matrix can assist decision-makers in the selection of suitable instruments according to the various NbS-related decision contexts they have to face when drawing up the plan's policies. The matrix is then applied to analyse the content of the two urban plans covering the Valletta urban area, to reveal which instruments are currently deployed in the existing plan's policies and which are not, hence highlighting missing opportunities that could be further exploited for scaling up NbS implementation.

Chapter 6 brings together and discusses the three parts of the analysis. It unveils the connections between the different sections of the thesis, summarizing them according to the following dimensions: i) critical aspects of integrating ES to favour NbS in planning decisions, and ii) advancing methods and tools to support NbS mainstreaming in urban planning. It also presents possible future research pathways emerging from the thesis.

Finally, Chapter 7 provides the conclusions by discussing the main findings of the thesis and their implications for mainstreaming NbS in urban planning.

Chapter 2

Practical applications of ecosystem services in spatial planning: A literature review*

2.1 Introduction

This chapter aims to explore the state of the art of Ecosystem Services (ES) knowledge integration into spatial planning processes and instruments. Spatial planning potentially plays a key role in promoting NbS, and the integration of ES knowledge can support NbS uptake. Revealing the main current trends and open issues associated with the support that ES science can offer to real-life spatial planning applications provides the background for the explorations conducted in the following chapters of the thesis.

ES have been advanced as a conceptual framework to promote awareness of socio-environmental interdependencies and interactions in decision-making (Bennett and Chaplin-Kramer, 2016; Daily et al., 2009). International bodies and agreements have endorsed the assessment of ES as a knowledge base on which to build and evaluate policies (IPBES, 2012; CBD, 2010; European Commission, 2011). In recent years, several national and local programmes have contributed to mainstream ES in different policy contexts (Beery et al., 2016; Schr¨oter et al., 2016), and guidance documents have been published to support practitioners in conducting policy-relevant assessments (European Commission, 2019; NCC, 2018; SEPA, 2018).
The increasing commitment to contribute to transformative changes in society has been accompanied by a growing reflection on the roles of scientific knowledge (Clark et al., 2016; Kirchhoff et al., 2013) and the ways in which it can influence decisions (Posner et al., 2016; van Oudenhoven et al., 2018). In this context, learning from existing

* This chapter is based on: Longato, D., Cortinovis, C., Albert, C., Geneletti, D. (2021). Practical applications of ecosystem services in spatial planning: Lessons learned from a systematic literature review. *Environmental Science & Policy*, 119, 72–84. https://doi.org/10.1016/j.envsci.2021.02.001

experiences and feeding-back into science is a fundamental step to ensure the relevance of scientific findings and their usability into decision-making processes (Clark et al., 2016; Dick et al., 2018; Mckenzie et al., 2014). However, in-depth explorations of cases of ES integration looking at the whole decision-making process, as opposed to content analyses of policy documents, are only few and linked to specific projects (e.g., Geneletti et al., 2020, 2018; Jax et al., 2018; Ruckelshaus et al., 2015) or topics, e.g. participatory planning (Spyra et al., 2019). Systematic collections of practical applications of ES in decision-making processes are still lacking.

Spatial planning is one of the most relevant decision-making fields affecting ES (Cortinovis and Geneletti, 2019; Rozas-V´asquez et al., 2018), and one towards which many efforts have been directed (Scott et al., 2018). Spatial plans – including urban plans (Cortinovis and Geneletti, 2018a), landscape plans (Albert et al., 2014a), conservation plans (García-Llorente et al., 2018), and related environmental assessments (Geneletti, 2011) – are key policy instruments to coordinate human activities and minimise their negative impacts on natural and land systems (Albert et al., 2020). Specific challenges for ES integration into spatial planning processes include strong regulatory frameworks, highly codified procedures with established outputs and instruments, and consolidated professional norms that often limit cross-sectoral dialogue (Saarikoski et al., 2018). At the same time, approaches for ES integration into spatial planning have many opportunities to be replicated and upscaled, because of the widespread use of such planning around the world (Ruckelshaus et al., 2015).

Researchers have monitored the uptake and integration of ES knowledge into spatial planning processes mainly by analysing the content of plans (Geneletti and Zardo, 2016; Jaligot and Chenal, 2019; Nordin et al., 2017) or eliciting the opinions of stakeholders and decision-makers involved (Albert et al., 2014b; Mascarenhas et al., 2014; Rall et al., 2015). However, specific studies on how ES knowledge has been integrated into practical spatial planning experiences revealed that enabling factors and constraints can be captured only by tracking the co-development and use of ES knowledge along the whole decision-making process (Di Marino et al., 2019; Mckenzie et al., 2014). Factors like the presence of policy windows or active involvement of social and intellectual capital promoting ES integration (Rosenthal et al., 2015; Saarikoski et al., 2018) are unlikely

to emerge without an in-depth analysis of the whole process (Geneletti et al., 2020). Most of all, the relevance and perceived legitimacy of ES knowledge, two key factors affecting its usability (Clark et al., 2016), depend on the establishment of an effective science-policy interface during the process (Adem Esmail et al., 2017; Rosenthal et al., 2015). Therefore, an in-depth analysis of spatial planning processes successfully integrating ES knowledge is needed to understand what support ES science can offer to decision-making.
The objectives of this chapter are:

I. to map scientific publications addressing the use of ES in spatial planning, thus providing an overview of how ES science is contributing to spatial planning practices in terms of level of integration of ES knowledge, scale of case studies, and type of planning addressed;

II. to analyse case studies described in the scientific literature where ES knowledge has been integrated into real-life spatial planning processes and instruments, thus revealing advantages, enabling factors, and constraints.

Accordingly, the research combines two methods: a systematic mapping of the scientific literature and a subsequent in-depth analysis of published real-life case studies. We focus on case studies where the explicit use of the ES concept and related knowledge contributed to a formal output, i.e. (part of) a policy instrument. The selected cases allow tracking the co-development, integration, and use of ES knowledge across the whole planning process, thus revealing both the outcomes generated and the procedures adopted.

2.2 Materials and methods

The systematic review followed two main analytical steps corresponding to the research objectives (Figure 1). In the first step, we screened relevant peer-reviewed publications to map the level of integration of ES knowledge, the type of planning addressed, and the scale of case studies described therein. In the second step, we focused on a sub-sample of case studies providing evidence of ES integration into a spatial planning process and instrument, and analysed them in detail by applying a review framework.

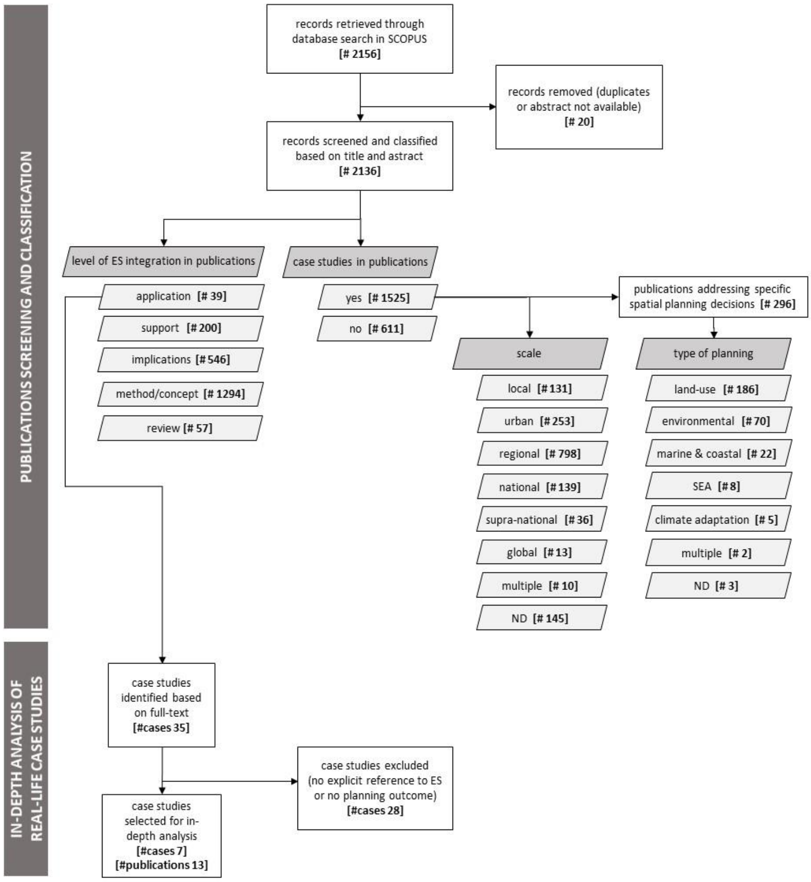

Figure 1. Flow diagram illustrating the stages of the literature review and the classifications of scientific publications. ND: Not Determined.

2.1.1 Publications screening and classification

We searched for relevant scientific publications in Scopus. After testing different combinations, we used the following string of keywords to search for publications in Scopus database (Table 1).
We selected Scopus because, compared to other databases, it has the broadest bibliographic coverage, with more than 22,000 titles from over 5,000 international publishers (Tavares et al., 2019).

Table 1. Combination of keywords used to select relevant publications.

"ecosystem service*"	AND	"spatial plan*" OR "conservation plan*" OR "strategic plan*" OR "urban plan*" OR "landscape plan*" OR "land use plan*" OR "environmental plan*" OR "territorial plan*" OR "planning process" OR "strategic environmental assessment" OR zoning	AND	case OR appl* OR integr* OR implement* OR adopt* OR inclu* OR use OR using

In addition to the term "ecosystem service*", we used a broad set of specific planning terms, including both planning typologies (e.g., "spatial plan*", "land use plan*", etc.) and related activities (e.g., "planning process", "strategic environmental assessment"), and a set of terms aimed at capturing the integration between the two. The latter covers various actions (e.g., apply/applying/application, adopt/adopting/adoption, etc.), as well as the term "case", which broadly refers to case studies. The selection of keywords was aimed at identifying right from the outset publications focusing on the integration and use of ES in spatial planning processes and instruments. The search was performed on February 21, 2019 on the title, abstract, and keywords fields and limited to all types of publications in English. It resulted in 2156 publications. After removing duplicates and studies without abstract (20), for each publication we recorded relevant data including authors, title, year and source of publication, abstract, and keywords in a database. We screened the publications in the database based on title and abstract to explore, for each publication, the level of ES integration into spatial planning considered, and the characteristics of case studies described (Figure 1).

First, we classified all the publications into the following five levels of ES knowledge integration:

- "application": publications describing case studies where ES knowledge is developed and applied as part of a planning process;
- "support": publications describing case studies where ES knowledge is developed with the explicit aim of supporting planning decisions, but outside of and with no stated impact on any planning process or instrument. Typical examples are

studies moving from an existing planning issue and proposing a possible, scientifically-sound solution based on the analysis of ES;

- “implications”: publications describing case studies where the development of new ES knowledge, although not explicitly aimed at supporting planning decisions, revealed potential implications for spatial planning (usually highlighted in the last sentence of the abstract). Typical examples are ES mapping and assessment exercises, whose results point to the need of certain planning actions or decisions, e.g. to safeguard ES provision;
- “method/concept”: publications with a methodological or conceptual focus, e.g. developing and testing new ES assessment methods or proposing innovative frameworks applicable to spatial planning. They may include a case study, but do not draw any context-specific implication for spatial planning;
- “review”: publications investigating ES integration into spatial planning practices through content analysis of planning documents and interviews with stakeholders or policy-makers.

Second, we classified each publication describing a case study into one of the following scales:

- local (e.g., plot areas, district areas, etc.);
- urban (i.e., the whole town/city, usually at the municipality administrative level);
- regional (e.g., supra municipal and subnational areas, metropolitan areas, transboundary regional areas, etc.);
- national (i.e., the whole country);
- supra-national (e.g., areas covering multiple countries – with at least one country fully included in the case study area –, continental areas, etc.);
- global (i.e., areas covering or spread over the World, such as “all the global protected areas”);
- multiple (i.e., case studies at different scales).

Third, we classified all the publications in the classes “application”, “support”, and “review” into the following types of planning:

- land-use planning;
- environmental planning;
- marine and coastal (spatial) planning;

- Strategic Environmental Assessment (SEA);
- climate adaptation planning;
- multiple types of planning (i.e., multiple case studies related to different types of planning).

Land-use planning, as understood here, mainly deals with the spatial allocation of land uses and functions, with scope and objectives beyond the mere conservation of nature. Environmental planning primarily deals with nature management and protection, including water and forest management, restoration, and conservation planning. The SEA category also includes publications that use interchangeably the term EIA to refer to the environmental assessment of spatial plans.

Publications screening and classification were performed by two of the authors. Whenever it was not possible to assign a class because of the lack of information, the field was marked as n.d. (no data). After reaching a common understanding of the categories, the authors coded the records independently, except for the uncertain ones that were discussed to reach an agreement. Overall, around 10% of the entries were cross-checked by the two coders.

2.1.2. In-depth analysis of case studies

Publications falling in the class "application" were further analysed to select the final sample of case studies for in-depth investigation. We analysed single case studies within each publication and grouped publications describing the same case study, hence the numbers of selected publications and case studies do not correspond (Figure 1). Based on the content of the full texts, we assessed if the case studies met two eligibility criteria:

- explicit use of the term "ecosystem service*" during the planning process;
- evidence of integration and use of ES knowledge in a planning process (i.e., interaction with stakeholders and/or decision-makers) resulting in a formal planning instrument (e.g., planning or policy documents such as spatial plans, Strategic Environmental Assessment (SEA) reports, etc.).

To collect relevant information and allow comparison across case studies, we designed a review framework (Table 2).

Table 2. The review framework for in-depth analysis of case studies.

GENERAL INFORMATION	
Reference publication(s)	
Case study	
Type and scale of planning	
Temporal horizon of the planning instrument	
Duration of the planning process	
KEY ASPECTS OF ES INTEGRATION INTO THE PLANNING PROCESS AND INSTRUMENT	
WHY	Policy question/planning issue addressed
	Specific reason(s) for using ES concept, as stated in the paper
WHEN/WHERE	Phase(s) of the planning process: 1. Identifying problems 2. Analysing the context 3. Defining goals and objectives 4. Developing and assessing alternatives 5. Defining actions 6. Monitoring the implementation and following-up on decisions
WHO	Institution that initiated the planning process
	ES champion(s)
	(Type of) Actors involved: • policy/decision-makers • experts and consultants • academics and researchers • economic sectors representatives • civil society representatives • individual citizens
	Degree of participation: a) Inform b) Consult c) Involve d) Collaborate/Partnership e) Empower
WHAT	Number and type of ES considered, with reasons for their selection
	Methods and indicators used for ES mapping and assessment
HOW	ES-based outputs produced
	Procedures and methods for integrating ES knowledge into the planning instrument
CRITICAL ASPECTS OF ES INTEGRATION (AS REPORTED IN THE PUBLICATION)	
Advantages	
External and internal constraints	
Enabling factors	

For most fields of the review framework, we reported a descriptive text to reflect the original content of the analysed publications as much as possible. For some other fields describing information of the planning process we used (or adapted) categorisations from the literature.

The categorisation of the phases of the planning process is based on the planning steps described in Steiner (2008) and Stoeglehner (2010), and includes the following:

1) identifying problems, i.e. the preparation phase mainly devoted to identifying existing issues and to determine needs and reasons of the planning process, and the overall goals;
2) analysing the context, i.e. the investigation phase consisting of information and data surveys and analyses to further define and clarify problems, concerns, and opportunities;
3) defining goals and objectives, i.e. the first step of the plan's drafting phase in which the planning objectives are elaborated in detail, weighed against each other and prioritised;
4) developing and assessing alternatives, i.e. the second step of the drafting phase aimed at developing plan alternatives, and measuring and assessing their impacts against planning objectives;
5) defining actions, i.e. the final decision making step where the selected solution is refined and designed in detail, including aspects related to implementation, financing, and management;
6) monitoring the implementation and following-up on decisions, i.e. the stages following the formal approval of the plan/programme, including the monitoring and continuous evaluation of the effectiveness of the planning decisions.

The categorisation of the type of actors involved in the planning process is based on the categories of stakeholders identified in Geneletti et al. (2020), but with a more detailed subdivision. It includes:

- policy and decision makers, including both those in charge of the planning process and others involved as representatives of public bodies and governmental agencies;
- experts and consultants, i.e. professionals and other experts other than academics;
- academics and researchers, other than those conducting the process;
- economic sector representatives, i.e. people representing the interests of the business sector;
- civil society representatives, e.g. NGOs and other representative of collective interests;
- individual citizens, accounting for the general public.

The categorisation of the degree of participation is based on Geneletti et al. (2020), who refer to the Arnstein's ladder of participation (Arnstein, 1969), as modified by Rau et al. (2012) and Lieberherr and Green (2018). The categories cover the whole "Spectrum of Public Participation" as defined by the International Association for Public Participation (IAP2, 2018). It includes:

a) inform, i.e. stakeholders are informed with objective information related to the decision-making process (e.g., problems, alternatives, opportunities, and/or solutions), without the possibility to provide their feedback;
b) consult, i.e. stakeholders can also have the opportunity to provide their feedback, which is acknowledged by decision makers and possibly used to influence decisions;
c) involve, i.e. stakeholders are directly involved in the process to ensure that their concerns and aspirations are consistently understood and considered;
d) collaborate/partnership, i.e. stakeholders have an active role in each aspect of the decision, including the development of alternatives and the identification of the preferred solution;
e) empower, i.e. stakeholders have full decision rights and the final decision is taken by them.

All the authors analysed the publications independently and then agreed upon the final version of the results.

2.3. Results

2.3.1. Level of integration of ecosystem service knowledge, scale of case studies, and type of planning

After removing duplicates and studies without abstract, the search resulted in 2136 eligible records, the vast majority of which (93%) were published after 2010 (Figure 2).

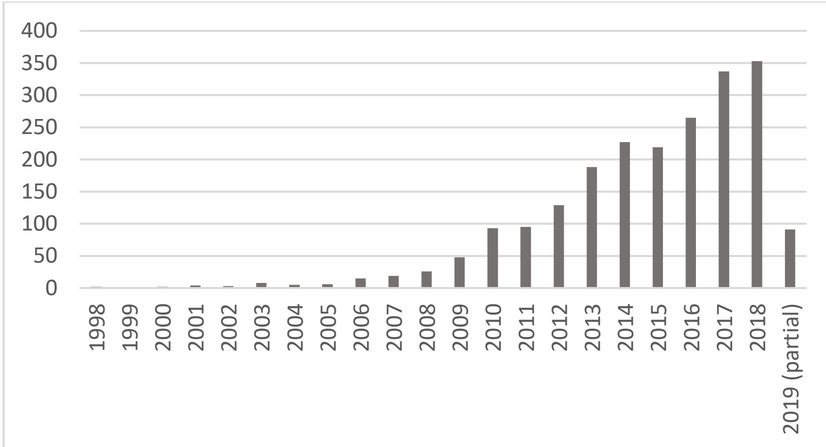

Figure 2. Number of publications per year. The year 2019 is partial because of the literature search was performed on February 21, 2019.

1,525 publications (71%) include one or more case studies. For 139 of them it was not possible to identify the country of the case study from the abstract. The remaining 1,386 publications cover 116 countries, with China (243) and USA (171) the most frequent (Figure 3). Continental and global case studies are described by 17 and 15 publications, respectively. The map reveals a quite widespread distribution around the world, with the exception of the African continent. However, it is recognizable a clear predominance of western countries such as Europe, USA, and Australia, in addition to China (similar results were found by Lautenbach et al., 2019).

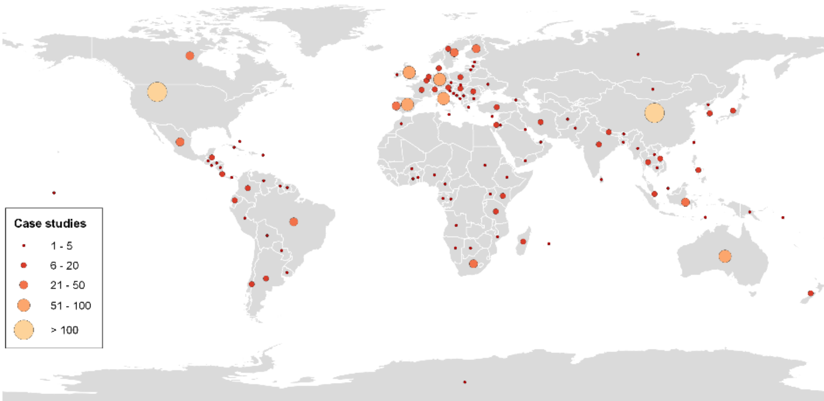

Figure 3. Location of the case studies identified in the literature review. For case studies related to more than one country, all the relevant countries were considered. Continental and global case studies are not represented in the map.

Of the 2136 publications, around 60% are methodological or conceptual studies that do not draw any context-specific implication for spatial planning (Figure 4). Another 25% are case studies in which the developed ES knowledge is claimed to have potential implications for spatial planning. Only 200 publications explicitly aim to support spatial planning decisions, while case studies where ES knowledge was developed and used as part of a spatial planning process are less than 2%. However, over the last 10 years, the share of conceptual/methodological studies has progressively decreased, while studies aimed at planning-support or with potential implications have substantially increased (Figure 4).

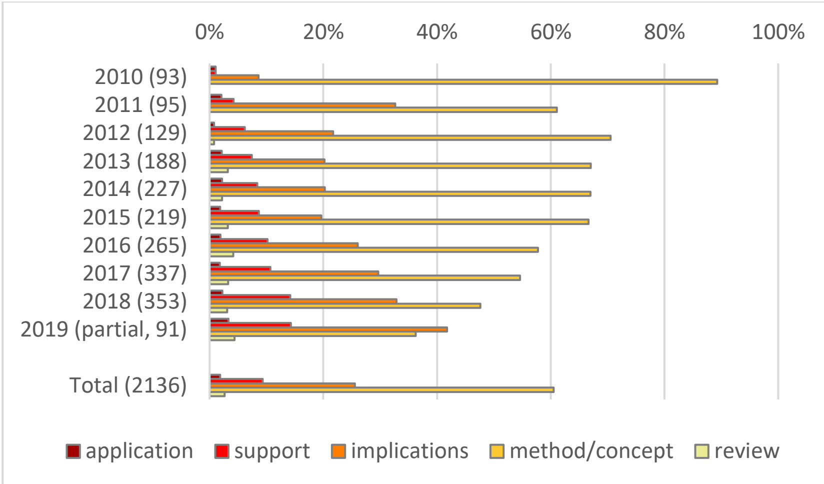

Figure 4. Percentage of publications per level of integration of ES knowledge into spatial planning: yearly results over the last 10 years and results for the overall sample. In brackets: number of publications.

Among the 1525 publications describing case studies (Figure 5a), the scale most frequently addressed is the regional one (52.3%), followed by urban (16.6%), and national (9.1%). In the subset of publications addressing specific spatial planning decisions (Figure 5b), the most common type of planning is land-use (61.8%), followed by environmental (23.6%). We found reviews covering all planning types, but no publications specifically aimed at supporting climate adaptation planning.

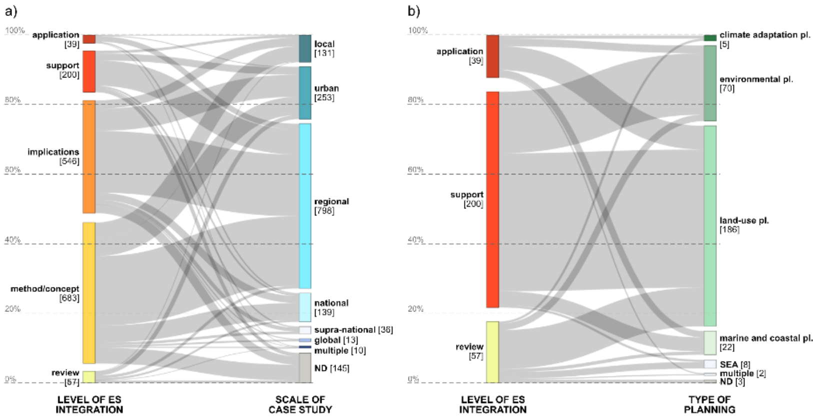

Figure 5. Frequency of the combinations of (a) level of ES integration and scale of case study, among publications including a case study; and (b) level of ES integration and type of planning, among publications addressing a specific spatial planning decision. ND: Not Determined.

2.3.2. In-depth analysis of selected case studies

In the 39 publications classified as application and screened based on the full text, we identified 35 single case studies, 7 of which were finally selected for in-depth analysis (Tables 3 and 4).

Tables 3 to 9 presents the outcomes of the in-depth analysis of each case study.

Table 3. General information and key aspects of ES integration into the planning process and instrument [Case study 1]. * (P) = Provisioning service, (R) = Regulating service, (C) = Cultural service.

Case study		City masterplan, Lathi (Finland)
Reference publication(s)		(Brunet et al., 2018)
Type and scale of planning		Land use planning, urban scale
Temporal horizon of the plan		4 years
Duration of the planning process		n.d.
Reference to plan material (available online)		https://www.lahti.fi/en/housing-and-environment/planning-of-urban-environment/city-planning/
WHY	**Policy question/ planning issue addressed**	How to incorporate the ES concept in urban planning of the city?
	Specific reason(s) for using ES concept, as stated in the paper	i) To introduce a new, more anthropogenic viewpoint on urban nature. ii) To provide a synthesizing perspective to the impact assessment of the plan.
WHEN/ WHERE	**Phase(s) of the planning process**	1. Identifying problems
WHO	**Institution that initiated the planning process**	Municipality of Lathi
	ES champion(s)	City planners
	(Type of) Actors involved	· policy and decision makers · experts and consultants · individual citizens
	Degree of participation	a) inform b) consult
WHAT	**Number and type* of ES considered, with reasons for their selection**	2 ES: preservation of groundwater quality (R) and recreation (C). The two ES are related to the plan's objectives regarding the preservation of the city groundwater area and citizens' recreational opportunities.
	Methods and indicators used for ES mapping and assessment	Land use/land cover classes used as proxies of ES supply.
HOW	**ES-based outputs produced**	A map of forest and groundwater areas as proxies of ES, which served as a tool to facilitate discussions and promoting ES as an interpretative lens through which to view the plan and its impact assessment.
	Procedures and methods for integrating ES knowledge into the planning instrument	A section on ES was included in the plan report's text.

Table 4. General information and key aspects of ES integration into the planning process and instrument [Case study 2]. * (P) = Provisioning service, (R) = Regulating service, (C) = Cultural service.

Case study		Integrated Coastal Zone Management Plan, Belize
Reference publication(s)		(Arkema et al., 2015; Arkema and Ruckelshaus, 2017; Loomis, 2015; Verutes et al., 2017)
Type and scale of planning		Marine and coastal planning, national scale
Temporal horizon of the plan		4 years
Duration of the planning process		6 years
Reference to plan material (available online)		https://www.openchannels.org/sites/default/files/literature/Belize%20Integrated%20Coastal%20Zone%20Management%20Plan%202016.pdf
WHY	**Policy question/ planning issue addressed**	Where coastal and ocean uses should be sited to reduce risk to marine ecosystems and enhance the benefits they provide to people?
	Specific reason(s) for using ES concept, as stated in the paper	i) To measure the impacts of human activities in terms of flow of benefits. ii) To be used as a dialogue tool for stakeholders.
WHEN/ WHERE	**Phase(s) of the planning process**	2. Analysing the context 3. Defining goals and objectives 4. Developing and assessing alternatives 5. Defining actions
WHO	**Institution that initiated the planning process**	Government of Belize who designated the Belizean Coastal Zone Management Authority and Institute (CZMAI)
	ES champion(s)	Scientists from the Natural Capital Project in collaboration with the CZMAI
	(Type of) Actors involved	· policy and decision makers · academics and researchers · civil society representatives · economic sector representatives · individual citizens
	Degree of participation	a) inform b) consult c) involve d) collaborate/ partnership
WHAT	**Number and type* of ES considered, with reasons for their selection**	3 ES: fisheries provision (P), coastal protection (R), and tourism recreation (C).

		Stakeholders agreed that such ES were of high economic and cultural importance.
	Methods and indicators used for ES mapping and assessment	Spatial estimates of production and economic value of ES were computed using InVEST. The models consider the extent of functional habitats and the distribution of human activities in each scenario, integrating ecological, physical, and socio-economic data. See also Arkema et al. (2014) and Arkema et al. (2019) for further details on assessment models.
HOW	**ES-based outputs produced**	Spatially explicit maps of ES supply (biophysical and economic values) in the current condition and under three future scenarios. Stakeholders selected and improved the preferred scenario by iteratively evaluating their feedback and model results.
	Procedures and methods for integrating ES knowledge into the planning instrument	The preferred scenario evolved into a science-based zoning scheme that informed the final designation of areas for preservation, restoration, and development uses in the plan.

Table 5. General information and key aspects of ES integration into the planning process and instrument [Case study 3]. * (P) = Provisioning service, (R) = Regulating service, (C) = Cultural service.

Case study		Sustainable Development Plan, Andros Island (Bahamas)
Reference publication(s)		(Arkema and Ruckelshaus, 2017)
Type and scale of planning		Land use planning, regional scale
Temporal horizon of the plan		25 years
Duration of the planning process		n.d.
Reference to plan material (available online)		https://www.vision2040bahamas.org/media/uploads/andros_master_plan.pdf
WHY	**Policy question/ planning issue addressed**	What and where public and private investments should be made to enhance food and water security, coastal resilience, transportation and connectivity, livelihoods and income inequality, and education and capacity building?
	Specific reason(s) for using ES concept, as stated in the paper	i) To understand how climate and the management decisions made today would affect the future of the island.
WHEN/ WHERE	**Phase(s) of the planning process**	2. Analysing the context 3. Defining goals and objectives 4. Developing and assessing alternatives
WHO	**Institution that initiated the planning process**	Office of the Prime Minister, with the support from the Inter-American Development Bank
	ES champion(s)	Scientists from the Natural Capital Project in collaboration with the Office of Prime Minister
	(Type of) Actors involved	· policy and decision makers · academics and researchers · economic sector representatives · civil society representatives
	Degree of participation	a) inform b) consult c) involve d) collaborate/ partnership
WHAT	**Number and type* of ES considered, with reasons for their selection**	3 ES: fisheries provision (P), coastal protection(R), and tourism recreation(C). The three ES are related to the plan's objectives regarding fisheries, tourism, and coastal resilience, the most important

		benefits that stakeholders want to secure in the future.
	Methods and indicators used for ES mapping and assessment	Spatial estimates of production and economic value of ES were computed using InVEST. The models consider the extent of functional habitats and the distribution of human activities in each scenario, integrating ecological, physical, and socio-economic data. See also Arkema et al. (2019) for further details on assessment models.
HOW	**ES-based outputs produced**	Spatially explicit maps of ES supply (biophysical and economic values) in the current condition and under several future scenarios.
	Procedures and methods for integrating ES knowledge into the planning instrument	n.d.

Table 6. General information and key aspects of ES integration into the planning process and instrument [Case study 4]. * (P) = Provisioning service, (R) = Regulating service, (C) = Cultural service.

Case study		ES framework to support spatial planning, South-East Queensland (Australia)
Reference publication(s)		(Maynard et al., 2015, 2011, 2010; Petter et al., 2013)
Type and scale of planning		Planning-support tool for land use planning, regional scale
Temporal horizon of the plan		Various temporal horizons
Duration of the planning process		4 years
Reference to plan material (available online)		http://www.seqcatchments.org/programs/planning-amp-innovation-seq-es-framework http://www.seqcatchments.org/_literature_70157/A_Guide_to_Incorporating_the_Ecosystem_Services_Framework
WHY	**Policy question/ planning issue addressed**	How to identify areas to be considered as valuable natural assets of the region, deserving appropriate protection measures or significant offsets if they are diminished or degraded in any way?
	Specific reason(s) for using ES concept, as stated in the paper	i) To direct conservation policies, environmental offsets and enhancement programmes to the right areas.
WHEN/ WHERE	**Phase(s) of the planning process**	2. Analysing the context
WHO	**Institution that initiated the planning process**	South East Queensland Catchments (SEQC), a regional non-government community-based not-for profit business established by the Federal Government
	ES champion(s)	The SEQC, acting as an interface between the government and the community
	(Type of) Actors involved	· policy and decision makers · academics and researchers · civil society representatives
	Degree of participation	a) inform b) consult c) involve
WHAT	**Number and type* of ES considered, with reasons for their selection**	28 ES (including provisioning, regulating, and cultural). The list of ES and their categories have been adapted from De Groot et al. (2002); Millennium

		Ecosystem Assessment (MA) (2005).
	Methods and indicators used for ES mapping and assessment	The assessment was based on expert judgement. Experts scored the capacity of each ecosystem type to provide ecosystem functions and associated ES.
HOW	**ES-based outputs produced**	Matrices of scores linking ecosystem categories, functions, and services, and related series of maps to be used as knowledge base for further planning processes.
	Procedures and methods for integrating ES knowledge into the planning instrument	The Framework composed of matrices of scores and related maps is now embedded in the superseding statutory regional plan and several other regional spatial policies, with the potential to be integrated into local planning schemes.

Table 7. General information and key aspects of ES integration into the planning process and instrument [Case study 5]. * (P) = Provisioning service, (R) = Regulating service, (C) = Cultural service.

Case study		Marine Spatial Plan, Latvia
Reference publication(s)		(Veidemane et al., 2017)
Type and scale of planning		Marine and coastal planning, national scale
Temporal horizon of the plan		n.d.
Duration of the planning process		16 months
Reference to plan material (available online)		https://jurasplanojums.net/english /
WHY	**Policy question/ planning issue addressed**	How to address conflicts and organise human activities in order to avoid negative impacts on marine health, functions and services?
	Specific reason(s) for using ES concept, as stated in the paper	i) To assess possible impacts of different sea use scenarios. ii) To raise stakeholder awareness concerning the importance of ecosystems in the provision of societal benefits.
WHEN/ WHERE	**Phase(s) of the planning process**	2. Analysing the context 3. Defining goals and objectives 4. Developing and assessing alternatives 5. Defining actions
WHO	**Institution that initiated the planning process**	Ministry of the Environmental Protection and Regional Development of Latvia
	ES champion(s)	The Baltic Environmental Forum – Latvia
	(Type of) Actors involved	· policy and decision makers · academics and researchers · economic sector representatives · civil society representatives
	Degree of participation	a) inform b) consult c) involve d) collaborate/ partnership
WHAT	**Number and type* of ES considered, with reasons for their selection**	7 ES: wild animals and their outputs (P), wild plants, algae and their outputs (P), bioremediation by micro-organisms, algae, plants, and animals (R), filtration by animals (R), maintaining of nursery population (R), global climate regulation (R), and experiential and physical use of land/seascapes (C). The choice of ES was influenced by data availability and knowledge of local experts.

