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Priority knowledge needs for implementing nature-based solutions in the Mediterranean islands

Miriam Grace[a,b,*], Mario Balzan[c], Marcus Collier[d], Davide Geneletti[e], Judita Tomaskinova[c], Ruben Abela[f], Duncan Borg[g], Giulia Buhagiar[h], Lorinda Camilleri[i], Mario Cardona[c,j], Nikolas Cassar[f], Ralph Cassar[c], Ivana Cattafi[k], Daniel Cauchi[l], Claudia Galea[m], Daniele La Rosa[n], Eleni Malekkidou[o], Maria Masini[g], Paul Portelli[p], Gloria Pungetti[q], Matthew Spagnol[r], Joseph Zahra[s], Antoine Zammit[t], Lynn V. Dicks[a,b]

[a] Department of Zoology, University of Cambridge, Downing Street, Cambridge, CB2 3EJ, United Kingdom
[b] School of Biological Sciences, University of East Anglia, Norwich Research Park, Norwich, NR4 7TJ, United Kingdom
[c] Malta College of Arts, Science and Technology, Triq Kordin, Paola, PLA 9032, Malta
[d] Trinity College Dublin, College Green, Dublin 2, Dublin, Ireland
[e] University of Trento, via Mesiano, 77 I-38123, Trento, Italy
[f] Wirt iż-Żejtun, PO Box 25, iż-Żejtun, Malta
[g] Environment & Resources Authority, Hexagon House, Spencer Hill Marsa, MRS 1441, Malta
[h] Directorate for the Environment and Climate Change, Ministry for the Environment, Sustainable Development and Climate Change, Casa Leoni, 476, St Joseph High Road, Santa Venera, SVR 1012, Malta
[i] Ministry for Health, Department for Policy in Health, 15 Palazzo Castellania, Merchants Street, Valletta, VLT 1171, Malta
[j] Manikata Farming Association, Ir-razzett tal-Qasam, Triq il-Manikata, MLH1010, Il-Manikata, Malta
[k] St Microelectronics, Ltd., Triq L-Industrija, Ħal Kirkop, Malta
[l] Ministry for Health, Department for Health Regulation, 15 Palazzo Castellania, Merchants Street, Valletta, VLT 1171, Malta
[m] Aurobindo, HF26 Hal Far Industrial Estate, BBG Birzebbuga, Malta
[n] Dipartimento Ingegneria Civile e Architettura, Università di Catania, Viale Andrea Doria, 6, 95125, Catania, CT, Italy
[o] Nicosia Development Agency, Evagora Pallikaridi, Nicosia, Cyprus
[p] Heritage Malta, Head Office, Ex Royal Naval Hospital, Triq Marina, Kalkara, KKR1524, Malta
[q] University of Sassari, Italy
[r] Department of Fisheries and Aquaculture, Ministry for the Environment, Sustainable Development and Climate Change, Malta
[s] Malta Planning Authority, St Francis Ravelin, Floriana, FRN1230, Malta
[t] Local Government Division, Malta

A R T I C L E I N F O

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A B S T R A C T

Mediterranean islands face significant environmental challenges due to their high population density, reliance on imports, and water scarcity, exacerbated by increasing risks from climate change. Nature-based solutions (NbS) could address these challenges sustainably and with multiple benefits, but their uptake in policy and planning is limited, and stakeholder perspectives are conspicuously lacking from current research. Here, we report the results of a collaborative, multi-stakeholder exercise to identify priority knowledge needs (KNs) that could enhance the uptake of NbS in Mediterranean islands. We used a well-established iterative prioritisation method based on a modified Delphi process. This was conducted by the authors, environmental policy and practice stakeholders from across the Mediterranean islands, representing business, government, NGOs and research. We developed a long list of potential KNs through individual submissions, and prioritised them through voting, discussion and scoring. Excepting workshop discussion, all individual contributions were anonymous. We present the 47 resulting KNs in rank order, classified by whether they can be addressed by knowledge synthesis and further research, or demand action in policy and practice. The top priority KNs are i) a more precise definition of NbS, ii) which NbS are adapted to dry Mediterranean conditions? iii) how to increase the adoption and use of NbS in urban plans?, iv) how can buildings and built-up areas be modified to accommodate green infrastructure and v)

* Corresponding author at: Department of Zoology, University of Cambridge, Downing Street, Cambridge, CB2 3EJ, United Kingdom.
E-mail addresses: miriam.grace@uea.ac.uk, mg2011@cam.ac.uk (M. Grace).

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cost-benefit analysis of urban green spaces. In collaboration with these stakeholders, our findings will determine future research strategies on NbS implementation in the Mediterranean islands.

1. Introduction

Nature-based solutions (NbS) are defined by the International Union for the Conservation of Nature (IUCN) as actions to protect, sustainably manage and restore ecosystems, which address societal challenges (e.g. climate change, food security or natural disasters) effectively and adaptively, while benefiting human well-being and biodiversity (Cohen-Shacham et al., 2016). NbS are a key priority for mainstreaming environmental protection at the European level (Faivre et al., 2017), and are supported by policy frameworks for conservation and sustainable development at the international level (see, e.g. (Davis et al., 2018; IUCN, 2020)). Improving policy uptake depends on identifying critical knowledge gaps that limit implementation, in collaboration with practitioners. We present a case study of this process in the context of highly urbanised Mediterranean islands.

Despite the considerable policy focus on NbS, mainstreaming into policy, planning and practice has been limited, with little knowledge of potential effects (Cortinovis and Geneletti, 2018). Greater uptake depends on identifying appropriate routes to implementation and addressing knowledge gaps hindering this within relevant sectors, such as government, business and environmental organisations. A concise guiding definition of NbS has been lacking, with the concept initially criticised for lacking specificity (see, e.g. (Eggermont et al., 2015)), though recent policy outputs have clarified this somewhat (see, e.g. (Cohen-Shacham et al., 2016)). Another obstacle is the limited synthesis of evidence for the benefits of most NbS. The few exceptions include several systematic reviews finding that urban natural environments benefit public health, as well as reducing temperatures (Bowler et al., 2010; Lachowycz and Jones, 2011; van den Bosch and Ode Sang, 2017).

