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Mapping deficit areas for adaptation planning: insights from flood protection ecosystem service in an Italian case study

Mappatura delle aree deficitarie per la pianificazione dell'adattamento: approfondimenti sul servizio ecosistemico di protezione dalle inondazioni in un caso di studio italiano

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ABSTRACT AND KEYWORDS

Mapping deficit areas for adaptation planning
Climate change is reducing ecosystems' ability to mitigate its impacts and help people adapt to it, calling for strengthening an integrated climate action while ensuring the protection of biodiversity and working to restore degraded ecosystems. One promising approach is to use ecosystem services (ES) to redesign and foster the resilience of cities and territories. However, in the planning domain, the integration of ES into plans and tools is still slow and partial. It seems thus necessary to systematically promote and communicate effective solutions for the better use and management of land resources. To this end, this study aims to produce outputs that adopt a 'language' that is understandable for planners, policy- and decision makers by adopting an ES-based approach. A three-step, cross-sectoral and multiscalar GIS-based methodology is developed to support decision-makers in identifying areas with a deficit of ES in response to flooding, i.e. where ES supply does not meet the demand. Moreover, it supports the integration of ecosystem-based actions intro adaptation planning for flood mitigation at the regional level.

Keywords: adaptation planning, ecosystem-based approach, flood protection, socio-ecological contexts

Mappatura delle aree deficitarie per la pianificazione dell'adattamento
Il cambiamento climatico sta riducendo la capacità degli ecosistemi di mitigarne gli impatti e di aiutare le persone ad adattarvisi, chiedendo di rafforzare un'azione integrata sul clima, garantire la protezione della biodiversità e ripristinare gli ecosistemi degradati. Un approccio promettente è quello di usare i servizi ecosistemici (SE) per riprogettare e promuovere la resilienza di città e territori. Tuttavia, nell'ambito della pianificazione, l'integrazione dei SE negli strumenti è ancora lenta e parziale. Appare quindi necessario promuovere e comunicare in modo sistemico soluzioni efficaci per un migliore uso e gestione delle risorse territoriali. Questo studio mira a produrre risultati che adottino un "linguaggio" comprensibile per i pianificatori, i responsabili delle politiche e delle decisioni adottando un approccio basato sui SE. Viene sviluppata una metodologia in tre fasi, intersettoriale e multiscalare basata su GIS per supportare i decisori nell'identificazione di aree con un deficit di SE in risposta alle inondazioni, ovvero dove l'offerta di SE non ne soddisfa la domanda. Inoltre, la metodologia supporta l'integrazione di azioni basate sugli ecosistemi nella pianificazione dell'adattamento per la mitigazione delle inondazioni a livello regionale.

Parole chiave: pianificazione adattiva, approccio basato sugli ecosistemi, protezione dalle inondazioni, contesti socio-ecologici

1. Introduction

The increase of climate and non-climate threats (IPBES, 2019), including land-use change, species exploitation, habitat fragmentation, pollution, and their interaction, leads to cumulative impacts that reduce the ability of ecosystems to mitigate climate change and help people adapt to it (Isbell et al., 2017; Pörtner et al., 2021). Moreover, the complexity of this interaction makes it challenging to understand biological responses to climate change and may lead to an underestimation of impacts on ecosystems themselves (IPCC, 2022). Conversely, a better understanding of the ecological dynamics of climate impacts can help identify vulnerability and resilience hotspots (Lavorel et al., 2015; Malhi et al., 2020).

There is an urgent need to strengthen climate action and promote more effective and integrated mitigation and adaptation measures, the first to reduce the effects of human activities and the second to adjust to actual and expected changing climate (IPCC, 2023) while ensuring the protection of biodiversity and working to restore degraded ecosystems (Gann et al., 2019; Hessen & Vandvik, 2022). In particular, adaptation planning is an iterative dynamic process of risk management (IPCC, 2022) based on awareness of this change in conditions, whether already occurring or future, and recognises the importance of taking action to revert to, maintain, or reach a desired state. Hence, adaptation planning can improve ecosystems' adaptive and response capacity to the stresses exacerbated by climate change (Arneth et al., 2020; IPBES, 2019; Morecroft et al., 2019), especially in anticipation of increasingly frequent and severe extreme weather events, including floods, heat waves, wildfires, and droughts. Indeed, 'The global goal on adaptation features three core components: enhancing adaptive capacity, strengthening resilience, and reducing vulnerability to climate change' (UNFCCC, 2021, p. 5). It is a process that takes proactive measures and involves changes in structures, practices, behaviour, and knowledge (UNEP, 2022b). Therefore, adaptation planning should be closely related to the local context to be successful (IPCC, 2022).

According to the 'Adaptation Gap Report 2023' of the United Nations Environment Programme (UNEP, 2023), 85% of countries currently have at least one national adaptation planning tool in force. On the implementation side, 67% of countries have allocated national funds to implement adaptation priorities. From the perspective of implemented adaptation actions, in 2022, most of the projects financed by the Adaptation Fund, the Green Climate Fund and the Global Environment Facility concerned the agricultural sector or flood and storm protection (UNEP, 2023).

Despite the steps forward, the Report registers a global slowdown in progress from the financial, planning, and implementation side of adaptation when, on the contrary, acceleration would be needed in response to the increasing severity of climate risks and their cumulative effects, partly due to their composite, cascading, and transboundary nature (Anisimov & Magnan, 2023). In fact, for the implementation of adaptation, which often takes a long time, countries need technical and financial support, especially in relation to the availability and mobilization of resources, as well as strengthening capacity building. For this reason, a flexible and systemic local approach is required for effectively advancing adaptation (Botequilha-Leitão & Díaz-Varela, 2020).

However, there are several shortcomings that may slow down or reduce the effectiveness of the adaptation process, including a lack of coherent and up-to-date knowledge frameworks; a sectoral, fragmented, small-scale approach focused on planning rather than implementation; the voluntary nature of adaptation initiatives; a prioritisation of short-term risk reduction accompanied by a failure to consider future climate risks that hinder transformative adaptation; a planning and implementation pace that is too slow compared to existing targets; and many gaps on funding, knowledge, and practices for effective implementation, monitoring, and evaluation (IPCC, 2023; UNEP, 2022c). Moreover, there is still little evidence of the effectiveness of actions taken (IPCC, 2022; Runhaar et al., 2018), measured in terms of climate risk reduction and improved human and ecological well-being (Owen, 2020).

One promising approach that may support more effective adaptation planning is to use ecosystem services (ES) to redesign and foster the resilience of cities and territories. The ES concept refers to the benefits people derive directly or indirectly from natural ecosystems and their functions (Burkhard & Maes, 2017; Costanza et al., 1997; Daily, 1997; MA, 2003). It is an inclusive and interdisciplinary approach that considers different values, perspectives, goals, and knowledge domains. Maintaining the health of ecosystems is of paramount importance in the provision of ES essential to human well-being (Daily, 1997; Haines-Young & Potschin, 2018; Millennium Ecosystem Assessment, 2005), in ensuring ecosystems' proper organisation and resilience to external pressures (Rendon et al., 2019) and is crucial to a resilient society and sustainable economy (Hernández-Blanco et al., 2022).

However, as already mentioned, the impacts of climate change on ecosystems are compromising their ability to provide these services (EEA, 2024a; IPBES, 2019; IPCC, 2022a; Pörtner et al., 2021; UNDRR, 2023). Furthermore, in the planning domain, particularly the urban one, the integration of ES into plans and tools is still slow and partial, limiting effective climate adaptation progress (Cortinovis & Geneletti, 2018; de Luca et al., 2021; Georgia et al., 2022; Longato et al., 2021). On the one hand, ES knowledge is often produced for purely academic purposes and lacks reference to the decision-making contexts in which it can be used (Bitoun et al., 2022). Consequently, this leads to a misalignment with its consequent use and is therefore very specific on certain aspects, e.g., a greater focus on the supply side at the expense of the demand side of ES (Dworczyk & Burkhard, 2023), which is instead indispensable for understanding where the benefits are (more) required and, consequently, for supporting decisions about where to locate adaptation interventions (Longato et al., 2023; Verhagen et al., 2017; Zhou & Wu, 2023). On the other hand, the concept of ES itself often appears difficult for decision- and policy-makers to understand, making its application more complicated (Ronchi, 2021).