	Methods and indicators used for ES mapping and assessment	For regulating ES, experts were asked to evaluate the link between ES and ecosystem types (yes/no). For provisioning and cultural ES, ecosystem types were scored based on a combination of expert judgement and empirical data.
HOW	**ES-based outputs produced**	ES maps representing the diversity of provisioning, regulating and cultural ES in four alternative scenarios. Optimal spatial solutions were proposed based on the results of scenarios' impact assessment and discussions with stakeholders as part of iterative assessment process.
	Procedures and methods for integrating ES knowledge into the planning instrument	Mapping results concerning the optimal spatial solutions were integrated into the environmental impact assessment of the plan.

Table 8. General information and key aspects of ES integration into the planning process and instrument [Case study 6]. * (P) = Provisioning service, (R) = Regulating service, (C) = Cultural service.

Case study		Collaborative landscape planning, Krummhörn region (Germany)
Reference publication(s)		(Karrasch et al., 2017, 2014)
Type and scale of planning		Climate adaptation planning, regional scale
Temporal horizon of the plan		n.d.
Duration of the planning process		4 years
Reference to plan material (available online)		https://www.heidekreis.de/home/bauen-planen/regional-und-bauleitplanung/regionales-raumordnungsprogramm/regionales-raumordnungsprogramm-entwurf-2015.aspx
WHY	**Policy question/ planning issue addressed**	Which land management alternatives might be suitable for a sustainable future of low-lying coastal landscapes?
	Specific reason(s) for using ES concept, as stated in the paper	i) To enrich the "social-ecological systems" framework with an ecological component.
WHEN/ WHERE	**Phase(s) of the planning process**	4. Developing and assessing alternatives
WHO	**Institution that initiated the planning process**	Researchers involved in the collaborative research project "Sustainable coastal land management: Trade-offs in ecosystem services" (COMTESS)
	ES champion(s)	Researchers of the project COMTESS
	(Type of) Actors involved	· policy and decision makers · economic sector representatives
	Degree of participation	a) inform b) consult c) involve d) collaborate/ partnership
WHAT	**Number and type* of ES considered, with reasons for their selection**	9 ES: food production (P), forage production (P), freshwater provision (P), biomass for energy (P), hazard regulation by water retention (R), prevention of saltwater intrusion (R), reduction of greenhouse gases (R), recreation and tourism (C), and community identification (C). Those ES were considered (by experts) to be affected by land

		use change in the analysed scenarios.
	Methods and indicators used for ES mapping and assessment	Land use/land cover classes used as proxies of ES supply.
HOW	**ES-based outputs produced**	A co-designed actor-based land use scenario synthesizing the former alternatives based on ES assessment results.
	Procedures and methods for integrating ES knowledge into the planning instrument	Essential elements of land use allocation developed in the actor-based scenario were implemented in the regional spatial plan.

Table 9. General information and key aspects of ES integration into the planning process and instrument [Case study 7]. * (P) = Provisioning service, (R) = Regulating service, (C) = Cultural service.

Case study		Protected area, Blanco River basin (Argentina)
Reference publication(s)		(Rubio et al., 2017)
Type and scale of planning		Environmental planning, regional scale
Temporal horizon of the plan		n.d.
Duration of the planning process		3 years
Reference to plan material (available online)		n.d.
WHY	**Policy question/ planning issue addressed**	How to delineate a protected area to safeguard the provision of ES in the wetlands, specifically the quality and quantity of water resources and the scenic beauty of the basin's landscape?
	Specific reason(s) for using ES concept, as stated in the paper	i) To design a conservation strategy that incorporates the community's perception of natural resources and ES.
WHEN/ WHERE	**Phase(s) of the planning process**	1. Identifying problems 2. Analysing the context 3. Defining goals and objectives
WHO	**Institution that initiated the planning process**	Municipality of Luján de Cuyo accompanied by the Ministry of Land, Environment and Natural Resources of the Government of Mendoza
	ES champion(s)	Researchers who led the stage related to the identification, assessment and mapping of ES
	(Type of) Actors involved	· policy and decision makers · academics and researchers · economic sector representatives · civil society representatives · individual citizens
	Degree of participation	a) inform b) consult c) involve
WHAT	**Number and type* of ES considered, with reasons for their selection**	6 ES: water for agriculture, human consumption, and industrial use (P), erosion regulation (R), regulation of the water cycle (R), regulation of the biotic environment (R), aesthetic, spiritual and non-use representations (C), and recreation and ecotourism (C). The six ES were selected according to the ranking made by the surveyed population.

	Methods and indicators used for ES mapping and assessment	Citizens were asked to identify the supply areas of the six priority ES on a land-use map. The results were used to select the most relevant land uses to be included in the protected area.
HOW	**ES-based outputs produced**	Identification of priority sites for a protected area according to the level of ES provision as perceived by the surveyed population.
	Procedures and methods for integrating ES knowledge into the planning instrument	A second proposal put forth by the Municipality was ultimately selected, disregarding the results of the participatory process, and prioritising the protection of a larger area over the provision of assessed ES.

A general objective common to most cases is to assess the impacts of and guide spatial planning decisions about land use and management (Tables 3 to 9, row "Why"). Three cases address ES integration solely in the first stages of the planning process, to analyse the planning context, to identify problems, and/or to establish objectives. The remaining ones additionally assess the impacts on ES of alternative spatial planning decisions and synthesize assessment results to define optimal spatial solutions ("When/where"). In all but one case, ES integration stemmed from a collaboration between public institutions in charge of spatial planning and scientists/researchers or non-government organizations. The actors involved in these planning processes included a wide variety of stakeholders and the level of participation was higher than the mere consultation ("Who"). In all but one case, selecting key ES by stakeholders and/or experts was preferred against covering a large number of ES. All the cases considering more than two ES included at least one for each category of provisioning, regulating, and cultural. Three common types of methods (Vihervaara et al., 2018) were adopted, sometimes combined, namely spatial proxy data (e.g., land use land cover maps), modelling tools for biophysical and economic assessment (e.g., InVEST), and scoring matrices based on expert/stakeholder judgments ("What"). Finally, the main ES outputs observed in all cases are maps showing the spatial distribution and, in some cases, levels of ES supply. The maps are either directly included among the plan documents, or used as a basis to produce the formal zoning scheme ("How").

We additionally searched for critical aspects of ES integration - i.e. advantages, constraints, and enabling factors - as reported by the authors. Most of the reviewed publications had a prevalent descriptive character, with critical reflections presented and discussed unsystematically. However, several recurring points emerged, as summarized in Tables 10 to 16. Section 2.4.2 discusses these findings in the light of the other key aspects emerging from the in-depth analysis and of the wider scientific literature.

Table 10. Critical aspects of ES integration [case study 1].

Case study	City masterplan, Lathi (Finland)
Advantages	i) ES acted as a synthesizing perspective to assess the plan's impacts on nature and human wellbeing. ii) ES allowed for a broader understanding of the human-nature relationships.
External and internal constraints	i) Multiple and overlapping scales of ES might get lost in the master plan-level maps. ii) Some aspects related to ES are not easily translatable into specific spatial units on a map. iii) Difficulties in communicating and understanding ES, especially to citizens.
Enabling factors	i) One of the city officials had a background in ES research. ii) Planning legislation requires that the impact on nature and people of plans are assessed. iii) ES were selected as one of the main focal points to work on during the previous planning round.

Table 11. Critical aspects of ES integration [case study 2].

Case study	Integrated Coastal Zone Management Plan, Belize
Advantages	i) ES secured the support of the plan from a diversity of stakeholders. ii) ES facilitated the interaction between science and policy. iii) ES facilitated explicit consideration of multiple objectives that resource managers typically evaluate separately.
External and internal constraints	i) Shadow trade-offs with unmeasured services. ii) Quality and scarcity of input data, dearth of tools, and uncertainty of models. iii) Difficulties in translating the jargon of ES into layman's terms.
Enabling factors	i) The government passed legislation in 1998 calling for cross-sector, ecosystem-based management of coastal and marine ecosystems. ii) Long-term institutional commitment and flexible resources from engaged donors. iii) Partnership with The Natural Capital Project. iv) Maps and quantitative data were some of the main reasons stakeholders were continuing to participate in the process.

Table 12. Critical aspects of ES integration [case study 3].

Case study	Sustainable Development Plan, Andros Island (Bahamas)
Advantages	i) ES facilitated explicit consideration of multiple objectives that resource managers typically evaluate separately. ii) ES helped to find synergies and minimise trade-offs in management objectives and solutions.
External and internal constraints	i) ES-related objectives might not clearly resonate with conventional planning objectives. ii) Limited understanding of local economic aspects and issues in island nations to link ES to measures of wellbeing.
Enabling factors	i) Funding opportunities from a multilateral development bank interested in connecting the development plan with subsequent loans for implementation. ii) Growing societal demand for information about ways ecosystems support economic development and human well-being.

Table 13. Critical aspects of ES integration [case study 4].

Case study	ES framework to support spatial planning, South-East Queensland (Australia)
Advantages	i) ES supported optimal land use zoning and spatial allocation of urban and industrial development. ii) ES created a common language that enabled experts from a wide range of disciplines to contribute.
External and internal constraints	i) Insufficient time, funding, and research capacity to construct complex ecological models for the whole region. ii) Lack of organization's capacity to incorporate ES assessments into planning. iii) Difficulties in tailoring ES actions due to governance and jurisdictional complexity.
Enabling factors	i) The involvement of local experts that provided credibility of results and garnered public and professional support. ii) The previous statutory regional planning document and natural resource management plan both identified the need for an ES assessment. iii) Growing interest in the use of ES for planning purposes by the SEQC and key stakeholders. iv) High value that the community of SEQ attach to environment.

Table 14. Critical aspects of ES integration [case study 5].

Case study	Marine Spatial Plan, Latvia
Advantages	i) ES enriched the perspective of the SEA since covering all relevant ecosystems, cultural aspects, and economic considerations.
External and internal constraints	i) Budget limitations, data scarcity, and high levels of uncertainty in ES mapping and assessment. ii) Difficulties in communicating ES as a justification for preventing human uses.
Enabling factors	i) The Marine Strategy Framework Directive (European Commission, 2008) that requires the application of an ecosystem-based approach to the management of human activities.

	ii) The presence of a (mandatory) Strategic Environmental Assessment of the Plan, suited for incorporating ES assessments.

Table 15. Critical aspects of ES integration [case study 6].

Case study	Collaborative landscape planning, Krummhörn region (Germany)
Advantages	i) ES enriched the "social ecological system" framework by an ecological component.
External and internal constraints	n.d.
Enabling factors	i) Partnership with a research project as an occasion to develop the informal planning process.

Table 16. Critical aspects of ES integration [case study 7].

Case study	Protected area, Blanco River basin (Argentina)
Advantages	i) ES helped to include citizens' values and perspectives in the identification of priority sites for conservation.
External and internal constraints	i) Other approaches to nature conservation can conflict with prioritising areas for ES provision.
Enabling factors	i) An initiative of permanent and temporary residents, who submitted a claim to the municipal authorities for the negative impacts on the provision of ES in wetland areas. ii) Institutional support of the Municipality of Luján de Cuyo that formed the Integrative Committee for the creation of the protected area.

2.4. Discussion

2.4.1. Main outcomes of the literature review

Despite the keywords selected to limit the results to publications dealing with integration and use of ES knowledge in spatial planning, conceptual and methodological studies remain the majority. The greater the level of ES integration, the smaller the number of publications. However, a fair number of ES studies (classified as support) are explicitly aimed at supporting spatial planning. These often involve simulations of realistic planning cases inspired by existing planning issues (e.g., Longato et al., 2019), thus potentially producing valuable and usable knowledge. The share of this type of study has steadily increased during the last 10 years.

The regional scale is the most widely targeted across all types of publications, including case study papers. This is not surprising, given that ES frameworks and assessment models, as well as ES-related decision-support tools, are primarily focused on the regional scale (Grêt-Regamey et al., 2017; Pandeya et al., 2016). Furthermore, some authors agree that the regional scale is the most suited to address certain ES in planning (Fürst et al., 2010; Mascarenhas et al., 2015). Consequently, local scale applications often suffer from poorer data availability and have to rely on coarser ES information, which may not provide reliable support to decision-making (Grêt-Regamey et al., 2014). The critical mass of human, technical, and political capacities may also play a key role in favouring ES integration in national and regional rather than in more local decision-making processes.

The analysis of spatial planning typologies reveals, beyond the most common land use and environmental plans, specific spatial planning instruments in which the integration of ES seems to be easier and more straightforward. These include Marine Spatial Planning (MSP) and SEA, where the ES concept provides a potentially useful tool to support systematic environmental assessments (Geneletti, 2011; Partidario and Gomes, 2013). This emerging role of SEA as an entry-point for integrating ES knowledge into planning processes is coherent with the findings of Mckenzie et al. (2014), who revealed that impact assessment of planning actions, including the analysis of trade-offs, is one of the main "instrumental" uses of ES knowledge in decision-making processes. MSP is a comparatively newer type of planning which addresses the co-existence and interactions of various environmental, social, and economic aspects while regulating different land and sea uses. In the EU, MSP is regulated by a legal framework (European Commission, 2008) that requires the application of an ecosystem-based approach to the management and planning of human activities, to which the ES concept is well suited. The need to balance socio-economic concerns in contexts characterised by higher environmental concerns and stricter environmental protections compared to many terrestrial ecosystems has made MSP a testing ground to experiment with ES approaches, not only in the EU (Arkema et al., 2015; Arkema and Ruckelshaus, 2017; Veidemane et al., 2017).

Finally, the small number of publications specifically dealing with climate adaptation planning might be surprising, given the emphasis on

ES-based approaches to tackle climate change-related issues (Munang et al., 2013). However, climate adaptation plans are rarely developed as standalone spatial plans. More often, climate adaptation planning is either a sectoral non-spatial planning process, or is integrated in other formal spatial planning instruments, such as in the case of the regional landscape plan in the Krummh¨orn region, Germany (Karrasch et al., 2017, 2014).

2.4.2. Lessons learned from in-depth analysis of case studies

The reviewed case studies reveal three main advantages of integrating ES into spatial planning processes. The first advantage concerns the capacity of the ES concept to broaden the scope of the planning process and enlarge the perspective on relevant issues to address. Two aspects (comprehensiveness and broadness) also listed by the stakeholders involved in the case studies presented by Dick et al. (2018). Karrasch and colleagues (2017) report on the use of ES as a way to enrich the social-ecological system framework by an ecological component. Veidemane et al. (2017) claim that the "ES approach enriches the perspective of the SEA as it covers all relevant ecosystems, cultural aspects as well as economic considerations". This shows how the ES concept provides an overall perspective to account for the social, ecological, and economic impacts of spatial planning decisions. However, it should be noted the lack of assessments of ES demand, which still is a serious challenge in ES science (Geijzendorffer and Roche, 2014).

The second advantage relates to the use of ES as a lens to synthesize and interpret multiple information. This clearly emerges in the description of the case studies in Belize and Bahamas (Arkema et al., 2015; Arkema and Ruckelshaus, 2017; Verutes et al., 2017), where the adoption of an ES approach resulting in spatially-explicit assessments led to the explicit consideration of multiple objectives, but also to the possibility of analysing the results altogether, thus helping to find synergies and minimise trade-offs through an iterative planning process. Brunet and colleagues (2018) stated that the ES approach "was used as a means to move forward from surveying and measuring toward processing and interpreting the existing data".

The third advantage concerns the use of ES as a boundary concept that facilitates interactions between multiple actors involved in the process

(Adem Esmail and Geneletti, 2017; Dick et al., 2018; Galler et al., 2016; Spyra et al., 2019). The ES concept can help to overcome communication gaps between scientists, policy-makers, and stakeholders, as in the case of Belize (Verutes et al., 2017), as well as across sectors and disciplines, as in the ES framework for South-East Queensland (Maynard et al., 2011). Rubio et al. (2017) maintain that ES served as an entry point to include citizens' values and perspectives in the otherwise fully top-down process for the identification of conservation sites.

Regarding the barriers, some are recurring to the adoption of ES in decision-making processes, for example data availability and accuracy, and lack of resources (time, competence, and money) to produce the assessments (Beichler et al., 2017; Palomo et al., 2018; Spyra et al., 2019). Brunet et al. (2018) discuss the difficulties in capturing "the multiple and overlapping scales of ES" in a plan at the urban scale, considering also that ES knowledge is not always easily translatable into specific spatial units. Similarly, several authors (Veidemane et al., 2017; Verutes et al., 2017) comment on uncertainties, errors, and simplifying assumptions of the models for ES mapping and assessment, at times not fitting the resolution required to take specific spatial planning decisions.

Other constraints are specific to ES integration into spatial planning. Linking ES goals to the objectives of the planning process is sometimes difficult, despite planning objectives implicitly or explicitly aiming to secure and enhance human wellbeing (Arkema and Ruckelshaus, 2017). The relationship between ES provision and the wellbeing of local communities is not always as straightforward in reality as it is at the conceptual level. In this context, methods and indicators used for ES assessments play a key role (Olander et al., 2018). While many efforts of ES science have focused on developing approaches, classifications, and tools as general as possible to ensure wide applicability and comparability, the case studies reveal a need for a deep understanding of the local context as a prerequisite to provide effective planning support. In fact, site differences in management goals, ecosystem function, and human use may affect the extent of ES integration (Arkema et al., 2006).

Communication is sometimes considered as a limitation, consistently with previous findings regarding stakeholders' opinion about ES (Albert et al., 2014b). For example, difficulties in communicating and understanding the ES concept, especially by citizens, were reported by Brunet et al. (2018). Some of the participants, when interviewed by the authors, made a distinction between the ES concept, helpful and enriching, and the related ES terminology. The need for scientists to work on translating the ES jargon into laymen's terms emerged also in another case (Verutes et al., 2017).

ES approaches may sometimes conflict with established spatial planning approaches. In one case, for example, the innovative approach of identifying priority conservation areas based on their relevance for ES provision was in conflict with more traditional approaches to conservation planning (Rubio et al., 2017). Eventually, the latter were chosen, demonstrating how traditionally-established professional norms and codes of conduct may prevent the integration of ES approaches into planning practices (Saarikoski et al., 2018). On the other hand, a successful integration of ES knowledge in established planning approaches and tools, such as zoning, may help to communicate ecosystem-based strategies and actions, paving the way to innovative solutions (Arkema et al., 2006). This particularly happened in the Bahamas case study, where ES assessments helped to demonstrate the importance of mangroves and other coastal habitats for reducing coastal risk, ultimately leading to a bank loan for a nature-based coastal protection project (Silver et al., 2019).

The analysed publications also report about a number of enabling factors that boosted ES integration into the planning process. Several authors identify a specific "window of opportunity" that made it possible to initiate an extra-ordinary collaborative planning process. The law approved in 1998 by the Belizean government calling for cross-sector, ecosystem-based management of coastal and marine ecosystems and the subsequent establishment of a dedicated authority with mandate to create a spatial plan is an example (Arkema et al., 2015). Similarly, in the case of the Marine Spatial Plan of Latvia, ES integration was promoted by the ecosystem-based approach required in the Marine Strategy Framework Directive (European Commission, 2008). In South East Queensland, previous statutory plans stated the need for an ES assessment, leading the path towards the participatory development of the framework and ensuring the mainstreaming of the results (Maynard et al., 2010). These cases reveal the importance of regulatory frameworks as facilitators for triggering ES integration into spatial planning.

In some cases, a supportive social environment – a broadening of what Saarikoski et al. (2018) define as "social capital" – also played a key role as an enabling factor. Arkema and Ruckelshaus (2017) highlight that "societal demand for information about the ways in which ecosystems support economic development and human well-being is growing", while Maynard et al. (2011) claims that "the impetus to develop an ecosystem services framework […] can in part be attributed to the importance the community and stakeholders attach to the environment". Then, perhaps not surprisingly, almost all authors reflect on the importance that "people" (Rosenthal et al., 2015) had for a successful integration of ES. This refers to the "policy champions" (Saarikoski et al., 2018) who promote ES integration: sometimes researchers and scientists, sometimes the institutions responsible for the planning process, or even stakeholders, as in the case of Latvia (Veidemane et al., 2017). But it also refers to the wider "intellectual capital" (Saarikoski et al., 2018) involved in the process, including scientists, planners, and experts of different sectors. For example in Lathi, where "one of the city officials had a background in ES research" (Brunet et al., 2018), or in South East Queensland, where problems of data availability were overcome thanks to local knowledge, which also enhanced credibility and legitimacy of the results (Maynard et al., 2011).

Overall, the analysed case studies suggest that the involvement of a wide variety of stakeholders is linked not only to a higher degree of participation, but also to more substantial and meaningful ES-based planning outputs. This is also true for the very first step of ES integration, i.e. the selection of ES to assess. An iterative science-policy interface (Rosenthal et al., 2015) and a process of knowledge co-production (Saarikoski et al., 2018) with planning institutions, ES champions, and other stakeholders involved emerge as essential factors to initiate and successfully complete the process of ES integration into spatial planning.

2.4.3. Limitations of the study

The keywords used in the search string, necessarily arbitrary, affected the results of the study. This is particularly true for the terms used to capture the integration between ES and spatial planning, but it also applies to the keywords related to spatial planning, mainly based on western countries' terminology and possibly overlooking definitions specific of other contexts. For example, we may have overlooked more studies dealing with MSP that did not explicitly use the term "spatial plan*" and studies dealing with water management planning. However, our search strategy was able to capture some studies in these fields that explicitly highlight the spatial dimension of planning, which is the primary focus of our analysis.

In addition, we searched publications only in Scopus, and did not consider grey literature, even though it could be a valuable source of case studies (Laurans et al., 2013). We focused our analysis on a homogeneous set of peer-reviewed publications that analyse the process of ES integration from a critical perspective, more likely to be found in scientific than in grey literature. However, this might have influenced some of the results, such as the fact that most of the ES champions found in the case studies are researchers. Furthermore, other case studies of ES integration mentioned in the literature (e.g., in publications classified as reviews) were excluded since providing insufficient information on the whole planning process and decisions that led to ES integration, which is the core objective of our review.

Finally, our synthesis of critical aspects is based on the information reported in the publications. The extent to which they reflect evidence produced during the planning process as opposed to the authors' perceptions and opinions is impossible to ascertain. However, the peerreview process should guarantee scientifically sound results, and we found correspondence for most of the findings in the wider scientific literature.

2.5. Conclusions and main open issues with respect to Nature-based Solutions

Our results revealed that methodological and conceptual studies are still the majority in scientific literature, while case studies with policyrelevant applications of ES are very few, confirming the mismatch between ES science and its use in practice (Lautenbach et al., 2019). Over the last few years, we observed an increase in the share of applied studies explicitly aimed at supporting spatial planning decisions, not just by providing usable tools and methods but trying to address real-world planning issues. However, such knowledge can produce a real impact only if the policy question is committed by decision-makers and if the process of knowledge (co-)production is incorporated within a planning process, eventually resulting in a formal policy instrument or programme.

The main advantages of introducing ES knowledge in spatial planning processes emerged from the case studies are: i) a broader inclusion of relevant issues to address during the planning process, ii) a synthesizing perspective to interpret multiple data and information, and iii) an effective involvement of stakeholders with higher degree of participation. Overall, this can contribute to legitimate decisions dealing with more sustainable spatial allocation of uses and management options. One of the most important factors may trigger ES integration is the "window of opportunity" offered by high-level regulatory frameworks (e.g., at national or EU level) promoting ES-based approaches, or by new planning processes and tools (e.g., SEA and MSP) more open to innovative concepts. However, also bottom-up initiatives such as informal planning processes with researchers and citizens' claims may push authorities to achieve this integration into statutory spatial planning.

The cultural background of policy-makers, stakeholders, and citizens seems to be a crucial pre-requisite for promoting ES integration into planning processes. In most of the analysed case studies, ES integration occurred because of the commitment of policy-makers and stakeholders and their high awareness of ES importance. This need for a "fertile ground" suggests limitations to the conceptual use of ES as the entry point to promote environmental awareness and pro-environmental attitudes, at least within spatial planning processes. Rather, the main advantages emerged point to practical aspects related to the instrumental use of ES knowledge, such as its usefulness in synthesizing and facilitating the understanding and use of complex socio-environmental information. However, specific contextual conditions are necessary for a successful integration, including the establishment of a science-policy collaboration across all stages of the planning process.

Overall, ES knowledge integration into real-life planning processes and instruments has shown a clear trend towards providing baseline information on ES supply, mainly applied to account for the impacts of spatial planning decisions, sometimes supporting the comparative assessment of different scenarios. This highlights a recurring tendency of using ES knowledge to identify areas for conservation purposes (e.g., preserving valuable ecosystems from land use change) or to reduce the impact deriving from future developments and functions allocation, rather than to properly include ecosystem-based development and management solutions to address current challenges. Only in one case there was an explicit reference to the use of the concept of societal demand (or needs) for ES during the planning process (Krummhörn case study (Karrasch et al., 2017, 2014)), although not spatially assessed. In this case, the outputs of the process were related to the inclusion of sustainable land use and management practices as a solution to address current societal challenges concerning climate-related impacts. In another case, a nature-based project was instead indirectly promoted by the maps of coastal protection provided by ecosystems, which made explicit the effectiveness of existing natural habitats to contrast coastal hazards (Silver et al., 2019), hence laying the foundation for replicating this kind of approach in other risk areas.

While these cases showed how the use of ES knowledge can stimulate the inclusion of NbS in planning decisions, a systematic integration of the demand side in ES mapping and assessments could lead to a more widespread uptake of NbS in spatial planning. Knowledge about the demand for specific functions and services provided by ecosystems, and vegetation in general, has been claimed to be crucial when it comes to the implementation of measures and the use of resources (Hoerbinger et al., 2018). However, contrary to ES supply, only few applications have attempted to assess and incorporate ES demand to support decisions (Larondelle and Lauf, 2016), despite the explicit consideration for the demand side and the identification of beneficiaries should be among the main improvements brought to the urban planning practice by the ES concept (Cortinovis and Geneletti, 2018a).

Among all spatial planning processes, urban planning has a main role in definingthe distribution of people and functions in the land, causing harmful environmental impacts but also determining the exposure of population to socioenvironmental pressures (Cortinovis and Geneletti, 2018a). At the same time, urban plans have the possibility to act where the demand for ES is the highest byputting in place specific actions and measures towards more sustainable and resilient delevopment and management of areas through appropriate implementation tools.

Advancing and incorporating ES demand mapping and assessment to support the implementation of (nature-based) solutions that address the existing challenges and provide benefits to citizens thus appears to be one of the main topics on which future studies, as well as future planning practices and processes, should focus.

Chapter 3

The case study of Valletta, Malta*

3.1 Introduction

This chapter presents the case study site of Valletta urban area (Malta), describing and analysing its spatial planning system and the main spatial characteristics in order to depict actual opportunities for mainstreaming and scaling up NbS, from both a spatial (i.e., available space) and planning (i.e., local planning regulations) point of view. In particular, it illustrates the analyses carried out to identify the available sites that may represent an opportunity for implementing NbS on the ground, called spatial opportunities for NbS, while discussing possible implementation options that can be derived according to the current planning regulations considered relevant for promoting NbS implementation.

To increase the uptake of NbS in urban planning, there is a need to know where and how much space exists for their implementation (Cortinovis et al., 2022). Spatial opportunities for NbS represent possible locations where proper conditions exist for their implementation on the ground (Guerrero et al., 2018). The identification of spatial opportunities for NbS is a key step towards identifying, planning, and actually implementing NbS, and can support the development of concrete options of NbS (Brillinger et al., 2020).

Such preliminary analyses, despite offering an overview of the case study and its potential to mainstream and scale up NbS, are instrumental to support the empirical applications developed and presented in the next chapters (Chapter 4 and Chapter 5).

3.2 Overview of the Maltese spatial planning system

Spatial and land use planning in Malta is regulated by the Development Planning Act of 2016, which lists the legal plans and policies in effect

* Part of this chapter is adapted (and figures and tables reprinted) by permission from Springer Nature Customer Service Centre GmbH: Springer Nature. Longato, D., Cortinovis, C., Balzan, M., Geneletti, D. (2022). Identifying Spatial Opportunities for Nature-Based Solutions Planning in Cities: A Case Study in the Area of Valletta, Malta. In: La Rosa, D., Privitera, R. (eds) Innovation in Urban and Regional Planning. INPUT 2021. Lecture Notes in Civil Engineering, vol 242. Springer, Cham. https://doi.org/10.1007/978-3-030-96985-1_12

on the Maltese islands that are to be considered when assessing development proposals (Government of Malta, 2016).
According to the Development Planning Act, on top of the spatial plan' hierarchy (meaning that underlying plans need to comply with the superordinate regulations and indications) there is the national "Spatial Strategy for Environment and Development", which is a strategic document that provides a long-term spatial strategy at national scale for the sustainable management of land and sea resources and the future distribution of development in line with the government's policy aims and objectives.
On a sub-national level, subsidiary plans represent the suite planning instruments that deal with more specific development planning in conformity with the national spatial strategy. They include subject plans, local plans, action plans or management plans, and development briefs. While subject plans address a specific planning matter and are generally applied to all relevant areas at the national scale, the others deal with development planning of a specific region or area. Local plans regulate land uses and functions of specific regions. Action plans or management plans, and development briefs instead set out more detailed policies and guidance exclusively targeted to specific areas/sites where development planning cannot be regulated solely on the basis of the local plans.
Among the subsidiary plans, local plans represent the cornerstone when it comes to land-use management. In total, there are seven local plans in the Maltese islands. They are aimed to regulate the land uses and functions and deal with the specific development planning requirements of an area by setting out detailed development policies for each of the 68 localities against which development requests are assessed. They provide land-use zoning and related indexes and parameters, define standards and other criteria to which development must conform, and indicate where development can take place and where protection from development is instead required, the type of development, and the criteria against which development proposals are to be assessed. Their overall strategy is "to improve the quality of the environment for the population living within the respective local plan areas and to ensure that sufficient provision of land has been made to meet demands not only with regard to housing and employment, but also to accommodate facilities such as social and community and recreational facilities. The strategy seeks to make efficient use of the land designated for

development through various policies, including a policy of containment of existing settlements" (Fomosa and Gauci, 2021).
The functions of the Maltese local plans can be comparable to those of a generic urban land use plan that defines land use and development policies and regulations at the municipal or metropolitan scale, typically used in other planning contexts (e.g., OECD, 2017), making them the most appropriate planning level to pursue NbS mainstreaming in urban areas.

3.3 Study site description

The case study area is defined by the boundaries of two out of the seven Local Plans covering the Maltese islands: the North Harbour Local Plan and the Grand Harbour Local Plan, respectively approved in 2006 and 2002 with subsequent partial revisions. It covers a total surface of 2363 ha and includes the city of Valletta and the surrounding compact urban agglomeration constituted by seventeen urban localities (called Local Councils) that form a unique urbanised continuum. Both Local Plans deal with the respective areas by adopting a twofold approach, that is setting a strategy that relates to wider issues of importance in the whole plan area, and bringing forward more detailed policies and proposals for individual localities. The North Harbour Local Plan area includes a total of nine Local Councils: Msida, Ta' Xbiex, Gzira, San Gwann, Pieta`, Sliema, St. Julian's, Swieqi, and Pembroke. The Local Plan area is predominantly urban and the land use is mainly residential, but with significant tourism-related uses and facilities (Malta Environment and Planning Authority, 2006). The Grand Harbour Local Plan deals with the main port area of Malta and those towns and industrial sites immediately surrounding the Grand Harbour itself. It includes a total of eight Local Councils: Valletta, Floriana, Marsa, Kordin, Senglea, Cospicua, Vittoriosa, and Kalkara. Besides the historical and cultural heart of Malta (Valletta and other historical fortified towns), the plan also includes densely populated residential areas, maritime-related activities, and heavy industrial uses, notably the Power Station at Marsa, and Malta Drydocks and Shipbuilding, which account for a significant workforce (Malta Environment and Planning Authority, 2002).

With a population density of almost 1400 inhabitants per km² and 21 guest nights per inhabitant (Eurostat, 2017), as well as almost a quarter (23.7%) of land covered by artificial surfaces (Eurostat, 2018), this small island state stands out for having the highest population density, tourism intensity, and share of man-made surfaces in all the EU. The case study is located in the most urbanised portion of the island, thus it is characterised by even higher rates of population density and artificial surfaces. Urban land uses cover a significant proportion, with almost 80% of artificial surfaces, while agricultural and natural/seminatural areas cover respectively 7% and 12% (Figure 6). It includes one of the major areas for tourism along the coastal belt from Sliema to Paceville, densely populated residential areas, heavy industrial uses together with maritime-related activities, several areas with significant natural elements, especially in the valley areas, and limited urban open and green space due to the densely populated nature of the region. However, the coastline forms an important area of open space and the majority of it is accessible and used for recreational purposes. In addition, the study area also contains the main public hospital, the University of Malta and the San Gwann Industrial Estate.

The case study is therefore relevant for NbS mainstreaming that could address a number of socio-economic and environmental challenges particularly felt in Malta, including exposure to pollution and climate-related hazards, and lack of green infrastructure and related benefits in urban core areas (Balzan et al., 2020, 2021).