Another major barrier to improving NbS implementation has been the lack of stakeholder-focussed perspectives on the process (though see (Kabisch et al., 2016) and (Frantzeskaki et al., 2019b)), with NbS research generally focussed on theoretical aspects. Well-established participatory processes exist to incorporate environmental practitioner perspectives into policy. In one framework, a defined group of stakeholders choose a set of priorities. This has been done for diverse environmental issues such as pollinator conservation (Dicks et al., 2013a), sustainability of agriculture (Dicks et al., 2013b) and aquaculture (Jones et al., 2015), landscape restoration (Ockendon et al., 2018) and management for ES (Sutherland et al., 2018). The methodology follows a modified Delphi process, in which participants provide information or opinions anonymously. These are discussed, followed by the opportunity for participants to anonymously revise their contributions (see, e.g. (Mukherjee et al., 2015)). This process aims to reduce the influence of participants perceived as more knowledgeable or powerful on others' scoring decisions, and has been shown to improve the accuracy of participant judgements (Burgman et al., 2011). Such exercises have informed policy, e.g. (Dicks et al., 2013a) identified a need for standardised pollinator monitoring methods, which were subsequently developed for a Government-funded UK-wide scheme (Carvell et al., 2016). The same resource informed the design of the EU Pollinator Initiative (Underwood et al., 2017). We use a similarly defined process in this study to identify stakeholder priorities for NbS implementation with a specific focus on Mediterranean islands.

Mediterranean-type ecosystems are one of the rarest terrestrial ecoregions, occupying only 2% of global land area (Cowling et al., 1996). They occur in five geographic areas, of which the largest is the Mediterranean Basin (Olson et al., 2001), all considered terrestrial biodiversity hotspots (Myers et al., 2000). Mediterranean islands' limited fresh water, and erosion exacerbated by infrastructure development, are key threats to agriculture. Their endemic biodiversity is vulnerable to changing agricultural practices, urbanisation and climate change, and subject to exceptional environmental impacts (Halpern et al., 2008). These anthropogenic effects have reduced the supply of ecosystem services (ES) such as the regulation of flooding and climate (Balzan et al., 2018a,b; García-Nieto et al., 2018; Geijzendorffer et al., 2018), increasing the region's vulnerability (Schröter et al., 2005).

Islands (Armstrong et al., 2012; Hall, 2010; Hopkins, 2002), and cities (Evans and Karvonen, 2014), have been used as "laboratories" to explore solutions to socioenvironmental challenges. Islands face particular barriers to sustainable development due to ill-defined policy objectives, low availability of local-scale data, and poor integration of decision-making across sectors (Hirano, 2008; Roberts, 2010; van der Velde et al., 2007). Island territorial planning approaches were largely designed for mainland areas and the use of spatially-explicit methods, proceeding from data gathering to policy implementation, is limited (Vogiatzakis et al., 2017). Most research focuses on managing island ecosystems' intense anthropogenic pressures (Balzan et al., 2018b), but recent studies assess Mediterranean island ES e.g. (Balzan et al., 2018a, b; Ciftcioglu, 2017; Vogiatzakis and Manolaki, 2017); Lorilla et al., 2018). The Mediterranean islands present suitable case studies for examining routes to implementing NbS, with diverse territorial planning and governance structures, notably the independent EU Member States Malta and Cyprus. Of the two, Malta is subject to greater anthropogenic impacts, with the highest population density of any Member State (FAO and World Bank, 2018).

This study, centred on Mediterranean islands, is an important step towards a strategy to promote NbS research and innovation for sustainable development in the region. It builds on observations that despite good examples of Mediterranean urban NbS, there is limited integration into existing policy sectors and no unique policy framework. Policy uptake could be improved by providing greater information about NbS options and their socio-economic impacts (IUCN, 2019). A necessary prerequisite is understanding the barriers to implementation; these are diverse, including insufficient knowledge of various types, limited resources, confounding legal structures, and poor stakeholder involvement. Our study focuses on a stakeholder consultation to identify the priority knowledge needs (KNs) limiting implementation of NbS in the Mediterranean region, the first of its kind to our knowledge in this context. We thus present a policy- and practitioner-led understanding of key knowledge gaps impeding NbS uptake, to facilitate research into NbS design and implementation in the Mediterranean.

2. Methods

The authors are a group of stakeholders and scientists representing sectors with particular implications for the environment or substantial contributions to Mediterranean island economies: agriculture, aquaculture, business, government, environmental non-governmental organisations and researchers. Participants at each stage of the process were categorised according to sector; if more than one sector was relevant, all were considered. Our group includes representatives from Malta, Cyprus, Sicily, and Sardinia. The authors comprise lead researchers together with workshop participants who scored the final list of priority knowledge needs (KNs), as described in more detail below. Participants initially provided lists of submitted knowledge needs (SNs) which were refined into an eventual list of KNs, over a three-round process.

Rounds 1 and 2 of the exercise were carried out by email. In Round 1, participants were asked to suggest up to 10 priority SNs as things they would need to know before implementing NbS in their organisation, through considering how NbS might be relevant for their organisation, and what knowledge gaps would prevent their deployment. They were

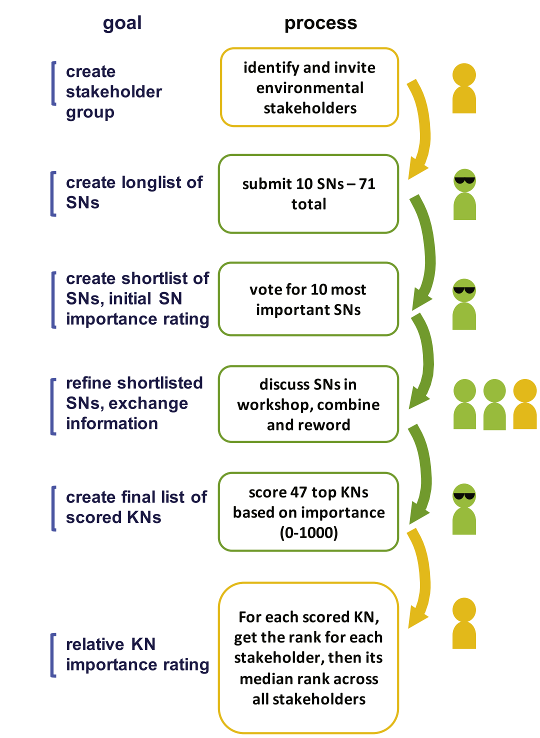

Fig. 1. Steps towards obtaining the priority knowledge needs for implementing nature-based solutions in the Mediterranean islands. Yellow-bordered boxes indicate steps carried out by yellow researchers; green-bordered were green stakeholder-led. Sunglasses indicate that the step was performed anonymously.

asked to consider a wide range of possible NbS and knowledge gaps, express these as questions and be as specific as possible. The participants were provided with two additional documents. The first contained five example of SNs from a previous similar exercise (Dicks et al., 2013b), which identified priority KNs for sustainable agriculture and was selected for an environmental remit without a focus on NbS. The second contained examples of diverse NbS and their applications.