It seems thus necessary to reduce the gap between the language of planning and the one of ES science to operationalise ES for climate change actions in the planning practice. The relationships between climate change and ES and, more generally, the complex links in socio-ecological systems should be explicitly depicted by adopting a systemic approach to promote and communicate integrated solutions for the better use and management of land resources (Schirpke & Tasser, 2024). Therefore, it would be beneficial to develop understandable methods of producing such knowledge to inform and support anyone involved in decision-making and planning processes (Batty & Yang, 2022; Riffat et al., 2023). Aim of such methodology is to produce outputs that adopt a 'language' that is understandable for planners, policy- and decision-makers, in order to facilitate their integration in adaptation and planning process.

In Europe floods represent the most significant natural hazard in terms of economic losses and the second in terms of casualties, after extreme temperatures (Dottori et al., 2020; Paprotny et al., 2023). For example, the flooding events occurred in July 2021 in Germany, Belgium, Luxembourg, and the Netherlands were recorded as the most expensive natural disasters in the region and demonstrated a significant gap in flood protection (Aouragh et al., 2023). In 2023 alone, severe floods were recorded in Emilia-Romagna (Italy), Greece, Bulgaria, Turkey, and Slovenia. Climate change and increased anthropogenic pressures including land consumption will exacerbate their effects, increasing their severity and frequency and leading to cumulative impacts such as climate migration, health risks, and habitat destruction (EEA, 2024b).

Several studies are already present in the literature dealing with flood risk reduction through the analysis of ES or using nature-based approaches (OECD, 2020; Rey, 2021; Wübbelmann et al., 2022). Many interesting studies have made progress in this type of assessment, but the use of planner language in the results still has room for improvement. For example, in the book by Geneletti et al. (2020), there are several suggestions for linking the science of ES with planning practice and decision-making. Nevertheless, the use of planning language for formulating solutions is lacking. Moreover, the scale of observation and application of such methodologies is predominantly micro (city or neighbourhood). In contrast, in our study, an effort is made to construct a language in this sense, and a larger scale of observation, i.e. regional level, is used.

To support the integration of ES into adaptation planning and implementation to reduce flood risks and impacts, this study (i) examines the ES supporting flood protection (Haines-Young & Potschin, 2013) in the affected case study of Friuli Venezia Giulia coastline, Italy, to define priority areas for action, and (ii) provides an overview of ecosystem-based actions that can be implemented to reduce risk and increase adaptive capacity in different priority areas (e.g., Zhou et al., 2024).

To this aim, a multi-scalar GIS-based methodology is developed to support decision-makers in identifying (i) areas with an ES deficit in response to flooding, i.e., where ES supply does not meet demand, and (ii) the most appropriate set of solutions that can maximize flood resilience by reintroducing required ES. The research questions that guided the construction of the methodology are:

1. How can the relationship between ES supply and demand be assessed?
2. What are the practical implications of identifying deficit areas in adaptive planning?
3. How can ES knowledge be effectively conveyed to help decision-makers?

The remainder of the paper is organised in four main sections. Section 2 presents the case study area. Section 3 provides the methodological steps of the proposed approach, and the input data used. Section 4 presents the results, including sample ES maps produced, summary statistics and graphics, and an overview of solutions that can be applied to adapt to flood. Finally, section 5 discusses the results and main aspects of the approach in light of supporting planning decisions, while providing the conclusions of the study.

2. Case study

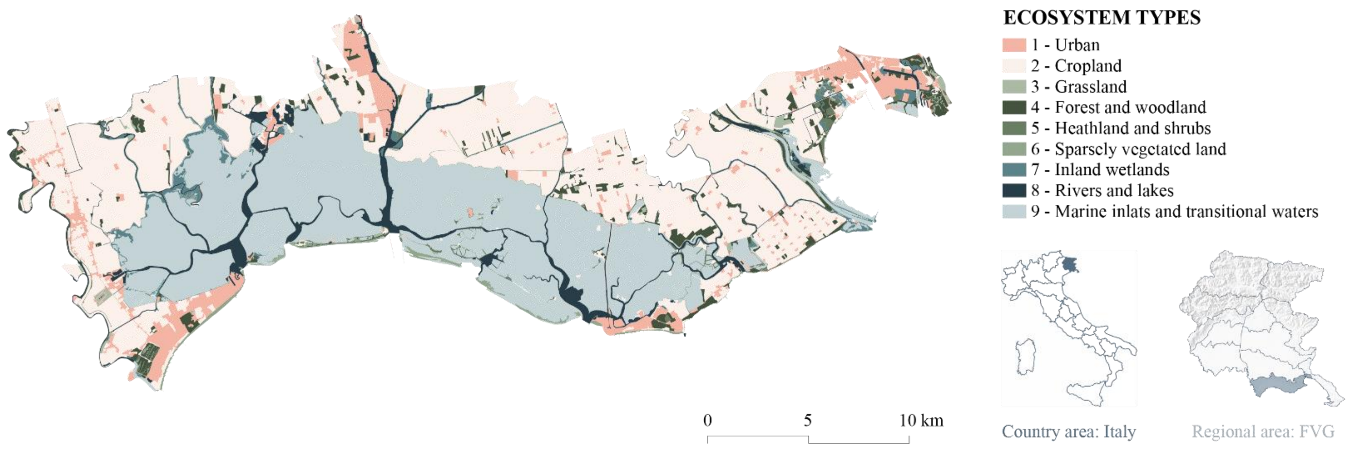
The Friuli Venezia Giulia (FVG) Region is one of the smallest regions in Italy in terms of population and size, with a population of 1.2 million inhabitants, corresponding to 2 per cent of Italian residents, an area of about 8,000 km^2 and a coastline of about 160 km. It is located in the northeast, on the border with Austria (north), Slovenia (east) and the Adriatic Sea (south).

The climate is moderately continental, with high rainfall and humidity in the high plain and pre-alpine areas. The region is also subject to intense thunderstorms, occasionally associated with hail episodes that, especially in summer, affect the central-southern area. Average annual temperatures vary from the north (winter minimum of -5 °C in the Alpine area) to the south (summer maximum of 25 °C towards the coastal zone), with an average of about 12-13 °C. Notably, it is among the Italian regions with the highest share of flood-prone areas due to coastal and river flooding (Longato et al., 2024).

In this study, a particular focus is placed on the coastal strip (Figure 1) in the south which is characterised by a lagoon landscape that is among the most fragile environments in the region due to the exposure to natural and anthropic pressures, such as coastal erosion, subsidence, storm surges, hydraulic risk, saline wedge intrusion, water pollution, sea level rise, and a growing proposal for urban expansion for tourism purposes.

The FVG region has undertaken a process of revision and updating of the regional planning instrument, where to propose the inclusion of the climate adaptation and ES topics that are therefore currently not dealt with. The present research is set within this context and takes the opportunity to examine the issue of flooding in more depth, given its relevance to the case study. An investigation of the potential ecosystem service supply capacity of the case study has already been published by Longo et al. (2024b) to support this integration. For further information, see the results of section 4.3 of the cited study.

Figure 1. Geographical framing of the case study analysed



Source: Authors' elaboration

3. Materials and methods

A method is developed to support identifying priority areas for adaptation actions through mapping and assessing ES demand and supply for flood mitigation. Such a block is then followed by recognising a set of EbA to enhance flood adaptation where the needed ES are not already provided.

The ArcGIS Desktop 10.8.2 software in combination with QGIS 3.26 Buenos Aires is used for the processing and creation of geographical information.

3.1 Mapping of flood protection deficit areas

In this first methodological section, the assumption is that through a spatial comparison, deficit situations can be identified where a specific ES is absent (i.e., not supplied) in an area where it is demanded, which are therefore called 'deficit areas'. The flood protection ES supply and demand are mapped and assessed based on a methodology developed in previous works (Longo et al. 2024a, 2024b). That allows the identification of deficit areas according to different impacted sectors in the illustrative case study of the coastal and lagoon area of the FVG region. The term 'impacted sectors' refers to 16 themes among terrestrial ecosystems and socioeconomic sectors (e.g., hydrogeological instability, health, forest, energy) that have been recognised at national level by the Climate Change Adaptation Strategy (Castellari et al., 2014) and taken up at local level by the Regional Agency for Environmental Protection of Friuli Venezia Giulia (ARPA FVG) to organize information on current and projected climate change impacts (ARPA FVG, 2018). Further details on the individual impacted sectors' descriptions can be found in these two reference documents.