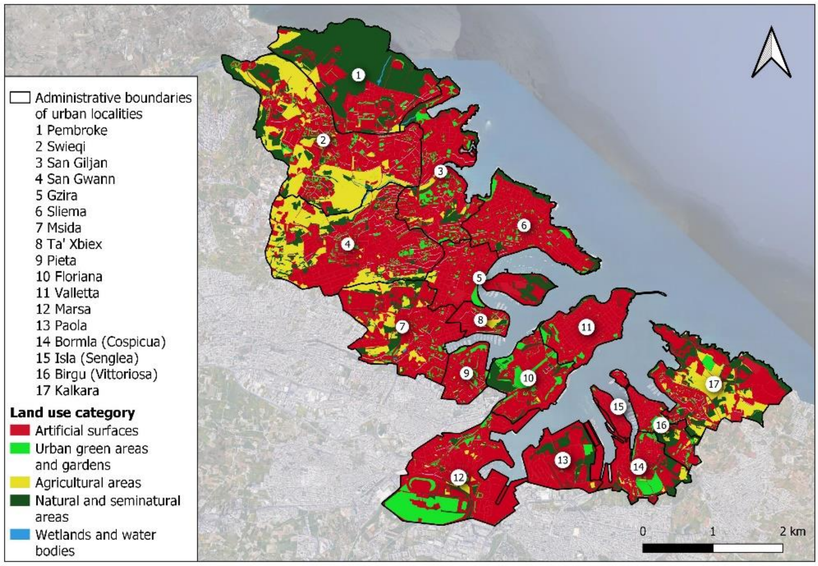

Figure 6. Administrative boundaries of the case study area and main land uses.

3.4 Identification of spatial opportunities for Nature-based Solutions

The approach used to identify spatial opportunities for NbS is based on two steps. Actually, besides the identification of physically available open space for NbS through spatial analysis, spatial policies adopted in the urban plans covering the study area are analysed to identify further opportunities and options for implementing NbS that cannot be identified through simple spatial analysis of open spaces (e.g., integration of NbS into the existing built-up spaces, public spaces and infrastructure, etc.).

We first identified urban open spaces (of undeveloped land) potentially suitable for the implementation of NbS on the ground. These are called physical opportunities. In order to avoid over-estimating the amount of space for effective (in terms of benefits to citizens) urban green (Fletcher et al., 2021), as well as the land take of areas that are not intended for urban uses such as farmland and natural spaces, only open spaces located within the urban footprint were considered. The urban footprint is represented by the area located within the development boundaries and/or urban conservation areas established by the local plans. Development boundaries enclose the area within which it is possible to apply for building permits and, thus, where land use change to urban uses is allowed. Urban conservation areas cover already urbanised areas where special attention is paid for the historical and landscape character of the built environment. The map of open spaces with urban ecosystem types developed for the case study area in 2017 (Balzan et al., 2021) during the EnRoute project (available at: https://oppla.eu/casestudy/19309) – further updated through photo interpretation to account for land use changes during the 2017-2020 period – was used as baseline for the identification of the physical opportunities by excluding open spaces outside the urban footprint or characterised by land cover categories that are unsuitable for land transformation (i.e., cliffs, beaches, wetlands, watercourses, garden areas, and open spaces within major government institutions). Consequently, physical opportunities mainly cover peri-urban zones potentially destined to city expansion, infill development sites, decommissioned sites, and open spaces whitin the urban fabric that are preserved from development.

Second, we mapped the areas and sites identified by the local plans' spatial policies and regulations as target spaces for NbS-related interventions, namely for the conservation, enhancement, or restoration of existing, and creation of new ecosystems (Cortinovis and Geneletti, 2018a). These are called opportunities related to planning regulations. We carried out a qualitative content analysis of the local plans to identify the spatial policies promoting NbS interventions (i.e., policies involving planning actions that explicitly include green elements, such as trees, green spaces, urban parks and playgrounds, and any kind of greenery associated with specific sites) and the related target areas and sites. They include development areas where developers are required to include green elements, green/open spaces to preserve from development, and public spaces (e.g., streets, plazas, pedestrian zones) and other sites (e.g., industrial activities, office complexes) to enhance through environmental improvements (e.g., street greenery, planting and landscaping measures for aesthetics or mitigation purposes). Once mapped, they were added to the physical opportunities to set up the final map of spatial opportunities for NbS.

A total of 332 ha of spatial opportunities for NbS were identified, corresponding to 14% of the case study area. 207 ha are covered by physical opportunities, namely urban open spaces, and 188 ha by opportunities related to planning regulations, with 63 ha covered by both typologies. When overlapping, the two typologies cover open spaces designated by the spatial policies to future development schemes or to ecosystem conservation and/or improvement actions. Opportunities related to planning regulations that do not overlap the physical opportunities instead cover elements of the built environment that are not identifiable through open space analysis, such as streets and other public and private built-up sites. Table 17 shows the different land use and cover categories characterising the areas mapped as spatial opportunities for NbS.

Table 17. Land use and cover categories of the areas mapped as spatial opportunities for NbS.

Typology of spatial opportunities	**Land use and cover category**	**Notes**
Physical opportunities, including opportunities related to planning regulations that overlap them	Brownfield land, or land within urban zones which was not developed and is not used for agriculture	Typically disturbed through human action
	Abandoned agricultural areas	Land use change to urban uses allowed
	Agricultural areas (arable, permanent crops)	
	Natural grassland	Land use change to urban uses allowed, except for conservation areas
	Shrubland	
	Woodland	
Opportunities related to planning regulations that do not overlap physical opportunities	Residential areas	-
	Commercial areas	-
	Industrial areas	-
	Roads and associated land	-
	Other public spaces	Squares and pedestrian areas, waterfront areas

As shown in Figure 7, significant physical opportunities are located in the northern part of the study area, namely in the urban localities of Pembroke and Swieqi, in the western part of Msida, in Manoel Island, in Floriana, and the southern part of Cospicua and Birgu. The central part with the touristic coastal belt has the lowest presence of spatial opportunities for NbS, especially in the localities of Sliema, San Julian, Gzira, San Gwann, and Pieta, together with Valletta and Senglea, the two historical and most compact cities.

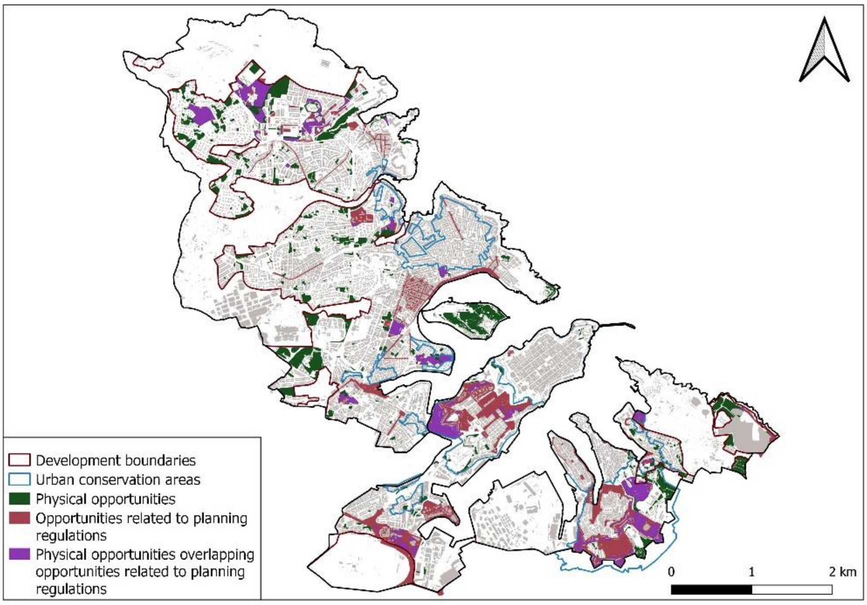

Figure 7. Spatial distribution of the spatial opportunities for NbS.

The distribution of the opportunities related to planning regulations is quite scattered. Floriana, Marsa, and Cospicua show significant opportunities, contrary to the capital city of Valletta and, to a lesser extent, the towns of Senglea, Sliema, San Gwann, and Pieta. Figure 8 shows the spatial distribution of the opportunities related to planning regulations classified in four main typologies of NbS interventions based on the scope and target area of the intervention: conservation of open and green spaces, sites for urban transformation and/or development that require the integration of green elements, environmental improvement of public spaces, and environmental improvement of existing urban sites. Respectively, they cover 106 ha, 42 ha, 28 ha, and 31 ha. However, except the areas for open and green space conservation that fully correspond to the available space for NbS implementation (like the physical opportunities), the areas corresponding to the other categories do not correspond to the available space for NbS, which are expected to be implemented only in a portion of the mapped site. For example, in the case of a street or public space identified for environmental improvement the space available for the greening intervention (e.g., street trees, public greenery) will be a portion of and not the whole street/public space area mapped.

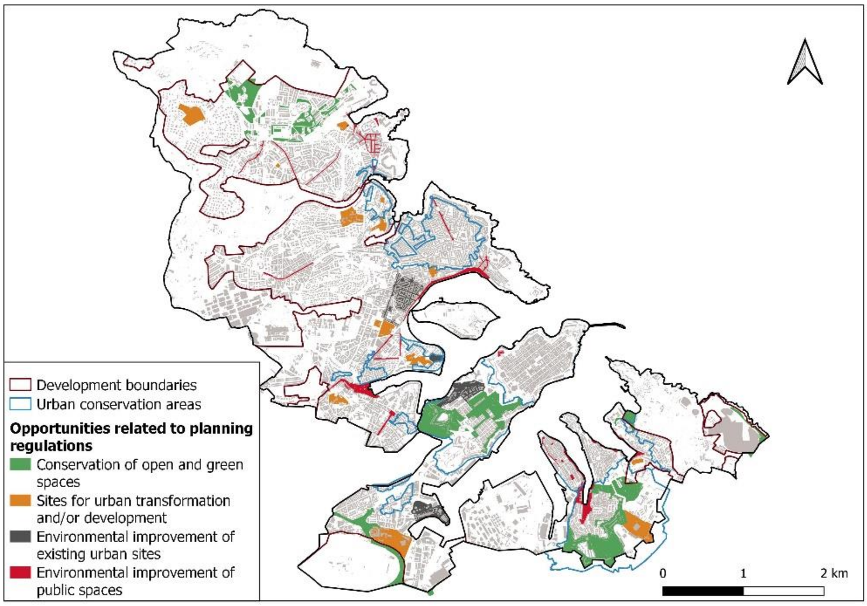

Figure 8. Spatial distribution of the different typologies of opportunities related to planning regulations.

3.5 Discussion and conclusions

In this chapter, spatial opportunities for NbS on the ground in the urban agglomeration around Valletta were identified. They are represented by undeveloped open spaces detected through spatial analysis (called physical opportunities) and the areas and sites identified by the urban planning instruments as target spaces for NbS-related interventions through content analysis of the local plans' spatial policies (called opportunities related to planning regulations). Some of the areas mapped as opportunities related to planning regulations overlap the physical opportunities, namely those targeting open space areas. The others are targeted to built-up spaces (e.g., streets and other public spaces, existing built-up sites, etc.), thus allowing the identification of further potential for implementing NbS that otherwise is not possible to capture solely on the basis of the spatial analysis. The two typologies of spatial opportunities can therefore be considered complementary in providing a more comprehensive picture of the space that is potentially available for implementing NbS, which could include: the creation of new ecosystems within the available open spaces through medium- and large-scale NbS projects (e.g., urban forests and parks); the integration of small-scale NbS interventions into the built environment (e.g., trees, playgrounds, and sustainable urban drainage systems), also through restoration interventions (e.g., de-paving public spaces); the conservation and/or enhancement of existing urban ecosystems (e.g., formal and informal green spaces). Moreover, the identification of the opportunities related to planning regulations revealed possible NbS implementation options that can be promoted through specific policies and instruments and potentially scaled up within the rest of the open space areas identified as physical opportunities. These include the definition of standards and requirements to apply when transforming an area (e.g., from agricultural to residential land use) with the objective to integrate NbS in the project, the definition of natural conservation zones or open space areas to be preserved from development and dedicated to greening interventions, and the promotion of best practices and criteria that include NbS in the design and improvement of public and private spaces. In particular, areas for new development and transformation projects by privates could integrate greening elements early on during the planning process with the interventions paid off by private developers, while their integration into the existing private spaces requires retrofitting interventions that can be mainly promoted through economic incentives provided by the public.

Overall, the spatial opportunities identified are not equally distributed among the study area and, for this reason, there may be significant city areas that cannot benefit from their implementation. However, a fair number of (public) open spaces that were not initially included within the spatial opportunities – because of covering areas with already established uses and functions, thus not meant for generic land use transformation and development – could offer further opportunities for NbS in such city areas that lack proper spatial opportunities. For example, existing public gardens could be re-designed not only to fulfil the recreational functions but also to accommodate, where possible, specific NbS to address urban challenges without affecting the recreational value and accessibility. Possible solutions may include floodable areas within specific portions of urban parks to reduce stormwater runoff, increased canopy cover to provide more shadow and reduce temperature and air pollution, and increased permeable soil in highly paved garden areas to improve water infiltration and carbon storage. Another opportunity is offered by the incorporation of green elements that go beyond the mere aesthetic purpose into the street and public space greenery to mitigate specific issues at the local scale, especially those requiring ES supplied by linear green infrastructures such as noise reduction and moderation of extreme events (Cortinovis and Geneletti, 2019). Possible NbS that may be introduced in such spaces include vegetation buffers to shield traffic noise or linear rain gardens and bioswales to reduce stormwater runoff in streets and highly impervious public areas. However, site-specific considerations are required to assess if enough space and technical feasibility exist for introducing such elements (e.g., vegetated noise barriers require a minimum width and multi-layered vegetation to perform the noise shielding function (Cortinovis and Geneletti, 2020)).

The mapping of spatial opportunities for NbS could offer a valuable tool that can be used as an entry point for planning NbS distribution and implementation. For example, when combined with ES mapping and assessment including both the demand and supply side, it can support decision-making to identify priority sites for NbS interventions, whether it is the conservation of existing ecosystems to secure ES provision, or the enhancement of existing and creation of new ecosystems in areas with high ES demand. In particular, the distribution of population and physical assets determines the demand for ES (Langemeyer et al., 2016) that, together with the spatial configuration of the societal challenges and related hazards, can be used to assess and map the distribution and magnitude of the ES demanded across a city (e.g., (Cortinovis and Geneletti, 2020)). Such knowledge is necessary to prioritize and locate the right solution, which delivers the right ES, in the right (available) place, which can be identified in the map of spatial opportunities.

Finally, the identification of spatial opportunities may help to analyse what city areas may benefit from NbS implementation on the ground and where there is instead the need to design and integrate solutions that do not require space on the ground (e.g., green roofs and walls).

The elements analysed and discussed in this chapter constitute the background for the applications shown in the following chapters.

Chapter 4 shows a practical application of ES mapping and assessment to allocate and prioritize NbS on the ground within the spaces mapped as physical opportunities in the Valletta case study area. Chapter 5 presents an overview of the suitable policy instruments that can be used to promote the implementation of different typologies of NbS in urban plans and analyses which instruments are currently used and which are not in the two local plans covering the study area.

Chapter 4

A method to prioritize and allocate Nature-based Solutions based on ecosystem service demand*

4.1 Introduction

This chapter moves from the results of the literature review in Chapter 2 to propose an operational approach for NbS selection and allocation based on the spatial assessments of ES. The application of ES demand mapping and assessment to support concrete planning decisions has been identified as one of the main open issues related to the application of ES knowledge in spatial planning, which still is a quite underexplored field especially when it comes to supporting NbS planning. Here, an innovative methodological approach is developed and applied in the study area of Valletta to support an effective allocation of NbS within the available sites (identified in Chapter 3) in order to maximize the delivery of benefits (i.e., ES) to residents. The proposed approach is based on the mapping and assessment of the demand for a set of ES that are considered particularly relevant to address the existing challenges, thus prioritizing NbS typologies and locations that deliver the most needed ES.

Ecosystem services (ES) mapping and assessment is considered an important tool for policy-makers to better understand the spatial links between ecosystems and their benefits for society (Burkhard and Maes, 2017; Feurer et al., 2021). Hence, advancing mapping and assessment methods is essential for ensuring proper consideration and integration of ES into planning practices (Goldenberg et al., 2017; Gómez-Baggethun and Barton, 2013, Mörtberg et al., 2017). Spatially explicit mapping and assessment of ES supply and demand can be used to “spot problem areas in need of intervention” (Bagstad et al., 2013), thus leading to more informed planning decisions dealing with the spatial

* This chapter is based on: Longato, D., Cortinovis, C., Balzan, M., Geneletti, D. (in review). A method to prioritize and allocate Nature-based Solutions in urban areas based on ecosystem service demand. *Landscape and Urban Planning.*

allocation and prioritization of interventions to tackle societal challenges and provide socio-environmental benefits through ES (Cortinovis and Geneletti, 2018b). ES supply reflects the capacity of ecosystems to deliver ES, while ES demand focuses on the beneficiaries of such ES and their level of need or dependence on them (Yahdjian et al., 2015). Understanding demand for ES is therefore fundamental to decision-making (Chan and Satterfield, 2020; Chen et al., 2019; Honey-Rosés and Pendleton, 2013) as it can be to identify where and which ES are most needed in relation to the targeted beneficiaries.

This is especially important in urban areas where the demand for ES is accelerating due to rapid urban growth (Charoenkit and Piyathamrongchai, 2019; Elmqvist et al., 2015, Gómez-Baggethun et al., 2013). Promoting urban greening through nature-based solutions (NbS), which are purposely designed to deliver multiple ES, is considered one of the key planning actions to address multiple urban challenges (Babí Almenar et al., 2021; Escobedo et al., 2019; Raymond et al., 2017), while enhancing human wellbeing (Frantzeskaki et al., 2019). The implementation of multifunctional NbS in urban areas is thus considered as an opportunity to deliver ES, such as temperature and runoff regulation (Venter et al., 2021), where they are most needed. This requires considering the spatial variation of environmental issues and urban pressures (e.g., air pollution, urban heat island effects, reduced soil permeability and access to nature) that determine the demand, as well as of the distribution and specific characteristics of the population (Cortinovis and Geneletti, 2020). In this context, the spatial assessment of ES can be used to understand ES flows, i.e. the spatial links between ES supply and demand areas (Bagstad et al., 2013; Schirpke et al., 2019), in order to identify priority sites where the ES supplied by NbS can reach the targeted beneficiaries (Verhagen et al., 2016).

However, real-life planning processes and documents that consider ES rarely address the demand side of ES (e.g., Longato et al., 2021; Cortinovis and Geneletti, 2018a). Even in studies on ES prioritization, the spatial variation of the demand is not always accounted for (Verhagen et al., 2016), potentially hindering planning decisions that involve the allocation of NbS to address the specific urban challenges affecting the different areas of the city. Notable exceptions include the work by Langemeyer and colleagues (2020), who mapped the demand for several ES in Barcelona, Spain to spatially prioritize green roof installations that provide the demanded ES in the city areas where they are most needed. Similarly, Cortinovis and Geneletti (2020) spatially assessed the supply of and demand for multiple ES in Trento, Italy, and developed an innovative performance-based planning approach to define NbS requirements for urban transformations based on such assessments. Both studies coupled ES demand mapping to define ES spatial prioritization with an estimation of the capacity to provide the needed ES by different types (or designs) of NbS. This capacity is expressed by numeric scores assigned to the NbS for each ES analysed. However, the former study focuses only on a specific type of NbS, while the latter identifies the preferred NbS based on the most demanded ES, without accounting for their multifunctionality. A multi-criteria analysis tool was recently developed to select suitable NbS based on their potential benefits in terms of multiple ES, thus capturing their multi-functionality (Croeser et al., 2021). However, the selection of priority ES is made here for the whole city, disregarding the spatial variation of the demand. Studies that combine the spatial assessment of ES demand with a scoring system that accounts for the multi-functionality of different NbS types are still missing, despite their potential usefulness in supporting planning decisions on prioritization and allocation of NbS.

The aim of this chapter is to develop and test a method to allocate different types of NbS in urban areas to deliver the most demanded ES. On the one hand, the method maps the demand for multiple priority ES in a city. On the other hand, it assesses the capacity of different types of NbS to supply the selected ES, adopting numeric scores that are estimated based on data collected from the literature. It then combines the results of the analysis to optimize the allocation of NbS. The method is applied to prioritize and allocate NbS within potentially available sites in the Valletta urban area, Malta.

The remainder of the chapter is organised into four main sections. Section 4.2 presents the case study area, the input data, and methodological steps of the proposed approach. Section 4.3 presents the results, including maps of the demand scores of potential NbS sites, a look-up table with the supply scores of selected NbS types, and the priority NbS identified in each potential site. Section 4.4 discusses the results and innovative aspects and limitations of the approach, and provides examples of the possible uses of the proposed approach to support planning decisions. Finally, Section 4.5 provides the conclusions of our study.

4.2 Materials and methods

4.2.1 Study area, potential Nature-based Solutions sites, and priority ecosystem services

The study area is the urban area around Valletta, the capital city of Malta. The case study area covers around 2,227 ha and includes seventeen urban localities that form a unique conurbation with scattered agricultural and natural/seminatural areas and urban green spaces (Figure 9). A detailed description of the study area is provided in Section 3.3.

To identify potential sites for NbS, we used the map of “physical opportunities” prepared by Longato and colleagues (2022) (see Chapter 3), who mapped the sites that potentially offer an opportunity for implementing NbS based on the map of urban ecosystem types (Balzan et al., 2021). The identified sites include non-urbanized areas where a greening intervention was considered feasible (e.g., excluding watercourses, beaches, cliffs with steep slopes, wetlands, and gardens). To these areas, which cover 207 ha, we added 15 ha of street green areas identified *ex novo*, for a total of 222 ha (Figure 9).

Most of these areas already contain some green infrastructure elements that provide a range of ES (Balzan et al., 2021), and are located within the urban development boundaries. This constitutes a risk, since future urban development projects may replace them, but it also represents an opportunity to minimise land take and enhance ES supply by integrating NbS that can better address the existing challenges. Operationally, new NbS could be realized either as part of wider transformation projects that include greening interventions or land conservation measures alongside urban development, or through interventions specifically aimed at improving/integrating existing ecosystems (Longato et al., 2022).

The selection of the priority ES to analyse is based on the main challenges affecting the area, which were discussed together with practitioners from the Malta Planning Authority during a meeting: high levels of air and noise pollution as a result of vehicular traffic, climate-related hazards (high temperatures and flooding), and lack of green infrastructure and open spaces in urban core areas (Balzan et al., 2020). Consequently, the ES selected are runoff regulation, microclimate mitigation, air purification, noise reduction, and nature-based recreation.

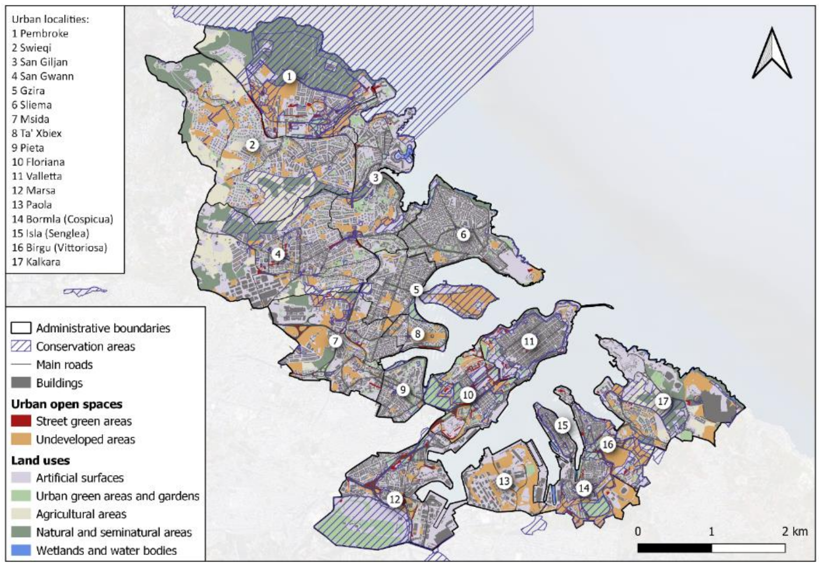

Figure 9. Administrative boundaries, main land uses, and potential NbS sites in the case study area.

4.2.2 Assigning ecosystem service demand scores to potential Nature-based Solutions sites

Following the approach proposed by Cortinovis and Geneletti (2020), the demand for each ES is defined by two factors: i) the intensity of the hazard (for regulating services) or level of deprivation (for recreation), and ii) the number of people or physical assets that are exposed to that condition.

To account for the population distribution we used a refined version of the 100m-resolution constrained population grid downloaded from the WorldPop database (WorldPop, 2020). The original grid was developed using census data and building footprints and/or built settlement masks to disaggregate the population to only those grid cells containing buildings and/or built settlement using Random Forests based modelling (Stevens et al., 2015), hence without considering the different uses of buildings/settlement areas. The population was consequently disaggregated also into commercial/industrial areas that usually are not inhabited. Existing residential areas were identified using the Urban Atlas high-resolution land use and cover layer produced by the Copernicus programme for the functional urban area of Valletta (https://land.copernicus.eu/local/urban-atlas/view) in combination with the land use zoning maps developed by the Malta Planning Authority in order to obtain a residential land use distribution as close as possible to the reality (e.g., excluding non-residential uses within urban areas such as hotel structures that are identified in the zoning maps, and including isolated residential structures outside main urban settlements that are identified in the Urban Atlas layer). We first identified the grid cells containing residential areas (i.e., applying the rule that at least 10% of the cell must overlap residential areas) and those that do not. Second, we calculated the proportion of the population living in each "residential" cell with respect to the total population living in all the "residential" cells of the corresponding urban district (i.e., the administrative level for which census data are provided and that was used to develop the original population grid). Third, we used such proportion to redistribute the total amount of population found in "non-residential" cells into the "residential" cells, with the final population count in each "residential" cell represented by the sum of the original population count with the proportional amount of population redistributed. For example, if a "residential" cell originally contained the 3% of the total population living in all the "residential" cells of a given urban district, the 3% of the total population found in all the "non-residential" cells of that urban district is redistributed into that "residential" cell. Figure 10 shows the final map showing the spatial distribution of the population.

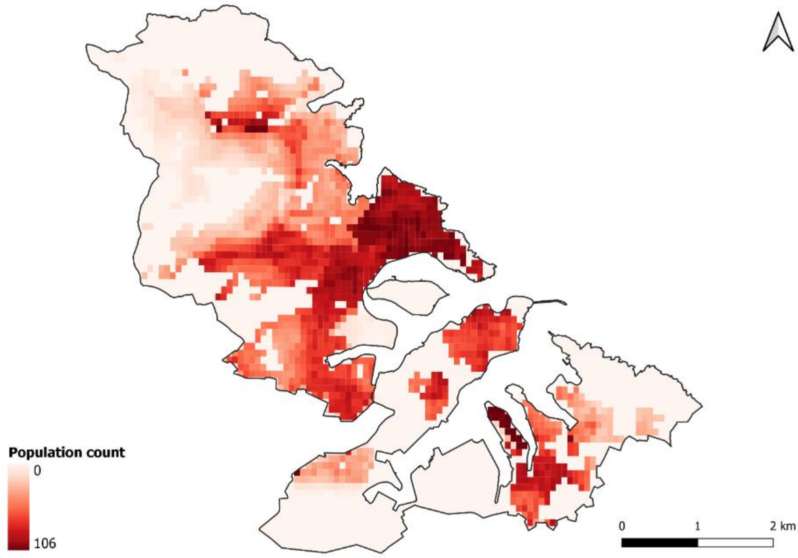

Figure 10. Population distribution map with population count.

The values of the demand for runoff regulation, microclimate mitigation, air purification, and recreation were spatially assessed in a raster map and subsequently assigned to each cell of the population grid depending on the number of people and the conditions to which they are exposed. Then, a demand score was assigned to each potential NbS site (i.e., the potential providing area) based on the level of demand in the potential benefitting area, i.e. considering the spatial flows of ES. For runoff regulation and microclimate mitigation, which produce their effects within and in the immediate surroundings of the providing area (Cortinovis and Geneletti, 2019), the benefitting area is accounted by creating a circular neighbourhood (i.e., buffer area) around the potential NbS sites. The same approach was used for recreation, with the circular neighbourhood representing the potential catchment area from which the site is accessible considering a (reasonable) walking distance. The demand score for these three ES was calculated by summing the values of all the pixels of the demand maps that fall within the corresponding benefitting (buffer) areas. Only for the air purification service, which effects are widespread beyond the local scale and the corresponding flow zone can be set at the city level (Verhagen et al., 2016), the demand score was calculated by summing only the values of the pixels within the sites themselves.

The values for the noise reduction ES demand were directly calculated within the potential NbS sites located between noise sources (i.e., traffic roads) and benefitting areas (i.e., the residential buildings exposed to noise). The values are based on the simulated noise levels of the sound beams that connect the main roads to the affected buildings, thus accounting for the directional effects of noise reduction (Fisher et al., 2009). The values were assigned to the sound beams that cross the potential NbS sites depending on the conditions to which buildings are exposed (i.e., on the noise levels affecting them and the capacity to shield noise of the current land covers characterising the sites). The final demand score assigned to each potential NbS site was then calculated by summing the demand values of all the sound beams crossing the same site.

Finally, for all the five ES, the demand scores were normalized with respect to the maximum value to obtain a 0 to 1 level of priority of the potential NbS sites to be transformed into providing areas of each ES (from 0, lowest priority, to 1, highest priority). The next section provides a detailed description of the methods and data used for mapping and assessing the demand for the five ES.

4.2.2.1 Methodology for ecosystem service demand mapping and assessment

Runoff regulation

The demand for runoff regulation was assessed using the methodology proposed by Cortinovis and Geneletti (2020), i.e. based on the current level of soil sealing (retrieved from the Copernicus High Resolution Imperviousness degree (IMD) layer for the year 2018), and the vulnerability to urban flooding of different city areas, represented by the number of residents and presence of areas dedicated to industrial and commercial activities that may be exposed to the negative consequences of flooding. The rationale is that the demand for runoff regulation is higher in areas with higher proportions of impervious surfaces that contribute to higher rates of surface runoff, and residents and/or activities exposed that may suffer health and economic damages. The demand indicator was calculated in each population grid cell by multiplying the average level of soil sealing within the cell with the vulnerability indicator represented by the average of the two contributions (population + industrial and commercial land uses), both normalised with respect to the maximum value over the study area:

$$D_{rurunoff.regulation,i} = \frac{IMP_i}{100} * \frac{\left(V_{pop,i} + V_{land.use,i}\right)}{2}$$

where $V_{pop,i}$ is the contribution of the population factor and $V_{land.use,i}$ is the contribution of the land use factor to the total vulnerability to flooding of the ***i***-th grid cell.

$$V_{pop,i} = \frac{pop_i}{max(pop_i)}$$

$$V_{land.use,i} = \frac{ind_i + comm_i}{max(ind_i + comm_i)}$$

The final demand indicator was then normalized with respect to the maximum pixel value to obtain a 0 to 1 demand map that was subsequently rasterized and used to calculate the runoff regulation demand scores of the potential NbS sites. These were calculated by summing the values of the pixels falling within a 100-m buffer area around the sites, which correspond to the average size of a small urban sub-watershed (Geneletti et al., 2022). They were then normalized with respect to the maximum value to obtain a 0 to 1 level of priority of the potential NbS sites to be transformed into providing areas of the runoff regulation service.

Microclimate mitigation

The demand for microclimate mitigation was assessed by combining the vulnerability indicator represented by the population factor and an indicator purposely built with remotely sensed data that represents the vulnerability to the heath stress condition (i.e., areas with higher temperatures and lower cooling capacities) experienced in the different city areas. Data used to develop this indicator are Land Surface Temperature (LST), Normalized Difference Vegetation Index (NDVI), and albedo. A summer average value (reference year 2020) for each of these three components was derived from four cloud-free Landsat 8 satellite images captured between June and August (downloaded from Landsat 8 Collection 2 Level-2 surface reflectance and surface temperature science products), using the thermal infrared band to derive LST, the red and infrared bands to calculate NDVI, and the *i.albedo* Grass tool to derive the albedo values from multiple spectral bands. LST represents the level of hazard intensity, while NDVI and albedo represent the local temperature mitigation capacity (i.e., as proxies of the ES supply side), which is represented by the presence of vegetation that can cool down temperatures (i.e., higher values of the vegetation index indicate denser vegetation) and the albedo effect (i.e., higher values of albedo indicate higher heat loss). These mitigation effects occur especially during the night (Zhou et al., 2014), when the urban heat island phenomenon is greater (Antunes Azevedo et al., 2016; Parker, 2009), thus they are not captured by the LST data alone, since detected during the day. The three components of the heat stress indicator ($I_{heat.stress}$) are combined together as follows in a new raster map to represent the heat stress condition in each pixel(*p*-th):

$$I_{heat.stress,p} = \frac{LST_p}{max(LST_p)} * (1 - \frac{(NDVI_p + ALBEDO_p)}{2})$$

The resulting raster map was then used to calculate the average values of the heat stress indicator within each population grid cell(*i*-th). These were then normalized with respect to the maximum value and multiplied with the population vulnerability to obtain the demand for microclimate mitigation:

$$D_{microclimate.mitigation,i} = \frac{I_{heat.stress,i}}{max(I_{heat.stress,i})} * \frac{pop_i}{max(pop_i)}$$

The final demand indicator was then normalized with respect to the maximum pixel value to obtain a 0 to 1 demand map that was subsequently rasterized and used to calculate the microclimate mitigation demand scores of the potential NbS sites. These were calculated by summing the values of the pixels falling within a 100-m buffer area around the sites, which correspond to the surrounding areas benefitting from the cooling effect provided by green areas (Cortinovis and Geneletti, 2020; Geneletti et al., 2022). They were then normalized with respect to the maximum value to obtain a 0 to 1 level of priority of the potential NbS sites to be transformed into providing areas of the microclimate mitigation service.

Air purification

The demand for air purification was assessed by combining the vulnerability indicator represented by the population factor with an indicator measuring the intensity of air pollution hazard, obtained by calculating the average values of NO2 concentrations (from a map developed by Balzan and colleagues (2018) showing NO2 concentrations spatial distribution in the study area) within the population grid cells and normalizing them with respect to the maximum value over the study area:

$$D_{air.purification,i} = \frac{pop_i}{max(pop_i)} * \frac{NO2_i}{max(NO2_i)}$$

The demand map was then rasterized and, to account for an improved air purification demand of the areas located near the main air pollution sources where the rates of pollutant removal by vegetation can be double (Derkzen et al., 2015), the values of the pixels within a 50-m buffer from main traffic roads were doubled. The resulting demand indicator was then normalized with respect to the maximum pixel value to obtain a 0 to 1 demand map that was subsequently used to calculate the air purification demand scores of the potential NbS sites. Since the areas benefitting from air purification do not rely on circular neighbourhoods around the service providing area, these were calculated by summing the values of the pixels falling within the potential NbS sites. Such scores were then normalized with respect to the maximum value to obtain a 0 to 1 level of priority of the potential NbS sites to be transformed into providing areas of the air purification service.

