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Assessing nature-based solutions uptake in a Mediterranean climate: insights from the case-study of Malta

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ABSTRACT

Nature-based solutions are increasingly promoted in regional and national policies because of their potential to contribute toward multiple Sustainable Development Goals (SDG) and promote resilient responses to climate change. However, several barriers continue to limit the effective implementation of NbS at local scales and hinder uptake by practitioners and businesses. This research analyses a database of 96 NbS implemented in Malta and a Mediterranean climate, compares local implementation with regional case-studies from a similar climate and, through interviews with stakeholders from the case-study area of Malta, identifies strengths, weaknesses, opportunities, and threats (SWOT) of current NbS implementation and assesses enablers and barriers to NbS uptake. Most NbS case-studies addressed biodiversity loss, climate action, health and wellbeing, and sustainable cities and communities. NbS were associated with multiple arising benefits but social and economic benefits, such as green job creation, social cohesion and ownership by communities, were less often identified in the analysed case-studies. Alignment with policies, arising public relations benefits from NbS implementation, the adoption of interdisciplinary approaches involving multiple stakeholders, and the availability of regional guidelines were identified by the interviewees as key enablers supporting local implementation. Multiple institutional, infrastructural and perception barriers continue to limit participation, ownership, integration of NbS in planning and governance, and uptake by businesses. Based on these observations, we identify the need to consider NbS as a means to address societal challenges faced by communities and therefore their involvement, and that of practitioners working across disciplines needs to be established early on in NbS co-design processes. We argue that experimentation is critical to address gaps in knowledge, and develop collaborations that permit the development of context-specific NbS which, in addition to considering the ecological and technological conditions in decisions relating to NbS siting and design, also reflect the perceptions and needs of communities.

Introduction

The Mediterranean region's landscapes have been shaped by prolonged human influence, which has led to the co-evolution of highly heterogeneous social-ecological systems [1,2] supporting high biodiversity and multiple ecosystem service synergies [3,4,5] . More recent changes associated with the abandonment of agrosilvopastoral practices, the intensification of primary sector activities in the most agriculturally productive areas [6,7,5], and increases in urban development [8,9,10], combined with the regional impacts of climate change [11,12,13], have been associated with trade-offs with biodiversity conservation and ecosystem service declines.

Nature-based solutions (NbS) are defined as "actions to protect, sustainably use, manage and restore natural or modified ecosystems, which address societal challenges, effectively and adaptively, providing human well-being and biodiversity benefits" [14]. NbS are increasingly promoted in global [14] and regional [15,16,17] policy fora because of their potential to support ecosystem services, address multiple societal

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challenges and promote resilient responses to local and climate drivers impacting societies [18,19]. There is also a growing awareness of the co-benefits provided by NbS, leading to a higher demand for NbS in urban areas, including in Mediterranean cities which tend to be characterised by complex land uses and functions, and high population density in compact urban areas [16]. In recent EU-wide assessments, Southern European cities had below-average green infrastructure availability [20], while Malta and Cyprus had, for example, the highest share of citizens favouring the establishment of more natural features in the urban areas in which they live [21]. In addition, Mediterranean cities and landscapes have been more strongly impacted by climate change when compared to the global mean [22], and when compared to other European cities had the greatest increases in forecasted premature mortality, damage to critical infrastructure due to weather extremes and high adaptation costs [23,24,25].

There is increasing ambition to improve NbS uptake to address societal challenges within the region, including biodiversity loss and ecosystem services declines [8,26,9], and the socio-spatial inequalities associated with the impacts of environmental and climate drivers and in access to nature's benefits [27,28,29]. However, several barriers continue to limit the effective implementation of NbS at local scales and hinder uptake by policymakers and businesses [30,31,32]. Existing bottlenecks include the lack of integrated urban policies [16], fragmented evidence about the multifunctionality of NbS, limited understanding of their cultural and social impacts [33,34], poor availability of examples of successful implementation that can be replicated at a local scale and upscaled to regional scale, knowledge gaps on NbS costs and benefits [31] and performance in different socio-ecological, climatic, and socio-economic contexts [35]. At the same time, the reality of competing land uses, perceptions, and preferences for different amenities, diverging economic interests, and limited resources and policy instruments of local authorities act as barriers to the realisation of the benefits to well-being [36,37,38].

NbS are ecologically and institutionally interdependent, and, therefore, their uptake and effective implementation can contribute to transformative changes that reframe social-ecological relationships [39, 40,41], and replace and reshape the current socio-technical systems. This implementation can also fill in existing knowledge gaps and facilitate context-adapted solutions at relevannt scales [42,43], and from a governance perspective, in the way NbS are planned within and between organisations and stakeholder groups [44,34]. We consider Mediterranean cities and landscapes as dynamic social-ecological-technological systems (SETS) with interactions among components that influence the uptake of NbS and their impact on ecosystem service flows to communities [45,46,47]. The SETS approach offers an integrated framework to analyse the transformative changes, or the fundamental, system-wide reorganisation across technological, economical and social factors, including paradigms, goals and values [48], needed to enhance the use of NbS as a holistic solution to adaptation and resilience-building [35], and for providing a deeper understanding of the systemic conditions that may give rise to barriers for NbS uptake [30]. The application of a systemic approach at the scale of implementation offers a pathway for tackling the complexity of SETS, understanding the ecological, socio-cultural, governance, political, financial, and technological practices and conditions that hamper the uptake of NbS approaches due to misalignments with incumbent mainstream urban regimes, and finding resilient strategies for change [36,30].

Within this context, we (1) analyse case-studies of recent nature-based solutions implementation in the local case-study of Malta and their use to address societal challenges and sustainability goals, and compare these to case-studies from a Mediterranean climate, and (2) use the SETS framework to identify the strengths, weaknesses, opportunities and threats of current NbS implementation at local scale in the case-study of Malta, and evaluate the potential for transformative change needed for NbS uptake for improved ecosystem services flows. This article, therefore, assesses past experiences of NbS uptake in Malta and presents research carried out within the EU Horizon 2020 ReNature[1] project, which aimed to establish and co-create a NbS strategy and stakeholder cluster for Malta to address societal challenges acting at regional and local scales.

Materials and methods

NbS case studies from Malta and a Mediterranean climate

To map and build on existing knowledge and experiences of NbS implementation and the associated challenges and benefits [21], and share these with the wider community of NbS practitioners and decision-makers to promote learning and connect existing networks [49], the ReNature project has developed a NbS compendium with case-studies from a Mediterranean climate. Case studies were first identified from grey literature during a pilot activity as described below, and, subsequently, through an open call for submission of case studies by the ReNature project. During the pilot, which was limited to a maximum of 20 NbS case-studies, we identified suitable case studies of NbS implementation in a Mediterranean climate from existing NbS repositories and publications [50,16]. Case studies were selected if they identified the societal challenges tackled; the co-benefits arising from NbS implementation, and the United Nations Sustainable Development Goals (UN SDGs) addressed. Given the focus of the project to establish a NbS cluster and strategy for Malta, we first focused on obtaining case studies from Malta, as described in Sapundzhieva et al. [51]. The initial search for NbS in Malta was carried out using the Google search engine with each of the following terms along with the word 'Malta': nature-based solutions; green roofs; green walls; noise pollution; trees planted; climate change; health and well-being. The identified initiatives and NbS owners were then contacted and asked to provide further information. In some cases, responses provided the name of other individuals and/or organizations, institutions and/or non-governmental organizations who had implemented the NbS, and these were also contacted accordingly. We also contacted key stakeholders, including representatives of local government, planning, environmental and heritage non-Governmental organisations, water management and private businesses, and invited them to submit information about implemented actions [51]. Subsequently, given that stakeholders identified the learning and collaboration opportunities created by sharing experiences from other case-study areas from a Mediterranean climate [51] and given that the identification of NbS adapted to the water-scarce Mediterranean environment was considered in recent research as a top knowledge need to foster the implementation of NbS in Mediterranean islands [31], an open call for NbS case-studies from a Mediterranean climate was launched by the ReNature project in October 2020 and was shared via social media and with researchers and practitioners primarily working in Mediterranean countries. We hypothesise that the case studies from Malta only represent a subset of the potential use of NbS to address societal challenges or to give rise to benefits to communities. Hence, the availability of experiences from a similar climate offers an opportunity for comparison, while, potentially, fostering cross-border networks and learning to improve NbS implementation at a local scale in view of similar environmental conditions and challenges associated with addressing regional climate change impacts that have been observed to exceed the average trend at global level [22].