The spatial comparison of supply and demand to identify deficit areas is performed in a GIS environment. More specifically, the demand areas correspond to the extent of the impacted sectors on the Friulian lagoon and coastline case study. From each of these areas, the flood protection service area is subtracted and, according to an in situ spatial relationship for which the ES supplied and demanded are located in the same place (Dworczyk & Burkhard, 2021), we obtained a benefit where there is overlap and a deficit where there is no overlap. In other words, ES demand is met when it spatially coincides with the supply and, therefore, the benefitting area corresponds to the supply area.

The input data are taken from previous works, particularly Longo et al. (2024a) for the ES demand assessment and Longo et al. (2024b) for the supply side. Getting into details of the methodologies these two works developed, the first one defines a cartographic level to assign a spatial dimension to the 16 impacted sectors (see Table 5.1 of the cited study for further information). That is because they are thematic and require mapping for comparison with the supply. The second one considers supply as the capacity of different land covers to provide flood protection-related ES. This capacity assessment is based on Bordt & Saner (2019), who reviewed literature about ecosystems' relevance for providing specific ES and classified it according to a so-called 'consensus level' emerging from the analysed studies. Longo et al. (2024b) use a high-resolution regional land cover map, reclassified according to the Corine Land Cover (CLC) 2018 third-level classification, and consider only medium and high consensus levels, corresponding to levels from 3 to 5 and 6-7 in Bordt & Saner (2019), respectively.

In summary, impacted sectors and land covers represent the main indicators of demand and supply.

Once the spatial overlap is performed, the deficit level of each impacted sector is defined according to the percentage of land occupied by the deficit out of the total demand area. The deficit level is then classified as follows: medium-low (<50%) and medium-high (≥50%).

3.2 Cluster of impacted sectors with flood protection deficits

The results of deficit areas assessment for each impacted sector are analysed and divided into homogeneous clusters of deficit areas in order to group those sectors where the deficit occurs with similar characteristics. Clusters are formed based on two criteria, namely deficit level and land cover similarity. The former considers the two levels of deficit identified in section 3.1, i.e., medium-low and medium-high. The land cover similarity criterion accounts for the land cover type(s) responsible for the deficit, based on the land cover patches that are included in the demand area but do not supply the flood protection ES (see Longo et al., 2024b for more details on the method used). Specifically, land covers are grouped into the urban or agricultural macro-category, so that the land cover similarity can be found for those impacted sectors whose deficit is caused by urban, agricultural, or both categories.

By applying these two criteria, the impacted sectors are grouped in homogeneous clusters, which bring together impacted sectors with similar deficit-related (i.e., deficit level and land cover similarity) characteristics.

3.3 Ecosystem-based actions for flood protection in adaptation planning

For each cluster identified in section 3.2, ecosystem-based interventions to support adaptation planning and implementation are defined and proposed. The documents of UNEP (2022b) and 'Ecosystem-based Adaptation Briefing Note Series: Protecting Nature To Protect People' jointly prepared by UNEP and the UNEP-World Conservation Monitoring Centre are adopted as they contains a list of possible ecosystem-based actions in different socio-ecological contexts. In particular, the first document proposes illustrative measures with case studies for urban areas, agricultural areas, forest landscapes, mountains, inland waters, and marine and coastal areas. The second consists of 11 notes aimed at facilitating the understanding of the Ecosystem-based Adaptation (EbA) concept and the implementation of strategies in urban, coastal, forest ecosystems, and agricultural systems. Of these notes, 8 and 11 are examined, which relate to urban and agricultural contexts, respectively (UNEP, 2022a, 2022d).

Given the focus of the present study and in light of the results of section 3.2, a content analysis of the identified documents is conducted, and information on actions to counter flooding in urban and agricultural ecosystems is selected. The result is a classification that collects the different actions, re-articulated and merged where there is repetition between documents. Actions are categorised by ecosystem type, and for each one, the following are indicated: the intervention type, the co-benefit(s) the action helps to provide, and the relevant cluster group, i.e., the impacted sectors for which it can be applied to address flood risks/impacts. Intervention types are attributed by the authors based on the content of individual actions. The benefits are extracted from the described purposes of the actions. Clusters are attributed to the two macro-categories of EbA actions corresponding to the deficient ecosystem found in the impacted sectors.

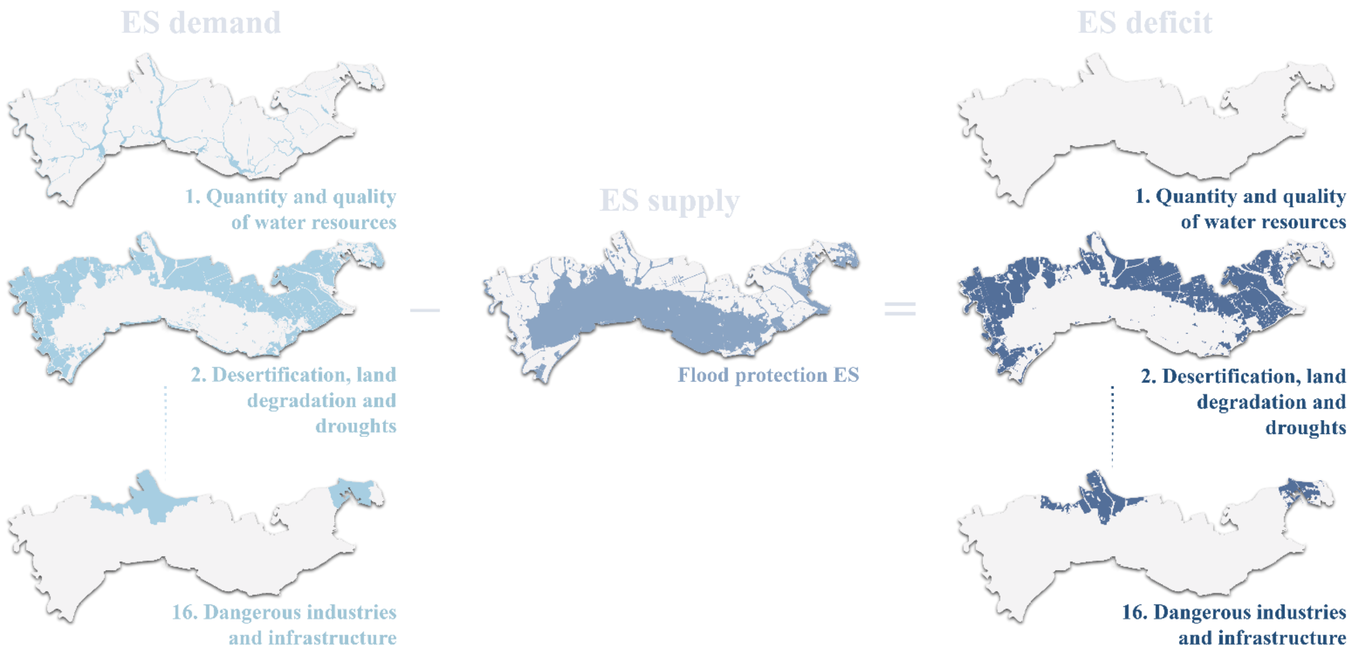
4. Results

4.1 Mapping of flood protection deficit areas

Results from section 3.1 are presented through a set of maps where deficit areas are identified and quantified. Figure 2 shows the process to produce the deficit areas' maps for just three samples of the 16 impacted sectors. It emerges that 13 of the 16 sectors examined are characterised by deficit areas. The sectors of water resources, inland and transitional water ecosystems, and forests have no deficit areas since the extent of the demand and supply areas coincide.