An inductive content analysis approach, i.e. determined by the data rather than intrinsic hypotheses, was used to categorise the long list of SNs, with the aim of obtaining similar numbers of SNs in each category. These categories were used to combine SNs in the subsequent workshop discussion. In Round 2, participants anonymously voted for the ten SNs they considered most important, across all categories, using specially prepared Microsoft Word documents sent individually. Participants were told that an important need was considered to be one which, if met, would lead to their organization changing policy or practice, with the objective of enhancing its environmental sustainability through implementing nature-based solutions. The wording was preserved verbatim with the exception of unambiguous spelling mistakes, in order to avoid prescriptive interpretation of SN meanings.

In Round 3, a face-to-face workshop, we followed a prioritisation method used by Sutherland et al., 2018 for horizon scanning. In this process, the SNs were discussed openly and scored privately. Each KN was allocated a guideline discussion timeslot of 10 min. Discussions were chaired by an experienced facilitator, and leading researchers at the workshop took part in discussions only to provide scientific information when required. Neither the facilitator, nor researchers, voted or scored. The facilitator drew attention to ambiguous aspects of SNs to promote discussion, e.g. prompting comments on the meaning of KN34 'How can you ensure the scalability of the outcomes of an NbS?' (Table 2). SNs were subject to rewording for clarity, and could be combined if participants agreed that they were the same. This was initiated by either the participants or the facilitator.

The default was not to score SNs with zero votes, but participants

Table 1
Categories assigned to submitted and priority knowledge needs (SNs and KNs) for NbS, and their meanings. Categories were developed to group similar SNs together for further refinement during the workshop discussion, aiming for a similar number of SNs in each category.

SN/KN category	SN/KN focus	Number of SNs	Number of KNs
Capacity and policy levers	Provision or availability of NbS expertise or policy action at the level of national or local government.	13	9
Cost-benefit	Information about NbS costs and/or benefits, including in comparison to conventional solutions.	14	11
Implementation	Details on a specific, narrowly defined NbS implementation context, or specific information about deploying a given NbS. Excludes cost-benefit, capacity and policy levers and societal engagement.	15	10
NbS options	Evaluating the range of NbS available or a deeper understanding of the NbS concept.	22	12
Societal engagement	Public or business engagement and involvement with designing or implementing NbS, including understanding the impacts on stakeholders. Excludes a capacity and policy context.	7	5

could request that these be brought back. After a SN was discussed, each participant anonymously allocated it a score of between 0 and 1000, where 0 is the least important and 1000 the most important. Important SNs were stated to be those that, if met, would lead to a change in policy or practice, accelerate or enhance the use of NbS in Mediterranean islands, or help to address a societal challenge through biodiversity. No two SNs were to have the same score. Scoring was conducted anonymously on private laptops, or, in two cases, on paper scoresheets. The scored SNs were then classed as priority knowledge needs (KNs). The scores were used to generate a ranking of KNs for each participant. Then, for each KN, across all stakeholders, the median rank and interquartile range were calculated. In a few instances (3.83 % of possible scores) participants scored some of the 24 SNs that were intended to be removed as they did not have any votes. These 24 were removed from the final set, but we retained the original ranking where these were scored, to calculate the median ranks. Every KN in the final list was scored by a minimum of 12 participants.

We performed a Friedman test to determine whether any KN ranks differed significantly from one another. Pairwise Wilcoxon Signed Rank tests were used to compare the ranks of each pair of KNs, including a Bonferroni correction to account for multiple comparisons; similar approaches are widely used in the analysis of data derived from Delphi processes (see, e.g. (Bunting, 2008; Jeste et al., 2010)). Data processing was performed in R 4.0.2 (R Core Team, 2020), with the additional packages "ggplot2″(Wickham, 2016) and "reshape2″(Wickham, 2007).

Through consensus among three leading authors (MG, LVD, MB), we assigned each KN the appropriate next steps in addressing it. A KN may be suited to one or both of: i) knowledge synthesis, followed by primary research if needed; ii) action or response by policy or business stakeholders. Both of these incorporate the co-production of knowledge, in which policymakers and practitioners work together with researchers.

All participants gave their full informed consent. Fig. 1 summarises the process of obtaining KNs, with the goal corresponding to each step.

Table 2
List of the 47 scored priority knowledge needs (KNs) ordered by median rank (highest rank first) and interquartile range (smallest first) across all participants. KNs are assigned appropriate next steps to enable NbS implementation, where tick and check marks indicate whether or not the KN is suited for a given next step. Wording largely reflects that originally submitted by participants.