The NbS Compendium was uploaded online in the form of an interactive case-study finder (https://renature-project.eu/compendium). For each case study, data about the key characteristics of the NbS, including the location, city size, the timeframe of implementation, budget and interventions carried out were obtained. NbS were categorised

[1] The ReNature project aims to establish a nature-based solutions research strategy in Malta and other Mediterranean islands. Available from: http://renature-project.eu/. Accessed 6 April 2022.

according to the scale or scope into six categories (Appendix 1), using the classification developed by [52]. Additionally, different categories were applied to determine the addressed SDGs, societal challenges, and benefits associated with the NbS intervention (Fig. 1). The NbS Compendium does not seek to achieve national or regional representation, or to indicate the level of NbS implementation in different countries but provides a tool to search case studies using the identified specific characteristics and variables to promote learning and knowledge sharing within the region, which is particularly important within the context of NbS case-studies in existing repositories most often appearing

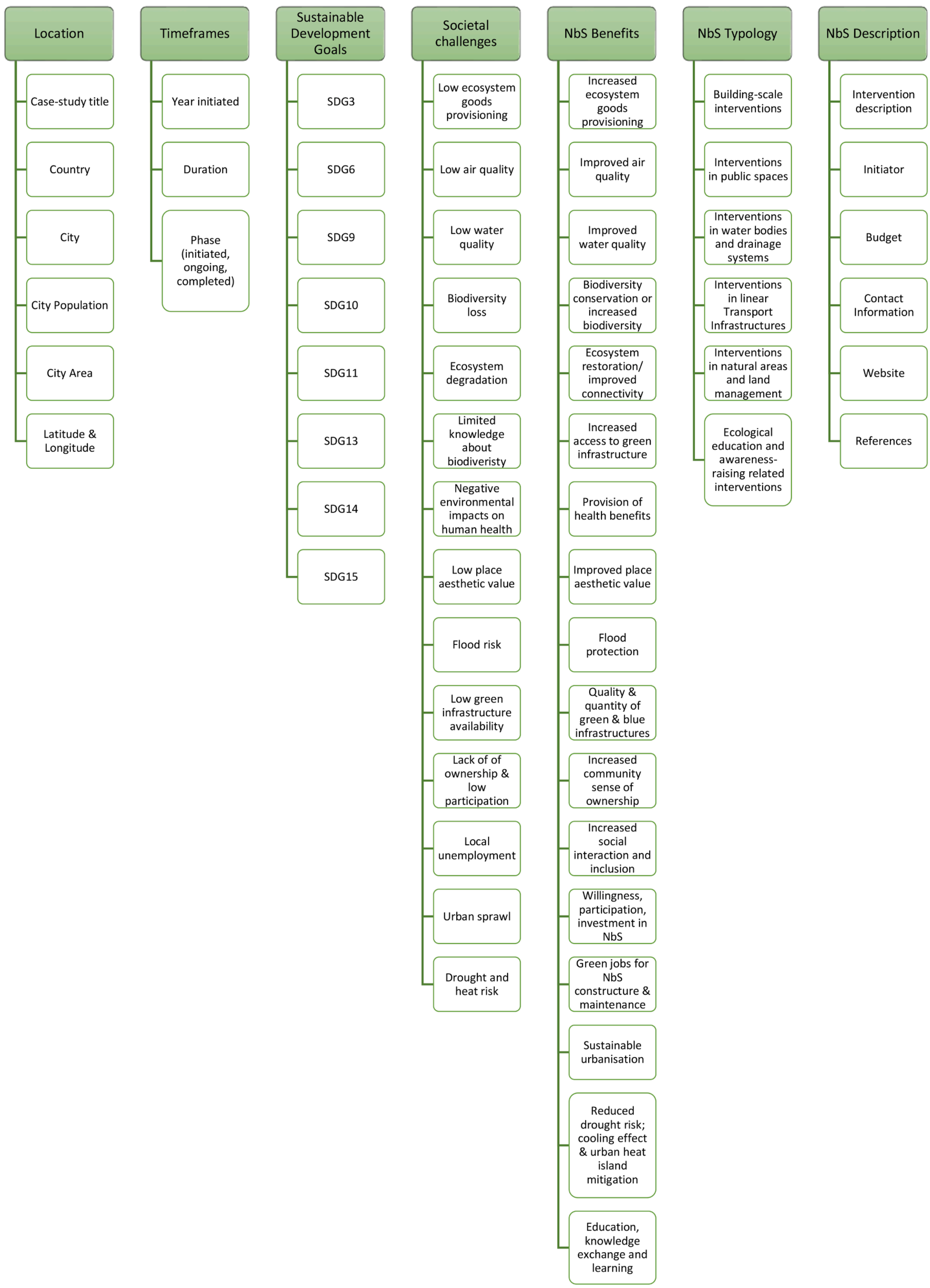

Fig. 1. An overview of the variables recorded for each NbS case-study.

in Central and Western Europe [49]. The results obtained from the analysis of the NbS Compendium case studies, described in this study, are presented in an online interactive toolkit (https://renature-project.eu/toolkit) that uses non-technical language and the development of a ranking system to identify which NbS interventions have been used to tackle specific societal challenges and the benefits associated with different NbS interventions.

Stakeholder interviews

NbS uptake depends largely on decisions taken at the country level [42], with previous literature highlighting the need to analyse NbS implementation in practice by involving national, municipal and business stakeholders [34] and develop context-dependent approaches to advance effective implementation [53,54]. Within this context, a total of 8 interviews were held with stakeholders from policy and business in Malta to obtain more in-depth insights about the uptake of NbS principles by organisations and associated barriers and enablers. The participants were considered as being key stakeholders in promoting NbS uptake at the national level in Malta either through policy or business. Policy stakeholders from the environmental, infrastructure, water, spatial planning, culture and local government sectors were invited to participate while in the case of business stakeholders, we identified large businesses that make a significant contribution to the national GDP, and already had an ongoing environmental programme, focusing on monitoring environmental impacts and the mitigation of these, and had a history of corporate social responsibility activities to promote improvement in societal well-being and the environment. The interview questions focused on understanding the use of existing definitions in guiding organisations to identify NbS, the identification of NbS implemented by the organisation, the specific challenges tackled, and opportunities associated with NbS implementation (Appendix 2). The interviews were semi-structured with questions used to prompt an open discussion leading to a deeper understanding of NbS uptake. The interview questionnaire and methodology were approved by the ethics committee of the MCAST, and informed consent was obtained from all participants.

Data analysis

Analysis of NbS case-studies

Descriptive statistics were calculated for each numerical data variable in the NbS compendium (Fig. 1). Data generated for case-study submission was analysed to indicate the strengths and gaps in NbS implementation. Additionally, an incidence matrix was created for each type of interaction to analyse the association between NbS type and the dependent variables, namely societal challenge addressed, associated benefits, and relevant SDGs. Subsequently, hierarchical clustering with Euclidean distance was carried out to assess how frequently different response variables were identified together in case-study submissions. This analysis was carried out using the heatmap.2 function from the gplots package [55] and was repeated with the entire dataset consisting of all case-studies submitted from a Mediterranean climate, and separately with case-studies from Malta.

An adjacency matrix showing how frequently societal challenges and benefits were identified together in the NbS case studies was created to evaluate whether multiple interconnected challenges are addressed together and to map interactions between multiple benefits that may arise from NbS implementation. Similarly, given that NbS are often assumed to be multifunctional [56,57], we evaluated whether tackling specific through NbS implementation can also give rise to a range of other benefits. This was done by creating an incidence matrix of association between challenges addressed and identified benefits arising from NbS implementation. These datasets were then used to create and visualise networks of associations between the variables using the igraph [58] and qgraph [59] packages. Data processing and analysis were performed in R 3.6.3 (R [60]).