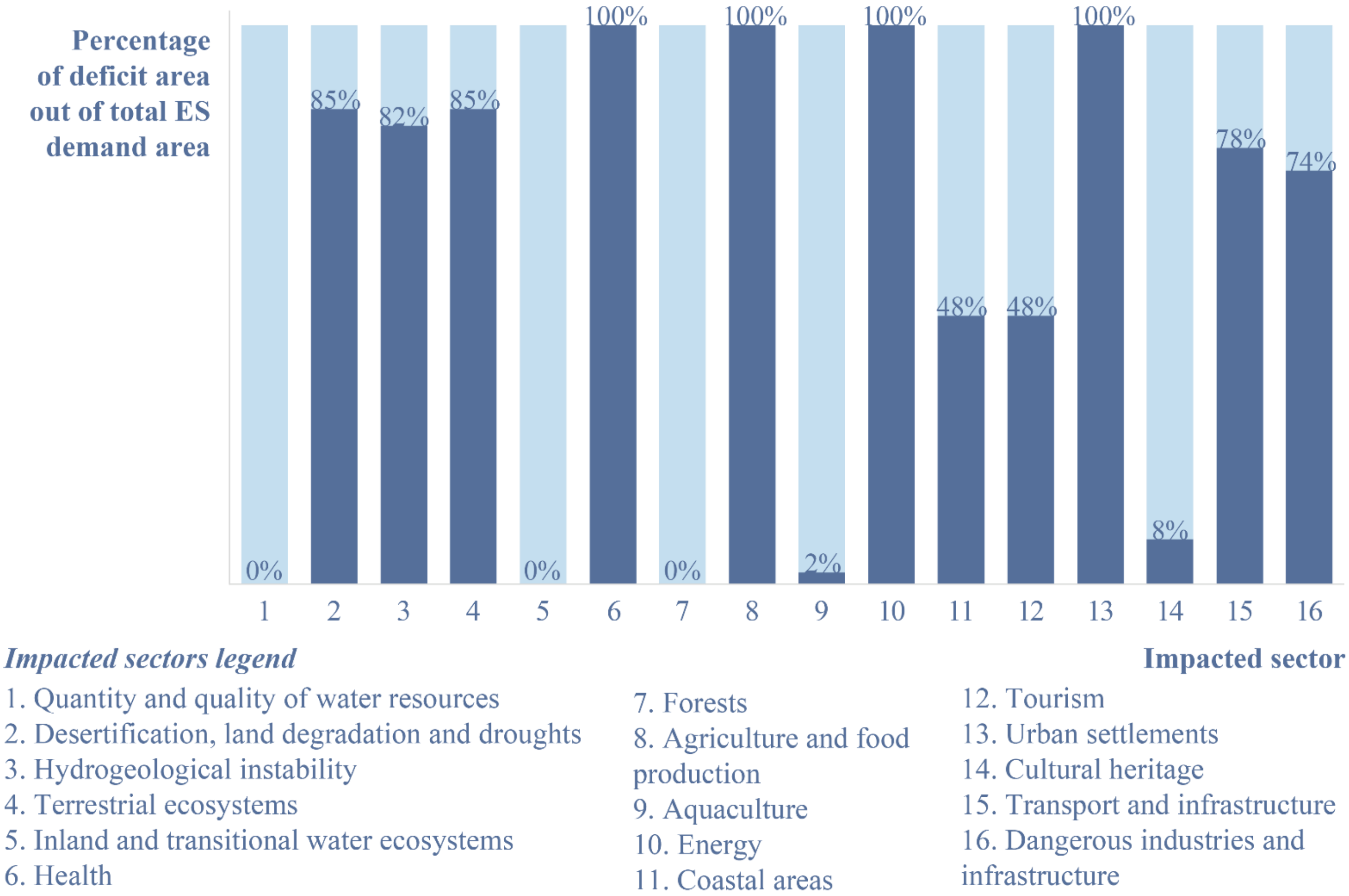
Figure 3 shows, for each impacted sector, the percentage of land occupied by the deficit over the total demand area. In the health, agriculture, energy, and urban settlements sectors, demand and supply areas do not overlap at any point, thus generating a deficit of 100%. The majority of the impacted sectors considered, i.e. about 70% (n = 9), show a deficit of more than 50% of the demand area, thus equivalent to a medium-high deficit level. An imbalance emerges between these and the aquaculture and cultural heritage sectors, whose deficit is less than 10%. In the middle (48%) are the tourism and coastal areas sectors, whose deficit area's extent corresponds as they have the same demand area. Consequently, the medium-low deficit level is found in about 30% (n = 4) of the impacted sectors.

Figure 2. Procedure for mapping deficit areas



Source: Authors' elaboration

Figure 3. Quantification of the deficit area in each impacted sector

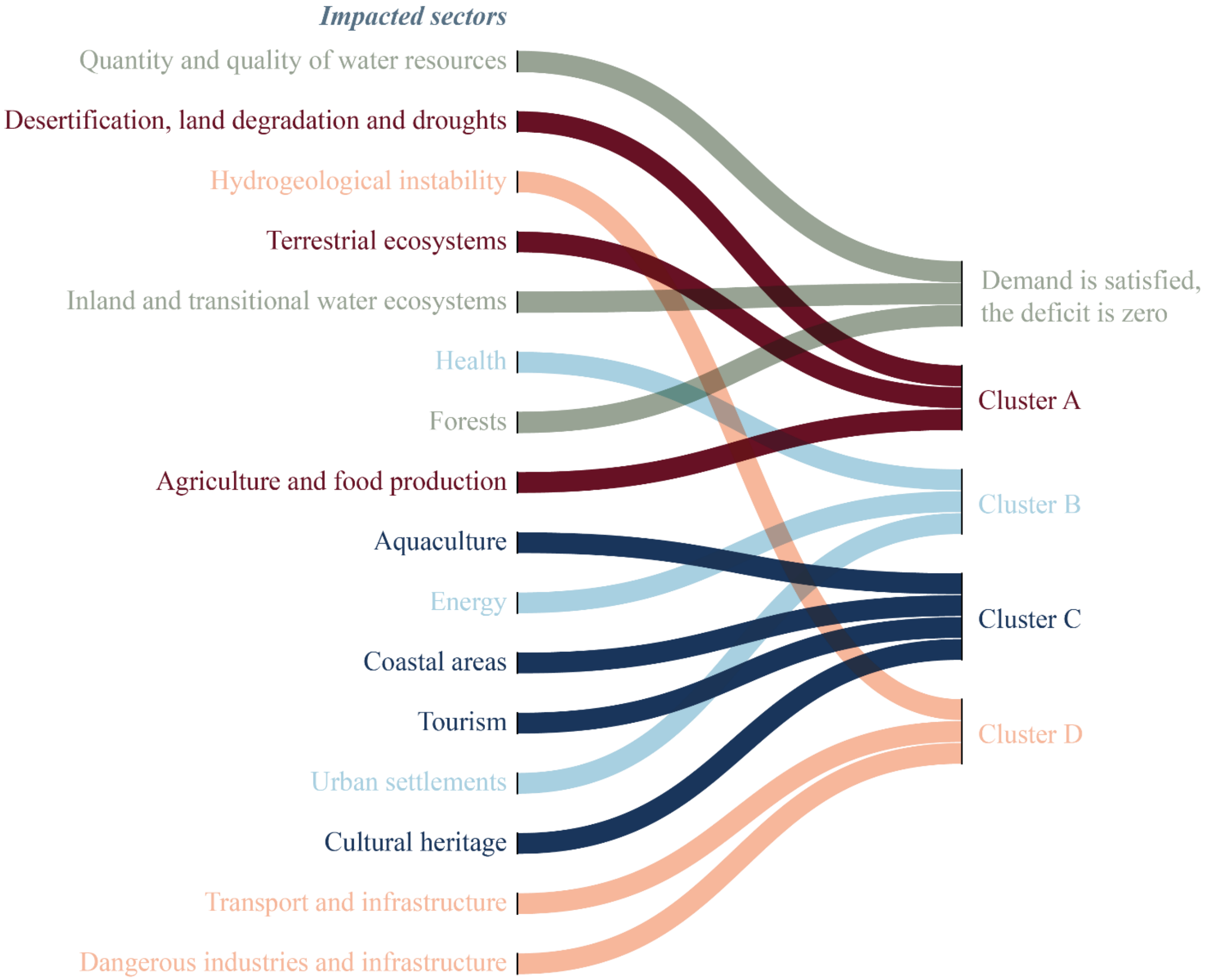


Source: Authors' elaboration

4.2 Cluster of impacted sectors with flood protection deficits

Figure 4 summarises the clusters emerging from combining the two criteria developed in section 3.2 (i.e., deficit level and land cover similarity in ecosystem type(s)). The diagram consists of the impacted sectors on the left and the clusters on the right. For three sectors, namely quantity and quality of water resources, inland and transitional water ecosystems, and forests (green), ES demand is satisfied, making the deficit equal to zero. Among the others, four clusters emerge. Clusters A, B and D present a medium-high deficit level and are characterised by agricultural land, urban ecosystems and both, respectively, representing the result of land cover similarity criterion analysis. Only for cluster C, the deficit level is medium-low and consists of both ecosystems. Below the graph, the composition of the clusters is shown in table format to help read the connections.