KN ID	Category	KN	Median rank	Interquartile range	Next steps to address KN:	
					Knowledge synthesis and research	Policy and business action
KN01	NbS options	[*]Need for a more precise definition: what exactly are NbS?	6.5	2.00–10.75	✓	×
KN02	Implementation	[*]Which NbS are adapted to dry Mediterranean conditions to minimise irrigation needs?	11.5	8.00–19.00	✓	×
KN03	Capacity and policy levers	[*]How to increase the adoption and actual use of NbS in urban plans?	11.5	5.00–18.00	✓	✓
KN04	NbS options	[*]How can new or existing buildings and built-up areas be modified to accommodate green infrastructure?	12	5.00–16.25	✓	✓
KN05	Cost-benefit	[†]Cost-benefit analysis of urban green spaces - long term benefits to human health vs the opportunity cost of not building on land	13.5	6.00–19.00	✓	×
KN06	Cost-benefit	How much is the difference in cost between NbS and [a] conventional solution?	15	9.75–35.50	✓	×
KN07	Cost-benefit	How can the tangible and intangible benefits to human health arising from green open spaces be measured?	15.5	10.00–29.00	✓	×
KN08	NbS options	[†]Which NbS are suited to dense urban areas with a built environment of high cultural heritage value?	16	13.75–41.25	✓	×
KN09	NbS options	How do we integrate NbS with current road infrastructure?	17	9.75–27.50	✓	×
KN10	NbS options	[*]What NbS can companies implement to mitigate climate change?	17	9.50–32.75	✓	✓
KN11	Societal engagement	[*‡]Social acceptance and clear definition of beneficiaries - who will benefit and is this acceptable to the public?	17.5	5.75–28.75	✓	×
KN12	Societal engagement	[*‡]How can we re-evaluate the role of farmers and shepherds as guardians of rural areas?	19.5	12.50–31.00	×	×
KN13	Capacity and policy levers	[*]Why are health and social impact assessments not compulsory for any large scale project in an urban setting?	20.5	16.00–31.00	×	✓
KN14	Cost-benefit	Economic benefits generated by NbS (key aspects in a CBA assessment to determine the feasibility of such projects)	21	6.00–29.00	✓	×
KN15	Implementation	[*]Which native plants are suitable for urban gardens and roadsides, and where can people buy them?	22	9.00–37.00	✓	×
KN16	Implementation	[*]Which NbS make the most efficient use of land, when land is scarce?	22.5	15.00–31.00	✓	×
KN17	Cost-benefit	[*]How can we ensure the effectiveness of the chosen key performance indicators and set baselines?	22.5	13.00–35.00	✓	✓
KN18	Cost-benefit	Does green infrastructure mitigate air pollution?	22.5	5.00–31.00	✓	×
KN19	Cost-benefit	What are the costs of maintenance for green infrastructure spaces in the long term?	23	18.00–29.00	✓	×
KN20	Capacity and policy levers	[†]How to include NbS into local policies in small municipalities with fewer resources?	23	11.00–29.00	✓	✓
KN21	Cost-benefit	Can a NbS address more than one different type of urban challenges in a city? How to measure the positive impact on these different dimensions?	23	10.00–30.00	✓	×
KN22	Implementation	Maintenance plans for native Mediterranean urban trees and gardens - proper pruning, watering etc.	23.5	16.00–33.00	×	✓
KN23	Capacity and policy levers	Is there any funding available to organisations to implement any NbS?	23.5	14.00–35.00	×	✓
KN24	Capacity and policy levers	Availability of solutions in the local market (what knowledge is available to ensure the correct installation of NbS)	24	12.75–31.00	×	✓
KN25	Capacity and policy levers	Information pack for Local Councils and for companies who compete for tenders and standard tender templates for upkeep and maintenance of public areas/gardens/streets.	25	20.00–28.00	×	✓
KN26	Implementation	A design of a tree pit for roadsides, including specifications for paving, lining of pit etc.	25	15.50–32.25	×	✓
KN27	NbS options	[*]Are there NbS that can help with management of plastic waste?	25	14.00–34.50	✓	×
KN28	NbS options	[*]What technologies and methods are suitable for sustainable urban drainage systems?	25	15.75–36.75	✓	×
KN29	Societal engagement	[*]What can industry do to contribute to NbS?	25	13.25–35.50	✓	✓
KN30	Implementation	How can rainwater running through valleys be utilised to rehabilitate aquatic species of fauna and flora?	26	20.00–37.00	✓	×
KN31	Implementation	[*]What crops or plants might be suitable for phytoremediation of wastewater including saltwater?	26	19.00–36.25	✓	×
KN32	NbS options	[*]What NbS are available for use in agriculture and pastoralism?	26	12.50–38.25	✓	×
KN33	Implementation	[*‡]How can protected areas be managed to safeguard natural heritage and increase their fauna and flora?	26.5	20.00–38.00	✓	✓
KN34	Cost-benefit	How can you ensure the scalability of the outcomes of an NbS?	27	17.00–37.00	✓	✓
KN35	Cost-benefit	[*]What are the disservices, disadvantages and limitations of NbS?	28.5	18.00–44.00	✓	×
KN36	Capacity and policy levers	[*‡]The need to include coastal resilience and erosion in policies	29.5	23.00–38.00	×	✓
KN37	Implementation	[*†]How can invasive alien species of flora and fauna be controlled or eliminated?	29.5	11.00–34.00	✓	×
KN38	Capacity and policy levers	[*]How important is the versatility of a NbS to fit different ecological and climatic conditions, as well as planning and governance mechanisms?	30	26.00–37.00	✓	×
KN39			32	15.00–36.50	✓	×

(*continued on next page*)

Table 2 (*continued*)

KN ID	Category	KN	Median rank	Interquartile range	Next steps to address KN:	
					Knowledge synthesis and research	Policy and business action
	Societal engagement	*How effective is development and implementation of NbS through co-production?				
KN40	Capacity and policy levers	†Establishing and communicating vulnerability metrics for coastal landscapes in order to develop resilience with the affected community is the most challenging	32.5	19.00–42.00	✓	✓
KN41	Societal engagement	*How can companies influence people to be more aware of NbS?	33	20.00–40.00	✓	✓
KN42	Cost-benefit	What are the trade-offs of leaving green open spaces to support biodiversity, as opposed to managed parks or urban green areas?	33	20.00–41.00	✓	×
KN43	NbS options	*Do any commercial nature-based algal cultures exist for waste water management?	35.5	20.00–44.25	✓	×
KN44	NbS options	How can ecosystem services support urban areas?	36	14.25–42.25	✓	✓
KN45	Implementation	People appreciate 'colour' in urban gardens and streets - which plants, trees and bushes can be used to add 'colour' to urban streetscapes and public areas?	40	26.50–44.75	✓	×
KN46	NbS options	†‡How can we replace the present anthropocentric management system with an ecocentric system?	41.5	26.00–46.00	✓	✓
KN47	NbS options	May a system be developed to alert personnel when something hazardous has been discarded in our water system?	46	38.50–47.00	✓	✓

* KN was reworded for brevity or clarity during the workshop discussion.
† KN was reworded after the workshop.
‡ KN does not meet our definition of NbS, as outlined in the Discussion.

3. Results

Of the 32 registered participants, 13 submitted SNs with 71 received in total. Table A1 contains the numbers of participants in each sector, at each stage of the process. The SNs were grouped into five categories: capacity and policy levers, cost-benefit, implementation, NbS options and societal engagement, as explained in Table 1. The list of original SNs is shown in Table A2. 22 SNs received no votes in Round 2, and 3 of these were brought back in the discussion to be scored. 22 were reworded for clarity, on agreement. A number of SNs were combined, as noted in Table A2. A final set of 47 KNs was scored by 18 participants excluding the lead authors, retaining a relatively even spread across the five categories (Table 1).