Hierarcical cluster analysis, using Jaccard distance as a dissimilarity measure and complete linkage criterion, was used to reveal dissimilarity of the considered cases. Distance-based redundancy analysis (dbRDA) with Jaccard dissimilarity was subsequently used to assess the impact of the case-study country on the addressed societal challenges and arising benefits. Permutational analysis of variance (ANOVA) was used to test the significance of NbS case-study country within the dbRDA. The cluster analysis was conducted using the R package 'stats' ([60]), while the analysis of dissimilarity and dbRDA were conducted using the 'vegan' package [61].

SWOT analysis of NbS implementation based on stakeholder interviews

The interviews provided qualitative data about the understanding of NbS principles, and the enabling and inhibiting factors that limit the uptake of NbS or which may compromise the effectiveness of implementation. We have carried out a SWOT analysis to categorise interview responses by assessing relevant strengths, weaknesses, opportunities and threats. SWOT analyses are increasingly used in environmental management to evaluate how internal and external factors may impact the success of developing and implementing future strategies [62,63,64]. We identified strengths of NbS implementation as the internal organisational variables that underpin the ability of an organisation to implement more effective and context-adapted NbS whilst providing co-benefits to biodiversity and well-being, according to principles identified in previous literature [65,66,67,68,69]:

(a) NbS are systemic solutions that are inspired by nature to give rise to benefits to people and biodiversity;
(b) NbS are inclusively designed, planned, implemented, and managed;
(c) NbS are place-specific and are effectively and efficiently managed to address societal challenges;
(d) NbS are based on transdisciplinary approaches and support mutual learning and social innovation.

By contrast, weaknesses are internal factors that undermine the achievement of the identified principles (a–d). Opportunities are the external political, social-economical, legal, technical and environmental variables, representing the context of NbS implementation, and which may facilitate the implementation of NbS according to the identified principles (a–d). Similarly, threats are the external variables that may prevent NbS implementation according to the identified principles.

The establishment of NbS by and with communities of interest is a context-sensitive issue that is embedded in the social-ecological and technological facets of communities. Andersson and colleagues identify three systemic filters that, because of their adaptability to local needs and given that ecosystem service flows are embedded in the social and technological facets of cities, may be used to represent the core properties of SETS [36,70]. The *infrastructure* filter refers to the composition and configuration of landscapes and blue-green and grey infrastructure, and is highly relevant to connect ecosystem services capacities and demand. *Institutions* represent the formal and informal rules and norms, and impact on the use and governance of natural resources, and the distribution of arising benefits. The third filter, human *perceptions* and capacities, includes the individuals' appraisal of the different actors and their capacity to use the system, and hence directly influence ecosystem services flows. These three filters frame ecosystem service flows to communities by mediating how and where ecosystem services are generated and to whom their benefits are available.

Within the SWOT analysis, all factors are categorised into these three filters and are considered a barrier if the overall effect of a filter is that it reduces the flow of benefits to communities while if it strengthens the flow of benefits, it is an enabling factor [36]. These barriers and enabling factors are then categorised into three steps representing the flow of ecosystem services benefits. *Potential* refers to the quality and management of green and blue infrastructure and the values attributed to it by communities, which are influenced by socio-economic and cultural factors. Sociotechnical systems *mobilise,* or make available, the ecosystem services potential by providing the infrastructure or institutional settings that lead to ecosystem service flows. Finally, *realisation* captures how individuals perceive and use ecosystem service flows to lead to benefits for communities [70].

Results and discussion

NbS case studies from Malta and a Mediterranean climate

A total of 96 case-studies were included in the NbS Compendium. Most of the case studies were implemented between 2010 and 2020 (Fig. 2a) and were from Malta ($n = 42$), Italy (15) and Portugal (10) but case studies from a Mediterranean climate were received from a total of 13 countries (Fig. 2b). Interventions in natural areas or through land management (46) were the most frequent while linear transport infrastructure actions were the least commonly identified (3) (Fig. 2c). Public funding, through programmes at a national or local scale (54.8%) or EU funding (19.4%), was the major source of funds to finance NbS uptake, with the rest funded by private organisations (25.8%) working within the territory.

Drought and heat risks, low biodiversity knowledge, biodiversity loss, and low green infrastructure availability were the most frequently identified societal challenges that are addressed through nature-based solutions while interventions in natural areas and through land management made up the majority of the case-studies from Malta (Fig. 3a). By comparison, when all case studies from a Mediterranean climate are considered, there is a wider variation in the use of different NbS categories to address societal challenges but addressing drought and heat risks, along with biodiversity loss and ecosystem degradation, remained the most commonly selected (Appendix 3a). Interventions in waterbodies were most frequently used to improve the aesthetics, address biodiversity loss and ecosystem degradation, and flood risks. In addition to tackling drought and heat risks, low aesthetic value, green infrastructure availability and air quality were the most tackled challenges for the other NbS categories.

Each NbS intervention was associated with multiple arising benefits (Fig. 3b). Biodiversity conservation and increased biodiversity, improved green infrastructure quality, air quality regulation, and ecological restoration and enhanced connectivity were the most chosen benefits arising from NbS interventions. Interventions in public spaces and at building scales were more dominant when all case-studies were considered, and were associated with improvements in green infrastructure quality, cooling effect and reduction in drought risks and sustainable urbanisation while education and awareness-raising interventions also led to enhanced access to green infrastructure, learning and knowledge exchange, participation, and investment in NbS management, and improved social cohesion.

When all case-studies from a Mediterranean climate are considered (Appendix 3c), NbS addressed multiple SDGs and the most mentioned were SDG11 – Sustainable Cities and Communities ($n == 96$), SDG15 – Life on Land (95), SDG3 – Good Health and Well-Being (77), and SDG13 – Climate Action (76). Interventions in natural areas and through land management, and waterbodies, were most often associated with SDG15. In the case of interventions in public spaces, at a building scale and through education and participation, the strongest association was with SDG11. The strongest association with SDG9 – Industry, Innovation and Infrastructure (8), SDG6 - Clean Water and Sanitation (14), SDG13 – Climate Action (21) and SDG14 – Life Below Water (8) were recorded for interventions in waterbodies. Interventions in public spaces (3) and through education and awareness-raising (3) were the most selected for SDG10 – Reduced Inequalities. However, the link between NbS and different SDGs was less developed for the case-studies from Malta (Fig. 3c), the majority of which were related to SDG 11 and SDG15.

The case-studies from Malta addressed a narrower range of societal challenges and SDGs, and acknowledged fewer benefits of NbS uptake, indicating that NbS implementation remains primarily sectoral and is mostly associated with natural land management. The assessment of case-study similarity based on hierarchical cluster analysis, indicated that the Maltese case-studies were often clustered together according to the (a) addressed societal challenges (Appendix 4a) and (b) identified benefits arising from NbS implementation (Appendix 4b). Country was a significant explanatory variable in the dbRDA, hence within the considered case-studies determining the addressed challenges ($F(10,82) = 3.82$, $p = 0.001$) and arising benefits ($F(12,82) = 3.00$, $p = 0.001$) from NbS implementation. The case-studes from Malta were negatively associated with the dbRDA1 component, which showed the strongest negative associations with the biodiversity loss, ecosystem degradation and biodiversity knowledge societal challenges (Fig. 4), showing that most NbS address similar challenges. Similarly, while a wider range of