Figure 4. Categorisation in clusters of the impacted sectors.



Clusters composition	Cluster A	Cluster B	Cluster C	Cluster D
deficit level	medium-high	medium-high	medium-low	medium-high
land cover similarity	agricultural	urban	both ecosystems	both ecosystems

Source: Authors' elaboration

More in detail, cluster A comprises three sectors, namely desertification, terrestrial ecosystems and agriculture. Cluster B includes the health, energy, and urban settlements sectors. Getting back to the results of section 3.2, three of the four sectors with 100% of the demand area occupied by the deficit are found in this cluster. In cluster C, there are four sectors, namely aquaculture, coastal areas, tourism, and cultural heritage. Finally, cluster D consists of hydrogeological instability, transport, and dangerous industries sectors.

4.3 Ecosystem-based actions for flood protection in adaptation planning

From the content analysis conducted in the three reference documents, i.e., UNEP (2022a, 2022b, 2022d) and presented in section 3.3, a total of 19 EbA actions to enhance flood protection are found: 9 for the urban context and 10 for agriculture. By combining the actions that were repeated in the different documents, thus presenting similar characteristics, the number dropped to 16, equally divided between the urban and agricultural ecosystem types (Figure 5). The content analysis also revealed a recurrence among the intervention types, summarised as EbA actions to protect, manage, restore, and create. In urban areas, the management prevails with 5 out of 8 actions (62.5%), followed by creation (37.5%, n = 3). Management is the prevailing type of intervention even in agricultural areas (50%, n = 4), followed by protection actions (37.5%, n = 3).

Figure 5. Classification of EbA actions by ecosystem type

Ecosystem type	EbA number	EbA description	Type of intervention	Co-benefit	Cluster
Urban	1	Promote conservation, management and restoration of parks, green roofs, rain gardens, bioswales, rivers, ponds and urban wetlands			B, C, D
	2	Renaturalize and restore riparian areas, rivers and floodplains in urban areas			
	3	Harvest rainwater through bioretention areas creatio, e.g. urban gardens, rain gardens and other green spaces			
	4	Create urban green and blue spaces and protected areas within and adjacent to cities			
	5	Improve rainwater drainage systems and flood risk management, including early warning systems			
	6	Identify flood risk zones and prohibit building in vulnerable areas			
	7	Use porous concrete or permeable pavement			
	8	Construct infiltration ditches on hills			
	9	Plant trees in crop fields and pastures in diverse agroforestry systems			
Agricultural	10	Use agroecological practices (e.g. cover crops, intercropping, mulching, reduced tillage, crop rotation or soil and water conservation practices)			A, C, D
	11	Conserve agrobiodiversity and diversifying crops to ensure species diversity			
	12	Restore degraded cropland and pastures through natural regeneration or active replanting			
	13	Protect forests, wetlands and vegetation in riparian zones and headwater and spring sources			
	14	Maintain organic matter, use cover crops in harvested areas and avoid use of heavy machinery			
	15	Avoid planting in flood-prone areas or use water-loving plants if necessary			
	16	Improve drainage and erosion control			

Type of intervention
Protect · Restore
Manage · Create

Co-benefit
Infiltration · Drainage
Capture and storage · Management/regulation of water flows
Aquifer recharge · Soil erosion

Source: Authors' elaboration

Concerning benefits, six main categories are identified: infiltration, capture and storage, aquifer recharge, drainage, management/regulation of water flows, and soil erosion. It should be noted that only water-related benefits are reported, although individual EbA actions can also reduce impacts other than flooding. For example, introducing green and blue spaces in cities can reduce heat stress, mitigate flooding, and absorb rainwater (UNEP, 2022d). Similarly, agroforestry helps buffer the impacts of extreme weather, heavy rainfall, drought, and high temperatures on crops and livestock (UNEP, 2022b).

Overall, almost all actions present at least one co-benefit (about 94%, n = 15), except for action EbA 6, specifically addressing flood risk in cities. About 38% (n = 6) have two or more co-benefits. In the group of EbA actions for urban contexts, the co-benefits of capture and storage and management/regulation of water flows prevail (37.5%, n = 3), while for agriculture, the latter prevails (62.5%, n = 5). The co-benefit of aquifer recharge appears only once in action EbA 3.

Finally, according to the associations between the EbA socio-ecological context and the deficient ecosystem of each cluster, clusters C and D are present in both macro-categories, while clusters A (agricultural) and B (urban) are in the ecosystem that characterises them.

5. Discussion and conclusions

This study aimed to propose an ES-based approach to support the integration of EbA into adaptation planning for flood mitigation at the regional level. The study developed a methodology providing results that can be used to support spatial planners, policy-makers and decision-makers due to its format linking the ES knowledge with the planning lexicon.

Thus, the methodology provides a new ‘brick’ in the attempt to bridge scientific knowledge and planning practice. In particular, it enables practitioners to visualise areas presenting a deficit in the ES provisioning for flood mitigation in their territory, as well as having a set of EbA that can respond to such deficit. The proposed EbA are categorised by land cover macro-areas (urban areas and agricultural areas) and by intervention type (protect, manage, restore, and create). Despite providing fewer details on the land covers responsible for the deficit, using such broad macro-categories allows for reducing the complexity of the information to be processed and facilitates reading the results.

Section 3.1 and its results (Section 4.1) focus on assessing, for each impacted sector within the study area, the proportion of the demand area (i.e., area demanding ES) that does not benefit from any supply area (i.e., area supplying ES), meaning there is a deficit of flood protection ES. This information can be already used by decision-makers, as it indicates which sectors will be the most impacted in terms of spatial extent due to the lack of ES provision, possibly leading to prioritising decisions towards them. In particular, having identified the largest deficits in the health, agriculture, energy, and urban settlements sectors (100%), compared to other sectors with smaller (e.g. tourism and coastal areas) or absent (e.g., forestry, inland and transitional water ecosystems, and water resources) deficits, may allow decision-makers to formulate decisions that promote cross-sectoral synergistic effects and with different degrees of priority. The proposed mapping approach is easily replicable in the case study adopted to assess also other ES that address different challenges (e.g., local temperature regulation for reducing heatwave’s impacts) given that the selection of relevant ES providing units based on land covers, as well as the demanding areas/sectors, can be adjusted depending on the single service to investigate. For example, introducing green and blue spaces in cities can reduce heat stress, mitigate flooding, and absorb rainwater (UNEP, 2022d). Similarly, agroforestry helps buffer the impacts of extreme weather, heavy rainfall, drought, and high temperatures on crops and livestock (UNEP, 2022b). Consequently, the method can be applied to identify ES deficit areas for several other services, as proposed in other similar approaches using land cover data to map supply, demand, and mismatches (e.g., Burkhard et al., 2012; 2014).