The complete list of ranked KNs is presented in Table 2. For the SNs and KNs, we aimed to retain the participants' original wording to ensure that we did not distort the meaning for voting and scoring, and this resulted in disparities in how the KNs were formulated. We restricted modifications to those which improved brevity or clarity, and the majority of these changes were made in the workshop, as indicated in Table 2. For the original phrasing of SNs and numbers of votes (Rounds 1 and 2), see Table A2. Boxplots of the ranks of each KN are shown in Fig. 2. Five KNs arguably do not meet the proposed definition of NbS, due to their strict focus on environmental protection or conservation, as discussed below. These KNs, marked with a ‡ symbol in Table 2, were prompted for discussion by the facilitator, and retained as the stakeholder group considered them important.

Each KN was assigned the appropriate next steps to address it. Thus we assigned 26 KNs as requiring knowledge synthesis followed by possible primary research, 7 as requiring policy and business action, 13 as requiring both, and one as neither.

The Friedman test indicated statistically significant differences between the KNs' ratings (Friedman chi-squared = 111.28, df = 46, p-value < 0.001). However, after applying the Bonferroni correction to the p-values obtained for the pairwise Wilcoxon Signed Rank Tests, no KNs were found to differ statistically (results not shown).

4. Discussion and conclusions

Our study identified a set of 47 KNs that, if met, we would expect to improve and widen implementation of NbS in Mediterranean islands. Most concerned urban environments, although some addressed agricultural or coastal settings. The top-ranked KNs were i) a more precise definition of NbS, ii) which NbS are adapted to dry Mediterranean conditions? iii) how to increase the adoption and use of NbS in urban plans?, iv) how can buildings and built-up areas be modified to accommodate green infrastructure and v) cost-benefit analysis of urban green spaces. There is a lack of consensus on NbS definitions and scope in our group of participants, with high variation in priority KN ranks, shown by the large interquartile ranges and the non-significant pairwise Wilcoxon Signed Rank Tests. As such, although the KNs are presented in rank order, it is not possible to assess the differences in priority between them. We obtained a diverse range of KNs, spanning the need for a better understanding of the concept, through specific well-defined implementation knowledge gaps, to greater information provision and access across society and in policy contexts. Our identified KNs are also strongly congruent with the eight principles for effective NbS outlined in the newly released IUCN Global Standard for NbS (IUCN, 2020).

The importance placed on a more precise definition of NbS suggests that scientific progress in clarifying the concept has not been transferred to policy and management, at least among this group of stakeholders. This has also been noted in recent Mediterranean NbS policy outputs such as (AFD et al., 2019; IUCN, 2019). A number of frameworks to better define NbS have been published (see, e.g. (Nesshöver et al., 2017; Frantzeskaki et al., 2019a; Seddon et al., 2019); some appear to provide appropriate guidance for policy-makers and managers, albeit with translation from the academic language. Notably, (Albert et al., 2019) argue for a definition of NbS as actions that (i) alleviate a well-defined societal challenge, (ii) utilize ecosystem processes of spatial, blue and green infrastructure networks, and (iii) are embedded within viable governance or business models for implementation.

Significant challenges remain and it is difficult for stakeholders to distinguish NbS from overall environmental protection and nature