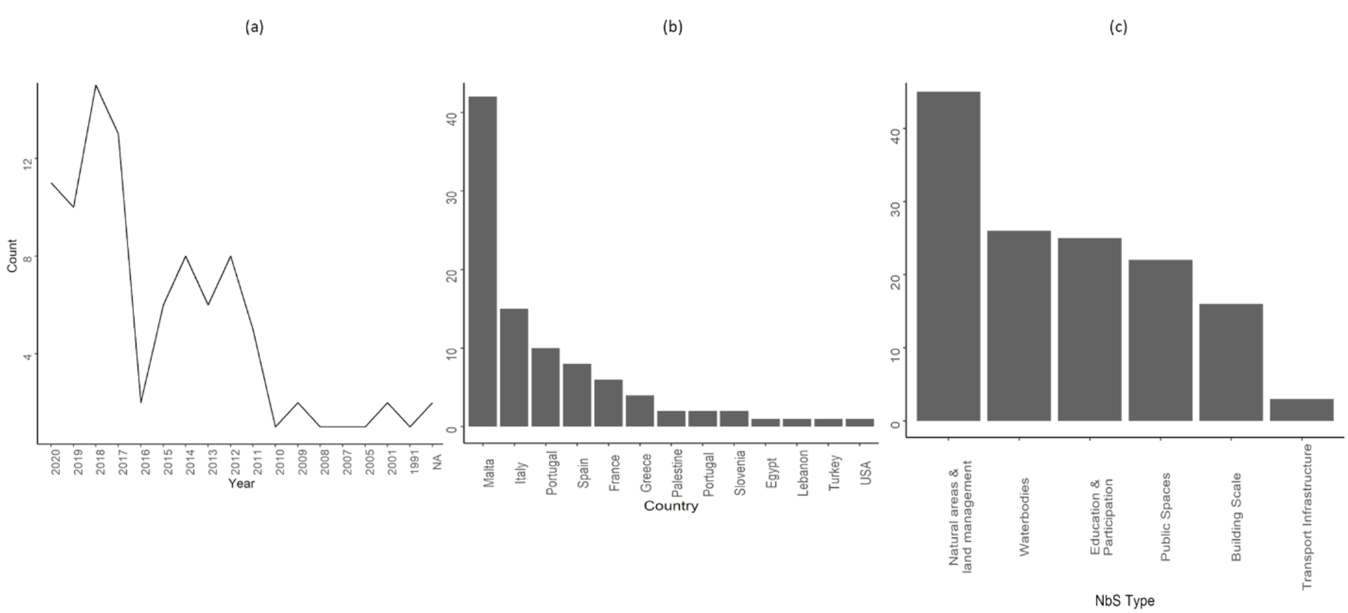

Fig. 2. Number of case-studies per (a) year, (b) country and (c) for each NbS type category.

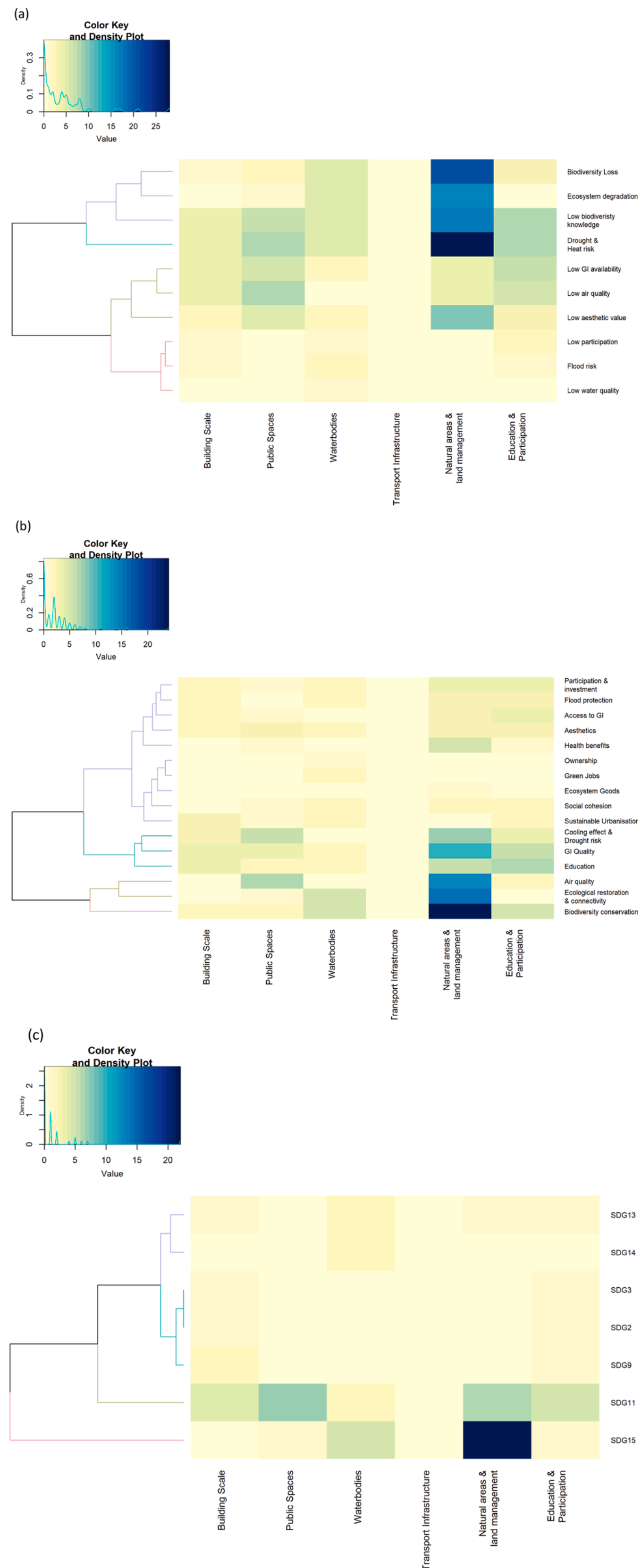

Fig. 3. Heatmaps showing the association between NbS types and (a) societal challenges, (b) arising benefits from NbS implementation, and (c) addressed SDGs in Malta. Dendrograms, obtained through hierarchical clustering and using a Euclidean distance measure, represent similar associations of studies in terms of the identified societal challenges/arising benefits (columns).

benefits arising from NbS implemenation in Malta is acknowledged (Fig. 3b) when compared to the addressed challenges, most of the case-studies from Malta associated with a relatively narrow range of benefits, including biodiversity conservation, improvement in air quality and ecosystem restoration (Fig. 5).

Even when all case-studies from a Mediterranean climate were considered, NbS were normally used to address different societal challenges simultaneously but were dominated by interactions between five network nodes, namely the challenges of tackling drought and heat risks, low place aesthetic value, low green infrastructure availability, biodiversity loss and low biodiversity knowledge (Fig. 6). Similarly, multiple benefits were associated with the NbS case-studies supporting the notion of multifunctional NbS and, in this case, no single set of interactions dominated the network analysis (Appendix 5). Addressing the five main societal challenges identified above gave rise to multiple social, economic and environmental benefits (Fig. 7). While all benefits were identified in the case studies, the weakest interactions were primarily recorded with social and economic benefits, such as green job creation, social cohesion and NbS ownership.

Stakeholder interviews

Uptake of NbS concepts and implementation

The first challenge for practitioners aiming to mainstream NbS is understanding exactly what NbS means [31]. When presented with definitions from academic [71] or policy literature [15,14], the interviewees showed different preferences which were influenced by the sector and by the NbS typologies that are implemented by the organisation. The EC definition was favoured because of previous familiarity and use in policy contexts, and its flexibility in accepting different types of interventions. The IUCN definition prioritises actions leading to ecological benefits and, while this was considered as being important for environmental organisations, these objectives were not always the main priority of the interviewed practitioners using NbS in other sectors. The definition by Albert et al. [71] was, in three cases, considered as more tangible because it includes reference to the embedding of NBS in governance and business models for implementation.

A wide range of NbS was identified by interviewees as being implemented by their organisation (Appendix 6). The most identified NbS were green roofs ($n == 5$), interventions in public gardens and open spaces (4), green living walls (4) and sustainable urban drainage systems (SUDS; 3). The identified NbS can be categorised into 3 NbS types, as identified by Dushkova and Haase [52], and were mainly associated with interventions at the building-scale, in public spaces, natural areas and land management, and in waterbodies and drainage systems (Appendix 1). The interviewees identified several planned actions that are aimed at increasing the understanding of NbS at national and local scales, including through the development of guidelines that present definitions, information about EU-level initiatives on NbS and guidance for context-adapted implementation. In line with the results from the case-study analyses, indicating that most interventions have focused on addressing biodiversity loss and environmental degradation, it was commented that guidance and regulations that focus primarily on biodiversity management and landscaping are already available but further guidance on the identification of the location, and the planning and design of NbS at local and national scales remains lacking. The interviewees considered projects that establish new NbS are important to increase awareness and acceptance of NbS, address uncertainties and gaps in knowledge about the performance, and costs and benefits of NbS, and test the adaptability of NbS to local climatic, environmental and social-economic conditions.