Section 4.2 is key for planners. The analysis of the land cover similarity criterion applied to the case study brings to a macro-categorisation into two ecosystem types: urban and agricultural areas. That is due to the nature and use of land covers associated with these ecosystem types, for which they produce specific ES (e.g. food production) at the expense of others (e.g. flood protection), thus generating a critical trade-off. The introduction of the land cover similarity criterion in the analysis represents an easy-to-understand element for those involved in spatial governance and a potential bridge between disciplines and uses, reducing, in this sense, the language gap highlighted in the introduction section. That makes it possible to link ES to socio-ecological systems, i.e., impacted sectors (socio), land covers (eco) and deficits (interactions). In the case study analysed, the classification into clusters (Figure 4) constitutes an additional level of synthesis. In this way, information can be more easily included into complex planning processes and tools. Clusters were designed to represent ready-to-use products for supporting adaptation planning choices: they represent different groups of areas that deserve specific decisions and considerations in terms of both prioritisation strategies and typologies of adaptation solutions that are most suitable to address the flood risk problem.

Finally, this study proposes a set of adaptation solutions (specifically, EbA actions) that can be deployed to prevent or reduce flood risk while linking each one to the clusters identified. There are many guidelines for designing and implementing ecosystem-based approaches for climate adaptation. In particular, several frameworks have been developed over the last decade, including coupling with other concepts (Green-Gray Community of Practice, 2020; CBD, 2019; UNEP, 2021), dealing with specific ecosystem typologies (Miralles-Wilhelm, 2021; Pörtner et al., 2021; UNEP, 2022b) or specific climate impacts (OECD, 2019; Sonneveld et al., 2018) and, increasingly, within urban contexts (Babí Almenar et al., 2021). However, indications for their design and implementation tend to be too general and preclude their inclusion in planning. To overcome this gap, the aim of this piece of research was to suggest what actions are best suited to be implemented in the different clusters of deficit areas. We built on existing knowledge and simply classified actions based on their possible implementation to support decision-makers in the spatial allocation and typological selection of EbA actions based on the location and characteristics of deficit areas. A further step contributing to the synthesis of knowledge to support decision-makers is the attribution of intervention types and co-benefits to each EbA action.

Overall, the application of the methodology to the case study presents some limitations. The reduced focus on land covers related to urban and agricultural contexts leaves several territories (e.g., coastal areas, mountainous areas) without data. The need for synthesis has led us to focus on those areas where the human presence is most marked - and so are the demands that arise - but future studies should also integrate the others, thus perhaps opening up opportunities that this work has not yet managed to see. Moreover, again, in an attempt to produce concise and immediate information to be included in a planning process, the final clusters lose the complexity of information that built them. It is relevant that the planners also receive the disaggregated information that enabled the cluster construction. Finally, the content analysis to link EbA to application clusters may have left room for interpretation.

In addition to the application to the case study itself and the consequent results, we consider the methodology to be the main output of this work. Indeed, the methodology lends itself to being replicated in other regional contexts in Europe. In Italy, replication is straightforward because the impacted sectors refer to data available for the entire country. It should be emphasised that impacted sectors and land-cover data are the two main types of data to be used when applying the methodology to a region. While land cover is retrievable for any region in Europe, impacted sectors outside Italy need to be supported by proxy data. The ease of replication in Italy also opens the door to a possible application on a national scale, which would allow reading similar situations across regions and disregard regional data, thus identifying trans-regional problems and solutions and activating mutual learning mechanisms.

The two general shortcomings of the metonym to date are the focus on a single ‘challenge’ (flood mitigation) and the list of proposed EbA. Regarding the challenges considered, focusing on flood mitigation implies the loss of mapping and knowledge related to trade-offs and possible synergies between ecosystem services. A natural continuation of this work could be expanding the analysis to other challenges (e.g., heat waves, landslides, salinisation, and drought) so that a synoptic reading can be set up at a regional scale to include ecosystem services in adaptation planning. Regarding the list of proposed EbA, only a first step of categorisation has now been taken to help planners and practitioners more easily identify which actions respond to urban or agricultural applications and to focus on what co-benefits and types of intervention each action represents, in summary. However, it should be noted that the adaptation solutions proposed (in Figure 5) are generic EbA actions that decision-makers should further tailor according to the local context. For this reason, once the most suited typologies of solutions are identified from the list, other evaluations and adjustments (e.g., assessing cost-benefits to select the most effective action(s) if more options are available/desired; analysing the space required by the interventions compared to the available space; defining in detail the management practices and transformative measures needed, etc.) are necessary to convert them into practical and more specific interventions, including the definition of what planning or policy instruments should be adopted to secure their implementation (e.g., Longato et al., 2024). More effort is needed to further systematise this part, especially in terms of the degree of effectiveness of the actions (thus creating a prioritisation system).

The novelty of this study mostly lies in its capacity to bridge the world of ecosystem services and its methods, lexicon and opportunities with the planning practice, with particular attention to climate adaptation. The methodology proposed provides results, summarised in the similarity criterion, that can become a tool for assessing spatial needs for EbA through land cover (above all where there is a deficit of flood protection ES) and simultaneously indicates potential EbA for a response.

Overall, testing the method on a case study made it possible to understand which elements are valuable in building knowledge on ES for climate action, i.e., the area of demand, supply, and deficit of ES, the land covers involved, the clustering onto different sectors, the synergies arising between them, and the solutions that can be implemented in the areas of each cluster. It would be interesting to further replicate the method in a different case study to investigate which elements persist, how they may change, and which may be worth planning.

Finally, it is worth noting that the methodology, applied to the case study and, if possible, to other regional contexts, would (i) build a new piece of knowledge through the production of comparable data for the integration of EbA and ecosystem services in planning for flood adaptation; (ii) benefit from the feedback by practitioners and be further updated and fine-tuned to be even more accessible and useful. We wish this piece of work to be a valuable contribution to promoting dialogue and cooperation across policy sectors, scales, and expertise.

Author Contributions

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Conflicts of Interest

The authors declare no conflict of interest.

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Originality

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References

Anisimov, A., & Magnan, A. K. (Eds.). (2023). *The Global Transboundary Climate Risk Report*. https://adaptationwithoutborders.org/knowledge-base/adaptation-without-borders/the-global-transboundary-climate-risk-report/

Aouragh, T., Basetti Sani Vettori, N., Benkhalfa, M., Krischanitz, C., Penfold, I., Portales, E., Rainaud, A., Semeraro, G., Shah, A., Silveiro, J., van Rooijen, M., & van Wijk, M. (2023). *Milliman Report on Extreme weather events in Europe for 2021 and beyond. Insurance industry impact and actionable steps for insurers to take a leading role in managing climate-related financial risks*.

Arneth, A., Shin, Y.-J., Leadley, P., Rondinini, C., Bukvareva, E., Kolb, M., Midgley, G. F., Oberdorff, T., Palomo, I., & Saito, O. (2020). Post-2020 biodiversity targets need to embrace climate change. Proceedings of the National Academy of Sciences, 117(49), 30882–30891. https://doi.org/10.1073/pnas.2009584117

ARPA FVG. (2018). Studio conoscitivo dei cambiamenti climatici e di alcuni loro impatti in Friuli Venezia Giulia. https://www.arpa.fvg.it/temi/temi/meteo-e-clima/pubblicazioni/studio-conoscitivo-dei-cambiamenti-climatici-e-di-alcuni-loro-impatti-in-friuli-venezia-giulia/

Babí Almenar, J., Elliot, T., Rugani, B., Philippe, B., Navarrete Gutierrez, T., Sonnemann, G., & Geneletti, D. (2021). Nexus between nature-based solutions, ecosystem services and urban challenges. *Land Use* Policy, 100. https://doi.org/10.1016/j.landusepol.2020.104898

Batty, M., & Yang, W. (2022). *A digital future for planning. Spatial planning reimagined*. University College London, Centre for Advanced Spatial Analysis. https://digital4planning.com/a-digital-future-for-planning/

Bitoun, R. E., Trégarot, E., & Devillers, R. (2022). Bridging theory and practice in ecosystem services mapping: a systematic review. In *Environment Systems and Decisions* (Vol. 42, Issue 1). https://doi.org/10.1007/s10669-021-09839-7

Bordt, M., & Saner, M. A. (2019). Which ecosystems provide which services? A meta-analysis of nine selected ecosystem services assessments. *One Ecosystem, 4*. https://doi.org/10.3897/oneeco.4.e31420

Botequilha-Leitão, A., & Díaz-Varela, E. R. (2020). Performance Based Planning of complex urban social-ecological systems: The quest for sustainability through the promotion of resilience. *Sustainable Cities and Society, 56*. https://doi.org/10.1016/j.scs.2020.102089

Burkhard, B., Kroll, F., Nedkov, S. & F. Müller (2012). Mapping supply, demand and budgets of ecosystem services. *Ecological Indicators, 21*, 17–29. https://doi.org/10.1016/j.ecolind.2011.06.019

Burkhard, B., Kandziora, M., Hou, Y., Müller, F. (2014). Ecosystem Service Potentials, Flows and Demands – Concepts for Spatial Localisation, Indication and Quantification. *Landscape Online, 34*(1). DOI 10.3097/LO.201434

Burkhard, B., & Maes, J. (2017). *Mapping Ecosystem Services*. Pensoft Publishers.