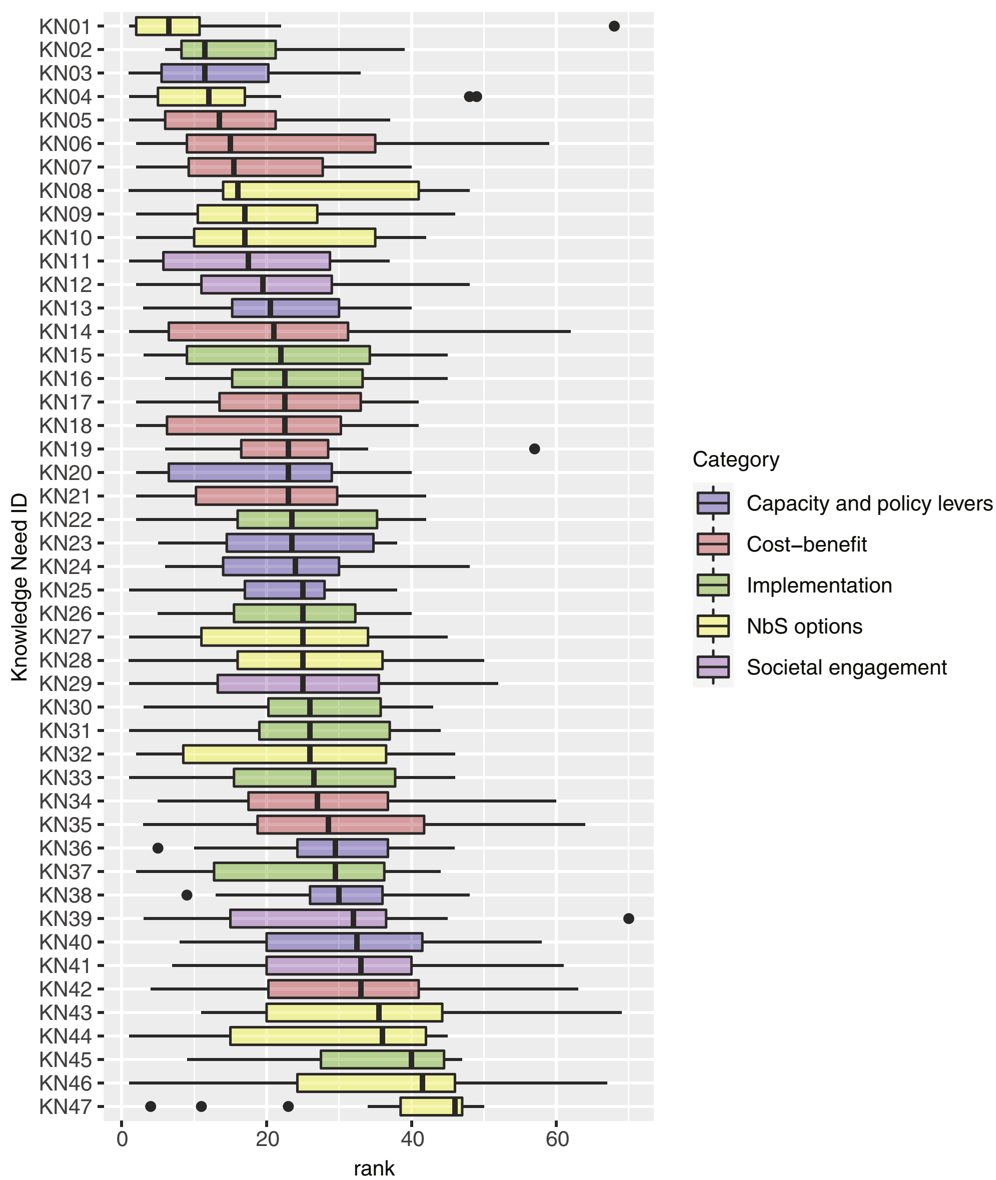

Fig. 2. Box and whisker plots of the rank of each knowledge need (listed in Table 2), indicating median, upper and lower quartiles (n = 18 scorers). Whiskers extend from the hinge to the largest or smallest value at most 1.5x the interquartile range from the hinge. Other points indicate outliers. Knowledge needs with the lowest median rank were considered the most important by the stakeholders.

conservation, demonstrated by KNs such as KN37 and KN33. Five KNs of this type appear in the priority list, although the issue was highlighted by the workshop facilitator (Table 2) as described in the Methods section. Whether these KNs concern responses to a societal challenge depends on whether one considers biodiversity loss a societal challenge to which NbS can be applied. To some of the authors, it feels circular and unhelpful for NbS to include addressing biodiversity loss with actions to enhance biodiversity. NbS may contribute to conservation, but specific interventions considered NbS should address societal challenges at the scale needed (Cohen-Shacham et al., 2019). Otherwise, "NbS" would include any type of conservation; this could be considered a drawback of the IUCN definition, and could be clarified by adding a statement such as "societal challenges not including conservation". Yet there is clearly no consensus on this in our group of stakeholders and work is needed to identify the parameters of frameworks such as the IUCN or Albert et al., 2019 definitions to improve NbS implementation from a practitioner perspective.

KN02, on identifying the most appropriate NbS for the water-scarce Mediterranean environment, would be suited to a knowledge synthesis, and potential primary research. This KN indicated policy and management awareness of the importance of NbS matching the local context, as did the need for incorporating coastal resilience and erosion assessment into policy-making. It is relevant to water management policy goals, such as the EU Water Framework Directive, and River Basin Management Plans. The role of context was also demonstrated by KN09, in line with significant road construction in Malta exacerbating urbanisation pressure, and KN04, identifying ways of modifying buildings for GI. GI featured in 10 of the 47 scored KNs. This is a relatively well-studied area of NbS, due to its perceived potential for improving air quality, biodiversity, health and climate control, and reducing noise and flooding. Our stakeholders mentioned the need for measuring GI's long-term outcomes and cost-benefits, whether it can address air pollution, and the effects of different types on biodiversity. In particular, ways of measuring less tangible effects of GI on health were emphasised. Intense urbanisation in Malta is expected to lead to a significant health burden: Malta has the 9th highest levels of asthma (Eurostat, 2014) and the greatest exposure to pollution in the EU (Eurostat, 2017). It would be informative to design studies in collaboration with national health organisations to assess the epidemiology of pollution-related illness related to green infrastructures provision.KN03, how to increase the adoption and application of NbS in urban plans, appears to be a recognition of implementation challenges rather than a knowledge gap appropriate for research. While few studies explore policy and planning uptake of NbS, the limited integration of ES and related concepts in planning processes has been highlighted in different geographical contexts (Mascarenhas et al., 2015; Scott et al., 2018). Reviews on ecosystem-based adaptation approaches identify four reasons for low policy uptake: (i) uncertainty on local, sustainable finance mechanisms; (ii) a mismatch between longer-term benefits and short-term political cycles; (iii) limited evidence of socioenvironmental effectiveness; and (iv) inflexible governance (Geneletti and Zardo, 2016; Seddon et al., 2016). It is assumed that these reasons also apply to NbS.

One approach to addressing KN03 could involve collating European case studies of appropriate implementation of NbS in policy and planning, to highlight effective finance mechanisms and evidence of benefits. This would involve applying frameworks as in (Albert et al., 2019). It remains challenging to synthesise evidence of related approaches such as ecosystem-based adaptation across research outputs, due to variations in context, study design and outcomes (Naumann et al., 2011). An IUCN report on NbS in Mediterranean cities (IUCN, 2019) identifies their benefits, but also the challenges in integrating NbS into policy, with the concept poorly understood outside the environmental community. The Renature project[1] is developing an NbS compendium across the Mediterranean islands. Such efforts must be accompanied by appraising environmental management in policy and planning, as has been done for various cities (see, e.g. (Hansen et al., 2015; Rall et al., 2015)). It is critical to systematically assess these examples' delivery of solutions and co-benefits. This assessment is a recognised limitation of NbS implementation both in the Mediterranean (IUCN, 2019) and more generally (Hanson et al., 2020), and was a key concern of our stakeholders with a dedicated category of KNs. Five KNs focussed on funding: identifying appropriate sources, increasing NbS priority in resource-poor local government, and understanding cost differences from conventional solutions. Similarly, our stakeholders recognised that appropriate NbS assessment involves measuring socioenvironmental indicators against baselines, preferably in the context of impact assessments, e.g. KN17. Key performance indicators must themselves be determined and evaluated.

Guiding frameworks for implementing NbS into urban plans have been developed (see, e.g. (Raymond et al., 2017)), and the importance of this has been recognised at the policy level (AFD et al., 2019), despite the challenges mentioned. Recent studies of Italian plans found that although such plans seldom explicitly refer to ES (La Rosa, 2019), many have actions that address ES (Cortinovis and Geneletti, 2018); and by extension, NbS. They also have limited analysis of demand or beneficiaries (Cortinovis and Geneletti, 2018). This finding corroborates our stakeholders' priority of KN11: they recognised that NbS benefits may be unevenly distributed, and this must be understood and discussed. While societal engagement was the least common KN category, it included diverse needs and many aspects of international NbS implementation. KN39 indicated recognition that involvement of the public is essential for acceptance of NbS. This suggests the potential for developing local case studies of co-production models and assessing their outcomes.