A SWOT analysis of NbS implementation

A SWOT analysis was carried out to analyse the interviews with stakeholders (Table 1). For each SWOT category, responses were categorised according to the 3 filters – institutions, infrastructure,

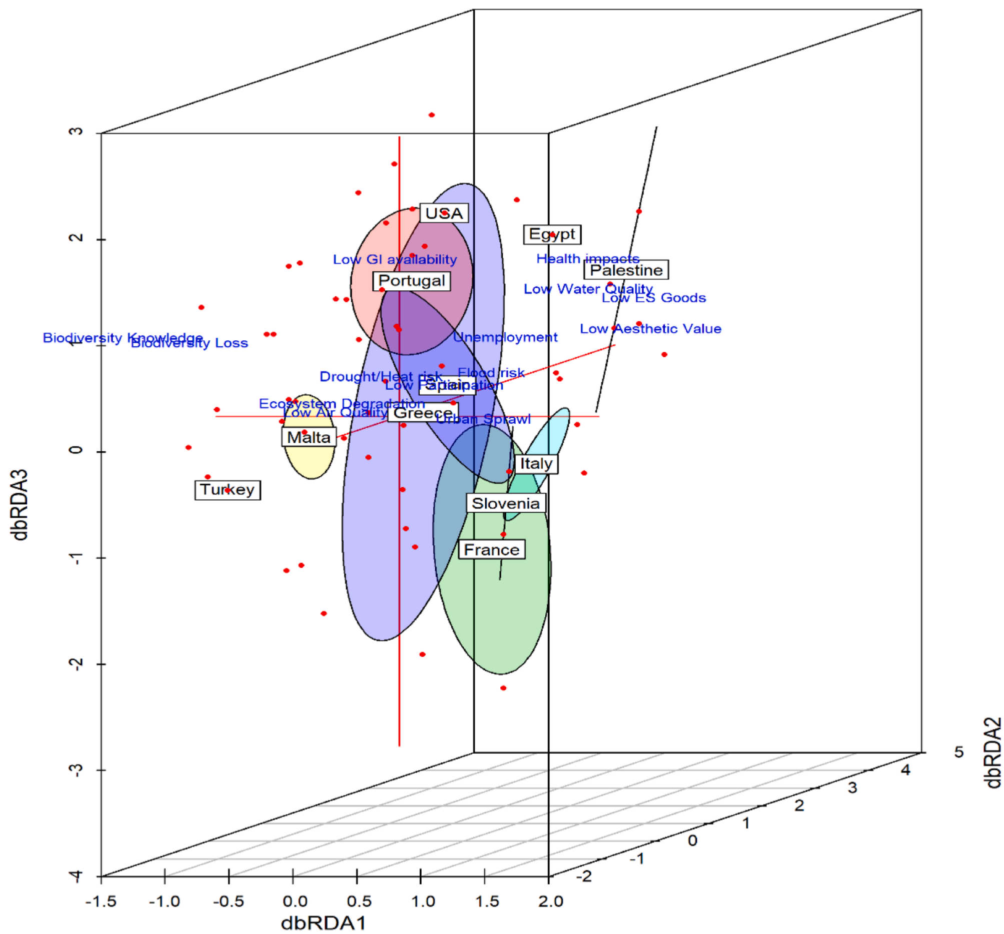

Fig. 4. Distance-based redundancy analysis (dbRDA) 3D plot for the societal challenges addressed through the NbS cases-studies. Polygons and country in centroid location represent the constraining variable; ellipses represent 95% confidence intervals. Together dbRDA1 (53.9%), dbRDA2 (18.2%) and dbRDA3 (12.46%) account for 84.5% of the cumulative variation when the addressed societal challenges (shown in blue) of each NbS are considered.

perceptions – that may be used to represent the core properties of SETS influencing ecosystem service flows to communities.

Strengths

Strengths were primarily associated with the institutions' filter and related to the availability of funding for institutions to implement NbS, the arising public relations benefits to the implementer and the adoption of interdisciplinary approaches that involved different stakeholders.

Weaknesses

The most frequently mentioned weakness was the lack of institutional capacity (5), with frequent changes in personnel being identified as an important weakness that limits institutional capacity in the public sector. The limited availability of information about costs and benefits (3), the non-monetary benefits arising from NbS (1) and the low awareness of NbS by developers (3) were identified as key weaknesses associated with knowledge availability. The other weaknesses were the lack of monitoring of established NbS and the potential ecosystem disservices arising from NbS implementation.

Opportunities

A total of 9 themes across the 3 systemic filters were identified within the Opportunities category, reflecting a positive outlook about the external variables that facilitate NbS implementation. The three top priority themes, each identified by 5 of the interviewees, were opportunities to include NbS in new developments and the upgrading of existing infrastructure and open spaces, the alignment of NbS with existing targets established by regional and national policies, including the biodiversity and sustainable development strategies, and regulations, and the contributions of research and data collection to fill key knowledge gaps and develop guidelines from context-adapted NbS. Opportunities to improve public awareness and for increased participation in the design, development, and management of NbS, and opportunities arising from guidance available at a regional scale were the other identified opportunities (all of which had a score of 1).

Threats

A total of 10 themes across the 3 systemic filters were identified in the Threats category. The lack of practical guidance (4) and standards (1) at the national scale, limited space availability for NbS implementation (3) and the complexity of establishing interdisciplinary working groups that involve different entities were the top three. Conflicting land uses and development rights arising from private land ownership, together with the high cost of the NbS options, limit the financial feasibility of NbS. The lack of appreciation and awareness of NbS options by municipalities and the public (2) and decision-makers (1) and limited co-ownership by communities (1) were identified as key threats relating to education, participation, and awareness. The limited availability of positive experiences of NbS implementation (2) and the availability of context-relevant knowledge and experiences about the irrigation requirements of NbS in a Mediterranean climate and sites of high cultural value were also perceived as threats by the interviewees.