Castellari, S., Venturini, S., Ballarin Denti, A., Bigano, A., Bindi, M., Bosello, F., & Zavatarelli, M. (2014). *Rapporto sullo stato delle conoscenze scientifiche su impatti, vulnerabilità ed adattamento ai cambiamenti climatici in Italia* (Ministero dell'Ambiente e della Tutela del Territorio e del Mare (MATTM), Ed.). https://www.mase.gov.it/notizie/strategia-nazionale-di-adattamento-ai-cambiamenti-climatici-0

Chertow, M. R. (2000). Industrial Symbiosis: Literature and Taxonomy. *Annual Review of Energy and the Environment*, *25*(1), 313–337. https://doi.org/10.1146/annurev.energy.25.1.313

Cortinovis, C., & Geneletti, D. (2018). Ecosystem services in urban plans: What is there, and what is still needed for better decisions. *Land Use Policy, 70*. https://doi.org/10.1016/j.landusepol.2017.10.017

Costanza, R., D'Arge, R., De Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R. V., Paruelo, J., Raskin, R. G., Sutton, P., & Van Den Belt, M. (1997). The value of the world's ecosystem services and natural capital. *Nature*, *387*(6630). https://doi.org/10.1038/387253a0

Daily, G. C. (1997). *Nature's services: Societal dependence on natural ecosystems*. Island Press.

de Luca, C., Martin, J., & Tondelli, S. (2021). *Ecosystem Services Integration into Local Policies and Strategies in the City of Bologna: Analysis of the State of the Art and Recommendations for Future Development* (pp. 127–139). https://doi.org/10.1007/978-3-030-54345-7_10

Dottori, F., Mentaschi, L., Bianchi, A., Alfieri, L., & Feyen, L. (2020). *Adapting to rising river flood risk in the EU under climate change*. KJ-NA-29955-EN-N (online). https://doi.org/10.2760/14505 (online)

Dworczyk, C., & Burkhard, B. (2023). Challenges Entailed in Applying Ecosystem Services Supply and Demand Mapping Approaches: A Practice Report. *Land, 12*(1). https://doi.org/10.3390/land12010052

European Environment Agency (EEA). (2024a). *European climate risk assessment*. EEA Report 01/2024. https://doi.org/10.2800/204249 (DOI)

European Environment Agency (EEA). (2024b). *Responding to climate change impacts on human health in Europe: focus on floods, droughts and water quality*. https://doi.org/10.2800/4810

Gann, G. D., McDonald, T., Walder, B., Aronson, J., Nelson, C. R., Jonson, J., Hallett, J. G., Eisenberg, C., Guariguata, M. R., Liu, J., Hua, F., Echeverría, C., Gonzales, E., Shaw, N., Decleer, K., & Dixon, K. W. (2019). *International principles and standards for the practice of ecological restoration*. Second edition. Restoration Ecology, 27(S1). https://doi.org/10.1111/rec.13035

Geneletti, D., Cortinovis, C., Zardo, L., & Esmail, B. A. (2020). *Planning for Ecosystem Services in Cities*. Springer International Publishing. https://doi.org/10.1007/978-3-030-20024-4

Georgia, P., Marilena, P., & Doukeni, K. (2022). Ecosystem services in strategic spatial planning: insights from a literature review. *Euro-Mediterranean Journal for Environmental Integration, 7*(2), 277–285. https://doi.org/10.1007/s41207-022-00315-5

Green-Gray Community of Practice. (2020). *Practical Guide to Implementing Green-Gray Infrastructure*.

Haines-Young, R., & Potschin, M. (2013). *Common International Classification of Ecosystem Services (CICES): Consultation on Version 4, August-December 2012*. EEA Framework Contract No EEA/IEA/09/003, December 2012.

Haines-Young, R., & Potschin, M. (2018). *Common international classification of ecosystem services (CICES) V5.1 and guidance on the application of the revised structure*. Available from Www.Cices.Eu, January.

Hernández-Blanco, M., Costanza, R., Chen, H., deGroot, D., Jarvis, D., Kubiszewski, I., Montoya, J., Sangha, K., Stoeckl, N., Turner, K., & van 't Hoff, V. (2022). Ecosystem health, ecosystem services, and the well-being of humans and the rest of nature. *Global Change Biology, 28*(17), 5027–5040. https://doi.org/10.1111/gcb.16281

Hessen, D. O., & Vandvik, V. (2022). Buffering Climate Change with Nature. *Weather, Climate, and Society, 14*(2), 439–450. https://doi.org/10.1175/WCAS-D-21-0059.1

IPBES. (2019). *Global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services*. https://doi.org/10.5281/ZENODO.6417333

IPCC. (2022). *Climate Change 2022 – Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* (H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, & B. Rama, Eds.). Cambridge University Press. https://doi.org/10.1017/9781009325844

IPCC. (2023). *Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Core Writing Team, H. Lee and J. Romero (eds.)]. https://doi.org/10.59327/IPCC/AR6-9789291691647

Isbell, F., Gonzalez, A., Loreau, M., Cowles, J., Díaz, S., Hector, A., Mace, G. M., Wardle, D. A., O'Connor, M. I., Duffy, J. E., Turnbull, L. A., Thompson, P. L., & Larigauderie, A. (2017). Linking the influence and dependence of people on biodiversity across scales. *Nature, 546*(7656), 65–72. https://doi.org/10.1038/nature22899

Lavorel, S., Colloff, M. J., Mcintyre, S., Doherty, M. D., Murphy, H. T., Metcalfe, D. J., Dunlop, M., Williams, R. J., Wise, R. M., & Williams, K. J. (2015). Ecological mechanisms underpinning climate adaptation services. *Global Change Biology, 21*(1). https://doi.org/10.1111/gcb.12689

Longato, D., Cortinovis, C., Balzan, M., & Geneletti, D. (2024). Identifying suitable policy instruments to promote nature-based solutions in urban plans. *Cities, 154*, 105348. https://doi.org/10.1016/j.cities.2024.105348

Longato, D. (2024). *Susceptibility of Flood-Prone Areas to Remain Inundated for Shorter or Longer Periods During a Flooding Event: An Assessment Method Applied in the Friuli Venezia Giulia Region (Italy)*. In: Granceri Bradaschia, M., Magni, F., Musco, F. (eds) Climate Change Adaptation, Flood Risk, and Beyond. Planning for Climate Proof Cities. Springer, Cham. https://doi.org/10.1007/978-3-031-65463-3_3

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

Longato, D., Cortinovis, C., Balzan, M., & Geneletti, D. (2023). A method to prioritize and allocate nature-based solutions in urban areas based on ecosystem service demand. *Landscape and Urban Planning, 235*. https://doi.org/10.1016/j.landurbplan.2023.104743

Longo, A., Zardo, L., & Longato, D. (2024a). *Spotting deficit areas: mapping ecosystem service demand and supply to define local preparedness to floods*. In M. Granceri Bradaschia, F. Magni, & F. Musco (Eds.), Climate Change Adaptation, Flood Risk, and Beyond. State of Play in the Science-Policy-Action Nexus. Springer Cham. https://link.springer.com/book/9783031654626

Longo, A., Zardo, L., Maragno, D., Musco, F., & Burkhard, B. (2024b). Let's Do It for Real: Making the Ecosystem Service Concept Operational in Regional Planning for Climate Change Adaptation. *Sustainability, 16*(2), 483. https://doi.org/10.3390/su16020483

Malhi, Y., Franklin, J., Seddon, N., Solan, M., Turner, M. G., Field, C. B., & Knowlton, N. (2020). Climate change and ecosystems: Threats, opportunities and solutions. In *Philosophical Transactions of the Royal Society B: Biological Sciences* (Vol. 375, Issue 1794). https://doi.org/10.1098/rstb.2019.0104

MEA. (2003). *Millennium Ecosystem Assessment: Ecosystems and Human Well-Being - A Framework for Assessment*. Island Press, Washington, D.C.