Noise reduction

The demand for noise reduction was assessed within the potential NbS sites using noise levels from main roads that were computed using the OpeNoise QGis plug-in – a tool purposely developed to assess noise levels in urban areas (Arpa Piemonte, 2019) – and the residential buildings as the exposed asset of the noise levels. First, noise levels from main roads were derived from the map of “day-evening-night noise indicator levels” downloaded from the Malta Spatial Data Infrastructure (representing the noise indicator for overall annoyance in roads according to the requirements of Directive 2002/49/EC relating to the assessment and management of environmental noise) and assigned to the corresponding road sections derived from the linear road layer downloaded from OpenStreetMap. Second, using the OpeNoise tool, we created the noise receiving points (i.e., points placed in the middle of each facade of residential buildings) and the direct sound beams that propagate from the linear noise source (i.e., the road layer) to each receiving point. The layer of direct sound beams also contains the information on the corresponding noise level measured at each receiving point (calculated starting from the noise levels previously assigned to road sections). Third, we assessed the demand for noise reduction for each sound beam crossing the potential NbS sites by creating an indicator that combines the noise levels at the receiving points, representing the level of hazard intensity, and a noise reduction supply indicator representing the site capacity to shield noise. The supply indicator combines the site's land cover and the length of the sound beam crossing the site, assuming that the more distance a sound beam covers to cross the space and the higher capacity to shield noise has the land cover crossed, the greater is the capacity to reduce noise levels of the sound beam. The noise reduction supply rates provided in the study by Derkzen and colleagues (2015) were assigned to the different land covers covering the sites (i.e., woodland, tall shrub, short shrub, herbaceous, other) and normalized with respect to the maximum value (corresponding to the tall shrub land cover). The lengths of the sound beams crossing the sites were normalized as well with respect to the maximum value in the study area. The formula of the noise reduction supply indicator is thus developed as follows:

$$S_{noise.redution,i} = \frac{landcover_i}{max(landcover_i)} * \frac{lenght_i}{max(length_i)}$$

where $landcover_i$ is the contribution of the land cover factor and $length_i$ is the contribution of the length factor to the total noise reduction supply $S_{noise.reduction,i}$ of the i-th sound beam.

The demand indicator for noise reduction was then assessed for each sound beam (i-th) as follows:

$$D_{noise.reduction,i} = \frac{noiselevel_i}{max(noiselevel_i)} * (1 - \frac{S_{noise.reduction,i}}{max(S_{noise.reduction,i})})$$

where *noiselevel*$_i$ is the hazard intensity represented by the noise level at the receiving point of the *i*-th sound beam.

Finally, the demand values of all the sound beams crossing a same potential NbS site were summed to obtain the total demand for all sound beams in each site. The total demand values were then normalized with respect to the maximum value to obtain a 0 to 1 level of priority of the potential NbS sites to be transformed into providing areas of the noise reduction service.

Nature-based Recreation

The demand for nature-based recreation was assessed according to the level of accessibility of residents to different public green spaces, which is based on the maximum attraction distances defined by Stessens and colleagues (2017) for different typologies of public green spaces. They classify public green spaces in different "theoretical functional levels" according to their size (i.e., "residential green" > 0.1 ha; "play green" > 0.5 ha; "neighbourhood green" > 2 ha; "quarter green" > 6 ha; "district green" > 15 ha; "city green" > 70 ha; "metropolitan green" > 450 ha) hypothesizing that green spaces of different sizes provide different functions (Stessens et al., 2017). In addition, according to the different theoretical functional levels, they defined a maximum attraction distance of 150, 350, 600, 1000, 1400, 2700, and 5900 m (Stessens et al., 2017), respectively, to simulate the distance from home one is willing to cover to reach a green space (for local to neighbourhood parks this distance can be assumed is covered by walking). The rationale for using this approach is that green spaces of different sizes can in principle be used for or offer different recreational activities and opportunities. For example, a larger green space may be more attractive for people going jogging than a smaller one. Despite the analysis does not consider the presence of specific recreational facilities within the green spaces, their presence is somehow (though not always) correlated with their size since they require space (e.g., a sports field is likely to be present in a larger green area than in a pocket park). Using the existing public green spaces identified from the land use and cover (Urban Atlas layer) and zoning maps (from Malta Planning Authority) in the study area (including properly designed public parks and other publicly accessible open spaces, such as picnic areas and informal gardens) we assessed what population grid cells are served by each typology of green space by creating different buffers around them to simulate the maximum attraction distances based on their theoretical functional levels. The grid cells covered by the green space's buffer areas are those where the recreation service is currently supplied, and different supply levels are assigned to them based on the number of green space typologies that serve them (the more typologies of green space are serving an area, the higher the recreation supply value is). According to the different sizes of the green spaces in the study area, corresponding to the theoretical functional levels of "residential green", "play green", "neighbourhood green", and "quarter green" (Stessens et al., 2017), the maximum attraction distances used are 150, 350, 600, and 1000 meters, respectively. Due to the geographical specificity of the case study area, which is characterised by a coastline with a very irregular shape and various inlets, it was necessary to refine some of the buffer areas to eliminate those buffer sections that are separated by a stretch of sea with respect to the green space since the distance one must cover to reach it by circumnavigating it is much higher than the attraction distance defined. To determine if a grid cell is served or not by one or more green space typologies, we assessed if the centroid of the cell falls within a green space's buffer area, keeping track of the typology of green space involved. Given that the maximum number of green space typologies that can serve an area is four, the cells that are served by all of them are assigned the maximum supply value of 1, which reduces as the number of typologies decreases. The supply values assigned to the grid cells are: 1 if served by four typologies; 0.9 if served by three typologies; 0.75 if served by two typologies; 0.5 if served by one typology; 0 if not served by any typology. This progressive decrease of the supply values was purposely defined to give more importance to the transition from 0 to 1 typology of green space, then from 1 to 2 typologies, and so on, in order to prioritise areas that are served by any green space. The demand indicator is then calculated in each grid cell (i-th) by combining the population vulnerability with the recreation supply indicator as follows:

$$D_{recreation} = \frac{pop_i}{\max(pop_i)} * \left(1 - S_{recreation,i}\right)$$

The demand map was then rasterized and used to calculate the recreation demand scores of the potential NbS sites. These were calculated by creating the buffer areas according to their size (using the same attraction distances used for existing public green spaces) to simulate their potential serving area, and summing the values of the pixels falling within the corresponding buffer area. Such scores were then normalized with respect to the maximum value to obtain a 0 to 1 level of priority of the potential NbS sites to be transformed into providing areas of the nature-based recreation service.

4.2.3 Estimating ecosystem services supply scores for different Nature-based Solutions types

We selected 11 types of NbS that can address the identified challenges by supplying the selected ES (Table 18). The list includes NbS that can be implemented on the ground, characterized by different management intensities and land covers. When relevant, we identified size, shape, and land use constraints that limit the suitability of certain NbS types to specific sites (see Table 18). In particular, minimum sizes are defined for urban forests (i.e., applying the concept of "Kyoto forests" (UNFCCC, 2001)) and parks (depending on park typology). A minimum width is applied to vegetation barriers, to ensure a (perceivable) noise reduction. The same threshold is also applied to urban forests and tree planting areas, to ensure adequate side space for planting more than one row of mature trees; to parks, to ensure adequate side space to include walking paths, playground areas, and/or other man-made features together with the vegetated areas; as well as to community gardens, to ensure adequate side space for (linear) plots and ancillary spaces.

Table 18. List of NbS considered in this study, and size/shape and land use constraints applied for their allocation in potential NbS sites.

NbS main categories	NbS type and description	Size/Shape constraints	Land use constraints
Vegetated areas (low to medium management intensity, no or few man-made features)	**Urban forest** (i.e., "Kyoto forest"): established woodland area with null or very low management intensity that requires a minimum size to mimic natural forest habitats with the presence of trees, grasses and other undergrowth layers of vegetation.	Size: > 0.05 ha (UNFCCC, 2001) Shape: > 15m width	Excluding street greenery areas (where the typologies of tree planting area and street trees are considered more suitable)
	Tree planting area: an area covered by clustered trees that is subject to a higher management intensity than urban forest, with the presence of just a grass layer or permeable soil. It is suitable to all the areas smaller than 0.05 ha, which is the minimum requirement for an urban forest.	Shape: > 15m width	-
	Vegetation barrier: a linear barrier made of a wooded strip combined with dense shrubs purposely built to shield noise.	Shape: > 15m width (to ensure at least ~5 dB of noise reduction (Van Renterghem et al., 2015))	-
	Low vegetation area: a permeable area covered by extensive herbaceous vegetation and grasses, possibly with short shrubs.	-	Excluding street greenery areas (where the typology of roadside green is considered more suitable)
	Stormwater infiltration system: a soil depression typically covered by low vegetation that is designed to collect and infiltrate stormwater. It can be an infiltration pond, a rain garden, or a bioswale/infiltration trench, depending on the location and size (e.g., infiltration trenches are usually applied in roadside spaces, rain gardens in small catchment	-	-

	areas, and infiltration ponds in larger catchment areas).		
Parks (open to public use for recreation, medium to high management intensity, often with the presence of man-made features, e.g. playground areas, walkway paths)	**Large park**: a neighbourhood park of at least 2 ha (Stessens et al., 2017) with significant tree coverage (approximately 30% of the area covered by clustered trees).	Size: > 2 ha (applied to neighbourhood green spaces (Stessens et al., 2017)) Shape: > 15m width	-
	Small park: a residential park (Stessens et al., 2017) with less space dedicated to tree planting (approximately 10% of the area covered by clustered trees).	Size: > 0.1 ha (applied to residential green spaces (Stessens et al., 2017)) Shape: > 15m width	-
Green elements connected to transport infrastructure (medium to high management intensity)	**Street trees**: a linear row of trees (planted in tree pits or strips or land) along streets.	-	Only street greenery areas
	Hedgerow: a row of medium-tall shrubs (of about 2 meters width).	-	Only street greenery areas
	Roadside green: a grass strip of amenity grassland, possibly with short shrubs and/or flowerbeds.	-	Only street greenery areas
Other areas (high management intensity)	**Community garden**: a piece of land where citizens can grow vegetables and fruits, among others, with the presence of cultivated plots and ancillary facilities.	Shape: > 15m width	-

To each NbS type, we assigned an ES supply score from 0 (no supply) to 5 (highest supply) for each of the analysed ES. The scoring method is grounded on a statistical analysis of ES supply values retrieved from existing studies. We selected studies reporting or assessing (in quantitative or qualitative terms) the level of ES supply of different land covers or typologies of green space, such as parklands and woodland, or green element, such as trees and hedgerows. When related to land covers, ES supply values extracted from the identified studies were assigned to each NbS type based on its land cover (e.g., woodland for urban forests). In the case of NbS types characterised by a mix of land covers (e.g., urban parks, which are assumed to have a mix of grassland and woodland areas), the ES supply values were weighted considering the share of the area occupied by each land cover. To ensure comparability among data provided in studies that used different

assessment methods and metrics applied in different parts of the world, we normalized the ES supply values with respect to the maximum value in each study.
The normalized ES supply values were then classified into six ranges of values corresponding to six scores (Table 19). The ES supply score assigned to each NbS type was the most frequent one, which corresponds to the range containing the majority of the normalized ES supply values from the analysed studies (Table 19). When two or more ranges showed the same frequency, the average of the respective scores was calculated and, if necessary, rounded down to the nearest value to maintain a conservative approach. Appendix A provides the details on the reviewed studies, the ES supply values collected, as well as on their statistical analysis, to derive the ES supply scores of NbS types.

Table 19. Ranges of values to classify the normalized ES supply values from the analysed studies and respective ES supply scores. Scores are assigned to NbS types based on the range with the highest frequency.

Range of values showing the highest frequency	ES supply score assigned to NbS types
0	0
0.01 - 0.2	1
0.21 - 0.4	2
0.41 - 0.6	3
0.61 - 0.8	4
0.81 - 1	5

4.2.4 Combining supply and demand scores to identify priority NbS types in each site

To identify the NbS types that deliver the most needed combination of ES in each site, a priority score was calculated for each combination of NbS types and potential NbS sites. The score is obtained by combining the demand scores assigned to the sites with the supply scores of NbS types using the following formula:

$$P_{NbS,j} = c_{j,NbS} \sum_{i=1}^{5} \left(D_{i,j} * S_{i,NbS}\right)$$

Where $P_{NbS,j}$ is the priority score of a defined NbS type in site j, $D_{i,j}$ is the demand score of the site j for the i-th ES, $Si_{,NbS}$ is the supply score of the NbS type for the i-th ES, and c is a binary factor summarizing the suitability constraints. c assumes a value of 0 if the site does not meet the size, shape, or land use constraints reported in Table 1, otherwise it is equal to 1.

The final priority scores potentially range from 0 (no suitability or no need to implement the NbS due to a lack of demand) to 25 (highest demand score in the site – 1 – for all ES and highest supply score of the selected NbS – 5 – for all the five ES). However, no site shows the maximum values of the demand score for all the ES simultaneously and no NbS type shows the highest values of the supply score for all the ES analysed. Finally, in each site the suitable NbS type that mostly contributes to addressing the demand for the five ES was identified (i.e., the one with the highest priority score).

4.3 Results

4.3.1 Ecosystem service demand in potential Nature-based Solutions sites

The distribution of the demand for the five ES analysed (Figure 11) is influenced by the spatial distribution of population above all, and of the industrial and commercial land uses or residential buildings in the case of runoff regulation and noise reduction. Higher demand for runoff regulation is found in the denser built-up areas characterised by few open spaces. These include a large proportion of the coast and urban areas in the immediate inland, and the industrial and commercial hubs that are located around port areas and on the western side of the case study. For microclimate mitigation, hotspots of ES demand can be identified in the most compact urban areas characterised by higher population density, such as the central coastal zone and the compact historical settlement of Senglea in the southern part. However, high demand values are found in almost all the urbanized areas, including the capital city Valletta, with the exception of those located in the most peripheral urban fringes characterized by lower densities.

The demand for air purification is higher along the main roads, especially where they cross dense residential areas. Here, the rates of pollutants reduced by vegetation can be greater, given that car traffic is the main source of air pollution in the study area. Hotspots of demand for recreation include the areas further away from the existing parks and are mainly located in the central coastal zone towards the interior and within the two fortified compact cities of Valletta and Senglea. The potential NbS sites showing a higher demand score for these four ES are those located across or in the surroundings of the demand hotspots. Finally, the sites characterised by higher demand for noise reduction are those covered by low vegetation – currently ineffective to shield noise - and located between the main traffic roads that pass through dense residential areas and the residential buildings affected by noise. Most of these sites are distributed along the trunk road crossing north-south the northern part of the urban agglomeration and along the road running from the capital city Valletta towards the West. Figure 12 shows the demand scores for the five ES calculated for some exemplary potential NbS sites.

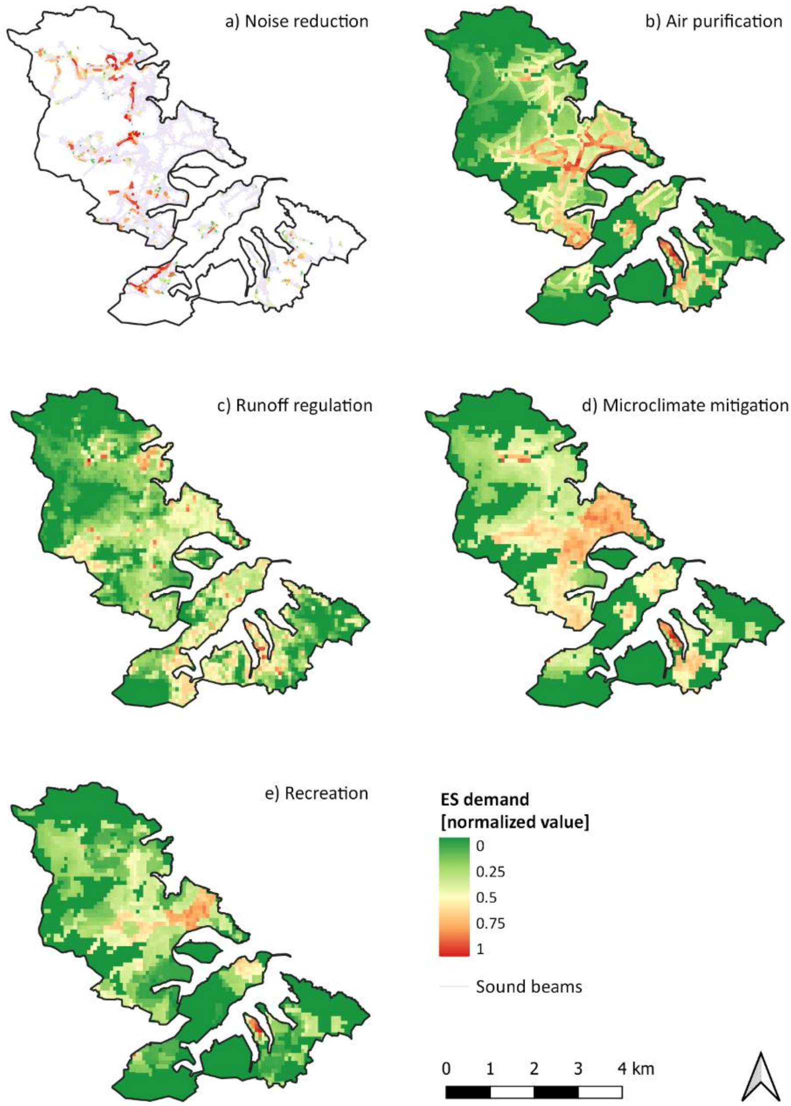

Figure 11. Maps of the demand for the five ES analysed.

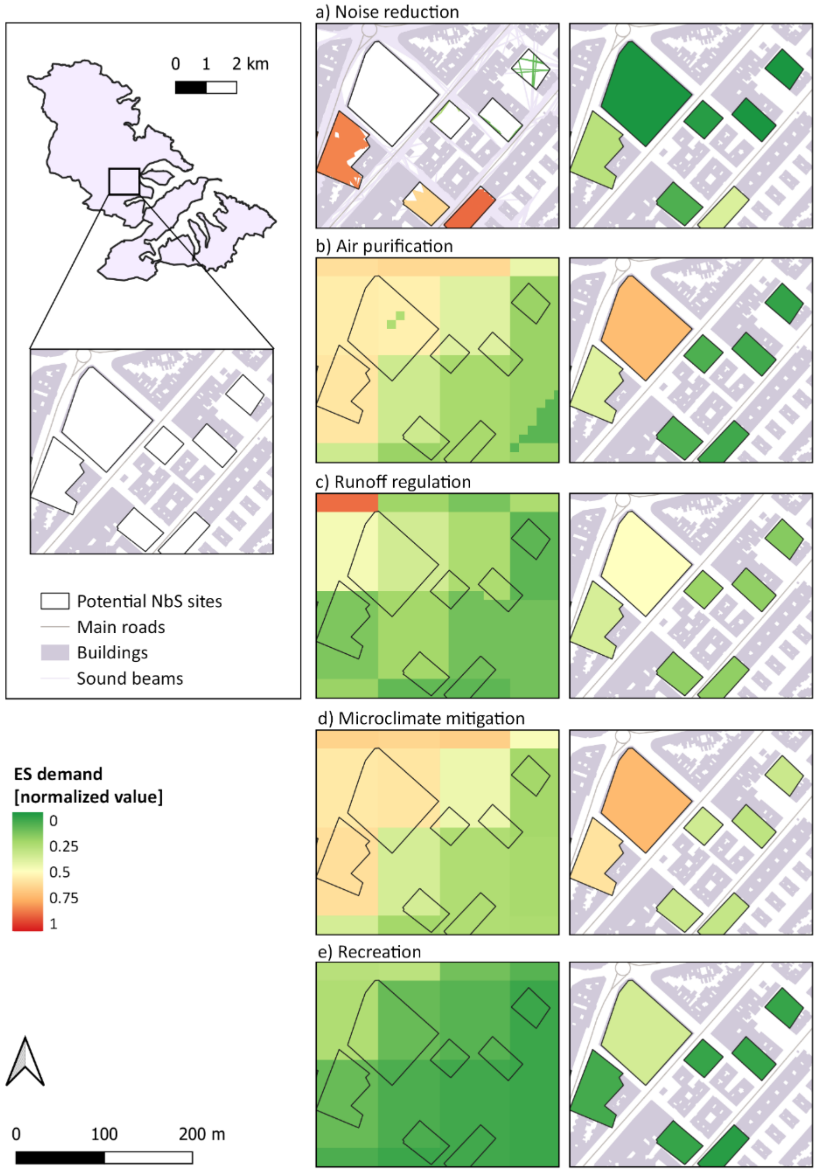

Figure 12. Zoom examples of potential NbS sites overlapping ES demand maps (left) and the ES demand scores calculated for the same sites by accounting for the potential ES flows from provisioning (the sites) to benefitting areas (see Section 4.2.2 for methods) (right).

4.3.2 Ecosystem services supply scores of proposed Nature-based Solutions types

The ES supply scores of the 11 proposed NbS types are reported in Table 20.

Table 20. ES supply scores for the five ES analysed for each NbS type.

NbS type	**ES supply scores**				
	Runoff regulation	**Microclimate mitigation***	**Runoff regulation**	**Noise reduction**	**Runoff regulation**
Urban forest	5	5 (> 2ha) 4 (< 2 ha)	5	3	3
Tree planting area	5	4	5	3	3
Vegetation barrier	4	3	4	5	2
Low vegetation area	4	2	1	1	3
Stormwater infiltration system	5	2	1	1	0
Large park	4	4	2	2	5
Small park	4	3	2	2	5
Street trees	5	4	5	0	3
Hedgerow	4	3	4	2	2
Roadside green	4	2	1	1	3
Community garden	3	3 (> 2 ha) 1 (< 2 ha)	1	1	3

* The scores are calculated for two different sizes (< 2 ha and > 2 ha) for those (non-linear) NbS types that may exceed 2 ha, since the cooling capacity of areas larger than 2 ha is greater than the one of smaller areas (Majekodunmi et al., 2020; Zardo et al., 2017). Large parks are always larger than 2 ha. For low vegetation areas, the final score was the same in the two cases. More information can be found in Appendix A.

The scores show that urban forests and tree planting areas are the NbS types that in general provide the best overall balance in the supply of all the five ES. However, in the case of noise reduction and recreation, vegetation barriers and a park, respectively, perform better. Concerning NbS types that can be implemented in roadside spaces, street trees demonstrate good performances in supplying all the ES except noise reduction. In this case a hedgerow – if there is not enough space for a vegetation barrier – is the best solution.

4.3.3 Allocation of Nature-based Solutions

Most of the priority NbS identified within the 222 ha of potential NbS sites (Figure 13) fall within the category of "vegetated areas". Urban forests (170 ha) are mostly concentrated in larger peri-urban sites and scattered in some larger sites within the urban cores, while tree planting areas (6,7 ha), cover especially small infill sites and larger street green areas (e.g., road junctions, roundabouts) that are not suitable for urban forests. Vegetation barriers (2 ha) are predominantly located along the main roads and road junctions nearby residential neighbourhoods. Sites where low vegetation areas are the priority are few (1,7 ha) and mostly scattered within some infill sites in residential areas. Stormwater infiltration systems cover 26,8 ha, especially concentrated in high-impervious industrial areas and along streets in the southern part of the study area. Of these, 2,5 ha are street green areas in which bioswales/infiltration trenches are the suitable solutions among the typologies of stormwater infiltration systems.

Large (23,5 ha) and small parks (4 ha) are the priority NbS type assigned to some peri-urban spaces close to the denser urban areas, where the availability of green spaces is scarce. Street trees (12,4 ha) are quite homogeneously distributed along roadside spaces within the residential areas, while hedges (0,9 ha) are predominantly located within some narrow street green areas where other more performing NbS types, such as vegetation barriers, cannot be implemented due to size and shape constraints. Roadside green and community gardens are not a priority in any space.

In some sites (covering a total of 25,9 ha) more than one NbS type obtained the same priority score. Examples include sites with two priority NbS types, such as stormwater infiltration systems and urban forests, low vegetation areas, or street trees; as well as urban forests and small parks. In some cases, three NbS types received the same priority score, for example, stormwater infiltration systems, tree planting areas, and street trees.

An overall indicator of the need for NbS implementation is provided by the maximum priority score (i.e., corresponding to the priority score of the NbS type that obtained the highest score among the 11 proposed) obtained in each potential NbS site, which ranges from a minimum of 0 (no need of NbS) to a maximum of 14,22 (highest NbS need) (Figure 14). The scores support the identification of areas where NbS implementation should be prioritized to effectively target areas characterised by a high demand for multiple ES.

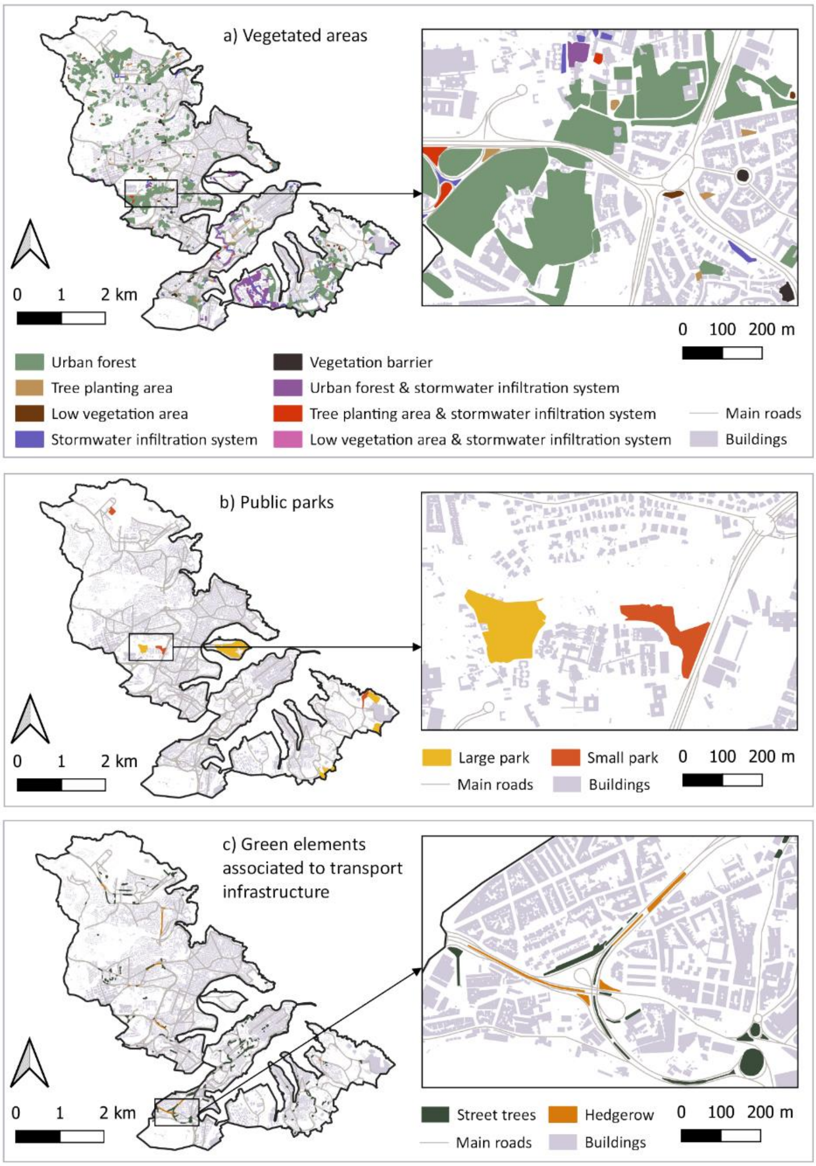

Figure 13. Distribution of priority NbS types within the potential sites for NbS on the ground, broken down by the main category: vegetated areas (a), urban parks (b), and green elements associated with transport infrastructure (c).

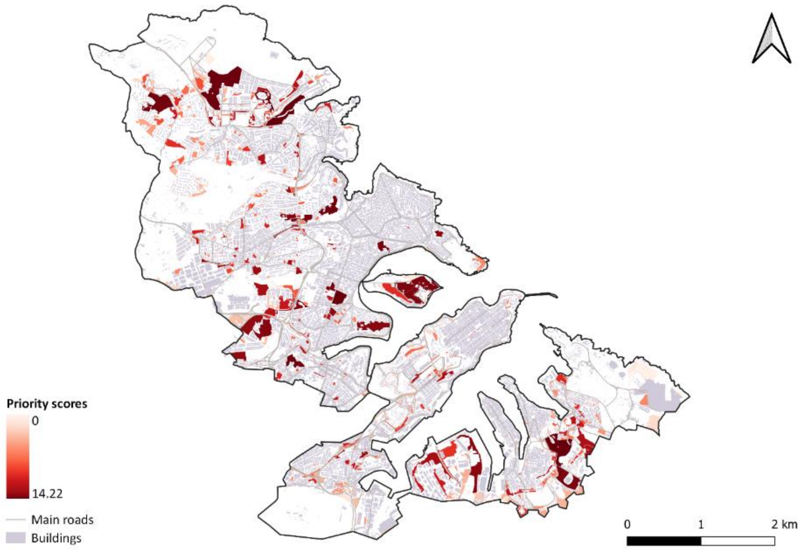

Figure 14. Maximum priority scores obtained by NbS within the potential sites.

4.4 Discussion

4.4.1 Nature-based Solutions allocation in the study area

Planting trees, through urban forestry/afforestation or street trees, is often seen as the best solution to tackle most urban environmental challenges (Cortinovis et al., 2022; Pataki et al., 2021). This is partly confirmed by the ES supply scores we developed and by the results of NbS allocation showing urban forests as the most widespread typology across the urban area of Valletta, and also supporting previous observations from the study area which prioritised tree cover increases to improve ES supplies (Balzan et al., 2021). This depends on the fact that the difference in supplying microclimate mitigation and air purification – which are among the more demanded ES in the study area – between high and low vegetation is significant, since they are mainly provided by evapotranspiration and shading functions of tall vegetation and canopy cover (Duncan et al., 2019; Livesley, McPherson, and Calfapietra, 2016; Coutts et al., 2012; Shashua-Bar and Hoffman, 2000), and through the absorption of gaseous air pollutant by leaves, deposition of particles on vegetation, and dispersion of pollutants resulting from increased surface roughness by vegetation (Tiwari et al., 2019; Escobedo and Nowak, 2009; Nowak et al., 2006), respectively. For this reason, urban forests and street trees are much better in cooling down temperatures and purifying the air than the other solutions.

In some cases, urban forests or street trees obtained the same priority as stormwater infiltration systems. This happened, for example, in areas where the demand for runoff regulation is high and that for the other ES low, which are mainly located in commercial/industrial sites. Here stormwater infiltration systems resulted as the priority NbS type together with urban forests. Also, street trees are the priority NbS type together with stormwater infiltration systems in several street green areas along residential roads for the same reason. Actually, our ES supply scores show that in general there is little difference in the capacity to regulate runoff between NbS characterised by low (e.g., grass) and high vegetation (e.g., tall shrubs, trees). This is because the supply of runoff regulation depends on a number of functions that are not exclusively related to the presence of tall plants, including water retention and infiltration in soil by permeable surfaces, reduction of flood velocities by vegetated surfaces, and water storage and infiltration by floodplains, besides rainfall interception by canopy cover (Livesley et al., 2016; Ossola, Hahs, and Livesley, 2015; Yang et al., 2015; Nisbet and Thomas, 2006; Blackwell and Maltby, 2006; Xiao and McPherson, 2002).

However, there are two specific cases in which other NbS are to be prioritized over urban forests and street trees. The first concerns the solutions to implement in sites along the main (noisy) roads. In fact, where the demand for noise reduction is particularly relevant, a vegetation barrier made of trees and large shrubs is the priority solution. Actually, despite the reduction of noise levels also depends on the reflection, diffraction, and absorption effects of vegetation and soil in general (Van Renterghem et al., 2012), it is mainly determined by the noise shielding function. However, this function is delivered most effectively by tall vegetation with higher vegetation densities than that usually characterising urban forests, such as tall shrubs. The second involves the areas characterised by a high demand for recreation. This in fact depends on the opportunities for active and passive recreation offered by accessible NbS (Davern et al., 2017; McCormick, 2017),

which are mostly provided by urban parks, whether characterised by (more or less) short or tall vegetation.
Finally, there are two NbS types that based on the results obtained from this study are not a priority in any site: roadside green and community gardens. For the former, the reason is that it provides fewer benefits than the other NbS types that can be implemented within the same street green areas (i.e., street trees and hedgerows), meaning that all areas that are currently covered by a strip of amenity grassland (i.e., the typical surface cover characterising roadside green areas) could be improved, for example planting street trees. For the latter, which capacity to supply ES is lower than most of the other solutions, especially concerning regulating services, its implementation needs to be promoted in the context of the wider social benefits that community gardens provide, such as social learning, cohesion, and well-being, in addition to food production (Dennis and James, 2017). Including some of these aspects among the analysed ES would have probably resulted in their prioritization in some areas of the city.
Overall, the priority of the potential NbS sites, which can be derived from the priority scores of NbS to be implemented therein, is linked both to the level of ES demand in the surroundings (or within the site in the case of noise reduction) and to the size of the site, since to larger sites potentially correspond larger benefitting areas. These two factors directly influence the number of people (or residential buildings in the case of noise reduction) potentially benefitting from the ES supplied by NbS. Larger sites nearby ES demand hotspot areas for the majority of the five ES considered are consequently the ones receiving higher priority scores.