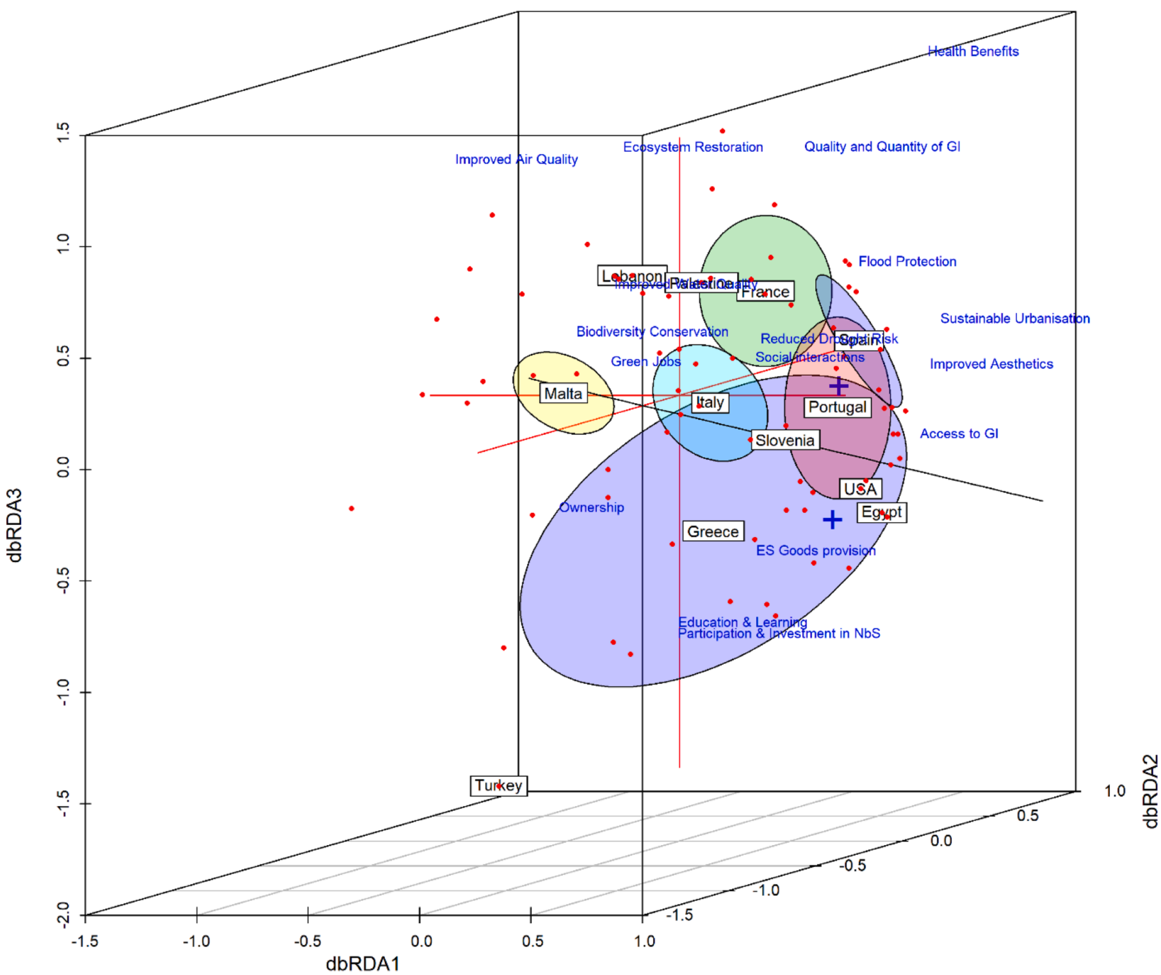

Fig. 5. Distance-based redundancy analysis (dbRDA) 3D plot for the benefits associated with the NbS cases-studies. Polygons and country in centroid location represent the constraining variable; ellipses represent 95% confidence intervals. Together dbRDA1 (56.4%), dbRDA2 (18.4%) and dbRDA3 (8.8%) account for 84% of the cumulative variation when the identified benefits (shown in blue) of each NbS are considered.

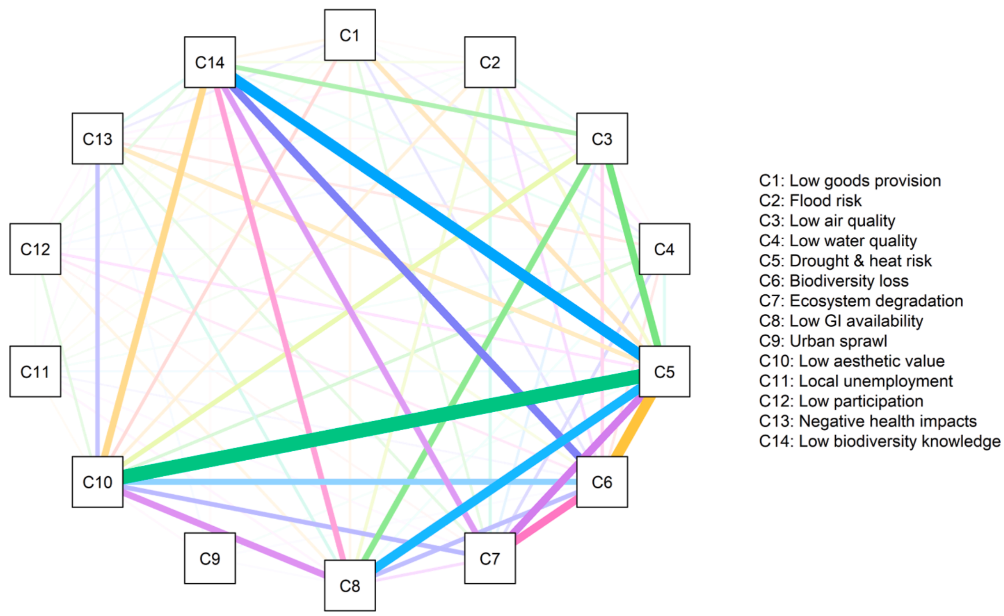

Fig. 6. A network analysis of the societal challenges tackled by the NbS case-studies. The line width indicates the frequence of association for each pair of societal challenges.

Assessing the transformative potential of NbS

What can these findings tell us about the fundamental, system-wide reorganisation across technological, economical and social factors, including paradigms, goals and values needed for more effective uptake of NbS principles? Barriers and enablers, reducing or strengthening the flow of benefits to communities (Table 2), and case-studies of NbS implementation, are analysed in this section.

Alignment with policy targets and funding availability

Enablers were mainly categorised within the perceptions and institutional systemic filters (Table 2) and were related to the potential and mobilisation steps that regulate ecosystem service flows to communities. These included the availability of funding and the alignment of NbS implementation with regional and national policy targets. At a regional scale, the promotion of NbS uptake includes the EU's Biodiversity Strategy for 2030, which recognises the need to promote NbS uptake, including in urban greening plans to improve biodiversity and accessibility to green infrastructure, and the Mediterranean Strategy for Sustainable Development 2016–2025, which calls for the uptake of blue and green infrastructure to improve ecosystem service capacities and build resilience to climate change. At the local scale, relevant policies are the National Biodiversity Strategy and Action Plan 2012–2020[2], which recognised the need to develop the knowledge base about biodiversity and its values and aims to integrate these into cross-sectoral decision-making and planning processes and to restore at least 15% of degraded ecosystems and safeguard essential services provided by vulnerable ecosystems. The Strategic Plan for the Environment and Development[3] (SPED, 2015) protects existing recreational areas to improve social cohesion, human health, air quality and biodiversity and supports the strengthening of the existing ecological network while the development of green infrastructure is considered critical for sustainable economic growth as outlined in the national green economy strategy[4].

In line with the regional policy objectives and targets, the availability of regional-scale guidance on NbS principles was considered an enabler for local implementation while public funding is made available to stakeholders through dedicated national and EU programmes. Since benefits arising from NbS implementation take the form of public goods and services, public funding was the major source of finance for NbS uptake [72]. The case studies were supported through funding from the European Commission, including the LIFE programme (8.6%), Horizon 2020 research and innovation projects (4.3%) that design and implement NbS and assess their impacts [73,74] while funding was also available through the Cohesion Policy, particularly the European Regional Development Fund (2.2%) which through the Interreg programme (1.1%) funds cooperation across countries through project funding. At a national level, case-studies that involved communities were often funded by non-governmental organisations or were carried out by businesses, including within their premises. National funding for these interventions was available through the Rural Development Programme (RDP) 2014–2020, aimed at the farming community to maintain green infrastructure in rural areas. The Common Agricultural Policy Strategic Plan for Malta 2023–2027[5] also identifies non-productive greening investments within the farming landscape to restore and enhance agricultural biodiversity and ecosystem services. The LEADER[6] Programme (Community Led Local Development) in which local councils and voluntary organisations could apply for funding to establish and restore green infrastructure to improve environmental performance and human well-being of the communities. Funding for public entities, local

[2] Malta's National Biodiversity Strategy & Action Plan 2012 – 2020. Available from: https://era.org.mt/maltas-national-biodiversity-strategy-action-plan-2012-2020. Accessed: 9 April 2022.

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[6] The LEADER programme aims to mobilise local actors in a bottom-up, territorial and integrated approach to pursue local development in rural areas Available from: https://eufunds.gov.mt/en/EU%20Funds%20Programmes/European%20Agricultural%20Fund/Pages/LEADER.aspx; Accessed: 9 April 2022.