A larger group of stakeholders would have allowed analysis of the impacts of different types of participant institution on scoring; it is expected that non-governmental organisations would differ from local and national government. A formal stakeholder analysis would ensure systematic and comprehensive inclusion of all relevant stakeholders. We could have benefitted from the perspectives of small-scale farmers, still relatively common in Malta. However, participants were aware of the NbS concept in agriculture, as evidenced by KNs such as KN12 and KN32.

Our approach here was designed to encourage the open submission and discussion of KNs, while limiting group biases, although these cannot be ruled out. Voting in the second round tended to eliminate KNs that were less relevant to NbS or overly specific, e.g. concerning individual sites. Some KNs were well-defined and would be simple to address, such as providing information packages to local government (KN25), maintenance plans for native Mediterranean urban trees (KN22); and a design of a roadside tree pit (KN26). However, addressing even such KNs requires financial and administrative resources. A consensus emerged in the discussion that environmental protection is not a policy priority in the Mediterranean, and this is a major obstacle to implementing NbS. Another outcome was the role of business, suggesting the potential of research partnerships with the private sector to trial NbS addressing commercial needs while limiting environmental impacts.

While there is a swiftly expanding body of literature exploring various aspects of NbS, specific socioenvironmental contexts must be considered in assessing NbS applicability (Cortinovis and Geneletti, 2020). Categorising the KNs according to appropriate next steps revealed that the majority are appropriate for in-depth knowledge synthesis exercises followed by additional primary research if insufficient information already exists. However, evidence synthesis is resource-intensive and not currently prioritised by funding bodies. In contrast, we consider that some KNs can only be addressed through action in relevant policy and business sectors. Suitable routes must be explored, and pilot study approaches appear a promising method of testing different NbS options in the Mediterranean islands. Effective

[1] http://www.renature-project.eu/

interventions can then be deployed at scale, which could also generate green jobs. Appropriate design and monitoring are essential for reliable outcomes (see, e.g. (Christie et al., 2019)). Certain KNs could be addressed in this way, e.g. NbS suitable for phytoremediation of wastewater, or adapted to dry Mediterranean conditions.

As mentioned in the Introduction, islands face unique challenges in implementing sustainable development approaches. Our study revealed that knowledge gaps remain at the policy level, including a lack of indicators, restricted deployment of available information, and limited integration across policy domains. Local-scale data on NbS costs and benefits, and tailored to the Mediterranean context, was another key requirement. Our work highlights the lack of relevant, locally tailored environmental information available at the level of policy and management in small Mediterranean countries. A joint Mediterranean Strategy for NbS has been suggested as a possible approach (AFD et al., 2019). Knowledge synthesis organisations could play a key role in facilitating this in the Mediterranean islands. Further, there is a clear need to establish a science-policy interface dedicated to sharing best practices and collated knowledge on NbS implementation. Regional data cooperation infrastructures across the Mediterranean islands could address this in a resource-efficient way.

CRediT authorship contribution statement

Miriam Grace: Data curation, Formal analysis, Methodology, Project administration, Investigation, Software, Visualization, Writing - original draft, Writing - review & editing. **Mario Balzan:** Conceptualization, Project administration, Funding acquisition, Resources, Writing - review & editing. **Marcus Collier:** Funding acquisition, Writing - review & editing. **Davide Geneletti:** Funding acquisition, Writing - review & editing. **Judita Tomaskinova:** Project administration, Writing - review & editing. **Ruben Abela:** Conceptualization. **Duncan Borg:** Conceptualization. **Giulia Buhagiar:** Conceptualization. **Lorinda Camilleri:** Conceptualization. **Mario Cardona:** Conceptualization. **Nikolas Cassar:** Conceptualization. **Ralph Cassar:** Conceptualization. **Ivana Cattafi:** Conceptualization. **Daniel Cauchi:** Conceptualization, Writing - review & editing. **Claudia Galea:** Conceptualization, Writing - review & editing. **Daniele La Rosa:** Conceptualization, Writing - review & editing. **Eleni Malekkidou:** Conceptualization. **Maria Masini:** Conceptualization. **Paul Portelli:** Conceptualization. **Gloria Pungetti:** Conceptualization. **Matthew Spagnol:** Conceptualization. **Joseph Zahra:** Conceptualization. **Antoine Zammit:** Conceptualization. **Lynn V. Dicks:** Conceptualization, Funding acquisition, Methodology, Investigation, Resources, Supervision, Writing - review & editing.

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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Appendix A

Table A1
List of the number of stakeholders in each type of organisation at each stage of the process of obtaining priority knowledge needs, from initial invitation to scoring knowledge needs in the workshop.

Organisation	Invited to participate	Agreed to participate	Submitted knowledge needs	Voted on knowledge needs	Scored knowledge needs
Business (aquaculture, agriculture, electronics, pharmaceuticals)	10	5	2	2	2
NGO	7	1	1	1	1
National government	17	7	2	2	4
Local government	5	3	1	1	2
National Park/Protected Area	2	0	0	0	0
Research	5	4	2	2	3
Foundation	1	0	0	0	0
Government-associated agency/authority/entity	6	11	4	4	5
Association or cooperative (agriculture, fishing)	2	0	1	1	1
Public equivalent body	1	1	1	1	1

Table A2
Complete list of submitted stakeholder knowledge needs (SNXX) and corresponding finalized knowledge needs (KNXX), with original phrasing, number of votes received, and modifications such as merging, wording during workshop discussion by consensus (*), or after the scoring process for brevity (†). Colours indicate the category assigned to each submitted need and match those in Fig. 2.

Submitted Need ID	Knowledge Need ID	Category	Knowledge Need	Votes	Scored	Modifications
SN01	KN24	Capacity and policy levers	Availability of solutions in the local market (what knowledge is available to ensure the correct installation of NbSs)	4	Yes	N/A
SN02	KN23	Capacity and policy levers	Is there any funding available to organisations to implement any nature-based solutions?	4	Yes	N/A
SN03	KN03	Capacity and policy levers	Inclusion/integration of NbS in urban policies and planning normatives: · How do I include NbS in	3	Yes	*How to increase the adoption and actual use of NbS in urban plans?