Millennium Ecosystem Assessment. (2005). *Ecosystems and Human Well-Being. Synthesis*. Island Press, Washington, D.C.

Miralles-Wilhelm, F. (2021). *Nature-based solutions in agriculture: Sustainable management and conservation of land, water and biodiversity*. FAO and The Nature Conservancy. https://doi.org/10.4060/cb3140en

Morecroft, M. D., Duffield, S., Harley, M., Pearce-Higgins, J. W., Stevens, N., Watts, O., & Whitaker, J. (2019). Measuring the success of climate change adaptation and mitigation in terrestrial ecosystems. *Science, 366*(6471), 1–5. https://doi.org/10.1126/science.aaw9256

Organisation for Economic Co-operation and Development (OECD). (2019). *OECD work in support of climate action*.

Organisation for Economic Co-operation and Development (OECD). (2020). *Nature-based solutions for adapting to water-related climate risks*. https://doi.org/https://doi.org/10.1787/2257873d-en

Owen, G. (2020). What makes climate change adaptation effective? A systematic review of the literature. *Global Environmental Change, 62*, 102071. https://doi.org/10.1016/J.GLOENVCHA.2020.102071

Paprotny, D., Terefenko, P., & Śledziowski, J. (2023). An improved database of flood impacts in Europe, 1870–2020: HANZE v2.1. *Earth System Science Data Discussions*, 2023, 1–37. https://doi.org/10.5194/essd-2023-321

Pörtner, H.-O., Scholes, R. J., Agard, J., Archer, E., Arneth, A., Bai, X., Barnes, D., Burrows, M., Chan, L., Cheung, W. L. (William), Diamond, S., Donatti, C., Duarte, C., Eisenhauer, N., Foden, W., Gasalla, M. A., Handa, C., Hickler, T., Hoegh-Guldberg, O., … Ngo, H. (2021). *Scientific outcome of the IPBES-IPCC co-sponsored workshop on biodiversity and climate change*. https://doi.org/10.5281/ZENODO.5101125

Rendon, P., Erhard, M., Maes, J., & Burkhard, B. (2019). Analysis of trends in mapping and assessment of ecosystem condition in Europe. *Ecosystems and People, 15*(1), 156–172. https://doi.org/10.1080/26395916.2019.1609581

Rey, F. (2021). Harmonizing Erosion Control and Flood Prevention with Restoration of Biodiversity through Ecological Engineering Used for Co-Benefits Nature-Based Solutions. *Sustainability, 13*(20). https://doi.org/10.3390/su132011150

Riffat, M., Adem Esmail, B., Wang, J., & Albert, C. (2023). Biodiversity and ecosystem services dashboards to inform landscape and urban planning: a systematic analysis of current practices. *Ecosystems and People, 19*(1), 1–15. https://doi.org/10.1080/26395916.2023.2263105

Ronchi, S. (2021). Ecosystem services for planning: A generic recommendation or a real framework? insights from a literature review. *Sustainability (Switzerland), 13*(12). https://doi.org/10.3390/su13126595

Runhaar, H., Wilk, B., Persson, Å., Uittenbroek, C., & Wamsler, C. (2018). Mainstreaming climate adaptation: taking stock about "what works" from empirical research worldwide. *Regional Environmental Change, 18*(4). https://doi.org/10.1007/s10113-017-1259-5

Schirpke, U., & Tasser, E. (2024). Potential impacts of climate change on ecosystem services in Austria. *Ecosystem Services, 68*(101641). https://doi.org/10.1016/j.ecoser.2024.101641

Schröder, P., Lemille, A., & Desmond, P. (2020). Making the circular economy work for human development. *Resources, Conservation and Recycling, 156*. https://doi.org/10.1016/j.resconrec.2020.104686

Secretariat of the Convention on Biological Diversity (CBD). (2019). *Voluntary guidelines for the design and effective implementation of ecosystem-based approaches to climate change adaptation and disaster risk reduction and supplementary information. Technical Series No. 93. Secretariat of the Convention on Biological Diversity*. https://www.cbd.int/ts/

Sonneveld, B. G. J. S., Merbis, M. D., Alfarra, A., Ünver, O., & Arnal, M. F. (2018). *Nature-Based Solutions for Agricultural Water Management and Food Security*. FAO.

Sørensen, F., & Bærenholdt, J. O. (2020). Tourist practices in the circular economy. *Annals of Tourism Research, 85*, 103027. https://doi.org/10.1016/j.annals.2020.103027

United Nations. (2015). *Transforming Our World: The 2030 Agenda for Sustainable Development*. New York.

United Nations Environment Programme. (2021). *Guidelines for Integrating Ecosystem-based Adaptation into National Adaptation Plans: Supplement to the UNFCCC NAP Technical Guidelines*. https://wedocs.unep.org/20.500.11822/36703

United Nations Environment Programme. (2022a). *Ecosystem-based Adaptation in Agriculture - Briefing Note 11*. https://wedocs.unep.org/20.500.11822/40405

United Nations Environment Programme. (2022b). *Harnessing Nature to Build Climate Resilience: Scaling Up the Use of Ecosystem-based Adaptation*. https://www.unep.org/resources/report/harnessing-nature-build-climate-resilience-scaling-use-ecosystem-based-adaptation

United Nations Environment Programme. (2022c). *Too Little, Too Slow: Climate adaptation failure puts world at risk*. In Executive Summary (Vol. 13).

United Nations Environment Programme. (2022d). *Urban Ecosystem-based Adaptation - Briefing Note 8*. https://wedocs.unep.org/20.500.11822/40404

United Nations Environment Programme. (2023). *Adaptation Gap Report 2023: Underfinanced. Underprepared. Inadequate investment and planning on climate adaptation leaves world exposed*. United Nations Environment Programme. https://doi.org/10.59117/20.500.11822/43796

United Nations Framework Convention on Climate Change (UNFCCC). (2021). *Approaches to reviewing the overall progress made in achieving the global goal on adaptation. Technical paper by the Adaptation Committee*. https://unfccc.int/sites/default/files/resource/AC_TP_GlobalGoalOnAdaptation.pdf

United Nations Office for Disaster Risk Reduction. (2023). *Regional Assessment Report on Disaster Risk Reduction 2023: Europe and Central Asia*. https://www.undrr.org/report/rar-2023-europe-and-central-asia

Verhagen, W., Kukkala, A. S., Moilanen, A., van Teeffelen, A. J. A., & Verburg, P. H. (2017). Use of demand for and spatial flow of ecosystem services to identify priority areas. *Conservation Biology, 31*(4). https://doi.org/10.1111/cobi.12872

Wübbelmann, T., Bouwer, L., Förster, K., Bender, S., & Burkhard, B. (2022). Urban ecosystems and heavy rainfall – A Flood Regulating Ecosystem Service modelling approach for extreme events on the local scale. *One Ecosystem, 7*. https://doi.org/10.3897/oneeco.7.e87458

Zhou, K., Kong, F., Yin, H., Destouni, G., Meadows, M. E., Andersson, E., Chen, L., Chen, B., Li, Z., & Su, J. (2024). Urban flood risk management needs nature-based solutions: a coupled social-ecological system perspective. *Npj Urban Sustainability, 4*(1), 1–12. https://doi.org/10.1038/s42949-024-00162-z

Zhou, Y., & Wu, X. (2023). Identification of priority areas for green stormwater infrastructure based on supply and demand evaluation of flood regulation service. *Environmental Development, 45*. https://doi.org/10.1016/j.envdev.2023.100815