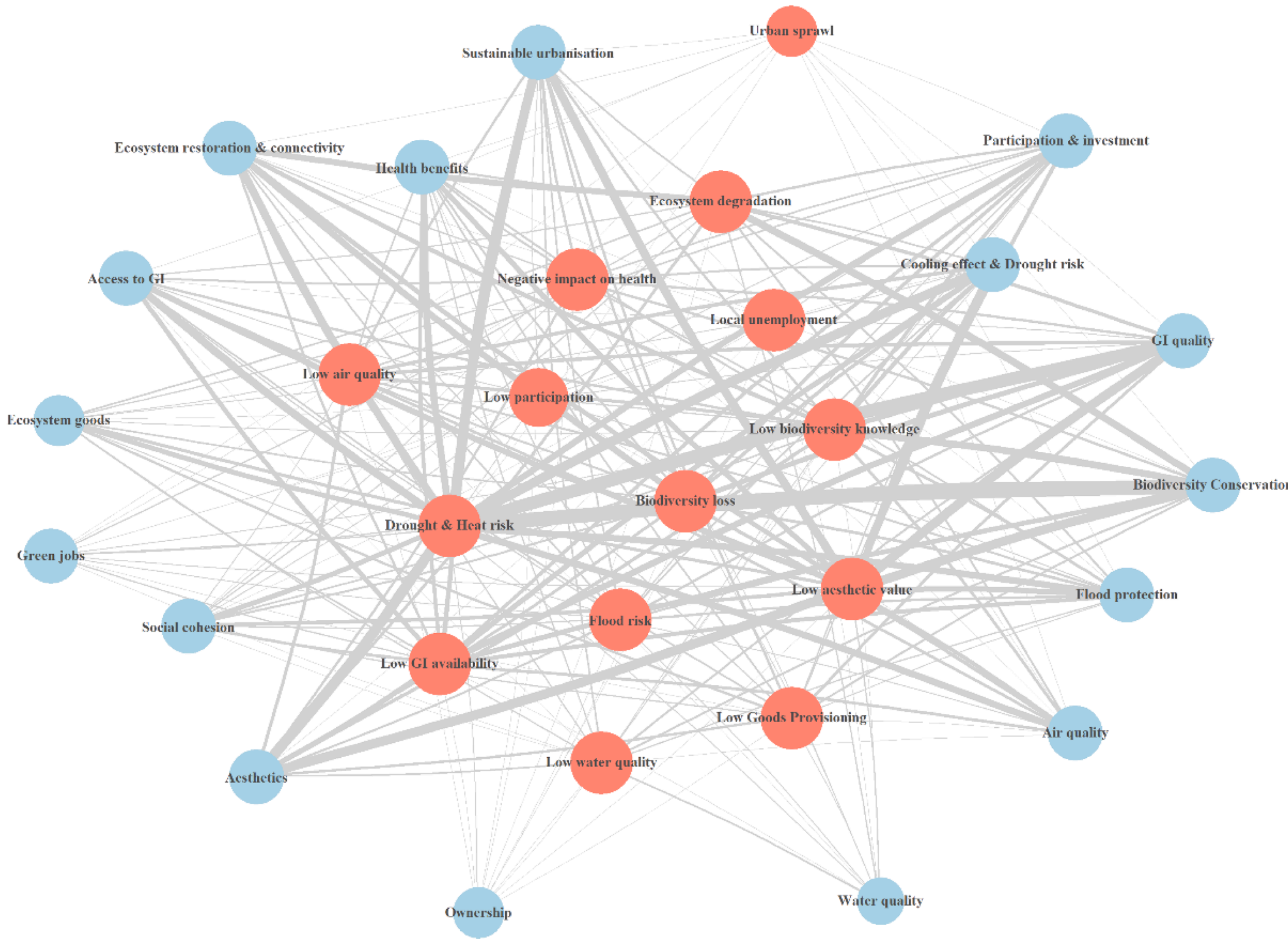

Fig. 7. The association of societal challenges (red) addressed using NbS with arising benefits (blue) from NbS implementation. Node width varies according to the degree of each node (number of connections that it has to other nodes in the network) while line width indicates the number of associations for each pair of nodes.

councils and non-governmental organisations is also available to improve the quality, accessibility and quantity of green and blue infrastructure[7]. Private investment was available through organisational corporate social responsibility budgets and as part of new development projects, but the availability of cost data was considered a necessity for the uptake of NbS in these projects while the uptake by the private sector was facilitated by the availability of external funding through dedicated grants or other financial measures such as tax deduction.

Limited awareness and understanding of the costs and benefits of NbS

The limited understanding and awareness of NbS represent a key barrier to NbS implementation, while the broad framing of NbS can lead to missed opportunities to improve the management of natural resources and the misuse of NbS, generating new trade-offs in decision-making [75]. The case-studies from Malta addressed a narrow range of societal challenges and SDGs when compared to case-studies from a Mediterranean climate and strongly focused on interventions in natural areas, which may indicate limited uptake and awareness of NbS principles, and limited understanding of the opportunities for a wider implementation of multifunctional NbS to address declining ecosystem service supplies across a rural-urban gradient [8]. The availability of regional case-studies and policy guidance was identified during the stakeholder interviews as providing an opportunity for improving the uptake of NbS at the local scale, through the sharing of experiential learning developed within SETS with similar conditions, such as high population densities, low space availability and climatic conditions. The availability of regional case-studies within the compendium may, therefore, inform local practice by sharing results arising from local experimentation from similar climatic conditions [31], and create opportunities for connecting networks and learning by comparing [49].

The traditional focus on grey technology and engineering expertise together with the limited availability of information about costs, and economic and socio-cultural benefits of NbS, which tend to be more context-specific [30,76], hinders comparisons of the effectiveness and feasibility of different NbS, and between NbS and other interventions such as grey technology or hybrid grey-NbS systems and is a key barrier to the development of a business case for NbS uptake [32]. Additionally, while NbS were widely considered as being multifunctional, with a wide range of benefits identified to local communities (Fig. 3b), some benefits, such as food and water provisioning, interactions with nature, carbon sequestration, are rarely assessed and evidence of multiple

[7] The Malta Planning Authority Development Planning Fund promotes improvement and embellishment works in urban areas, such as landscaping, traffic management and other urban projects which are considered beneficial to the wider community. Available from: https://www.pa.org.mt/en/development_planning_fund; Accessed 9 April 2022. The Environment & Resources Authority BELLUS call issued under the Environment Fund aims to bring nature back to our cities, towns and villages through green initiatives and the application of nature-based solutions in urban, peri-urban and rural areas, with activities aimed to implement more green spaces within public areas. Available from: https://era.org.mt/environment-fund/bellus/; Accessed: 9 April 2022.

Table 1
SWOT themes are ranked according to their importance based on the frequency of responses during interviews with stakeholders ($n = 8$), and categorised according to the 3 systemic filters perceptions, infrastructure and institutions.

	Internal	External
Positive	**Strengths** *Institutions* • Availability of funding for NbS implementation (5) • NBS provide PR benefits to the implementer (1) • Business CSR actions and budgets (1) • Adopting interdisciplinary approaches involving multiple stakeholders (1)	**Opportunities** *Perceptions* • Co-creation and co-ownership of NbS by communities (1) *Infrastructure* • Implementing NbS in projects upgrading existing public infrastructure (e.g. urban parks and transport infrastructural projects) (3) • Demonstration of financial benefits from NBS (2) • Terms of reference for new development may include reference to NbS (2) • Increase public awareness (1); *Institutions* • R&I provide an opportunity to fill key knowledge gaps and develop guidelines and context-adapted NbS (3) • Alignment with targets under regional biodiversity and sustainable development strategies for increasing NbS implementation (e.g. EU Biodiversity Strategy to 2030, Mediterranean Strategy for Sustainable Development 2016-2025) (2); • Alignment with targets, policies and regulations at a national scale (2); • Availability of guidance at the regional scale (1)
Negative	**Weaknesses** *Perceptions* • Limited awareness of NbS alternatives by developer/ promoter and traditional vision focusing on grey solutions (3) *Infrastructure* • Potential negative impacts (disservices) arising from NbS implementation (1) *Institutions* • Lack of institutional capacity (5) • Limited quantitative estimates of benefits and costs (3) • Lack of understanding of non-monetary benefits associated with NbS (1) • Lack of ongoing compliance monitoring (1)	**Threats** *Perceptions* • Lack of appreciation by municipalities and the general public (2) • High cost of NbS (2); • Lack of political willingness (1) • Lack of NbS co-ownership by communities in existing projects (1) *Infrastructure* • Limited space availability and competing value of land (3) • Few positive NBS examples are available at the national and regional level (2) • Finding a balance between establishing NbS and protecting cultural heritage in cities (1) *Institutions* • Lack of practical guidance for NbS implementation at a national scale (4) • Difficulty in establishing coordination/cooperation between different entities (3) • Irrigation requirements of applied NbS (1) • Lack of mandatory standards (1)

Table 2
A categorisation of the SWOT analysis variables into three steps (potential, mobilisation, realisation) representing the flow of ecosystem services benefits to communities. Symbols indicate if the filter is considered a barrier (X) or an enabling factor (+), depending on whether it reduces or strengthens the flow of benefits to communities.