4.4.2 Options to implement the findings

The approach presented in this chapter can be applied to support a variety of planning decisions related to NbS. Various options to implement the analysed types of NbS exist depending on the current land uses and covers, considering that typologies of intervention on urban ecosystems include conservation, restoration, enhancement, and creation of new ecosystems (Cortinovis and Geneletti, 2018a).
Taking the case of urban forest as an example (implementation of afforestation programmes is among the main ecological objectives at the national level in Malta (ERA, 2018)), implementing this solution

would require restoration interventions to reverse degradation in areas currently affected by human-induced impacts, especially tracts of urban vacant land with disturbed ground; the enhancement of the existing wooded remnants, for example by densifying and/or diversifying the vegetation (using indigenous trees) or – if possible – directly enlarging them to designing urban forests that are more effective in delivering ES; the creation of new ecosystems that involves land cover change, for example, to address the issue of abandoned agricultural land that offers an opportunity for extensive tree planting (Cassar and Conrad, 2014).
A similar argument can be applied to street green areas. For instance, those already covered (at least partially) by street trees can be improved by densifying or enlarging them. The others can be used to implement new tree planting schemes or other specific priority solutions such as hedgerows or vegetation barriers.
In addition, combinations of NbS types can also be promoted, especially in those areas showing more than one priority solution (e.g., urban forests or street trees in combination with stormwater infiltration systems such as infiltration ponds – in large sites – and bioswales/infiltration trenches – in street green areas –). However, for ensuring the long-standing existence of NbS within the identified sites, the definition of their conservation status (if not already established, see Figure 9 for conservation areas that are preserved from development) is needed to preserve them or, more likely, portions of them from development, since they are mostly located within development boundaries. This can be secured by applying appropriate instruments that can be used to allocate proper space for and promote NbS early on in the planning process for new development projects, to preserve the undeveloped land from future urban expansions, or to promote the implementation of NbS in public spaces such as street green areas (Longato et al., 2022).

4.4.3 Potential of the proposed approach to advance performance-based planning of Nature-based Solutions

Besides the application tested in the case study of Valletta, the proposed approach can be adapted and used to address other planning issues, for example for identifying the most suitable NbS when regenerating built-up areas such as in brownfield redevelopment projects. Instead, the combination of the two tools for the calculation of NbS priority scores can be applied to identify the NbS needed in various city areas that provide the best combination of ES benefits delivered to residents in public-driven NbS implementation mechanisms. Examples may include applications for identifying the most suitable solutions to implement in areas where direct government provision is possible, for selecting the most beneficial areas for a specific NbS type (e.g., areas showing urban forest as a priority and, among these, the ones showing the higher scores to concentrate afforestation programmes), and for defining the type of out-of-kind compensation measures to enforce when an area is about to be developed and that developers must respect. Most notably, the methodology we proposed can be used to develop innovative performance-based approaches that are applied to assess urban development projects, which has recently been proposed as a suitable way to promote and integrate NbS in new developments since their flexibility in embracing multi-functionality and urban complexity (Dorst et al., 2019). Actually, our approach that combines ES demand mapping and assessment and NbS performance scores (i.e., the ES supply scores) can support the implementation of scoring systems (i.e., through defining scores/weights and thresholds) that establish locally-specific NbS requirements, or can be used to integrate/improve existing approaches and tools that usually make use of them separately (i.e., only ES demand mapping and assessment without NbS performance scores or the contrary) and/or through scoring systems that do not account for NbS multifunctionality. Examples of existing approaches and tools include the “performance-based green area indicators” (Stange et al., 2022) adopted in various cities, including the blue-green factor of Oslo (Oslo Kommune, 2018), the green factor of Helsinki (Juhola, 2018), the biotope area factor of Berlin, the green factor of Seattle, the green space factor of Malmo (Szulczewska et al., 2014), and the green factor tool of Melbourne (Bush et al., 2021).

Such tools combine two complementary mechanisms for screening urban transformation projects that can be flexibly defined according to the various city needs: criteria weighting of different green-blue surfaces and performance thresholds to achieve for granting development permits (Stange et al., 2022). They use a scoring system that combines the weights, namely the performance scores, of the different green-blue surfaces, which are usually defined by experts according to their capacity to support ecosystem functions and/or deliver ES, but do not include spatial assessment of ES demand to define context-specific requirements that better meet the ES needed in each area. Integrating spatially-explicit ES demand assessments can support the definition of ES-demand-based weights that can be used to adjust such performance-based indicators and define green area requirements according to local conditions and needs. Actually, the methods we used to assess the demand for ES that account for the spatial flows of ES from the providing to the benefitting areas may help to (partially) overcome a limitation of these tools, namely the non-inclusion or accounting for the character or quality of the area surrounding the development site (Stange et al., 2022).

While a more innovative performance-based approach grounded on spatial assessments of ES demand for defining the performance requirements of urban transformations has been proposed by Cortinovis and Geneletti (2020), the scoring method they adopted to define NbS requirements and scoring criteria is not grounded on NbS performance scores and favours NbS that deliver the single most needed ES (Geneletti et al., 2022), thus often not allowing to harness NbS multifunctionality that can address the demand of multiple ES simultaneously. Our approach can be used to refine such scoring methods by defining NbS requirements and scoring criteria based on the calculation of NbS priority scores that capture the multiple benefits delivered according to the demand profiles of each area. For example, in the approach previously proposed a vegetation barrier is usually selected when noise reduction is (or is among) the most needed service(s) (Geneletti et al., 2022). Nevertheless, in some cases, selecting an urban forest instead of a vegetation barrier could provide the best compromise between a slightly lower capacity to shield noise and a higher capacity to supply other ES such as air purification and microclimate mitigation. The presented approach is able to capture this compromise. This is especially important when the available space forces to select one or another solution, and when the demand for air purification and microclimate regulation is significant – even if not as much as noise reduction.

Finally, the look-up table(s) we developed can provide performance scores that are based on quantitative estimates of ES supply, which can be used instead of (or in combination with) expert scores to limit the risk of subjectivity, as suggested by Campagne and colleagues (2020). Integrating such scores would promote more evidence-based decision-making where data from the literature are explicitly used to score/weight the different green elements included in urban transformation projects. This would be more straightforward in approaches using scoring criteria related to NbS types or land covers (e.g., Cortinovis and Geneletti, 2020). For scoring systems that also include detailed design criteria for green areas and elements (e.g., related to tree species, tree size, or green-grey surface combinations), the integration of expert opinion and local knowledge to adjust the scores would remain crucial.

4.4.4 Strengths and limitations

The data and methods we used to map and assess ES demand to prioritize NbS allowed to directly account for the benefits (in terms of ES) provided by existing vegetation, hence the ES demand mapped corresponds to the actual demand by residents (i.e., the current supply of ES in the study area is already discounted from the demand assessments). Instead, other approaches usually map and assess ES demand and supply separately, possibly combining them only at a second stage to quantify mismatches (e.g., Larondelle and Lauf, 2016; Chen et al., 2019). For example, in the assessment of runoff regulation, imperviousness density is used as a proxy to quantify the intensity of the hazard (i.e., the more impervious is an area, the more runoff is potentially generated), but it also represents the ES supply side that is associated with the density of permeable surfaces, which support rainwater infiltration and runoff velocity reduction. In the assessment of microclimate mitigation, the use of Land Surface Temperature, vegetation and albedo indices derived from real-time monitoring data, allows depicting the current situation in which the mitigation effects of existing vegetation are already accounted for. The same reasoning can be applied to the demand for air purification, since it is based on an air pollution distribution map generated from real-time data measured by monitoring stations, thus measuring pollutant rates net of the pollutants already captured by existing vegetation. Finally, the methods applied for assessing the demand for noise reduction and recreation instead directly incorporated the ES supply component in the determination of the demand, which is based on the capacity of the current land covers to reduce noise and on the distribution of and accessibility to the existing public green spaces, respectively.

The approaches used for mapping and assessing ES demand are in general replicable in other areas, with some limitations. While for assessing the demand for some ES we used data that are in principle available worldwide (e.g., satellite data) or in large parts of the world (e.g., imperviousness data at EU level), for other ES local data are needed (e.g., air pollution map, distribution of public green spaces, noise levels from roads). However, some ES assessment methods can be used with different input data (e.g., generic noise parameters can be set if specific data on noise levels from roads is not available).

The list of NbS types used in this study is non-exhaustive and only includes NbS that can be implemented on the ground. Other types of NbS exist and can be added to our list for specific planning applications that involve, for example, the implementation of NbS on buildings (e.g., green roofs), such as in performance-based planning approaches. These solutions would require the analysis of additional suitability criteria for identifying constraints for NbS implementation (e.g., building-related constraints), as well as the assessment of their capacity to supply ES. In addition, different design typologies exist for these solutions (e.g. extensive and intensive green roofs), which involve different vegetation types and mixes to be installed that deliver more or less ES. A number of standard design criteria need therefore to be introduced to allow for assessing their capacity to supply ES and, consequently, for assigning the ES supply scores to NbS using the same method we applied to NbS types characterised by a combination of land covers can be used (e.g., a standardised proportion of different land covers for urban parks), which can be also further used to define some minimum design requirements for that type of solution. However, the attribution of a standardised proportion of land covers to NbS does not always correspond to the reality, where the same NbS type can be designed in different ways (even if meeting possible minimum design requirements). In any case, the ES supply scores can be adjusted relatively easily to reflect the capacity to supply ES of NbS with different land cover characteristics.

In addition, the potential NbS sites that were used in this study do not always correspond to the space that in reality is to be transformed. This in fact depends on a variety of factors such as the fragmentation of land properties or the definition of specific unitary development or management areas that do not correspond to the whole site area, but cover only a portion of it. The NbS priority scores calculated in this

study instead reflect the transformation of the whole site area. However, the main purpose of the study is to provide the methodological details of our approach and test it in order to highlight a possible use to provide spatial indications on the priority NbS types that are needed across the case study area using the available data on the potential sites for NbS on the ground. Different mapping methods and input data can be applied according to the various needs without affecting the rationale of the proposed approach, such as working on pixels to provide the priority NbS needed in each pixel area or using, when available, land parcel data to identify the ES demand profiles and the priority NbS needed in light of single parcel transformations.
Finally, our approach does not provide ready-to-use outcomes that can be automatically applied to planning decisions, but spatial indications (and indicators) that can support decision-making processes and the related negotiations that are required to balance the different interests (e.g., privates versus public, costs versus benefits, etc.) at stake. For example, weighting factors can be introduced to additionally weight the different ES based on their relative importance when calculating the priority scores of NbS to reveal specific local conditions and policy orientations (Cortinovis and Geneletti, 2020).

4.5 Conclusions

The approach presented in this chapter highlights the potential of combining the mapping and assessment of ES demand with the analysis of the potential ES supply of selected NbS types. It is aimed to support planning decisions towards the reduction of urban pressures and alleviation of socio-environmental challenges in cities, allowing decision-makers not only to identify priority locations but also the specific NbS that maximise the benefits to residents, which is paramount for promoting more effective outcomes within a context of competing demands for budgets and for the use of land. Compared to existing approaches, the strength of our approach is that it suggests as priority solutions the NbS type that provides the best balance between the supply of multiple ES, accounting for the most needed services but at the same time minimizing trade-offs between the different ES supplied. With our method, we have tried to address two of the elements that are deemed as essential for the next generation of ES research (Chan and Satterfield, 2020), namely the integration of biophysical and social information that couples multi-metric valuations towards ES provision for human wellbeing, and the provision of a decision-support approach that can be adapted and applied to context-appropriate decision-making for both the NbS planning and design phase (e.g., prioritizing locations for NbS during the planning phase, and supporting the definition of assessment criteria and NbS requirements that guide site design in urban transformation projects using performance-based approaches). Further adjustments and simulations to demonstrate the value of our approach to support real-life planning decisions need to be investigated together with practitioners for technical and political validation.

Chapter 5

Policy instruments to promote Nature-based Solutions in urban plans*

5.1 Introduction

This chapter moves from the planning of NbS (Chapter 4) to their implementation. In particular, it focuses on the use of specific policy instruments to promote NbS implementation in urban plans, identifying what instruments are suitable to promote the implementation of different typologies of NbS according to the transformations permitted by the plan. The application of such instruments is especially important in urban core areas where, besides a high demand for ES, dense urban form, many competing uses for land, and land ownership are important factors potentially hindering NbS implementation if appropriate measures and policies are not taken (Johns, 2019).

Current processes of urbanisation and climate change urge cities to reconsider the sustainability of urban planning approaches and resulting development patterns (Dorst et al., 2019). At the same time, there is increasing evidence showing how Nature-based Solutions (NbS), defined as actions that utilize ecosystem processes of green and blue infrastructure to safeguard or enhance the delivery of ecosystem services (ES) (Albert et al., 2019), can contribute to counteract or alleviate many of today's urban challenges (Babí Almenar et al., 2021). Integrating NbS in the planning and design processes that steer urban development is therefore promoted as a sustainable and cost-effective strategy to address societal challenges and enhance human well-being (Czúcz et al., 2018; Lafortezza et al., 2018; Maes and Jacobs, 2017).
Urban and peri-urban areas offer several opportunities to implement NbS (Castellar et al., 2021). These include building greening (e.g., green roofs and walls), greening interventions on private open spaces (e.g., renaturing community spaces and garden areas) and public areas

* This chapter is based on: Longato, D., Cortinovis, C., Balzan, M., Geneletti, D. (in review). Identifying suitable policy instruments to promote Nature-based Solutions in urban plans. *Cities.*

(e.g., street trees and urban parks), as well as rural and natural land management actions (Dushkova and Haase, 2020; Gutiérrez et al., 2017). New urban developments, as well as urban regeneration interventions, offer the possibility of an early integration of NbS, during project proposals (Gutiérrez et al., 2017). More difficult is their integration into the existing built-up spaces, which requires retrofitting and renovating existing buildings and open spaces (Grace et al., 2021). Often, NbS implementation is promoted by sectoral policies that address a specific issue, such as stormwater management (Puddephatt and Heslop, 2007) and wastewater treatment (e.g., Cross et al., 2021). These policies focus on a limited range of NbS or on specific benefits (e.g., increasing stormwater infiltration and reducing run-off), and lack the spatial and systemic approach required to promote the scaling up of NbS. Urban (spatial) planning can ensure the spatial coordination of NbS implementation and urban development, and provide a platform for policy integration (Stead and Meijers, 2009). This integration is even more needed when considering the potential cumulative impacts of NbS implementation, for example on the ecological connectivity of green and blue infrastructures (Xie and Bulkeley, 2020) and on equity in the distribution and access to green areas (Cousins, 2021).

Planning decisions can influence the availability, distribution, and management of NbS through dedicated actions and regulations that control the main features of green and blue infrastructure (i.e., location, typology, and size) involved in the process of ES provision (Cortinovis and Geneletti, 2019). In urban areas, planning decisions are typically formalized in urban plans through dedicated planning policies that are implemented through specific policy instruments (Bouwma et al., 2015). Policy (implementation) instruments constitute the linkage between policy formulation and policy implementation and are adopted to achieve the policy targets stated in the urban plan (Ali, 2013).

Several cities incorporate in their plans a number of policy instruments to explicitly promote the implementation of specific NbS. Examples are incentives for green roofs, regulations for on-site stormwater retention, and indices to measure the “green performance” of interventions (e.g., Carter and Fowler, 2008; Johns, 2019; Lakes and Kim, 2012). However, many plans still lack appropriate instruments to promote NbS or use generic regulations to implement greening interventions, for example by prescribing the share of green areas that should be maintained in different zones (Cortinovis and Geneletti, 2020). These regulations have a limited capacity to capture the multiple qualities and benefits of different types of NbS (Cortinovis and Geneletti, 2020; Ronchi et al., 2020). For example, a densely-vegetated area provides different ecological functions, ES, and benefits than a lawn or a green roof. Such regulations lead to a pattern of "routinization" (Capano and Lippi, 2017) in planning, where most of the greening interventions are conceived as a "toll" to be paid by developers rather than a proactive strategy to address societal challenges (Ronchi et al., 2020), thus limiting the options to effectively integrate NbS in everyday planning decisions. Moreover, the lack of innovation, boosted by the lack of knowledge of and experience with NbS planning and implementation instruments (Grace et al., 2021), acts as a barrier to their wider uptake (Naumann et al., 2020).

The aim of this chapter is to support the identification and selection of policy instruments that can be used in urban plans to promote the implementation of NbS. To this purpose, we provide an overview of the available instruments, and review their suitability to different typologies of NbS. The article addresses the following three specific objectives:

- to identify and classify policy instruments that can be used in urban plans to promote the implementation of NbS;
- to analyse the suitability of the available policy instruments to different typologies of NbS, and summarize the findings in a matrix showing what types of NbS can be promoted by each instrument;
- to demonstrate a potential use of the matrix to review the policy instruments currently deployed in two real-life urban plans, and to compare them with the full range of available options.

The analysed plans cover the urban area around Valletta, Malta. This small island state is one of the EU countries with the highest share of built-up areas and population density, which, together with the highly fragmented nature of land ownership (Irvine et al., 2019), make it an exemplary case where NbS implementation is particularly challenging (Balzan et al., 2021).

The remainder of the chapter is organised into four main sections. Section 5.2 presents an overview and classification of policy instruments that can be used in urban plans to promote NbS implementation, and illustrates their application through examples. Section 5.3 describes the criteria used to combine policy instruments and typologies of NbS and presents the matrix. Section 5.4 applies the matrix to analyse and classify the policies through which urban plans promote NbS implementation in the case study area. Section 5.5 discusses the usefulness and the opportunities offered by the proposed matrix to support decision-making, and frames the findings of the case study in the wider scientific literature. Finally, Section 5.6 provides the conclusions of our study.

5.2 Policy instruments to promote Nature-based Solutions implementation

In environmental policy, policy instruments are typically classified according to the degree of coerciveness (Pacheco-Vega, 2020), following the popular threefold classification proposed by Vedung (Vedung, 1998) and derived from Etzioni's classification of power (Etzioni, 1961). Accordingly, they can be classified into regulations, economic means, and information instruments. Regulatory instruments are usually legally binding. Economic instruments, which involve incentive-based and financial tools, are usually applied on a voluntary basis – just like information-based ones – and are non-legally binding until agreement, but with few exceptions (e.g., Daniels, 2007).

With specific reference to the concept of NbS, Bhardwaj and colleagues described the three categories of instruments as follows: "Regulatory instruments are compulsory measures imposing regulations, restrictions, limits and caps on activities (sectoral) that have implications on ecosystems and their services. […] Economic and financial instruments encourage stakeholders to reduce or limit the impact of their activities on ecosystems/environment. These instruments often provide financial/budgetary support for adopting solutions/alternatives which can reduce the impact of their activities. […] Information and education-based instruments ensure that stakeholders are well-informed about the approach [NbS] and its benefits" (Bhardwaj et al., 2020: 414).

The same categories of policy instruments can usually be found also in spatial plans, even if there is a lack of systematic and generalizable categorisations that accounts for policy instruments specifically applicable in the spatial planning domain (Stead, 2021). Considering policy instruments to promote the implementation of ecosystem-based actions or NbS in spatial plans, some authors proposed variations to these three categories, or added new ones. For example, Bengston and colleagues (2004) identified and classified the main policy instruments for managing urban growth and protecting open space in the United States into regulations, incentives, and land acquisition programs. Brody and colleagues (2004) used the same categories, with the addition of information-based instruments, to classify policy tools adopted to implement ecosystem-based actions at the city- and county-scale in Florida.

Starting from Brody and colleagues' classification, Cortinovis and Geneletti (2018a) analysed the state of ES inclusion in Italian urban plans and identified five categories of policy instruments adopted to implement nature-based actions: regulatory instruments, design-based instruments, land acquisition programs, incentive-based (including economic and non-economic incentives) and financial instruments, and information-based instruments. While regulatory, incentive-based and financial, and information-based instruments are applied in public policies in general, design-based instruments and land acquisition programs are specific of spatial planning. Both are based on command and control regulations. The former is used to control new developments through a masterplan that defines developers' obligations, either negotiable or non-negotiable (Turk, 2018), to realize on-site interventions. The latter is used by the public authorities to purchase private undeveloped land.

This study builds on the list of policy instruments classified in the five categories by Cortinovis and Geneletti (2018a) and integrates it with additional instruments found in the literature or used in specific case studies. Table 21 presents the list of instruments classified according to the different categories and provides a short description of each of them, together with some relevant examples.

Table 21. List of policy instruments to promote NbS implementation. Based on Cortinovis and Geneletti (2018a), expanded with additional information and instruments retrieved from Naumann et al. (2020), Bush and Hes (2018), and Duerksen et al. (1997).

Category	Instrument (code)	Description	Examples of possible applications to promote NbS
Regulatory instruments	Quantitative targets or standards (R1)	Definition of quantitative targets/standards that must be met when developing or redeveloping an area.	Square meters or percentage of pervious/green areas to maintain or include, number of trees to plant per each new inhabitant.
	Technological requirements (R2)	Definition of technologies that must be included when developing or redeveloping an area.	Mandatory green roof or wall installation.
	Compensation measures (R3)	Definition of mandatory (on-site or off-site) actions that must be included when developing or redeveloping an area as a way to compensate for the negative (environmental) impacts of the new development.	Mandatory tree planting along a new road, creation of a new public green area.
	Performance-based approaches with scoring systems (R4)	Definition of a minimum performance score that must be gained by attaining defined levels of green and blue surfaces when developing or redeveloping an area.	Scores gained by integrating green-blue surfaces in the development project (e.g., by planting trees, creating public green, maintaining permeable surfaces, and installing green roofs).
	Conservation zones or protected areas and sites (R5)	Identification of specific sites or green elements to be preserved and definition of restrictions to their use and transformation.	Protection of forest areas or conservation of monumental trees.
	Other regulatory instruments related to zoning (R6)	Other types of rules enforced through zoning regulations.	Cluster zoning to allow for wider open space preservation.
Design-based instruments (D1)		Definition of specific design solutions and regulations to apply to a specific development area, which are formalized in a (master)plan that identifies the approximate location, typology and size of the	Masterplan/detailed plan indicating the location and typology of private and public green spaces.

		main elements over the entire project.	
Land acquisition programs (L1)		The public administration buys the land from the owners to prevent development or to realize public projects (also called "fee simple" acquisition programs).	Preservation from development of natural/agricultural land or environmental improvement of the purchased areas, for example through afforestation programmes.
Incentive-based and financial instruments	Preferential tax treatments (F1)	Definition of tax incentives and fee reductions under certain property conditions or actions.	Tax rebates based on the measured amount of rainwater allowed to naturally infiltrate in the property rather than entering the public stormwater system.
	Subsides/grants (F2)	Direct subsidies and grants as payment for the public benefits of private investments attached to private properties.	Subsidies for green roof installation.
	Density bonuses (F3)	Increase in the floor area/building volume allowed in the site in exchange for meeting certain criteria.	Criteria may include the provision of private and/or public green, such as green roofs and street green.
	(Green) Financial bonds (F4)	Loans made by an investor to a borrower (typically corporate or governmental, e.g., municipalities) to finance projects and operations.	Public green projects such as the development of sustainable urban drainage systems.
	Transfer of development rights mechanisms (F5)	Giving rights to build in another area or to sell the development rights in exchange for the preservation of the original area from development.	Preservation from development of natural/agricultural land.
	Purchase of development rights or development rights acquisition programs (F6)	The public administration pays landowners to forgo land development rights documenting the transfer from the landowner to a public agency or organization. A conservation easement is recorded on the title of the property that limits development permanently.	Preservation from development of natural/agricultural land.
	Conservation easements (F7)	Legal agreement placed on a piece of property to restrict the development,	Preservation from development or intensive use of

		management, or use of the land. It involves the voluntary selling or gifting of one or more rights (e.g., occupy, use, lease, sell and develop the land, as well as harvest the vegetation and minerals on it) from the landowner to a public agency or organization.	natural/agricultural land
	Fast-tracking approval process (F8)	Fast-tracking of approvals for projects that incorporate urban greening interventions.	Green roofs and walls installation, green open space provision.
Information-based instruments	Guidelines and criteria for public space design and management (I1)	Definition of design guidelines or criteria that should be applied when realizing and/or managing public spaces.	Suggestion of suitable tree species for public spaces, guidance for park design.
	Promotion of good practices (I2)	Suggestion of principles, best practices and techniques to apply in private areas.	Suggestion of suitable NbS for retaining stormwater within the property area.
	Other information-based instruments (I3)	Other instruments aimed at supporting planning activities by providing information and knowledge, including the drafting of reports and documents, as well as the definition of monitoring actions and assessment criteria for proposed interventions.	Drafting of public green management policies/plans, inventories of public trees.

Regulatory instruments

Examples of quantitative targets or standards that must be achieved in urban development/redevelopment areas (i.e., without specifying the technology to achieve them) are the minimum share of available (private) and accessible (public) green open spaces (e.g., Cortinovis and Geneletti, 2020; Naumann et al., 2020), and the minimum volume of water to retain on-site in the property area, such as in the case of Toronto, Canada (Johns et al., 2018). On the contrary, regulatory instruments that define technological requirements prescribe the adoption of a specific technology (i.e., the specific type of intervention). Examples include mandatory requirements for implementing rainwater retention/infiltration systems in the case of new constructions (e.g., in Berlin, Germany through the “living soil layer” in private open spaces (Naumann et al., 2020)), or rules defining that all buildings of a certain type or size must green all or part of their roof, with new large commercial buildings with flat roofs often identified as candidates (Carter and Fowler, 2008).

Compensation measures refer to ecological compensation through greening interventions, such as mandatory replanting of trees if removed (Coria and Sterner, 2011). Compensations originate from the environmental impacts produced by new urban development/redevelopment and can be applied on-site or off-site (Kravchenko, 2019). Ecological compensation may be associated with a wide range of NbS, from ecosystem protection (e.g., preserving portions of land from development through mandatory land property transfers to compensate for environmental impacts occurred elsewhere (Cortinovis and Geneletti, 2018a)); to the improvement of existing and creation of new green spaces such as green roofs, tree planting, and public green areas (Ngan, 2004), also through restoration interventions (e.g., restoring sealed areas to compensate for new soil sealing projects (Tobias, 2013)). These can be implemented directly by the developers or by the public administration using the funding collected from the payment of the compensation fees (e.g., in Berlin (Hansen et al., 2019)).

As regards performance-based approaches with scoring systems, examples include the green factor tools (Juhola, 2018), also called biotope area factor in Berlin, Germany (Lakes and Kim, 2012) or blue-green factor in Oslo (Oslo kommune, 2018), which are used to regulate urban development primarily by setting limitations on its impacts rather than on densities or uses. This approach grants freedom of choice in the selection of green and blue elements – which are scored based on their importance for providing ES or specific functions – and in their location within the area, as long as the minimum performance score is achieved (Juhola, 2018). In some cases, scores are also gained by preserving existing vegetated areas (e.g., Helsinki green factor (City of Helsinki Environment Centre, 2016)) or improving vegetation on adjacent public spaces (e.g., Seattle green factor (Roehr and Kong, 2010)).

The definition of conservation zones or protected areas can be applied to preserve open spaces from development and protect valuable ecosystems, such as biotope areas in Berlin, Germany (Fischer et al., 2013). This instrument can be also applied to specific green areas and elements in public and private spaces, including among others, historic gardens and single heritage trees (Jim, 2017). Many cities and regional administrations around the world have enacted specific regulations to

protect urban trees of outstanding value from development and bad management (see e.g., Government of South Australia, 2012). Even when approved outside the planning process, urban plans usually play a key role in enforcing such regulations, as well as in creating and updating the related inventories.
Finally, among the other instruments related to zoning regulations, an example is the use of cluster zoning in new development projects, which provides flexibility for developers to construct buildings in clusters while remaining within the constraints of overall average density restrictions, thus designating greater part of the site to be green open space (Duerksen et al., 1997). A similar approach has been used also as a voluntary tool in rural areas, with the aim of preserving farmland, environmentally sensitive areas, and open space areas in large parcels by clustering rural uses and activities affecting the open space character and ecological functions of the area (e.g., policy n. 8420 "Rural land-use subdivision" in the Land Use and Development Code of Summit County, USA (Summit County, 1995)). Another example involves the definition of permitted and forbidden uses related to specific land use zones (Cortinovis and Geneletti, 2018a), which for instance can be applied for the management of rural and natural areas.

Design-based instruments and land acquisition programs
Still among command and control instruments are design-based instruments and land acquisition programs. The former are applied in specific large development projects (with land subdivision) where the public administration wants to control action implementation with a quite high level of detail (Cortinovis and Geneletti, 2018a), for instance by providing detailed design and dimensional parameters that may include specific greening interventions and open space requirements. They are usually part of a development agreement between the public and developers (see e.g., Hanssen, 2012; Oppio et al., 2019 for urban development agreements). Land acquisition programs concern the definition of a program by the public administration to acquire private land not – yet – developed, with the aim of realizing a public project such as a public park (Lawrence et al., 2013) or of preventing urban development and maintaining the area as natural as possible (Duerksen et al., 1997).

Incentive-based and financial instruments

Among preferential tax treatments, an example is the "imperviousness fee". This fee aims to reduce the amount of rainwater reaching the mixed sewage system by making property owners pay based on the property's actual imperviousness (Naumann et al., 2020). It may include a discount for the presence of stormwater source controls such as green roofs (Ngan, 2004). Preferential tax treatments can also be applied to new developments, taking the form of a reduction or waiving of the planning fees in exchange for NbS integration into their projects (Bush and Hes, 2018).

As concerns the provision of direct subsidies and grants, some examples are given by the green roof subsidy programmes targeting existing and new buildings adopted in various cities, such as in Hamburg and Chicago (Carter and Fowler, 2008; Naumann et al., 2020). Rather, cases of density bonus relevant for NbS promotion consist of allowing developers to increase the maximum permitted buildable area or volume on a property in exchange for greening interventions for the community, such as in Minneapolis and Chicago, USA, where developers were responsible for the implementation of parks and street trees, and the provision/preservation of open and green space in general (Morris, 2000). Density bonus regulations can also include green roofs as compensation for higher density (Ngan, 2004).

On the possible use of financial bonds to finance public environmentally oriented projects, an example is the introduction of green municipal bonds as debt instruments that are employed to support projects (including land use projects) declared to be sustainable or green, as happened in Mexico City, Mexico (Hilbrandt and Grubbauer, 2020). Another case of bond usage is represented by the bonds issued for acquiring, preserving and protecting environmentally sensitive non-urbanized land in Palm Beach County (Pienaar et al, 2019).

Several examples of incentive-based instruments concern mechanisms for preventing development on and conserving private farmland and natural/seminatural areas by transferring or buying land development rights that are attached to such areas (i.e., "transfer of development rights" and "purchase of development rights"), or restricting the management or use of the land (i.e., "conservation easements"). Exemplary cases of the use of such instruments are for creating city greenbelts (e.g., Bengston et al., 2004) and protecting wildlife habitats (Duerksen et al., 1997).

Finally, a practical application of a fast-tracking approval during the planning process is the “green door” instrument in Melbourne, Australia, where it is used as a non-financial incentive during the planning process to stimulate NbS integration and open space provision in new urban developments (Bush and Hes, 2018).

Information-based instruments

Among information-based instruments, examples of non-statutory guidelines and standards targeting public and private spaces can be found in several cities, such as guidelines for new and existing public parks in Gold Coast City, Australia (City of Gold Coast, 2018), and guidelines for green roofs installation in new and existing buildings in Barcelona, Spain (Contreras and Castillo, 2015). Finally, among the “Other information-based instruments” we can mention the preparation of tree management plans and inventories that can be used to support the identification of valuable species that deserve protection or to define suitable management practices, such as in Sweden where they are especially used by municipalities for managing existing trees and suggesting species selection in public and private spaces (Östberg et al., 2018). Another example is represented by the promotion of (voluntary) certification schemes that include the assessment of greening interventions in masterplans or in building construction and refurbishment projects (e.g., BREEAM rating system (Bowen et al., 2020)). Information-based instruments are usually not part of the urban plan’s formal policy documents, but are used to supplement the urban plan’s policies and regulations (Drumond et al., 2020) and can serve to raise citizens’ awareness on the importance of protecting and enhancing urban green spaces.

5.3 A matrix linking policy instruments to typologies of Nature-based Solutions

In this section, we develop a matrix that links the policy instruments previously identified with the different typologies of NbS that they can promote. The classification of NbS typologies follows the three main NbS categories proposed by Eggermont and colleagues (2015) based on the intensity of intervention: type 1 corresponds to “no or minimal intervention", type 2 refers to "management approaches that develop sustainable and multifunctional ecosystems and landscapes", and type 3 involves "managing ecosystems in very intrusive ways or even creating new ecosystems". The three categories reflect three different aims that urban plans can pursue with respect to green areas and related ES by implementing NbS: safeguarding existing green areas to maintain ES provision (type 1), improving existing green areas to increase their multifunctionality and enhance ES supply (type 2), and creating new green areas to provide ES (type 3).

Within this overall classification, different typologies of NbS can be identified based on the areas in which they are applied. Despite different – more or less prescriptive – approaches (Cortinovis and Geneletti, 2020), all urban plans divide the municipal territory into areas where different transformations are allowed (Lambin et al., 2014). This affects the typology of NbS that can be promoted in each area. For example, areas for new development offer the opportunity to both conserve existing green spaces and elements (type 1) and create new green areas (type 3), while actions on existing built-up areas are mostly aimed at improving the existing greenery (type 2). Crucially for our analysis, different permitted transformations correspond to different instruments that can be put in place to promote NbS in the different areas identified by the plan. Overall, we identified eight typologies of NbS and linked them to the policy instruments listed in the previous Section 2 (Table 22).

The identification of suitable instruments that can be used to promote the different typologies of NbS was mostly based on the information and practical examples found in the scientific and grey literature. We made only a few assumptions on the transferability of policy instruments among different typologies of NbS when no particular limitations exist to apply the instrument to other typologies, even if not explicitly addressed in the literature. For example, we found evidence of the use of subsidies/grants to finance the greening of existing buildings and the creation of new private green spaces, but the instrument can be reasonably applied also to incentivize the improvement of existing private open spaces (e.g., greening communal open spaces, installation of rainwater infiltration systems), including in non-urbanized areas (e.g., to integrate natural elements in agricultural areas).

Table 22. Matrix to guide the identification of suitable policy instruments (marked with ✓) to promote NbS implementation in urban plans (codes are described in Table 21).

Policy instruments

	Typologies of NbS	**R1**	**R2**	**R3**	**R4**	**R5**	**R6**	**D1§**	**L1**	**F1**	**F2**	**F3**	**F4**	**F5**	**F6**	**F7**	**F8**	**I1**	**I2**	**I3**
TYPE 1	Conserving green elements and open spaces in new development areas	✓[a]			✓[b]	✓[c]	✓[d]	✓[g]				✓[e]					✓[f]		✓*	✓*
	Protecting non-urbanized land (agricultural and (semi)natural)			✓[g]		✓[h]	✓[i]		✓[d]				✓[x]	✓[d, j]	✓[d, j]	✓[d, j]			✓*	✓*
TYPE 2	Improving existing greenery in private open spaces									✓[k]	✓*	✓*							✓*	✓[v]
	Improving existing public greenery and green areas			✓[l]									✓*					✓[m]		✓[v]
	Ensuring sustainable management and multifunctionality of rural and natural areas			✓*			✓[g]			✓*	✓*					✓[d]		✓*	✓*	✓[v]
TYPE 3	Greening existing buildings									✓[l]	✓[k, n]	✓[l]							✓[u]	✓[w]
	Ensuring the integration of private greenery in new developments	✓[o]	✓[k, n]	✓[l, p]	✓[b, q, r]			✓[g]		✓[f]	✓[k, n]	✓[e]					✓[f]		✓[u]	✓[w]
	Creating new public greenery and green areas	✓[k§]		✓[l]	✓[r§]		✓*	✓[g]	✓[s]	✓*		✓[e]	✓[t]				✓[f]	✓[m]		✓[w]

[a] Cortinovis and Geneletti, 2020; [b] City of Helsinki Environment Centre, 2016; [c] Jim, 2017; [d] Duerksen et al., 1997; [e] Morris, 2000; [f] Bush and Hes, 2018; [g] Cortinovis and Geneletti, 2018a; [h] Fischer et al., 2013; [i] Summit County, 1995; [j] Bengston et al., 2004; [k] Naumann et al., 2020; [l] Ngan, 2004; [m] City of Gold Coast, 2018; [n] Carter and Fowler, 2008; [o] Johns et al., 2018; [p] Tobias, 2013; [q] Oslo kommune, 2018; [r] Hirst, 2008; [s] Lawrence et al., 2013; [t] Hilbrandt and Grubbauer, 2020; [u] Contreras and Castillo, 2015; [v] Östberg et al., 2018; [w] Bowen et al., 2020; [x] Pienaar et al., 2019. * No limitation to apply the instrument, even if the literature shows evidence of application only to other typologies of NbS (vertical transferability). § Only applicable to new development areas with land subdivision.

NbS in new development areas, including conservation of existing and implementation of new (private) green spaces, can be promoted through most of the command and control (regulatory, design-based, land acquisition) instruments, and – to a lesser extent – incentive-based instruments, including both economic (e.g., subsidies) and non-economic incentives (e.g., fast-tracking approval process). NbS for improving the greenery of existing built-up areas (including buildings) can be almost exclusively promoted using incentive-based and financial instruments (e.g., preferential tax treatments). For NbS aimed at protecting non-urbanized areas, command and control (regulatory, land acquisition) and incentive-based instruments targeting the property rights (e.g., transfer of development rights) can be applied, while for improving and/or promoting sustainable management of rural and natural areas a few regulations (e.g., based on allowed uses related to zoning or compensation mechanisms) and incentives can be used (e.g., direct subsidies and fast-tracking approval process). Finally, the creation of new public green areas can be promoted through regulations and incentives that force or incentivize private developers in delivering public green alongside their private developments, or through instruments that allow the public administration to directly realize the planned green spaces (i.e., land acquisition programs or emission of financial bonds).

5.4 A case study application of the matrix

The case study application includes the two spatial plans (a description of the Maltese spatial planning system is provided in Section 3.2) covering the urban area around Valletta (Malta): the North Harbours

Local Plan (Malta Environment and Planning Authority, 2006) and the Grand Harbour Local Plan (Malta Environment and Planning Authority, 2002).

A qualitative content analysis of the two local plans was carried out by reviewing the current plan's policies to identify what are the ones that promote NbS-related interventions and classify them according to the typologies of NbS and related policy instruments used to promote their implementation, using the categories and instruments defined in the proposed matrix. The information collected was then organized in the matrix in order to show to what extent the policy instruments promoting NbS are already deployed against the full range of available options (Table 23).

Table 23. Number of policies promoting NbS identified in the two local plans, classified according to the typologies of NbS and policy instruments used to promote their implementation, among the suitable ones (non-blank cells).

		Policy instruments																		
	Typologies of NbS	**R1**	**R2**	**R3**	**R4**	**R5**	**R6**	**D1**	**L1**	**F1**	**F2**	**F3**	**F4**	**F5**	**F6**	**F7**	**F8**	**I1**	**I2**	**I3**
TYPE 1	Conserving green elements and open spaces in new development areas	1			0	2	0	2				0					0		0	1
	Protecting non-urbanized land (agricultural and (semi)natural)			0		6	0		0				0	0	0	0			0	0
TYPE 2	Improving existing greenery in private open spaces									0	0	0							4	0
	Improving existing public greenery and green areas			0									1					17		1
	Ensuring sustainable management and multifunctionality of rural and natural areas			0			0			0	0					0		1	0	2
TYPE 3	Greening existing buildings									0	0	0							0	0
	Ensuring the integration of private greenery in new developments	5	1	1	0			2		0	0	0					0		0	3
	Creating new public greenery and green areas	3		1	0		0	4	0	0		0	0				0	13		2

In total, 57 policies were identified in the two analysed local plans, which promote 72 specific NbS (among the eight typologies of NbS proposed) through 73 specific instruments (among the 19 different policy instruments identified) (Table 23). Some policies address more than one typology of NbS with the corresponding instrument (e.g., a design-based instrument promoting conservation of existing green spaces in a portion of the development site while requiring a greening intervention in another part of it). In other cases, one instrument is used to promote more than one typology of NbS (e.g., defining guidelines and criteria for both improving/managing existing and creating new public spaces). Overall, NbS are promoted mainly for creating new green spaces (type 3) (47%), followed by the improvement of existing ecosystems (type 2) (36%) and their protection (type 1) (17%), and especially target public spaces.

Information-based instruments were the most common instrument (60%) followed by regulatory and design-based (27% and 11%, respectively). Only one financial instrument was recorded, while land acquisition programs are not covered. The definition of guidelines and criteria for public space design and management is the most widespread instrument, while regulations are mostly covered by the definition of quantitative targets or standards and conservation zones or protected areas and sites.

Table 24 shows some examples of the policy instrument applications retrieved from the two local plans analysed. The full list of policies identified as relevant for promoting NbS implementation and classified per typology of NbS promoted and policy instrument(s) adopted can be found in Appendix B.

Table 24. Examples of policy instrument applications to promote the implementation of NbS identified in the two Maltese local plans. Policies starting with "NH" relate to the North Harbours Local Plan, with "G" to the Grand Harbour Local Plan.

Category	Instrument (code)	Example from Local Plans (with policy ID)
Regulatory instruments	Quantitative targets or standards (R1)	A portion of development site (identified as a minimum share of the site area) to retain as open space, or to transform to a public landscaped area (e.g., NHGT15, NHSW01).
	Technological requirements (R2)	Inclusion of effective landscaped buffering to protect any surrounding residential uses from undesired uses, such as industrial (e.g., NHMP12).
	Compensation measures (R3)	Replacement of trees if removed during development projects (e.g., NHCV05).
	Conservation zones or protected areas and sites (R5)	Designation of protected garden and tree areas to maintain as open (semi-)natural space (e.g., GG19, NHSJ11).
Design-based instruments (D1)		Definition of specific land use and design solutions, including green space typologies and their location, in a masterplan for a specific development area (e.g., GK03, NHSW08).
Incentive-based and financial instruments	(Green) Financial bonds (F4)	Possibility to stipulate financial bonds to ensure compliance with the area's objectives to include the implementation of adequate measures to mitigate against flood risk, among others (e.g., NHMP02).
Information-based instruments	Guidelines and criteria for public space design and management (I1)	Definition of desired tree planting and/or other landscaping elements to introduce in selected streets and public spaces, with different levels of design details (e.g., planted strip parallel to the carriageway) (e.g., GG18, NHMP04).
	Promotion of good practices (I2)	Encouraging privates to take measures to improve their sites, such as tree planting and other landscaping measures to mitigate possible undesirable environmental effects of or to screen industrial activities (e.g., GD04).
	Other information-based instruments (I3)	Consideration of implementation of future planning documents that include greening interventions, such as environmental upgrading and landscaping/management schemes, development briefs, rehabilitation schemes, or afforestation programmes in selected areas (e.g., GM15, NHRL06, NHSW06).

5.5 Discussion

5.5.1 Policy instruments to mainstream and upscale Nature-based Solutions

The matrix proposed in this chapter can help practitioners to identify the range of suitable policy instruments that can be deployed to promote NbS implementation in urban plans, covering different areas and typologies of NbS. The final selection shall then be based on real-life considerations and context-dependent factors such as policy objectives, affordability and financial aspects, technical feasibility, and alignment with other sectoral policies, among others.

The synthesis provided by the matrix shows that, to each typology of NbS, it always corresponds more than one possible instrument. This is especially important considering that a mix of different policy instruments is considered necessary for the long-term stability and scale up of NbS projects (Kabisch et al., 2017), as well as for advancing policy shift from grey to green (Johns et al., 2018). Integrating different instruments for NbS implementation, some of which are typically used in other sectors (e.g., financial instruments), alongside more traditional regulatory urban planning instruments allows promoting different typologies of NbS and targeting different areas and potential developers or investors. An effective mainstreaming of NbS in urban plans should therefore adopt a mix, or portfolio, of policy instruments with interactive effects - complementary or supplementary – among them (Capano and Howlett, 2020).

Possible combinations of policy instruments may involve instruments of the same category, such as the definition of density bonuses within transfer of development rights programmes (both incentive-based) (Linkous, 2016), or from different categories. Regulatory instruments, for example, can be combined with incentives to make them more effective, such as exempting targets from other regulations if specific performance criteria are met (Henstra, 2016). A practical example comes from Toronto, where besides the mandatory requirement of on-site water retention amount for all new development applications, a higher level of performance can be voluntarily achieved allowing access to a financial incentive (Johns et al., 2018). Information-based instruments can promote or push innovation supporting the development of knowledge and building broader community support, but can also be used to reinforce regulations (e.g., targets and standards) (Bush and Hes, 2018). For example, a list of nature-based actions that can be implemented to achieve minimum scores or standards set by regulatory instruments could be provided by the municipality to support developers in integrating suitable solutions in their projects (Cortinovis and Geneletti, 2018a). They can also be used to encourage people to take advantage of incentive-based instruments or to explain the rationale for authoritative regulations (Henstra, 2016). Although all these possible combinations are not explicitly included in our matrix, the list of suitable policy instruments that can be used for each specific typology of NbS provides the information base for possibly formulating combinations of instruments that can be deployed in each specific decision context.

With our work, we try to respond to part of the knowledge needs and gaps related to the design of NbS implementation processes and their institutional embedding and operationalisation, especially concerning the direct inclusion of NbS approaches into urban plans (Frantzeskaki et al., 2020). By providing locally adaptable policy implementation options to support NbS scaling up, the matrix can contribute to more systematic incorporation and promotion of NbS into governance instruments and regulations. In this regard, it should be noted that the study focused on substantive policy instruments, namely those affecting the delivery of policy goals, rather than procedural instruments, which instead support the process and procedures of policy formulation (Howlett, 2000; Stead, 2021). The latter are equally important for a successful mainstreaming of NbS in planning policies (Frantzeskaki et al., 2020).

5.5.2 Gaps and opportunities to promote Nature-based Solutions: contextualizing the case study's findings in the wider scientific literature

Besides suggesting options for new policy development, policy instrument classifications can support the analysis of existing policies and reveal what instruments (among the available ones) are not deployed in specific contexts, as in Heurkens et al. (2018). Our case study application shows that the analysed plans overlook several options of policy instruments to promote NbS implementation. The lack of incentive-based and financial instruments stands out from the analysis. While regulatory and design-based instruments offer to the public administration a good degree of control over the outcomes, their application is mostly limited to areas undergoing urban development or redevelopment and their effectiveness may be hampered by ineffective monitoring and enforcement by the responsible authorities (Steinebach, 2019). On the contrary, the impact of voluntary instruments such as incentive-based and financial instruments is more uncertain, but they can be directed to areas where NbS implementation cannot be promoted otherwise, including private green spaces. Existing residential areas cover most of the city's built-up areas and are recognised as being difficult for governments to manage (Lin et al., 2015). In a high-density urban area with high presence of fragmented private landownership such as the Valletta urban area, instruments that promote NbS implementation in existing private spaces through economic incentives and fee charges would be very important to stimulate private property owners to pursue alternative interventions than those that offer them the best value for money (Droste et al., 2017) and invest in interventions that provide more benefits to the community. However, to spread the use of such instruments, a different recognition of NbS in both the structure of municipal revenues and the competing public functions defining the municipal spending behaviour is required, to divert part of the revenues (e.g., municipal fees and charges, taxes, and fiscal transfer between governmental levels) for NbS financing (Droste et al., 2017). Moreover, as highlighted by Hartmann and colleagues (2019), to foster their use it is imperative that such instruments are communicated in a way that "non-experts" can comprehend the consequences and implications.

If this finding about the lack of incentive-based and financial instruments were valid for most urban plans beyond the specific case study, as the results of other studies suggest (Cortinovis and Geneletti, 2018a), there would be a risk for NbS to be implemented mostly in combination with new developments, either on greenfield or brownfield sites. This would leave behind large portions of urban areas, especially high-density ones where the opportunities for interventions in public spaces are also scarce. Such areas are the most vulnerable to several environmental and social issues that NbS can contribute to address, from climate change impacts to segregation, hence in a sense the most in need of NbS implementation. Overlooking policy instruments that can support NbS implementation in these areas would therefore undermine the impacts of NbS scaling up and likely promote or strengthen existing inequalities in access to green and ES (Cousins, 2021).

Another missing opportunity is the lack of instruments that promote the integration of NbS at the building scale. This emerges even for new development projects, which could integrate greening elements during the planning process more easily (e.g., through specific regulations, thus paid off by private developers) compared to existing built-up areas that require retrofitting interventions (e.g., through economic incentives provided by the public) (Longato et al., 2022). This finding is in line with what discussed by Pearlmutter and colleagues (2020), who found very little prioritization of policies promoting design strategies that involve the greening of built surfaces. Similarly, the analysis of NbS integration in urban policies in Poznan (Poland) revealed building green as one of the opportunities not yet explored (Zwierzchowska et al., 2019).

However, in the Valletta area the lack of financial and building-related instruments promoting NbS in local plans may have been partially tackled by more recent schemes, at regional and national scale, providing subsidies for NbS implementation on private buildings and spaces, or supporting the establishment of NbS in public buildings. For example, funding for local actors has been made available through Local Action Groups under the LEADER Programme (Community Led Local Development) of the Rural Development Programme (RDP) 2014-2020, in which local councils and voluntary organisations could apply for funding to establish and restore green infrastructure within the built environment (and including buildings and open spaces). Local councils and non-governmental organisations can also apply for funds, termed as Development Planning funds, to cover the costs associated with improving the quality, accessibility and quantity of green and blue infrastructure to address inequalities, provide increased opportunities to experience and value nature and contribute to economic regeneration (Planning Authority, 2020). Public entities, local councils, voluntary organisations and educational institutions can also apply for funding under the BELLUS call issued under the Environment Fund, which aims to improve the local environment through urban greening and measures for biodiversity and nature protection. Integrating these funding opportunities for NbS implementation in a systematic way into the local plan's policies (e.g., by creating policy instrument mixes with other typologies of instruments) may be beneficial to enhance their prioritisation and scaling up to address the specific socioenvironmental challenges and sustainability policy goals of the plans.

Finally, the regulatory instruments identified that promote the creation of new green spaces are exclusively based on quantities of green, without providing any additional design and/or functional requirement. The definition of standards and requirements that include qualitative specifications is desirable to promote NbS that are really effective in delivering multiple ES. This is especially important for larger development areas that require land subdivision, in which the regulatory instruments can be used to promote green spaces and elements not only at the building scale or within the private properties but also to pursue the creation and greenery of new public spaces, such as public parks and streets. For instance, performance-based approaches with scoring systems such as the green factors (e.g., Juhola, 2018) or systems based on ES demand (e.g., Cortinovis and Geneletti, 2020) are along these lines. They constitute valuable instruments in the policy mix to promote NbS in new development/redevelopment areas that really address societal challenges, even if they require higher computational and administrative efforts.

5.5.3 Limitations of the study

Our study is mainly based on information provided by the literature that still is in its infancy regarding the topic of NbS implementation. However, our search was not limited to NbS as a keyword, and to policy instruments used exclusively in urban planning: it included other concepts (e.g., green infrastructure, ecosystem services, and integrated urban water management) and relevant fields of application (e.g., sectoral policies, such as stormwater management policies). Considering that most of our references rely on reviews and analyses of real-life policies and applications, the list of policy instruments that we identified reflects the most frequently used ones in real-life practices, even though we might have missed instruments (of variations of them) that are not extensively adopted.

As described in Section 3, the development of the matrix involved some assumptions about the possibility to use specific policy instruments in different contexts of application than the ones explicitly addressed in the literature. Hence, further research involving practitioners (e.g., through interviews, workshops, etc.) who are experienced in the use and formulation of policy instruments can be useful to expand the list of instruments and verify their contexts of application, as well as to understand the extent to which the findings of the case study can be generalized. Finally, the possibility to use instruments in each case is assigned based on a binary choice (yes/no). This might not fully represent the complexity faced by users in the reality, thus resulting in an oversimplification of the decisions. For example, the use of certain instruments may be restricted by other rules/policies (e.g., the use of specific regulations only in areas larger than a given size or with a specific land use), or by "hybrid" situations concerning the land tenure of the target areas (e.g., semi-private or semi-public areas, private areas with public use, etc.). While the restrictions coming from other rules/policies can be addressed solely by complementing the matrix with such information, further research to improve our work should focus on addressing the complexity of "hybrid" land tenure situations, as well as on depicting the possible combinations of instruments among the available options.

5.6 Conclusions

Recent studies have highlighted the lack of suitable, locally adapted policy instruments to promote NbS implementation (Naumann et al., 2020). Identifying policy levers that can support the integration of NbS into urban plans has been defined as a priority knowledge need for NbS mainstreaming (Grace et al., 2021). In this chapter, we proposed a matrix to guide the identification and selection of suitable policy instruments that can be integrated into urban plans to promote NbS. We then applied the matrix to analyse two urban plans and identified which instruments are currently deployed and which are not. The findings of the analysis showed (yet) unexplored opportunities that the proposed matrix can reveal, for example in the light of the plan's policy revision, in terms of both neglected typologies of NbS and policy instruments for their implementation. Planning has long recognized the importance of green spaces for cities and their inhabitants, but policies that incorporate

NbS are recent additions to public policy suites (Bush and Doyon, 2019). As such, city plans, especially those approved a (relatively) long time ago, often overlook the potential positive impacts of greening interventions and the available policy options to ensure their implementation at scale.
With our matrix, we aim to provide practitioners with the knowledge base to widen the (policy) options for promoting NbS implementation. Different instruments can be applied to promote each typology of NbS. This variety makes it possible to identify the most suitable options for implementing NbS in different contexts, as well as to diversify and to combine more instruments to better secure the scaling up of NbS, which represents one of the ambitions of EU policies, among others (e.g., European Environmental Agency, 2021). Urban plans have a fundamental role in pushing policy innovation toward NbS mainstreaming and scaling up in cities, in terms of both contents (i.e., green qualities and benefits) and ways for practical implementation, which is the focus of our study. Future lines of investigation should focus on co-developing and combining instruments with practitioners and decision-makers, monitoring their application to different city areas and typologies of NbS, and assessing their effectiveness in delivering high-performing NbS, as well as on barriers and constraints as reported by the involved stakeholders.

Chapter 6

Discussion

This thesis addressed three interlinked aspects relevant for NbS mainstreaming in urban planning.

The first aspect concerns the integration and use of ES knowledge in spatial planning. It was addressed in Chapter 2 through a literature review aimed at analysing practical applications of ES in spatial planning processes and instruments that successfully integrated ES knowledge. The review critically analysed real-life applications so as to gather the key aspects concerning the integration of ES to support planning decisions, which are formalized in spatial plans (urban plans in the case of cities). The results of the review frame the context within which the knowledge produced in this thesis can be applied and serve to understand the innovation proposed in the following chapters. The in-depth analysis of selected cases allowed tracking the co-development, integration, and use of ES knowledge across the whole planning process, thus revealing both the outcomes generated and the procedures adopted to integrate them into the planning instruments, as well as the main advantages, constraints, enabling factors, and open issues associated with ES knowledge integration in spatial planning that can be relevant for creating the contextual conditions and supporting planning decisions in favour of NbS.

The second aspect is related to the use of spatial assessments of ES demand to support effective NbS planning. It was investigated in Chapter 4, in which an approach based on ES demand was developed to allocate and prioritize NbS in order to deliver ES for addressing the existing urban challenges. The approach was tested in the case study area of Valletta (Malta) within the available sites (i.e., potential NbS sites) identified in Chapter 3, by combining spatial assessments of the demand for five key ES (i.e., runoff regulation, microclimate mitigation, air purification, noise reduction, nature-based recreation) and performance scores that reflect the capacity of eleven NbS types to supply the analysed ES.

The third aspect involves the promotion of NbS implementation through the use of policy instruments. It was addressed in Chapter 5 by providing an overview of the suitable policy instruments (including regulatory, incentive-based, and information-based instruments) that can be adopted in urban plans to promote NbS implementation, and developing a matrix that links the policy instruments to different typologies of NbS. The latter are identified according to the possible transformations permitted in the different areas regulated by the plan (e.g., conservation or improvement of existing spaces and areas, greening of existing or new buildings, creation of public or private green in new development areas). The matrix can help practitioners to identify the range of suitable instruments that can be deployed to promote the implementation of each NbS type. The matrix was then applied to analyse the content of the two urban plans in force in the study area of Valletta, revealing which instruments are currently deployed and which are not, hence the missing opportunities to promote NbS implementation that could be further explored.

The following sections (6.1 and 6.2) attempt to bring together the main elements of the different thesis sections dealing with each of these three aspects and to unveil the main connections between them, summarized according to the following two dimensions:

- critical aspects of integrating ES to favour NbS in planning decisions;
- advancing methods and tools to support NbS mainstreaming in urban planning.

Finally, Section 6.3 describes possible future pathways for NbS research and practice in urban planning.

6.1 Critical aspects of integrating ecosystem services to favour Nature-based Solutions in planning decisions

Given the strong relationship between the NbS and ES concepts, advantages, constraints, and enabling factors of integrating ES into spatial planning processes and instruments revealed by the cases analysed in Chapter 2 have a direct influence on the successful (or not) uptake of NbS into planning decisions.

The main advantages identified concern the potential of the ES concept to synthesize and interpret multiple (socio-environmental) information and to facilitate interactions between multiple actors involved in the process (Adem Esmail and Geneletti, 2017; Dick et al., 2018; Galler et al., 2016; Spyra et al., 2019), which can also facilitate NbS integration through supporting the combination of different expertise and resources that are required to plan and manage them (Croeser et al., 2021). Another advantage emerging from the literature is related to the capacity of the ES concept to broaden the scope of the planning process and enlarge the perspective on relevant issues to address, which can be crucial for stimulating the uptake of NbS in planning decisions, especially since the ES concept is seen as a useful communication tool to promote the benefits of nature (Grunewald et al., 2021).

Regarding the barriers, some of those identified in the case studies are recurring to the adoption of ES in decision-making processes, such as data availability and accuracy, and lack of resources (time, competence, and money) to produce the assessments (Beichler et al., 2017; Palomo et al., 2018; Spyra et al., 2019). Others are specific to ES integration into spatial planning, such as the difficulty in linking ES goals to the objectives of the planning process and in communicating and understanding the ES concept (and, consequently, NbS) by all the stakeholders involved in the process. The need for a deep understanding of the local context as a prerequisite to provide effective planning support before applying ES approaches, classifications, and tools that are developed to be as general as possible to ensure wide applicability and comparability also emerged. These limitations can potentially hinder NbS uptake, especially in urban planning processes focusing on the local scale, thus often suffering from poorer data availability and coarser ES information that may not provide reliable support to decision-making (Grêt-Regamey et al., 2014), compared to processes for the development of regional-scale plans that can benefit from a wider variety of ES frameworks, assessment models, and ES-related decision-support tools (Grêt-Regamey et al., 2017; Pandeya et al., 2016). This causes difficulties in developing appropriate and replicable assessment methods to identify the relevant issues to address and/or to measure the beneficial effects of NbS, since both issues and benefits are mostly dependent on local-scale factors, opportunities, and constraints. For example, in the approach based on ES demand developed and tested in Chapter 4, local data about air pollution and noise levels from roads were used as input to spatially define the challenges to address. Similarly, detailed land use and cover/zoning data were used in Chapter 3 to identify the potential NbS sites. In addition, the characteristics of the local context in which the NbS would potentially operate have been analysed considering the land use and physical constraints that limit the applicability of certain types of NbS. The collection, interpretation, and elaboration of all the necessary data and information have been time-consuming and involved collaborative work between scientists and public institutions: all aspects that often do not match with timelines of and expertise involved in real-life planning processes.

Possible enabling factors that can boost ES integration into the planning process, as emerging from the literature review, are represented by specific “window of opportunities” that can make it possible to initiate an extra-ordinary collaborative planning process, and the presence of specific regulatory frameworks that can act as facilitators for triggering ES integration into spatial planning. Integrating ES in a planning law, regulation, or mandatory tool can support a more explicit consideration of such a concept early on during the planning and design processes and can promote effects at a larger scale (Grunewald et al., 2021). The same can be applied to NbS, which can be explicitly promoted using specific regulations and other types of policy instruments that can be adopted in spatial plans, as presented in Chapter 5 with a specific focus on urban plans.

Overall, the case studies analysed in Chapter 2 suggest that the involvement of a wide variety of stakeholders is linked not only to a higher degree of participation, but also to more substantial and meaningful ES-based planning outputs. This is also very relevant when it comes to the NbS concept, since it embraces a variety of disciplines (e.g., planning, design, ecology) and the engagement of actors from different fields can contribute to more effective and reliable NbS planning outcomes (Dorst et al., 2019). Finally, an iterative science-policy interface and a process of knowledge co-production with planning institutions and all the stakeholders involved emerge as essential factors to initiate and successfully complete the process of ES integration into spatial planning, all aspects that were found prominent also with regards to NbS (Frantzeskaki, 2019).

The main ES outputs observed in all the cases considered for in-depth analysis are maps showing the spatial distribution and, in some cases, levels of ES supply, either directly included among the plan documents, or used as a basis to produce the formal zoning scheme. This revealed a recurring tendency of integrating ES knowledge almost exclusively based on the supply side, with no cases incorporating the mapping and assessment of ES demand, despite the explicit consideration for the demand side and the identification of beneficiaries should be among the main improvements brought to planning practices by the ES concept (Cortinovis and Geneletti, 2018a). This tendency has also been reported by other authors. For example, Larondelle and Lauf (2016) found that, contrary to ES supply, only a few applications attempted to assess and incorporate ES demand to support decisions. This could potentially hamper the process of NbS mainstreaming in planning decisions. Actually, integrating ES demand can make more explicit the link between NbS and the existing planning issues and challenges (Babí Almenar et al., 2021), which can be addressed by delivering (the demanded) ES.

6.2 Advancing methods and tools to support Nature-based Solutions mainstreaming in urban planning

With the aim to (partially) fill the gap identified in Chapter 2 about ES demand applications, Chapter 4 attempted to advance ES demand mapping and assessment methods to support a more informed and effective NbS allocation and prioritization. The proposed approach was tested in Valletta urban area and supports both the prioritization of potential NbS sites according to the spatial variation of ES demand (i.e., sites within or close to ES demand hotspot areas are identified as a priority) and the allocation of the specific NbS types that maximise the benefits by providing the best balance of multiple ES among those that are most demanded in each site. Since many benefits (i.e., ES) provided by NbS in urban areas are local in nature, with effects only on a limited (benefitting) area (Hansen and Pauleit, 2014), NbS allocation plays an essential role in defining the beneficiaries (Meerow and Newell, 2019). An informed allocation can therefore lead to a better use of resources and to address environmental injustices (Sarabi et al., 2022).

Results show that, overall, the priority of the potential NbS sites is linked both to the level of ES demand in the surroundings (or within the site in the case of noise reduction) and to the size of the site, since to larger sites potentially correspond larger benefitting areas. These two factors directly influence the number of people (or residential buildings in the case of noise reduction) potentially benefitting from the ES supplied by NbS. Larger sites nearby ES demand hotspot areas for the majority of the five ES considered are consequently the ones receiving higher priority scores.
The proposed approach that combines ES demand and performance scores reflecting the capacity of NbS to supply ES has thus proved to support an effective prioritization and spatial allocation of NbS in the study area. This is crucial in order to deliver the most demanded ES where they are most needed, hence promoting effective NbS outcomes within an overall context of competing demands for budgets (Fletcher et al., 2021), as well as for the use of land.

Urban forest is the most needed NbS type identified in the study area, being the one with the highest capacity to supply the ES analysed. Planting trees, through urban forestry/afforestation or street trees, is often seen as the best solution to tackle most urban environmental challenges (Cortinovis et al., 2022; Pataki et al., 2021). However, identifying the type of solution that may contribute to addressing the existing challenges is not sufficient to ensure effective NbS outcomes, since other factors may affect them. For example, afforestation with non-native monocultures can lead to maladaptation to climate change and low biodiversity value (Seddon et al., 2020). On the other hand, this does not mean that afforestation programmes must all be implemented exclusively using native species. Especially in urban areas, the mixing of native with non-native species providing similar valuable functional traits is usually preferrable to provide ecosystems that are better adjusted to urban environmental conditions (Berthon et al., 2021; Kabisch et al., 2022).

Besides the application tested in the case study of Valletta, the proposed approach can be adapted and used to address a variety of other planning issues and decisions, for example for identifying the most suitable NbS when regenerating built-up areas such as in brownfield redevelopment projects, or the NbS needed in various city areas that provide the best combination of ES benefits delivered to residents in public-driven NbS implementation mechanisms. Examples along these lines may include applications for identifying the most suitable solutions to implement in areas where direct government provision is possible, for selecting the most beneficial areas to dedicate to a specific NbS type (e.g., areas showing urban forest as a priority and, among these, the ones showing the higher scores to concentrate afforestation programmes), and for defining the type of out-of-kind compensation measures to enforce when an area is about to be developed and that developers must respect. While such an approach can be used as a planning support tool during the planning (process) phase(s), NbS implementation should then be secured and promoted by applying appropriate instruments that can be used, for example, to allocate proper space for and promote NbS early on in the planning process for new developments, to preserve the undeveloped land from future urban expansions, or to promote the implementation of NbS in public spaces such as street green areas, as well as to conserve and improve existing ecosystems and areas in order to enhance ES provision. In particular, according to the findings of Chapter 5, in which a matrix was developed to link suitable policy instruments that can be adopted in urban plans (i.e., the municipal planning instrument in which the decisions taken during the planning process are formalized) to the different typologies of NbS that they can promote, regulatory instruments can be especially used to integrate NbS early on in new development areas (e.g., regulations for integrating NbS in new buildings or private open spaces, as well as in public spaces resulting from land subdivision processes), as well as for conserving existing green areas, while incentive-based and financial instruments are suitable to promote NbS in refurbishing and renovating the existing built environment (e.g., incentives to stimulate the greening of existing buildings and private open spaces).

An important condition influencing the application of policy instruments for promoting NbS implementation is land ownership. For example, in areas where private landowners have the right to develop their property in line with the plan's provisions, the municipality can articulate regulations that require the creation of green spaces (Brokking et al., 2020). These can be applied both to promote NbS implementation on the private property and to pursue the creation of new public green spaces, such as public parks, in larger projects requiring land subdivision that involves the transfer to the municipality of part of the land (e.g., for the creation of streets and other public areas). Hence, land ownership enables municipalities to push for NbS in private projects to raise the sustainability objectives targeting the whole municipal area (Brokking et al., 2021).
In existing private urbanized areas, instead, incentive-based and financial instruments become relevant for promoting NbS implementation that cannot be promoted otherwise (e.g., through regulations). Here, private property owners can be stimulated through incentives (e.g., subsidies or tax reduction) to pursue alternative interventions than those that offer them the best value for money (Droste et al., 2017) and invest in interventions that provide more benefits to the community (such as NbS). This is especially important since such areas are the most vulnerable to several environmental and social issues that NbS can contribute to address, from climate change impacts to segregation, hence in a sense the most in need of NbS implementation.

However, one of the main shortcomings of policy instruments for NbS implementation, especially regarding regulations, is that they often neglect green space's qualities and functional traits that influence ES provision, focussing exclusively on quantities (irrespective of the type of green) set out in planning standards as a "toll" to be paid (Ronchi et al., 2020), or lacking binding detailed instructions related to ES and/or NbS typologies (Brokking et al., 2021).
In this regard, performance-based approaches with scoring systems are emerging as promising approaches to promote and integrate NbS in new

developments since their flexibility in embracing the multi-functionality of green (Dorst et al., 2019). Among the notable examples (still few) there are the "performance-based green area indicators" (Stange et al., 2022) or systems based on ES demand (e.g., Cortinovis and Geneletti, 2020). They combine two complementary mechanisms for screening urban transformation projects that can be flexibly defined according to the various city needs: criteria weighting of different green-blue surfaces or NbS and performance thresholds to achieve for granting development permits (e.g., Stange et al., 2022). They use a scoring system that combines the weights/scores of the different green-blue surfaces or NbS according to their capacity to support ecosystem functions and/or deliver ES and define a minimum performance score that must be gained by attaining defined levels of green and blue surfaces or NbS (e.g., by planting trees, creating public green, maintaining permeable surfaces, and installing green roofs) when developing or redeveloping an area.

The approach proposed in Chapter 4 that combines ES demand mapping and assessment and NbS performance scores, besides the application for supporting NbS allocation and prioritization in Valletta urban area, can be adapted and used to develop innovative performance-based approaches that allow to harness NbS multifunctionality for addressing the demand of multiple ES simultaneously. It can support the implementation of scoring systems (i.e., through defining scores/weights and thresholds) that establish locally-specific NbS requirements according to the spatial variation of ES demand, or can be used to integrate/improve the existing approaches and tools that usually make use of them separately, hence only ES demand mapping and assessment without NbS performance scores (e.g., the approach proposed by Cortinovis and Geneletti (2020)) or the contrary (e.g., the family of "performance-based green area indicators" (Stange et al., 2022)).