	Potential	Mobilisation	Realisation
Perceptions	X Need to increase public awareness of NbS alternatives and benefits	X Need to increase opportunities for NbS co-creation and co-design with communities	X Need to tackle the perception that NbS are high-cost alternatives
	X Need to increase awareness by developer/ promoter of NbS alternatives to traditional vision focusing, primarily, on grey solutions X Need to tackle the lack of political willingness X Need to tackle the lack of appreciation by municipalities and the public ✓ NbS provide PR benefits to the implementer		
Institutions	X Limited availability of quantitative estimates of benefits and costs, and understanding of non-monetary benefits of NbS implementation	X Need to develop interdisciplinary approaches involving multiple stakeholders	X Difficulty in establishing coordination/ cooperation between different entities
	X Need for increased institutional capacity X Need to demonstrate the financial benefits arising from NbS	X There is generally limited availability of practical guidance at a national/local scale	X Lack of ongoing compliance monitoring
	✓ NbS are considered as CSR actions for businesses ✓ Interdisciplinary approaches involving multiple stakeholders	✓ The availability of guidance documents produced by regional (e.g. EU, IUCN) scales supports local implementation	X Lack of mandatory standards at national/local scales
	✓ R&I actions can fill key knowledge gaps and lead to new guidance for context adapted NbS at local scales ✓ Alignment with targets under national and regional biodiversity and sustainable development strategies for	✓ Funding availability for NbS implementation	

(continued on next page)

Table 2 (*continued*)

	increased NbS implementation		
Infrastructure	X Limited space availability for NbS implementation and competing value of land	X Need for better integration of NbS principles in the terms of reference of projects upgrading existing public infrastructure or leading to new private development	X Need to tackle the potential negative impacts (disservices) arising from NbS implementation
	X Few positive NbS examples are available at the national and regional level	X Finding a balance between planning for new NbS and protecting cultural heritage in cities and landscapes of high cultural and historical value	X Need to improve the understanding of irrigation requirements of NbS in a Mediterranean climate

benefits remains scarce and fragmented [77,78,76]. Within this context of limited availability of cost-effectiveness data at the scale of implementation, NbS were sometimes considered by the interviewees as being high-cost alternatives to grey technology and engineering interventions while in other cases there was lower interest in investing in NbS given the uncertainty about their costs and performance. This barrier interacts with other external barriers associated with the competition for land and fragmented ownership, and therefore the high cost of land, in dense urban environments which also tend to have lower ecosystem service capacities but higher demand when compared to peri-urban areas [8,79,80].

Low institutional capacities, and limited access to funding and resources [81,82], hinder effective implementation through the adaptation of the NbS to the local conditions [69] and while guidance for NbS implementation is available at regional scales, guidelines and standards regulating the local implementation remain are in many cases unavailable. This could give rise to the ‘copy-paste implementation approaches’ that are not adapted to the specific contexts of NbS implementation [69]. For example, despite the uptake of NbS to address water management issues, few projects incorporate comprehensive monitoring or assess how multiple NbS interact and address the societal challenge of runoff and flood mitigation at the landscape scale [83,84,85], which is particularly relevant since NbS projects are often too small to substantially yield ecological and well-being improvements [81,84]. Additionally, knowledge gaps about the identification of NbS that are adapted to dry Mediterranean conditions or the suitability of different NbS types to the climate and upgrading dense urban areas and existing infrastructure may limit the cost-effectiveness of nature-based solutions in a Mediterranean climate [31,86].

Experimentation and collaborative approaches to NbS uptake

Within the context of existing uncertainty about the performance of NbS implementation [30,87], and the cost-effectiveness of NbS [88,31,76], interviewees considered experimentation as an important catalyst to fill these knowledge gaps, demonstrate the economic viability of NbS in comparison to other types of solutions, including grey technologies and the combined use of nature-based and grey solutions, and develop the evidence base by testing and showcasing new experiences of context-adapted NbS implementation in the form of pilot projects with systematic monitoring of their impact. Strategies for experimentation, which include monitoring and adaptive management, formalise a process for evidence-based management and supporting or contesting knowledge claims about future implementation [89], and are increasingly playing a more dominant role in the governance of SETS [67,90].

Experimentation enables the testing of NbS principles and projects within the local context, and the development of novel and context-specific NbS in real-world situations [81], while providing tangible and visible evidence that action is being taken [89] and involving communities in implementing and evaluating solutions [91,87]. Our case-study analysis contributes to formalising this evidence from experiments, demonstrating how NbS have been used to address multiple and interconnected societal challenges and contribute towards achieving several SDG targets. Therefore, their integration in landscapes through transdisciplinary and place-based transformative approaches contributes to achieving multiple sustainability goals, and reframing social-ecological interactions to adaptively promote human well-being and social justice [92,41]. However, we identify gaps in implementation, and challenges to governing NbS, that continue to limit the transformative potential of NbS and their contributions toward regenerative and healthy landscapes. NbS have addressed specific topics, such as biodiversity loss, climate action, air quality and public health, but their use to address socio-cultural challenges remains limited [88,33,34]. Notably, few NbS addressed the societal challenges of increasing participation or local unemployment (Fig. 6) while the goals of achieving decent work and economic growth (SDG8), reduced inequalities (SDG10) and zero hunger (SDG2) were less tackled by NbS. Similarly, despite the increasing public spending focusing on the development and upgrading of green infrastructure networks, testing and monitoring NbS implementation and restoring ecosystems [72,21,74], relatively few case studies addressed SDG9 of building resilient infrastructure through sustainable industrialization and improved innovation capacities.

Experimentation embodies both bottom-up and top-down approaches that provide tangible and visible interventions while involving different stakeholders through processes of participation and deliberation about contested views and assessments of the outcomes of NbS uptake [91,89]. Without the consideration of the wider social, economic, and environmental context and clearly defined goals, partner and beneficiary groups, and management systems, such actions should not be considered as NbS [69]. Stakeholder involvement and wider community engagement in NbS co-creation was a threat identified by the interviewees as limiting effective NbS uptake, while few case studies addressed community ownership and participation through NbS, indicating that this deliberation and debating of NbS visions by communities may be limited and that NbS uptake is often the consequence of top-down processes and of the environmental characteristics and logistics criteria rather than the communities and their needs, relationships, and preferences [27,93].

Conclusions

First, we conclude that recent regional and national policy targets, together with the access to public funding and the participation of the private sector and communities, have facilitated NbS uptake at the national scale, and that implementation was associated with multiple benefits to communities across the social, environmental and economic pillars. Second, we argue that multiple institutional, infrastructural and perceptions barriers continue to limit participation and ownership, integration of NbS into urban and landscape planning mechanisms, governance, and the business case for NbS.

Third, we conclude that while the uptake of NbS gave rise to a wide range of benefits and addressed the societal challenges of climate resilience, biodiversity loss and sustainable cities, gaps in implementation remain in the use of NbS to address key societal challenges. Multiple challenges have been addressed using a wide range of NbS but there remains a relatively limited awareness and understanding of NbS performance. Similarly, the goals of achieving decent work and economic growth (SDG8), innovation (SDG9), reduced inequalities (SDG10) and zero hunger (SDG2) were less often tackled by NbS. The identified gaps in implementation continue to limit the understanding and awareness of NbS by stakeholders and communities, and hinder comparisons of the performance and cost-effectiveness of different NbS, or when compared to hybrid or technological systems. By sharing experiences and knowledge across regions through NbS compendia, it is possible to compare implementation at local and national scales with regional implementation, and can provide an opportunity for learning by comparison and further network development at national and regional scales.

Finally, we conclude that experimentation is critical to closing these evidence gaps, testing new ideas, developing collaborations and new knowledge and skills, and implementing monitoring as part of an adaptive management process that also informs future NbS uptake. Experimentation provides new knowledge about the conditions needed for sustainability in NbS deployment while developing the evidence supporting further replication and upscaling of NbS principles by the public and the private sector as new data about the cost-effectiveness, including resource use and impacts of NbS, is collected based on these experiences. In this paper, we argue that this top-down approach for NbS uptake has been relatively common and has focused on the development of an improved understanding of the ecological and technological suitability of NbS options, but we identified threats to effective NbS implementation arising from the limited involvement of key communities and stakeholders. Based on these observations, we identify the need to consider NbS as a means to address societal challenges faced by communities and therefore their involvement, and that of practitioners working across disciplines needs to be established early on in NbS co-design processes to identify the challenges, build trust and develop co-ownership, but also new knowledge and skills. This permits the implementation of context-specific NbS which, in addition to considering the ecological and technological conditions for NbS siting and design, also reflects the perceptions, needs, and visions of communities.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Supplementary materials

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