Taking a step back to the matrix developed in Chapter 5, it shows that to each typology of NbS it always corresponds more than one possible instrument. This is especially important considering that a mix of different policy instruments is considered necessary for the long-term stability and scale up of NbS projects (Kabisch et al., 2017). Integrating different instruments for NbS implementation, some of which are typically used in other sectors (e.g., financial instruments), alongside

more traditional regulatory urban planning instruments allows promoting different typologies of NbS and targeting different areas and potential developers or investors. For example, a full list of NbS that can be implemented to achieve minimum scores (e.g., in the case of performance-based approaches) or standards set by regulatory instruments, which can be classified as an information-based instrument, could be provided by the municipality to support developers in integrating suitable solutions in their projects (Cortinovis and Geneletti, 2018a). Such regulatory instruments could also be combined with incentives to make them more effective, for example by exempting targets from other regulations if specific performance criteria are met (Henstra, 2016).
An effective mainstreaming of NbS in urban plans should therefore adopt a mix, or portfolio, of policy instruments with interactive effects - complementary or supplementary – among them (Capano and Howlett, 2020).

6.3 Future pathways for Nature-based Solutions research and practice in urban planning

A strong collaboration between science and policy is needed to improve the uptake of NbS into urban planning. One the one hand, research should provide the evidence base to support policy decisions in favour of NbS that can be tailored and applied to the different planning processes (and related phases) and practices in which NbS implementation can be promoted. In this direction, methods and approaches based on ES mapping and assessment that support the spatial identification of the socioenvironmental conditions to consider and challenges to address, as well as of the solutions to prioritize and the potential benefits delivered, are important tools that can be used to pursue the goal of mainstreaming NbS in urban plans, which are spatially-explicit in their nature. On the other hand, the policy side should offer appropriate opportunities and tools for anchoring this evidence base to real-life planning processes and instruments to support the implementation and scaling up of NbS, meaning that existing processes and instruments need to be developed, improved, and tailored to effectively integrate the innovations brought by the ES and NbS concepts. Despite these general challenges that should be accounted for in future works aimed at mainstreaming NbS in urban planning, a number of more detailed fields of investigation that should be approached across the science-policy interface can be derived from the studies carried out within this thesis. They include the integration of ES demand knowledge to support NbS planning and the use and combination of specific policy instruments to promote and scale up NbS implementation.

6.3.1 Integrating ecosystem service demand to favour Nature-based Solutions uptake

As outlined in Chapters 2 and 4, the integration of ES mapping and assessments in spatial planning processes and instruments, with a particular focus on the demand side, can support the creation of the contextual conditions and offer appropriate spatially-explicit knowledge for the mainstreaming of NbS in planning decisions. ES mapping and assessment can be applied to support different decisions at different stages of the planning process. For example, the variety of methods that are used to predict the change in ES supplies resulting from the implementation of the proposed interventions, as well as the demand for ES that originates from the spatial variation of current or foreseen socio-economic and demographic conditions, can be used to analyse the potential consequences of NbS on human wellbeing (Geneletti et al., 2022). With specific reference to the mapping and assessment of ES demand, it can be used to support planners in specific decisions, such as for identifying priority locations to reduce resident exposure to climate-related or other hazards (Baker et al., 2021) or for providing accessible green spaces to people currently not living close to existing green areas (Syrbe and Grunewald, 2017), and can be incorporated into the planning process to develop possible alternatives for NbS allocation scenarios that address such policy objectives.
Future works should therefore especially focus on understanding the applicability of and adapting ES demand mapping and assessments to the different decision contexts and phases of the planning process, as well as on understanding possible pathways for their formal use and integration to support the development of the urban plan’s regulatory framework (e.g., zoning scheme, development control regulations, etc.)

and/or of the policy instruments adopted to implement the plan's actions. While the former requires (almost exclusively) working on the policy side with policy-makers, as regards the latter, particularly interesting for future research is the application of ES demand mapping and assessments to define locally-specific NbS requirements, which can be possibly translated into regulatory instruments that require to developers to integrate NbS within their urban transformation projects to attain the development permit. In line with this objective, an interesting option is offered by the so-called performance-based planning instruments, which have recently been proposed as a suitable way to promote and integrate NbS since their flexibility in embracing multi-functionality and urban complexity (Dorst et al., 2019). They can be applied as a regulatory instrument to assess future development's compliance with the established (score) requirements.

Examples of existing real-life applications include the so-called "performance-based green area indicators" (Stange et al., 2022) already adopted in various cities, including the blue-green factor of Oslo (Oslo Kommune, 2018), the green factor of Helsinki (Juhola, 2018), the biotope area factor of Berlin, the green factor of Seattle, the green space factor of Malmo (Szulczewska et al., 2014), and the green factor tool of Melbourne (Bush et al., 2021). Such tools are aimed at defining minimum performance scores that must be gained by attaining defined levels of green and blue surfaces when developing or redeveloping an area, granting freedom of choice in the selection of green and blue elements – which are scored based on their importance to provide ES or specific functions – and in their location within the area, as long as the minimum score is achieved (Juhola, 2018). However, their application is not informed by ES demand mapping and assessments, thus they do not consider the spatial variation of the demand across the city to define the NbS requirements, with the risk of not properly capturing the (most) needed benefits at the local level.

The possibility to use ES mapping and assessments in performance-based planning of NbS has been recently explored by Cortinovis and Geneletti (2020), who proposed an innovative approach that combines both ES supply and demand maps to define NbS requirements. However, the scoring method they use is not grounded on NbS (or green-blue surfaces) performance scores and mostly favours NbS that deliver the single most needed ES, thus not considering their multi-functionality.

The approach we developed and tested in Chapter 4 combines the spatial assessment of ES demand with a scoring system that accounts for the multi-functionality of different NbS. It can be quite easily adapted and deployed to build a performance-based planning approach (or to improve existing approaches) that allows harnessing NbS multi-functionality to address the local demand of multiple ES simultaneously, with the added advantage that the performance scores are defined based on evidence data about ES supply, hence they can support more scientifically sound decisions. Future research should then focus on supporting the development of a performance-based planning approach that attempts to overcome the limitations of the existing approaches starting from the approach we proposed.

Further, the work should benefit from the collaboration of practitioners and experts that can support the development and validation of the scoring system and the requirements against which the compliance of the project is to be assessed. Moreover, to assess the effectiveness of the various approaches (i.e., existing and new ones) in delivering NbS that really address the needs of residents, a test simulating their application in some sample areas should be carried out and the outcomes assessed in terms of benefits delivered and beneficiaries targeted (e.g., Geneletti et al., 2022). Based on that, the pros and cons of each approach can then be identified and compared, for example to verify if more complex, resource- and time-consuming approaches lead to much better results (or not) than others.

Finally, another investigation field that is worth mentioning and that should be further exploited when mapping and assessing ES demand is related to the integration of other socio-demographic data (besides population count or density like in our study) in the assessment to include environmental justice aspects (e.g., income data, ethnic groups, etc.), which is another important aspect to consider when planning for greener cities to tackle existing urban challenges (Herreros-Catis and McPhearson, 2021).

6.3.2 Promoting the implementation of Nature-based Solutions in urban plans

In Chapter 5, suitable policy instruments that can be used to promote the implementation of different typologies of NbS are identified in a matrix, providing the knowledge base that can be used to support the uptake of NbS in urban plans. Future works and experimentations in this field should be approached in strong collaboration with the policy sector and oriented to the practical applications of such instruments. In particular, scientists should work with practitioners and decision-makers to test the co-development and combination of different policy instruments for ensuring a successful integration of NbS into the urban plan's policies. This does not mean coming up with completely new instruments but tailoring existing ones to the need of NbS implementation in order to achieve the plan's objectives for addressing the existing challenges and issues. Actually, a wide range of planning-related problems can be addressed through NbS and urban planners are already equipped with a large and variegated set of instruments that can be used to implement them (Cortinovis and Geneletti, 2018a), which can be (more or less easily) combined to better ensure the long-term stability and scale up of NbS projects in cities (Kabisch et al., 2017). Taking one step further, monitoring with practitioners and stakeholders their application and scaling up to different city areas and typologies of NbS, as well as assessing their effectiveness in delivering high-performing NbS, should provide the evidence and information base for assessing their usefulness and promoting their replicability, possibly expanding or reducing their use according to pros (e.g., user-friendliness, transparency) and cons (e.g., technical and political barriers and constraints) as reported by the involved stakeholders (e.g., policy-makers, developers, citizens, etc.).

However, new policy and governance frameworks that favour NbS through mixes of policy instruments of different typologies (e.g., regulations, incentives, and information) must be accompanied by additional efforts and resources, especially regarding appropriate financial investment models to ensure continuity and maintenance of NbS postscaling (Bai et al., 2018; Frantzeskaki et al., 2019), and increased human and technical resources to ensure the application and monitoring of instruments and their outcomes, among others. The former is especially true when it comes to incentive-based instruments providing economic incentives to privates for implementing NbS, for which part of the revenues - including municipal fees and charges, taxes, and fiscal transfer between governmental levels – need to be diverted in the light of a different recognition of NbS in both the structure of municipal revenues and the competing public functions defining the municipal spending behaviour (Droste et al., 2017). The latter is relevant for those instruments requiring continuous updating (e.g., inventories included as information-based instruments such as tree inventories), and for those characterised by a higher complexity in terms of amount of information to be processed and/or skills required within the public administration, which can also result in an increase of transaction costs (e.g., performance-based instruments requiring the application of more complex assessment and monitoring criteria than more traditional instruments (Cortinovis and Geneletti, 2020)). Thus, when it comes to practical applications of policy instruments to promote NbS implementation, further investigation is needed on how such related issues can be addressed, both in terms of supporting financial models and increased complexity and resources needed to apply them.

Chapter 7

Summary of research findings and conclusions

7.1 Main findings

The overall aim of the thesis was to develop and test methods and tools to advance the mainstreaming of NbS in urban planning processes and instruments. Given the strong relationship between the NbS and ES concepts, considering that the NbS concept has emerged to operationalize an ES approach within spatial planning policies and practices (Dushkova and Haase, 2020), the research was significantly oriented to the application of ES knowledge to support the uptake of NbS in spatial planning decisions (Chapter 2 and 4). Chapter 5 instead (with some elements introduced as early as Chapter 3) elaborates on the implementation aspects of NbS connected to the urban plan’s policies and instruments.

One of the major strengths of the thesis is then represented by the exploration of multiple concerns that need to be approached for mainstreaming NbS in urban planning processes and instruments, ranging from planning to implementation aspects, even if allowing only for a narrow view of such a broad topic. From the use of ES knowledge during the planning processes, to the development of appropriate approaches based on ES demand spatial assessments that support the planning of NbS to effectively address the existing urban challenges, to the promotion of their implementation through the use of appropriate policy instruments that can be adopted in urban plans. As reported in the introduction, such aspects are all related to the main innovations that the NbS concept recently brought to the science and policy sectors compared to more traditional and long-established ecological concepts: the value of nature to address societal challenges, the strong connection to the land use and spatial planning policy dimension, and the relevance of the implementation aspects (Babí Almenar et al., 2021; Pauleit et al., 2017; Raymond et al., 2017; Kabisch et al., 2016).

Within this context, the thesis was structured around three specific objectives. The first objective was addressed in Chapter 2, which aim was to analyse practical applications of ES in spatial planning processes that successfully integrated ES knowledge. In particular, through a systematic review of the literature, this chapter sought to map the state of the art of ES use in spatial planning and critically analyse real-life cases to identify possible advantages, enabling factors, and constraints of ES knowledge integration and formalization into spatial planning processes and instruments.
Outcomes of the review revealed to what extent ES science is already used to support real-life planning decisions and shape planning instruments and regulations, the critical aspects of ES integration into planning processes and instruments, and the open issues associated with the integration of ES knowledge into spatial planning. In the case studies identified, ES knowledge has been applied mainly during the planning phase devoted to analysing the context through mapping and assessing ES supply in order to provide baseline information aimed at assessing and possibly reducing the impacts of spatial planning decisions. In several cases, this knowledge is further iteratively applied to define/refine the policy goals and objectives and/or to develop and assess alternative scenarios, possibly supporting the implementation of the formal land use zoning scheme starting from the selected preferred scenario. Only one case made explicit reference to the demand side of ES during the planning process, but ES demand was not spatially assessed in any of the case studies identified. Integration of ES demand mapping and assessments therefore still is an open issue when it comes to ES knowledge application in spatial planning processes, practices, and instruments, as already observed in other studies reviewing real-life applications (e.g., Cortinovis and Geneletti, 2018a).
Urban planning – more than all the other spatial planning processes – determines the distribution of people and functions that cause harmful environmental impacts and at the same time are affected by socioenvironmental pressures, as well as can put in place specific actions and measures toward more sustainable and resilient development and management of areas where the demand for ES is high through appropriate implementation tools (Cortinovis and Geneletti,

2018a). Actually, the explicit consideration for the demand side, as well as the identification of beneficiaries, should be among the main improvements that the ES concept may provide to the urban planning field, which would strengthen planners' arguments in favour of NbS against other sectoral interests during planning decisions that require the balancing of public and private benefits and interests (Hauck et al., 2013; Cortinovis and Geneletti, 2018a).

Overall, the real-world case studies analysed revealed advantages of integrating ES knowledge into spatial planning processes mainly linked to practical aspects, such as synthesizing complex socio-environmental information and promoting participation. Windows of opportunity offered by regulatory frameworks and innovative processes and instruments, such as marine spatial plans and strategic environmental assessments, are among the main key factors triggering the integration. However, supportive contextual conditions are necessary, including science-policy collaborations across the entire planning process and environmental awareness among policy-makers and stakeholders.

While Chapter 3 introduced the case study area of Valletta (Malta) and presented the preliminary analyses to identify the spatial opportunities for NbS that supported the empirical applications presented in the following chapters, the second objective was addressed in Chapter 4. Its aim was to develop and test an approach based on ES demand mapping and assessment to support planning decisions towards an effective allocation and prioritization of NbS to address the existing urban challenges while providing as many benefits as possible to citizens. The approach was applied to allocate NbS on the ground within the potential NbS sites identified. First, the demand for five key ES for the study area was spatially assessed, namely runoff regulation, microclimate regulation, air purification, noise reduction, and (nature-based) recreation, and ES demand scores were calculated for each ES in each potential NbS site accounting for the ES flows from the providing (the sites themselves) to the benefitting areas (the areas receiving the benefits in terms of potential ES delivered by NbS). Second, the site's demand scores were combined with performance scores reflecting the capacity to supply the analysed ES of eleven NbS types. Such performance scores were calculated based on a statistical analysis of ES supply values retrieved from existing studies that measure (quantitatively or qualitatively) the ES supplied by different land covers or green elements that can be associated with the proposed NbS types (e.g., woodland for urban forests, single trees for street trees, etc.). Based on this combination, each NbS type was scored in each site and the one gaining the highest score represents the priority solution that best meets the demand profile of the site, since having the highest capacity to supply the (most) demanded ES in that area. In addition, the maximum priority score (i.e., corresponding to the priority score of the NbS type that obtained the highest score among the proposed ones) obtained in each potential NbS site reflects the need for NbS implementation, allowing the identification of the sites where NbS implementation should be prioritized, namely those characterised by high demand levels for multiple ES.

Results show that urban forest is the most needed NbS type across the study area, being the one with the highest capacity to supply most of the ES analysed. However, there are specific cases in which other typologies are more suitable: in sites showing demand hotspots for specific services, such as noise reduction and nature-based recreation, and in sites where size, shape, or land use constraints hinder the implementation of urban forests.

The proposed approach can be used to inform planning decisions aimed at prioritizing both the locations and the specific typologies of NbS in order to deliver the most demanded ES across urban areas, thus responding to the main goal of addressing the existing urban challenges while maximizing the ecosystem’s benefits to citizens taking advantage of their multifunctionality. It can be used and adapted to support a variety of planning decisions dealing with the prioritization and/or spatial allocation of NbS, including the development of performance-based planning approaches aimed at integrating NbS within urban transformation projects through the definition of ES-based scoring systems and minimum score requirements.

Finally, the third objective was addressed in Chapter 5, which investigated what policy instruments can be used in urban plans to promote the implementation of different typologies of NbS in order to support the identification and selection of the suitable instruments for each NbS typology. An overview of the different policy instruments that can be used in urban plans to promote the implementation of NbS was provided according to the literature, including regulatory, other command and control instruments (i.e., design-based instruments and land acquisition programmes), as well as incentive-based (i.e., including financial and non-financial incentives) and information-based instruments that are mostly applied on a voluntary basis. The suitability of each instrument to different typologies of NbS was then analysed. The different NbS typologies were identified and classified based on the areas in which they are applied (e.g., new private development or public areas, existing private or public open/green spaces and buildings, non-urbanized – rural and natural – areas), which correspond to different permitted transformations by the plan, and following the three main categories proposed by Eggermont and colleagues (2015) according to the intensity of intervention. From NbS that involve “no or minimal intervention”, to those requiring “management approaches that develop sustainable and multifunctional ecosystems and landscapes”, and the ones that involve “managing ecosystems in very intrusive ways or even creating new ecosystems”.

The findings were summarized in a matrix showing what instruments can be used to promote the implementation of each type of NbS, thus providing the knowledge base to support practitioners in their identification and selection according to the different NbS they seek to promote. Regulations can be especially used to integrate NbS early on in new development areas, while incentive-based and financial instruments are suitable to promote NbS in refurbishing and renovating the built environment. In addition, to each typology of NbS, it always corresponds more than one possible instrument, providing alternative options and allowing combinations of instruments of the same category or pertaining to different categories (e.g., regulatory and incentive-based). This is especially important considering that a mix of different policy instruments is considered necessary for the long-term stability and scale up of NbS projects (Kabisch et al., 2017), and for advancing policy shift from grey to green (Johns et al., 2018), allowing to promote different typologies of NbS and target different areas and potential developers or investors.

The proposed matrix was then applied to analyse the two urban plans in force in the case study area of Valletta, revealing which instruments are currently deployed and which are not, thus identifying missing opportunities that could be further exploited. These include the use of incentive-based instruments for promoting the greening of existing spaces, the adoption of building-related policies and instruments for the greening of existing (i.e., incentives) and new (i.e., regulations) buildings, and the development of regulations that include qualitative specifications of green, which may overcome the limitations of more traditional regulatory instruments that only specify quantitative targets (e.g., size of the area) but no typologies/qualities of green. Most of these findings are reflected also in other studies that reviewed current urban plans and policies in several cities (e.g., Cortinovis and Geneletti, 2018a; Zwierzchowska et al., 2019), indicating that these unexplored opportunities are rather generalizable. However, such gaps may be partially addressed by other policy schemes that are external to the urban plan's policy framework, such as observed in the Valletta area (e.g., subsidies for NbS implementation in Malta can be accessed through the Rural Development Programme). Nevertheless, systematically promoting the implementation of NbS in urban plans (e.g., by creating policy instrument mixes with multiple typologies of instruments) may be surely more beneficial to systematically address the socioenvironmental challenges and sustainability policy goals of an area while securing the scaling up of interventions, all factors that instead are hardly accounted when implementing single NbS projects without the spatial coordination offered by the urban plan.

7.2 Concluding remarks

The availability and distribution of green and blue infrastructure elements in cities are directly linked to urban planning decisions, which are formalized within urban plans and policies, together with the spatial distribution and vulnerability profile of the population and physical assets (Cortinovis and Geneletti, 2019). The relationship between urban planning and NbS therefore stems from the fact that planning decisions can influence the existence, spatial extent and allocation, and even the management of green and blue infrastructure, while controlling and influencing the distribution of population and physical assets that in turn create the demand for ES to address the existing challenges. To act as an effective solution, NbS must then be carefully planned, designed, and distributed to target - in space and time - the issues and challenges affecting a city, a neighbourhood, or a specific site, while providing benefits to as many beneficiaries as possible.

Within this framework, this thesis explored multiple aspects related to the mainstreaming of NbS in urban planning in order to offer a multi-faceted view on how NbS can be planned, integrated and promoted in planning decisions. The topics span from ES knowledge integration in planning processes that can stimulate decisions in favour of NbS (Chapter 2), to the use of ES demand mapping and assessment to support the allocation of NbS in order to effectively target the existing challenges and provide benefits to citizens through ES (Chapter 4), to the use of policy instruments in urban plans to promote their implementation and scaling up (Chapter 5).

However, despite NbS have been shown to be a valuable solution to many of today's urban challenges (e.g., resulting from climate-related hazards, massive urbanization and congestion, etc.), they cannot be considered a panacea for addressing or alleviating all the existing societal issues. An example is represented by the benefits provided by vegetation in purifying the air. Despite the capacity of NbS (more or less high, depending on the NbS typology and related vegetation components) to purify the air is unquestionable, the overall benefit provided in terms of pollutants removed is almost negligible with respect to the total airborne pollutants that are constantly released in the atmosphere by human activities. This is especially true in urban areas, where the magnitude of emissions is huge, and even if we plan for extensive implementation of NbS with a high capacity to capture pollutants (e.g., urban trees and forests) the benefits will be limited (Pataki et al., 2021; Nemitz et al., 2020). Therefore, the effect on air quality of NbS needs to be considered in the context of their wider benefits (e.g., microclimate mitigation, stormwater interception, increased physical and mental health), thus focussing on their multifunctionality, when promoting them in planning decisions (Nemitz et al., 2020).

Overall, today more than ever urban planning decisions need to be directed towards the development of truly sustainable cities (in terms of both social and environmental sustainability), without excluding any population group. The integration of nature in cities through NbS not only offers the opportunity to make cities greener and provide multiple benefits while reducing socioenvironmental pressures, but also to reimagine the overall planning and design of our cities in a more people-friendly direction. This is possible and desirable since urban NbS do not exist in isolation but are part of socioecological systems (Kabisch et al., 2022), influenced by both biophysical processes and social and political practices (Ernstson, 2013; Moosavi et al., 2021; Tzoulas et al., 2021). They are interconnected with grey urban infrastructures, including streets and pedestrian paths (Kabisch et al., 2022) and they can function in synergy with them to more liveable, resilient, just and sustainable urban environments (Frantzeskaki et al., 2021). For example, creating spaces for nature could require reducing spaces dedicated to cars (e.g., reducing traffic road and car parking areas), while favouring other more environmental- and human-friendly functions (e.g., enhancing public transport, enlarging pedestrian areas and promoting walking/cycling), which can jointly contribute to the wellbeing of citizens.

This would require more complex decisions and cross-sectoral collaboration across departments, meaning getting different municipal departments such as transport and mobility, social policy, water infrastructure, and green space planning together to combine the resources and skills needed to plan NbS in an inclusive and multifunctional way (Kabisch et al., 2016; Bush, 2020; Frantzeskaki et al., 2020; Moosavi et al., 2021; Kabisch et al., 2022). as well as co-creation and co-design with different stakeholders to generate appealing and social acceptance of NbS and related decisions (Frantzeskaki, 2019). Hence a change in the paradigms that currently guide the planning of many cities, often characterised by short-circuits and limitations. For instance, designers may favour familiarity preferring traditional grey solutions, or politicians may favour aesthetic impact (Croeser et al., 2021), as well as short-term benefits rather than NbS benefits that usually become apparent in the longer term. In addition, NbS differ in the skills and resources required to plan, design, deliver, and maintain them, with some requiring specific technical and/or ecological knowledge (e.g., ES knowledge) and others primarily relying on social capital leverage (Williams et al., 2010; Qiao et al., 2018; Croeser et al., 2021), and with different financial needs for both implementation and maintenance. Even in institutional bodies that do have the specialised skills and resources, internal relationships and governance structures, which are often characterised by the silo mentality and a lack of collaboration between stakeholders that should be involved in the planning, co-creation, and management of NbS

(Kabisch et al., 2016; Sarabi et al., 2020; 2022), may facilitate the use of one skillset over others (Brown and Farrelly, 2009; Kronenberg, 2015), and hamper NbS uptake in planning processes and practices. All these factors need to be carefully considered and addressed when planning for NbS in the real world. However, the increasing number of best practices involving NbS across the world shows that working towards this direction is actually possible when planning and designing cities.

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Appendices

Appendix A: Supplementary Material to Chapter 4

Methodology for estimating the capacity to supply ecosystem services of different Nature-based Solutions

The following tables (A.1 to A.10) report, for each ES analysed, i) the land-cover-based ES supply values assigned to the different NbS (A.1, A.3, A.5, A.7, A.9), which are derived from existing studies (references are provided in the first row of the tables reporting the ES supply values), and ii) the statistical analysis for the quantification of the ES supply scores for each NbS (A.2, A.4, A.6, A.8, A.10). In some cases, the typology of land cover reported in the analysed study is directly linked to the NbS. In others, a number of assumptions were needed to link a certain land cover, a combination of land covers, or other elements, to the NbS.

Runoff regulation

Table A.1. Runoff regulation ES supply values assigned to the NbS.

NbS type	Liu and Russo, 2021			Derkzen et al., 2015		
	Runoff retention (l/m2)	**Normalized supply value**	**Land cover type**	**Runoff retention (l/m-2)**	**Normalized supply value**	**Land cover type**
Urban forest	9,85	0,86	Woodland	8,70	0,84	Woodland
Tree planting area	9,85	0,86	Woodland	8,70	0,84	Woodland
Vegetation barrier	8,08	0,71	Tall shrub	7,30	0,70	Tall shrub
Low vegetation area	8,77	0,77	Herbaceous	8,00	0,77	Herbaceous
Stormwater infiltration system	11,40	1,00	Assuming herbaceous + 30% infiltration rates*	10,40	1,00	Assuming herbaceous + 30% infiltration rates*
Large park	9,10	0,80	Assuming 70% herbaceous and 30% woodland	8,21	0,79	Assuming 70% herbaceous and 30% woodland
Small park	8,87	0,78	Assuming 90% herbaceous and 10% woodland	8,07	0,78	Assuming 90% herbaceous and 10% woodland
Street trees	9,41	0,83	Tree	8,40	0,81	Tree
Hedgerow	8,08	0,71	(Tall) shrub	7,30	0,70	(Tall) shrub
Roadside green	8,77	0,77	Herbaceous	8,00	0,77	Herbaceous
Community garden	6,45	0,57	Other	6,00	0,58	Other

Table A.1 (continued). Runoff regulationES supply values assigned to the NbS.

NbS type	De Manuel et al., 2021			Bush et al., 2021			Farrugia et al., 2013	
	Runoff retention (non-dim)	**Normalized supply value**	**Land cover type**	**Runoff mitigation (non-dim)**	**Normalized supply value**	**Land cover type**	**Flood control (non-dim)**	**Land cover type**
Urban forest	0,88	1,00	Clustered trees	2,83	1,00	Assuming large, medium and small tree (avg)	1,00	Seminatural woodland with dense undergrowth
Tree planting area	0,88	1,00	Clustered trees	2,83	1,00	Assuming large, medium and small tree (avg)	0,80	Planted woodland with sparce undergrowth
Vegetation barrier	0,85	0,97	Shrub	2,00	0,71	Large shrub	0,90	Dense scrub with dense undergrowth
Low vegetation area	0,57	0,65	Grasslands	2,00	0,71	Lawn/turf	0,60	Grassland
Stormwater infiltration system	0,74	0,84	Assuming grasslands + 30% infiltration rates*	2,60	0,92	Assuming lawn/turf + 30% infiltration rates*	0,78	Assuming grassland + 30% infiltration rates*
Large park	0,66	0,75	Assuming 70% grasslands and 30% clustered trees	2,25	0,80	Assuming 70% lawn and 30% large, medium and small tree (avg)	0,73	Assuming 70% parkland/scattered trees and 30% planted woodland
Small park	0,60	0,68	Assuming 90% grasslands and 10% clustered trees	2,08	0,73	Assuming 90% lawn and 10% large, medium and small tree (avg)	0,71	Assuming 90% parkland/scattered trees and 10% planted woodland
Street trees	0,80	0,91	Street trees	2,75	0,97	Assuming medium and small tree (avg)	0,90	Individual trees
Hedgerow	0,85	0,97	Shrub	2,00	0,71	(Large) shrub	0,70	Hedge
Roadside green	0,57	0,65	Grasslands	2,00	0,71	Lawn/turf	0,50	Amenity grassland
Community garden	-	-	-	-	-	-	-	-

* Infiltration rates of a stormwater infiltration system, taking as reference a rain garden (but the process of water infiltration into the ground is similar also for the other systems; see, for example, “infiltration types” practices in Ontario Ministry of the Environment, 2003), is assumed to be around 30% more than a conventional patch of lawn, as reported in several stormwater management manuals (e.g., Wisconsin Department of Natural Resources, 2003).

Table A.2. Quantification of runoff regulation ES supply scores of NbS.

NbS type	Frequency of the normalized ES supply values among the different ranges of values						Number of studies
	0	**0,01-0,2**	**0,21-0,4**	**0,41-0,6**	**0,61-0,8**	**0,81-1**	
Urban forest	0	0	0	0	0	5	5
Tree planting area	0	0	0	0	1	4	5
Vegetation barrier	0	0	0	0	3	2	5
Low vegetation area	0	0	0	1	4	0	5
Stormwater infiltration system	0	0	0	0	1	4	5
Large park	0	0	0	0	5	0	5
Small park	0	0	0	0	5	0	5
Street trees	0	0	0	0	0	5	5
Hedgerow	0	0	0	0	4	1	5
Roadside green	0	0	0	1	4	0	5
Community garden	0	0	0	2	0	0	2

Table A.2 (continued). Quantification of runoff regulation ES supply scores of NbS.

NbS type	% of the different ranges of values covered						ES supply score [0-5]
	0	0,01-0,2	0,21-0,4	0,41-0,6	0,61-0,8	0,81-1	
Urban forest	0	0	0	0	0	1	5
Tree planting area	0	0	0	0	0,2	0,8	5
Vegetation barrier	0	0	0	0	0,6	0,4	4
Low vegetation area	0	0	0	0,2	0,8	0	4
Stormwater infiltration system	0	0	0	0	0,2	0,8	5
Large park	0	0	0	0	1	0	4
Small park	0	0	0	0	1	0	4
Street trees	0	0	0	0	0	1	5
Hedgerow	0	0	0	0	0,8	0,2	4
Roadside green	0	0	0	0,2	0,8	0	4
Community garden	0	0	0	1	0	0	3

Microclimate mitigation

Table A.3. Microclimate mitigation ES supply values assigned to the NbS.

NbS type	Bartesaghi-Koc et al., 2019				Zardo et al., 2017		
	Mean diurnal LST (°C)	**Delta LST (°C) from "highly impervious" land cover [14,80°]**	**Normalized supply value**	**Land cover type**	**Cooling capacity score (non-dim)**	**Normalized supply value**	**Land cover type**
Urban forest (> 2 ha)	8,30	6,50	1,00	Dense trees with shrubs and grasses	98,00	1,00	Assuming grass with up to 100% tree cover
Urban forest (< 2 ha)*	8,30	6,50	0,80	Dense trees with shrubs and grasses	54,00	0,55	Assuming grass with up to 100% tree cover
Tree planting area*	11,20	3,60	0,44	Mixed grasses with clustered trees	46,00	0,47	Assuming grass with up to 80% tree cover
Vegetation barrier*	9,90	4,90	0,60	Assuming mixed grasses with shrubs and trees	-	-	-
Low vegetation area (> 2 ha)	13,00	1,80	0,28	Mostly non-irrigated grasses	74,00	0,76	Grass without tree cover
Low vegetation area (< 2 ha)*	13,00	1,80	0,22	Mostly non-irrigated grasses	20,00	0,20	Grass without tree cover
Stormwater infiltration system*	13,00	1,80	0,22	Assuming mostly non-irrigated grasses	20,00	0,20	Assuming grass without tree cover
Large park	11,37	3,43	0,53	Assuming 70% mostly irrigated grasses and 30% mostly irrigated grasses with clustered trees	79,40	0,81	Assuming 70% grass without tree cover and 30% grass with up to 80% tree cover
Small park*	11,59	3,21	0,40	Assuming 90% mostly irrigated grasses and 10% mostly irrigated grasses with clustered trees	22,60	0,23	Assuming 90% grass without tree cover and 10% grass with up to 80% tree cover
Street trees*	12,80	2,00	0,25	Assuming mixed surfaces with aligned trees	33,00	0,34	Assuming sealed with around 50% tree cover (to simulate a line of street trees in tree pits)
Hedgerow*	-	-	-	-	-	-	-
Roadside green*	11,70	3,10	0,38	Mostly irrigated grasses	20,00	0,20	Grass without tree cover
Community garden (> 2 ha)	13,20	1,60	0,25	Assuming mixed surfaces (imp-perv) without trees	66,00	0,67	Assuming heterogeneous with 0% tree cover
Community garden (< 2 ha)*	13,20	1,60	0,20	Assuming mixed surfaces (imp-perv) without trees	19,00	0,19	Assuming heterogeneous with 0% tree cover

Table A.3 (continued). Microclimate mitigation ES supply values assigned to the NbS.

NbS type	**De Manuel et al., 2021**			**Derkzen et al., 2015 (also used in Liu and Russo, 2021)**		
	Cooling (non-dim)	**Normalized supply value**	**Land cover type**	**Cooling (UGS fraction weight)**	**Normalized supply value**	**Land cover type**
Urban forest (> 2 ha)	0,80	1,00	Clustered trees	1,00	1,00	Woodland
Urban forest (< 2 ha)*	0,80	0,80	Clustered trees	1,00	0,8	Woodland
Tree planting area*	0,80	0,80	Clustered trees	1,00	0,8	Woodland
Vegetation barrier*	0,40	0,40	Shrub	1,00	0,8	Tall shrub
Low vegetation area (> 2 ha)	0,37	0,46	Grasslands	0,50	0,50	Herbaceous
Low vegetation area (< 2 ha)*	0,37	0,37	Grasslands	0,50	0,4	Herbaceous
Stormwater infiltration system*	0,37	0,37	Assuming grasslands	0,50	0,4	Assuming herbaceous
Large park	0,50	0,63	Assuming 70% grasslands and 30% clustered trees	0,65	0,65	Assuming 70% herbaceous and 30% woodland
Small park*	0,41	0,41	Assuming 90% grasslands and 10% clustered trees	0,55	0,44	Assuming 90% herbaceous and 10% woodland
Street trees*	0,75	0,75	Street trees	1,00	0,8	Tree
Hedgerow*	0,40	0,40	Shrub	1,00	0,8	(Tall) shrub
Roadside green*	0,37	0,37	Grasslands	0,50	0,4	Herbaceous
Community garden (> 2 ha)	-	-	-	0,50	0,50	Other
Community garden (< 2 ha)*	-	-	-	0,50	0,4	Other

* NbS that are assumed to be typically smaller than 2 ha. For these NbS a cooling potential weight factor of 0,8 is applied to the supply values, instead of the factor of 1 applied to NbS larger than 2 ha, to account for the improved cooling potential of larger areas (Majekodunmi et al., 2020). This factor is not applied to the supply values by Zardo et al. (2017) since they already account for such variation in their cooling capacity values.

Table A.3 (continued). Microclimate mitigation ES supply values assigned to the NbS.

NbS type	Bush et al., 2021			Farrugia et al., 2013 (Gibson method)			Farrugia et al., 2013 (LAI method)		
	Temp. regulation (non-dim)	**Normalized supply value**	**Land cover type**	**Cooling (non-dim)**	**Normalized supply value**	**Land cover type**	**Cooling (non-dim)**	**Normalized supply value**	**Land cover type**
Urban forest (> 2 ha)	2,83	1,00	Assuming large, medium and small tree (avg)	0,80	1,00	Seminatural woodland with dense undergrowth	1,00	1,00	Seminatural woodland with dense undergrowth
Urban forest (< 2 ha)*	2,83	0,80	Assuming large, medium and small tree (avg)	0,80	0,80	Seminatural woodland with dense undergrowth	1,00	0,80	Seminatural woodland with dense undergrowth
Tree planting area*	2,83	0,80	Assuming large, medium and small tree (avg)	0,80	0,80	Planted woodland with sparce undergrowth	0,90	0,72	Planted woodland with sparce undergrowth
Vegetation barrier*	2,00	0,57	Large shrub	0,40	0,40	Dense scrub with dense undergrowth	0,90	0,72	Dense scrub with dense undergrowth
Low vegetation area (> 2 ha)	1,00	0,35	Unirrigated lawn/turf	0,30	0,38	Grassland	0,60	0,60	Grassland
Low vegetation area (< 2 ha)*	1,00	0,28	Unirrigated lawn/turf	0,30	0,30	Grassland	0,60	0,48	Grassland
Stormwater infiltration system*	1,00	0,28	Assuming unirrigated lawn/turf	0,30	0,30	Assuming grassland	0,60	0,48	Assuming grassland
Large park	2,25	0,80	Assuming 70% lawn and 30% large, medium and small tree (avg)	0,77	0,96	Assuming 70% parkland/ scattered trees and 30% planted woodland	0,84	0,84	Assuming 70% parkland/ scattered trees and 30% planted woodland
Small park*	2,10	0,59	Assuming 90% lawn and 10% large, medium and small tree (avg)	0,71	0,71	Assuming 90% parkland/ scattered trees and 10% planted woodland	0,72	0,58	Assuming 90% parkland/ scattered trees and 10% planted woodland
Street trees*	2,75	0,78	Assuming medium and small tree (avg)	0,80	0,80	Individual trees	1,00	0,80	Individual trees
Hedgerow*	2,00	0,57	(Large) shrub	0,60	0,60	Hedge	0,80	0,64	Hedge
Roadside green*	2,00	0,57	Irrigated lawn/turf	0,50	0,50	Amenity grassland	0,50	0,40	Amenity grassland
Community garden (> 2 ha)	-	-	-	-	-	-	-	-	-
Community garden (< 2 ha)*	-	-	-	-	-	-	-	-	-

Table A.4. Quantification of microclimate mitigation ES supply scores of NbS.

NbS type	Frequency of the normalized ES supply values among the different ranges of values						Number of studies
	0	0,01-0,2	0,21-0,4	0,41-0,6	0,61-0,8	0,81-1	
Urban forest (> 2 ha)	0	0	0	0	0	7	7
Urban forest (< 2 ha)	0	0	0	1	6	0	7
Tree planting area	0	0	0	2	5	0	7
Vegetation barrier	0	0	2	2	2	0	6
Low vegetation area (> 2 ha)	0	0	3	3	1	0	7
Low vegetation area (< 2 ha)	0	1	5	1	0	0	7
Stormwater infiltration system	0	1	5	1	0	0	7
Large park	0	0	0	1	3	3	7
Small park	0	0	2	4	1	0	7
Street trees	0	0	2	0	5	0	7
Hedgerow	0	0	1	2	2	0	5
Roadside green	0	1	4	2	0	0	7
Community garden (> 2 ha)	0	0	1	1	1	0	3
Community garden (< 2 ha)	0	2	1	0	0	0	3

Table A.4 (continued). Quantification of microclimate mitigation ES supply scores of NbS.

NbS type	% of the different ranges of values covered						ES supply score [0-5]
	0	0,01-0,2	0,21-0,4	0,41-0,6	0,61-0,8	0,81-1	
Urban forest (> 2 ha)	0	0	0	0	0	1	5
Urban forest (< 2 ha)	0	0	0	0,1428571	0,8571429	0	4
Tree planting area	0	0	0	0,2857143	0,7142857	0	4
Vegetation barrier	0	0	0,3333333	0,3333333	0,3333333	0	3
Low vegetation area (> 2 ha)	0	0	0,4285714	0,4285714	0,1428571	0	2
Low vegetation area (< 2 ha)	0	0,1428571	0,7142857	0,1428571	0	0	2
Stormwater infiltration system	0	0,1428571	0,7142857	0,1428571	0	0	2
Large park	0	0	0	0,1428571	0,4285714	0,4285714	4
Small park	0	0	0,2857143	0,5714286	0,1428571	0	3
Street trees	0	0	0,2857143	0	0,7142857	0	4
Hedgerow	0	0	0,2	0,4	0,4	0	3
Roadside green	0	0,1428571	0,5714286	0,2857143	0	0	2
Community garden (> 2 ha)	0	0	0,3333333	0,3333333	0,3333333	0	3
Community garden (< 2 ha)	0	0,6666667	0,3333333	0	0	0	1

Air purification

Table A.5. Air purification ES supply values assigned to the NbS.

NbS type	Derkzen et al., 2015 (also used in De Manuel et al., 2021 and Liu and Russo, 2021)			Fowler et al., 2004		
	Air purification (g m-2 y-1)	**Normalized supply value**	**Land cover type**	**Aerosol deposition velocity [Vd (m s−1)]**	**Normalized supply value**	**Land cover type**
Urban forest	2,69	0,68	Woodland (Clustered trees)	9	1,00	Woodland
Tree planting area	2,69	0,68	Woodland (Clustered trees)	9	1,00	Woodland
Vegetation barrier	2,05	0,52	Tall shrub	-	-	-
Low vegetation area	0,90	0,23	Herbaceous	3,3	0,37	Grass
Stormwater infiltration system	0,90	0,23	Assuming herbaceous	3,3	0,37	Assuming grass
Large park	1,44	0,36	Assuming 70% herbaceous and 30% woodland	5,01	0,56	Assuming 70% grass and 30% woodland
Small park	1,08	0,27	Assuming 90% herbaceous and 10% woodland	3,87	0,43	Assuming 90% grass and 10% woodland
Street trees	3,97	1,00	Tree (Street trees)	-	-	-
Hedgerow	2,05	0,52	(Tall) shrub	-	-	-
Roadside green	0,90	0,23	Herbaceous	3,3	0,37	Assuming grass
Community garden	0,82	0,21	Other	-	-	-

Table A.5 (continued). Air purification ES supply values assigned to the NbS.

NbS type	Bush et al., 2021		
	Air purification (non-dim)	**Normalized supply value**	**Land cover type**
Urban forest	3,00	1,00	Assuming large, medium and small tree (avg)
Tree planting area	3,00	1,00	Assuming large, medium and small tree (avg)
Vegetation barrier	3,00	1,00	Large shrub
Low vegetation area	0,00	0,00	Lawn/turf
Stormwater infiltration system	0,00	0,00	Assuming lawn/turf
Large park	0,90	0,30	Assuming 70% lawn and 30% large, medium and small tree (avg)
Small park	0,30	0,10	Assuming 90% lawn and 10% large, medium and small tree (avg)
Street trees	3,00	1,00	Assuming medium and small tree (avg)
Hedgerow	3,00	1,00	(Large) shrub
Roadside green	0,00	0,00	Lawn/turf
Community garden	-	-	-

Table A.6. Quantification of air purification ES supply scores of NbS.

NbS type	**Frequency of the normalized ES supply values among the different ranges of values**						**Number of studies**
	0	**0,01-0,2**	**0,21-0,4**	**0,41-0,6**	**0,61-0,8**	**0,81-1**	
Urban forest	0	0	0	0	1	2	3
Tree planting area	0	0	0	0	1	2	3
Vegetation barrier	0	0	0	1	0	1	2
Low vegetation area	1	1	1	0	0	0	3
Stormwater infiltration system	1	1	1	0	0	0	3
Large park	0	0	2	1	0	0	3
Small park	0	1	1	1	0	0	3
Street trees	0	0	0	0	0	2	2
Hedgerow	0	0	0	1	0	1	2
Roadside green	1	1	1	0	0	0	3
Community garden	0	1	0	0	0	0	1

Table A.6 (continued). Quantification of air purification ES supply scores of NbS.

NbS type	**% of the different ranges of values covered**						**ES supply score [0-5]**
	0	**0,01-0,2**	**0,21-0,4**	**0,41-0,6**	**0,61-0,8**	**0,81-1**	
Urban forest	0	0	0	0	0,333333	0,666667	5
Tree planting area	0	0	0	0	0,333333	0,666667	5
Vegetation barrier	0	0	0	0,5	0	0,5	4
Low vegetation area	0,333333	0,333333	0,333333	0	0	0	1
Stormwater infiltration system	0,333333	0,333333	0,333333	0	0	0	1
Large park	0	0	0,666667	0,333333	0	0	2
Small park	0	0,333333	0,333333	0,333333	0	0	2
Street trees	0	0	0	0	0	1	5
Hedgerow	0	0	0	0,5	0	0,5	4
Roadside green	0,333333	0,333333	0,333333	0	0	0	1
Community garden	0	1	0	0	0	0	1

Noise reduction

Table A.7. Noise reduction ES supply values assigned to the NbS.

NbS type	Derkzen et al., 2015 (also used in Liu and Russo, 2021)		
	Noise reducton (dB(A) 100/m2)	**Normalized supply value**	**Land cover type**
Urban forest	1,13	0,56	Woodland
Tree planting area	1,13	0,56	Woodland
Vegetation barrier	2,00	1,00	Tall shrub
Low vegetation area	0,38	0,19	Herbaceous
Stormwater infiltration system	0,38	0,19	Assuming herbaceous
Large park	0,60	0,30	Assuming 70% herbaceous and 30% woodland
Small park	0,45	0,23	Assuming 90% herbaceous and 10% woodland
Street trees	-	-	Tree
Hedgerow	0,64	0,32	Assuming the 32% of the value attributed to vegetation barrier*
Roadside green	0,38	0,19	Herbaceous
Community garden	0,38	0,19	Other

* This percentage is derived by accounting for the fact that a 2-meters-width hedge can reduce noise by 1,6 dB on average (Van Renterghem et al., 2014), which corresponds to the 32% of the ~5 dB reduced by a vegetation barrier of 15 meters (Van Renterghem et al., 2015).

Table A.8. Quantification of noise reduction ES supply scores of NbS.

NbS type	Frequency of the normalized ES supply values among the different ranges of values						Number of studies
	0	**0,01-0,2**	**0,21-0,4**	**0,41-0,6**	**0,61-0,8**	**0,81-1**	
Urban forest	0	0	0	1	0	0	1
Tree planting area	0	0	0	1	0	0	1
Vegetation barrier	0	0	0	0	0	1	1
Low vegetation area	0	1	0	0	0	0	1
Stormwater infiltration system	0	1	0	0	0	0	1
Large park	0	0	1	0	0	0	1
Small park	0	0	1	0	0	0	1
Street trees	0	0	0	0	0	0	0
Hedgerow	0	0	1	0	0	0	1
Roadside green	0	1	0	0	0	0	1
Community garden	0	1	0	0	0	0	1

Table A.8 (continued). Quantification of noise reduction ES supply scores of NbS.

NbS type	**% of the different ranges of values covered**						**ES supply score [0-5]**
	0	**0,01-0,2**	**0,21-0,4**	**0,41-0,6**	**0,61-0,8**	**0,81-1**	
Urban forest	0	0	0	1	0	0	3
Tree planting area	0	0	0	1	0	0	3
Vegetation barrier	0	0	0	0	0	1	5
Low vegetation area	0	1	0	0	0	0	1
Stormwater infiltration system	0	1	0	0	0	0	1
Large park	0	0	1	0	0	0	2
Small park	0	0	1	0	0	0	2
Street trees	0	0	0	0	0	0	0*
Hedgerow	0	0	1	0	0	0	2
Roadside green	0	1	0	0	0	0	1
Community garden	0	1	0	0	0	0	1

* We assumed that street trees do not provide any barrier that could shield noise, since constituted by a row of singles trees that are planted in tree pits or in narrow strip areas covered by herbaceous elements with negligible noise absorption capacity.

Nature-based recreation

Table A.9. Nature-based recreation ES supply values assigned to the NbS.

NbS type	Derkzen et al., 2015 (also used in Liu and Russo, 2021)			Bush et al., 2021		
	Recreation (Index value /m2, with rate doubles in parks)	Normalized supply value	Land cover type	Recreation (non-dim, with rate doubles in parks)	Normalized supply value	Land cover type
Urban forest	2,90	0,55	Woodland	2,83	0,63	Assuming large, medium and small tree (avg)
Tree planting area	2,90	0,55	Woodland	2,83	0,63	Assuming large, medium and small tree (avg)
Vegetation barrier	2,55	0,48	Tall shrub	1,00	0,22	Large shrub
Low vegetation area	2,55	0,48	Herbaceous	2,00	0,44	Lawn/turf
Stormwater infiltration system	-	-	-	-	-	Assuming lawn/turf
Large park	5,31	1,00	Assuming 70% herbaceous and 30% woodland	4,50	1,00	Assuming 70% lawn and 30% large, medium and small tree (avg)
Small park	5,17	0,97	Assuming 90% herbaceous and 10% woodland	4,17	0,93	Assuming 90% lawn and 10% large, medium and small tree (avg)
Street trees	2,15	0,40	Tree	2,75	0,61	Assuming medium and small tree (avg)
Hedgerow	2,55	0,48	(Tall) shrub	1,00	0,22	(Large) shrub
Roadside green	2,55	0,48	Herbaceous	2,00	0,44	Lawn/turf
Community garden	2,35	0,44	Other	-	-	-

Table A.10. Quantification of nature-based recreation ES supply scores of NbS.

NbS type	**Frequency of the normalized ES supply values among the different ranges of values**						**Number of studies**
	0	**0,01-0,2**	**0,21-0,4**	**0,41-0,6**	**0,61-0,8**	**0,81-1**	
Urban forest	0	0	0	1	1	0	2
Tree planting area	0	0	0	1	1	0	2
Vegetation barrier	0	0	1	1	0	0	2
Low vegetation area	0	0	0	2	0	0	2
Stormwater infiltration system	0	0	0	0	0	0	0
Large park	0	0	0	0	0	2	2
Small park	0	0	0	0	0	2	2
Street trees	0	0	1	0	1	0	2
Hedgerow	0	0	1	1	0	0	2
Roadside green	0	0	0	2	0	0	2
Community garden	0	0	0	1	0	0	1

Table A.10 (continued). Quantification of nature-based recreation ES supply scores of NbS.

NbS type	% of the different ranges of values covered						ES supply score [0-5]
	0	0,01-0,2	0,21-0,4	0,41-0,6	0,61-0,8	0,81-1	
Urban forest	0	0	0	0,5	0,5	0	3
Tree planting area	0	0	0	0,5	0,5	0	3
Vegetation barrier	0	0	0,5	0,5	0	0	2
Low vegetation area	0	0	0	1	0	0	3
Stormwater infiltration system	0	0	0	0	0	0	0*
Large park	0	0	0	0	0	1	5
Small park	0	0	0	0	0	1	5
Street trees	0	0	0,5	0	0,5	0	3
Hedgerow	0	0	0,5	0,5	0	0	2
Roadside green	0	0	0	1	0	0	3
Community garden	0	0	0	1	0	0	3

* We assumed that stormwater infiltration systems have access restrictions, thus they do not provide active (nature-based) recreation.

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Appendix B: Supplementary Material to Chapter 5

Table B.1. Classification of the Local Plans' policies identified as relevant for promoting NbS implementation per typology of NbS promoted. Policies starting with "NH" relate to the North Harbours Local Plan, with "G" to the Grand Harbour Local Plan.

Policy ID	TYPE 1 (no or minimal intervention)		TYPE 2 (management approaches that develop sustainable and multifunctional ecosystems and landscapes)			TYPE 3 (managing ecosystems in very intrusive ways or even creating new ecosystems)		
	Conserving green elements and open spaces in new development areas	**Protecting non-urbanized land (agricultural, natural, and seminatural)**	**Improving existing greenery in private open spaces**	**Improving existing public greenery and green areas**	**Ensuring sustainable management and multifunctionality of rural and natural areas**	**Greening existing buildings**	**Ensuring the integration of private greenery in new development projects**	**Creating new public greenery and green areas**
NHSE01 Urban Development Boundaries		X						
NHSE06 Soft Landscaping Schemes				X				X
NHCV05 Protection of Trees	X						X	X
NHRL06 Walkways/ Heritage Trails/Cycle Routes				X				
NHGT05 Environmental Upgrading of Streets				X				

Table B.1 (continued). Classification of the Local Plans' policies identified as relevant for promoting NbS implementation per typology of NbS promoted. Policies starting with "NH" relate to the North Harbours Local Plan, with "G" to the Grand Harbour Local Plan.

Policy ID	TYPE 1 (no or minimal intervention)		TYPE 2 (management approaches that develop sustainable and multifunctional ecosystems and landscapes)			TYPE 3 (managing ecosystems in very intrusive ways or even creating new ecosystems)		
	Conserving green elements and open spaces in new development areas	**Protecting non-urbanized land (agricultural, natural, and seminatural)**	**Improving existing greenery in private open spaces**	**Improving existing public greenery and green areas**	**Ensuring sustainable management and multifunctionality of rural and natural areas**	**Greening existing buildings**	**Ensuring the integration of private greenery in new development projects**	**Creating new public greenery and green areas**
NHGT06 Drainage Pumping Station Site	X							
NHGT08 Gzira and Ta' Xbiex Design Priority Areas							X	
NHGT14 Gzira Employment Node							X	
NHGT15 Central Ta` Xbiex Opportunity Site								X
NHMP02 Valley Road Regeneration				X				
NHMP04 Transport and Environmental Upgrading				X				
NHMP12 Small-Scale Industrial Area							X	
NHPE03 Protection and Upgrading of Open Spaces		X						

Table B.1 (continued). Classification of the Local Plans' policies identified as relevant for promoting NbS implementation per typology of NbS promoted. Policies starting with "NH" relate to the North Harbours Local Plan, with "G" to the Grand Harbour Local Plan.

	TYPE 1 (no or minimal intervention)		TYPE 2 (management approaches that develop sustainable and multifunctional ecosystems and landscapes)			TYPE 3 (managing ecosystems in very intrusive ways or even creating new ecosystems)		
Policy ID	**Conserving green elements and open spaces in new development areas**	**Protecting non-urbanized land (agricultural, natural, and seminatural)**	**Improving existing greenery in private open spaces**	**Improving existing public greenery and green areas**	**Ensuring sustainable management and multifunctionality of rural and natural areas**	**Greening existing buildings**	**Ensuring the integration of private greenery in new development projects**	**Creating new public greenery and green areas**
NHPV09 Environmental Improvements				X				
NHPV13 Villa Rosa	X						X	X
NHSG06 Environmental Upgrading of Vjal Rihan				X				
NHSJ04 Parking and Environmental Improvements				X				
NHSJ05 Environmental Improvement of Town Centres				X				
NHSJ10 Site at Triq St. Elija, St. Julian's							X	X
NHSJ11 Balluta Site	X							

Table B.1 (continued). Classification of the Local Plans' policies identified as relevant for promoting NbS implementation per typology of NbS promoted. Policies starting with "NH" relate to the North Harbours Local Plan, with "G" to the Grand Harbour Local Plan.

Policy ID	TYPE 1 (no or minimal intervention)		TYPE 2 (management approaches that develop sustainable and multifunctional ecosystems and landscapes)			TYPE 3 (managing ecosystems in very intrusive ways or even creating new ecosystems)		
	Conserving green elements and open spaces in new development areas	**Protecting non-urbanized land (agricultural, natural, and seminatural)**	**Improving existing greenery in private open spaces**	**Improving existing public greenery and green areas**	**Ensuring sustainable management and multifunctionality of rural and natural areas**	**Greening existing buildings**	**Ensuring the integration of private greenery in new development projects**	**Creating new public greenery and green areas**
NHSJ12 Ta` Giorni Opportunity Site							X	X
NHSJ13 Villa Bonici								X
NHSW01 Local Centres	X							
NHSW03 Road Upgrading				X				
NHSW06 Wied Ghomor Rural Conservation Strategy					X			
NHSW08 Central Madliena Opportunity Site							X	X
GN02 Public Utilities			X					
GE02 Environmental Improvements To Main Road Corridors				X				X

Table B.1 (continued). Classification of the Local Plans' policies identified as relevant for promoting NbS implementation per typology of NbS promoted. Policies starting with "NH" relate to the North Harbours Local Plan, with "G" to the Grand Harbour Local Plan.

Policy ID	**TYPE 1 (no or minimal intervention)**		**TYPE 2 (management approaches that develop sustainable and multifunctional ecosystems and landscapes)**			**TYPE 3 (managing ecosystems in very intrusive ways or even creating new ecosystems)**		
	Conserving green elements and open spaces in new development areas	**Protecting non-urbanized land (agricultural, natural, and seminatural)**	**Improving existing greenery in private open spaces**	**Improving existing public greenery and green areas**	**Ensuring sustainable management and multifunctionality of rural and natural areas**	**Greening existing buildings**	**Ensuring the integration of private greenery in new development projects**	**Creating new public greenery and green areas**
GE04 Afforestation				X			X	
GC06 Recreational Footpath System								X
GC07 Existing Afforestation Zones								X
GP07 Overall Landscape Requirements								X
GD04 Upgrading Of Existing Industrial Estates			X					
GD06 Town Centres				X				
GV21 Development Of Sitting-out Areas				X				
GF13 Areas Of Open Space And Public Gardens				X				

Table B.1 (continued). Classification of the Local Plans' policies identified as relevant for promoting NbS implementation per typology of NbS promoted. Policies starting with "NH" relate to the North Harbours Local Plan, with "G" to the Grand Harbour Local Plan.

Policy ID	**TYPE 1 (no or minimal intervention)**		**TYPE 2 (management approaches that develop sustainable and multifunctional ecosystems and landscapes)**			**TYPE 3 (managing ecosystems in very intrusive ways or even creating new ecosystems)**		
	Conserving green elements and open spaces in new development areas	**Protecting non-urbanized land (agricultural, natural, and seminatural)**	**Improving existing greenery in private open spaces**	**Improving existing public greenery and green areas**	**Ensuring sustainable management and multifunctionality of rural and natural areas**	**Greening existing buildings**	**Ensuring the integration of private greenery in new development projects**	**Creating new public greenery and green areas**
GF14 Jubilee Gardens Urban Park								X
GF16 Public Office Enclave				X				
GM13 Triq Aldo Moro/Triq il-Labour 'Corridor' - Environmental Treatment				X				
GM15 Marsa Park Development								X
GM22 Marsa Power Station			X					
GI07 Industrial Park							X	
GI10 Sports Area							X	
GB01 Urban Development Boundary		X			X			

Table B.1 (continued). Classification of the Local Plans' policies identified as relevant for promoting NbS implementation per typology of NbS promoted. Policies starting with "NH" relate to the North Harbours Local Plan, with "G" to the Grand Harbour Local Plan.

Policy ID	TYPE 1 (no or minimal intervention)		TYPE 2 (management approaches that develop sustainable and multifunctional ecosystems and landscapes)			TYPE 3 (managing ecosystems in very intrusive ways or even creating new ecosystems)		
	Conserving green elements and open spaces in new development areas	**Protecting non-urbanized land (agricultural, natural, and seminatural)**	**Improving existing greenery in private open spaces**	**Improving existing public greenery and green areas**	**Ensuring sustainable management and multifunctionality of rural and natural areas**	**Greening existing buildings**	**Ensuring the integration of private greenery in new development projects**	**Creating new public greenery and green areas**
GB11 Cottonera 'Waterfront Revival Area' - Cospicua Section								X
GB12 Urban Park		X						X
GB13a Site For Sports and Recreational Facilities					X			
GL06 Traffic Calming Measures And Embellishment Of Streets								X
GL14 Cottonera 'Waterfront Revival Area' - Senglea Section				X				X
GG18 Kalkara Creek Waterfront								X
GG19 Valley At Tal-Hawli		X						

Table B.1 (continued). Classification of the Local Plans' policies identified as relevant for promoting NbS implementation per typology of NbS promoted. Policies starting with "NH" relate to the North Harbours Local Plan, with "G" to the Grand Harbour Local Plan.

Policy ID	**TYPE 1 (no or minimal intervention)**		**TYPE 2 (management approaches that develop sustainable and multifunctional ecosystems and landscapes)**			**TYPE 3 (managing ecosystems in very intrusive ways or even creating new ecosystems)**		
	Conserving green elements and open spaces in new development areas	**Protecting non-urbanized land (agricultural, natural, and seminatural)**	**Improving existing greenery in private open spaces**	**Improving existing public greenery and green areas**	**Ensuring sustainable management and multifunctionality of rural and natural areas**	**Greening existing buildings**	**Ensuring the integration of private greenery in new development projects**	**Creating new public greenery and green areas**
GK01 Urban Development Boundary		X						
GK03 Residential Development In Wied Kalkara	X							X
GK05 Kalkara Transport Strategy								X
GK12 Kalkara Waterfront Opportunity Area								X
GK16 Wied Rinella								X
GK20 Ricasoli Industrial Estate			X					

Table B.2. Classification of the Local Plans' policies identified as relevant for promoting NbS implementation according to the policy instrument(s) adopted. Policies starting with "NH" relate to the North Harbours Local Plan, with "G" to the Grand Harbour Local Plan. Codes of the instruments are described in Table 21 in Chapter 5.

Policy ID	**R 1**	**R 2**	**R 3**	**R 4**	**R 5**	**R 6**	**D 1**	**L 1**	**F 1**	**F 2**	**F 3**	**F 4**	**F 5**	**F 6**	**F 7**	**F 8**	**I 1**	**I 2**	**I 3**
NHSE01 Urban Development Boundaries					X														
NHSE06 Soft Landscaping Schemes																	X		
NHCV05 Protection of Trees			X		X														
NHRL06 Walkways/ Heritage Trails/Cycle Routes																	X		X
NHGT05 Environment al Upgrading of Streets																	X		
NHGT06 Drainage Pumping Station Site					X														
NHGT08 Gzira and Ta' Xbiex Design Priority Areas	X																		
NHGT14 Gzira Employment Node	X																		
NHGT15 Central Ta` Xbiex Opportunity Site	X																		
NHMP02 Valley Road Regeneration												X							

Table B.2 (continued). Classification of the Local Plans' policies identified as relevant for promoting NbS implementation according to the policy instrument(s) adopted. Policies starting with "NH" relate to the North Harbours Local Plan, with "G" to the Grand Harbour Local Plan. Codes of the instruments are described in Table 21 in Chapter 5.

Policy ID	R 1	R 2	R 3	R 4	R 5	R 6	D 1	L 1	F 1	F 2	F 3	F 4	F 5	F 6	F 7	F 8	I 1	I 2	I 3
NHMP04 Transport and Environmental Upgrading																	X		
NHMP12 Small-Scale Industrial Area		X																	
NHPE03 Protection and Upgrading of Open Spaces					X														
NHPV09 Environmental Improvements																	X		
NHPV13 Villa Rosa							X												
NHSG06 Environmental Upgrading of Vjal Rihan																	X		
NHSJ04 Parking and Environmental Improvements																	X		
NHSJ05 Environmental Improvement of Town Centres																	X		
NHSJ10 Site at Triq St. Elija, St. Julian's	X																		
NHSJ11 Balluta Site																			X
NHSJ12 Ta` Giorni Opportunity Site	X																		
NHSJ13 Villa Bonici																			X

Table B.2 (continued). Classification of the Local Plans' policies identified as relevant for promoting NbS implementation according to the policy instrument(s) adopted. Policies starting with "NH" relate to the North Harbours Local Plan, with "G" to the Grand Harbour Local Plan. Codes of the instruments are described in Table 21 in Chapter 5.

Policy ID	**R 1**	**R 2**	**R 3**	**R 4**	**R 5**	**R 6**	**D 1**	**L 1**	**F 1**	**F 2**	**F 3**	**F 4**	**F 5**	**F 6**	**F 7**	**F 8**	**I 1**	**I 2**	**I 3**
NHSW01 Local Centres	X																		
NHSW03 Road Upgrading																	X		
NHSW06 Wied Ghomor Rural Conservation Strategy																			X
NHSW08 Central Madliena Opportunity Site	X						X												
GN02 Public Utilities																		X	
GE02 Environmental Improvements To Main Road Corridors																	X		
GE04 Afforestation																	X		X
GC06 Recreational Footpath System																	X		
GC07 Existing Afforestation Zones																	X		
GP07 Overall Landscape Requirements																	X		
GD04 Upgrading Of Existing Industrial Estates																		X	

Table B.2 (continued). Classification of the Local Plans' policies identified as relevant for promoting NbS implementation according to the policy instrument(s) adopted. Policies starting with "NH" relate to the North Harbours Local Plan, with "G" to the Grand Harbour Local Plan. Codes of the instruments are described in Table 21 in Chapter 5.

Policy ID	**R1**	**R2**	**R3**	**R4**	**R5**	**R6**	**D1**	**L1**	**F1**	**F2**	**F3**	**F4**	**F5**	**F6**	**F7**	**F8**	**I1**	**I2**	**I3**
GD06 Town Centres																	X		
GV21 Development Of Sitting-out Areas																	X		
GF13 Areas Of Open Space And Public Gardens																	X		
GF14 Jubilee Gardens Urban Park																	X		
GF16 Public Office Enclave																	X		
GM13 Triq Aldo Moro/Triq il-Labour 'Corridor' - Environmental Treatment																	X		
GM15 Marsa Park Development							X												
GM22 Marsa Power Station																		X	
GI07 Industrial Park																			X
GI10 Sports Area																			X
GB01 Urban Development Boundary					X														X

Table B.2 (continued). Classification of the Local Plans' policies identified as relevant for promoting NbS implementation according to the policy instrument(s) adopted. Policies starting with "NH" relate to the North Harbours Local Plan, with "G" to the Grand Harbour Local Plan. Codes of the instruments are described in Table 21 in Chapter 5.

Policy ID	R1	R2	R3	R4	R5	R6	D1	L1	F1	F2	F3	F4	F5	F6	F7	F8	I1	I2	I3
GB11 Cottonera 'Waterfront Revival Area' - Cospicua Section																	X		
GB12 Urban Park					X												X		
GB13a Site For Sports and Recreational Facilities																	X		
GL06 Traffic Calming Measures And Embellishment Of Streets																	X		
GL14 Cottonera 'Waterfront Revival Area' - Senglea Section																	X		
GG18 Kalkara Creek Waterfront																	X		
GG19 Valley At Tal-Hawli					X														
GK01 Urban Development Boundary					X														
GK03 Residential Development In Wied Kalkara							X												
GK05 Kalkara Transport Strategy																	X		

Table B.2 (continued). Classification of the Local Plans' policies identified as relevant for promoting NbS implementation according to the policy instrument(s) adopted. Policies starting with "NH" relate to the North Harbours Local Plan, with "G" to the Grand Harbour Local Plan. Codes of the instruments are described in Table 21 in Chapter 5.

Policy ID	R1	R2	R3	R4	R5	R6	D1	L1	F1	F2	F3	F4	F5	F6	F7	F8	I1	I2	I3
GK12 Kalkara Waterfront Opportunity Area																	X		
GK16 Wied Rinella																			X
GK20 Ricasoli Industrial Estate																		X	

This thesis addresses three interlinked aspects that are relevant for mainstreaming Nature-based Solutions in urban planning.
The first aspect concerns the integration and use of ecosystem service knowledge in spatial planning. A literature review aimed at analysing practical applications of ecosystem services in real-life planning processes and instruments reveals both the outcomes generated and the procedures adopted to integrate them, as well as the main advantages, constraints, enabling factors, and open issues associated with ecosystem service knowledge integration in spatial planning processes and instruments.
The second aspect is related to the use of spatial assessments of ecosystem service demand to support an effective planning of Nature-based Solutions at the city scale. An approach is developed to allocate and prioritize Nature-based Solutions in cities in order to deliver ecosystem services for addressing the existing urban challenges while maximising the benefits for residents. The approach is tested in the case study area of Valletta (Malta), identifying the potential sites for the implementation of eleven types of Nature-based Solutions, assessing the demand for five priority ecosystem services, and identifying what type(s) of Nature-based Solutions, among the eleven proposed, should be implemented in each potential site, as well as the sites that should be prioritized first.
The third aspect involves the promotion of the implementation of Nature-based Solutions in urban plans through the use of suitable policy instruments. A matrix that links the suitable instruments identified to different typologies of Nature-based Solutions reveals the range of instruments that can be deployed to promote the implementation of each type of Nature-based Solution. The matrix is then applied to analyse which instruments are currently deployed and which are not in the two urban plans covering the case study area of Valletta, hence the missing opportunities that could be further exploited.

Davide Longato holds a MSc in “Planning and Policies for Cities, Environment and Landscape” from the University IUAV of Venice, Italy. His main research interests include the use of ecosystem service knowledge in planning processes and instruments, the development of climate change adaptation and urban greening strategies, with the overall aim to promote more sustainable and resilient decisions in urban and spatial planning. His current research focuses on the implementation of green infrastructure strategies and Nature-based Solutions at the regional and urban scale, and on their mainstreaming in planning decisions through appropriate methods and tools, with a particular focus on spatially-explicit assessments of ecosystem services.