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Table A2 (*continued*)

Submitted Need ID	Knowledge Need ID	Category	Knowledge Need	Votes	Scored	Modifications
			urban plans? · How to increase the adoption and actual use of NbS in urban plans? · Which existing policies or norms can be reformed to increase/ ensure the use of NbS in planning? At which scale?			
SN04	KN40	Capacity and policy levers	Establishing and communicating vulnerability metrics for coastal landscapes in order to develop resilience with the affected community is the most challenging in my opinion.	2	Yes	N/A
SN05	KN38	Capacity and policy levers	How important is the flexibility of a NbS to fit different ecological and climatic conditions, as well as planning and governance mechanisms?	2	Yes	*How important is the versatility of a NbS to fit different ecological and climatic conditions, as well as planning and governance mechanisms?
SN06	KN20	Capacity and policy levers	How to include NbS into local policies in small municipalities with less resources?	2	Yes	N/A
SN07	KN25	Capacity and policy levers	Information pack for Local Councils and for companies who compete for tenders and standard tender templates for upkeep and maintenance of public areas/gardens/streets.	2	Yes	N/A
SN08	KN36	Capacity and policy levers	Our Ministry is also responsible for coastal resilience and the mitigation of coastal erosion apart from storm water management. The problem of flooding is well documented. The problem of coastal resilience and coastal erosion seems to have been omitted though some mentioned ecosystem-based management approaches mitigate coastal erosion. There are myriad of non-structural (policy, flood warning, flood proofing by relocation, etc.) and structural (barriers, etc.) approaches.	2	Yes	*The need to include coastal resilience and erosion in policies
SN09	KN13	Capacity and policy levers	Why are health impact assessments not compulsory for any large scale project in an urban setting?	2	Yes	*Why are health and social impact assessments not compulsory for any large scale project in an urban setting?
SN10	N/A	Capacity and policy levers	Are there any local opportunities derived from the TEN-G initiative as proposed by the EU?	0	No	N/A
SN11	N/A	Capacity and policy levers	Is it possible to use NbS as a tool related to the Carbon emissions trading?	0	No	N/A
SN12	N/A	Capacity and policy levers	What local or EC regulations exist for permits re. constructed effluent treatment wetlands? What about if any are constructed adjacent to heritage buildings?	0	No	N/A
SN13	N/A	Capacity and policy levers	Who can implement a NbS – do you need a degree or title (biology, architect etc.) or is it concept to apply by anyone?	0	No	N/A
SN14	KN06	Cost-benefit	How much is the difference in cost between NbS and conventional solution?	5 (11)	Yes	SN16 and SN21 merged into this.
SN15	KN05	Cost-benefit	The evidence for NbS to improve health is incontrovertible, lacking only the political will to implement these solutions. Most actions that can be taken to improve human health lie outside of the health sector, so the challenge lies in convincing other sectors (e.g. transport, energy, urban planning, tourism) to think about the impact of projects/actions on human health. Taking the example of the need for more green urban spaces where people can be physically active, some aspects of the knowledge gap that I believe prevents their creation are: The lack of cost-benefit analysis of their creation (i.e. in monetary terms, what are the long term benefits to human health vs the 'opportunity cost' of not building on that land, given the situation of property speculation that Malta finds itself in?)	5	Yes	
SN16	N/A	Cost-benefit	Evidence (or confidence) on cost-benefits and economic convenience/sustainability to more traditional solutions/approaches: · how much do NbS cost? · Who's going to pay for them? · Is their maintenance more expensive than traditional solutions?	4	No. Merged into SN14 with SN21.	N/A
SN17	N/A	Cost-benefit	How to measure and put an economic value to the positive impact on environment from NbS?	4	No. SN25 scored instead.	N/A
SN18	KN19	Cost-benefit	What are the costs of maintenance for green infrastructure spaces in the long term?	4	Yes	N/A
SN19	KN21	Cost-benefit	Can a NbS address more than one different type of urban challenges in a city? How to measure the positive impact on these different dimensions?	3	Yes	N/A

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Table A2 (*continued*)

Submitted Need ID	Knowledge Need ID	Category	Knowledge Need	Votes	Scored	Modifications
SN20	KN07	Cost-benefit	How can the tangible and intangible benefits to human health arising from green open spaces be measured?	3	Yes	N/A
SN21	N/A	Cost-benefit	cost evaluation of NbS interventions (what is the added cost of application of NbS as opposed to mainstream solutions)	2	Merged into SN14 with SN16.	N/A
SN22	KN17	Cost-benefit	How can we ensure the effectiveness of the chosen Performance Indicators (social, economic and environmental outcomes) and set baselines?	2	Yes	N/A
SN23	KN34	Cost-benefit	How can you ensure the scalability of the outcomes of an NbS?	2	Yes	N/A
SN24	KN18	Cost-benefit	Does green infrastructure mitigate air pollution?	1	Yes	N/A
SN25	KN14	Cost-benefit	Economic benefits generated by NbS (key aspects in a CBA assessment to determine the feasibility of such projects)	1	Yes	N/A
SN26	KN35	Cost-benefit	What are the most disservices, disadvantages and limitations associated to NbS?	1	Yes	*What are the disservices, disadvantages and limitations of NbS?
SN27	KN42	Cost-benefit	What are the trade-offs of leaving green open spaces to support biodiversity, as opposed to managed parks or urban green areas?	1	Yes	N/A
SN28	KN37	Implementation	How can invasive alien species be controlled or eliminated?	2	Yes	*How can invasive alien species of flora and fauna be controlled or eliminated?
SN29	KN30	Implementation	How can rain water running through Wied Dalam be utilised to create new habitats for aquatic species of fauna and flora?	2	Yes	How can rain water running through valleys be utilised to rehabilitate aquatic species of fauna and flora?
SN30	KN16	Implementation	Which NbS make most efficient use of land when land is scarce?	2	Yes	*Which NbS make the most efficient use of land, when land is scarce?
SN31	KN33	Implementation	How can protected areas be managed to safeguard natural heritage and increase its flora and fauna?	1	Yes	*How can protected areas be managed to safeguard natural heritage and increase their fauna and flora?
SN32	N/A	Implementation	How can the valley habitat of Wied Dalam be restored?	1	No. Merged into SN29.	N/A
SN33	KN02	Implementation	How can NbS be adapted to dry Mediterranean conditions to minimise irrigation needs?	1	Yes	*Which NbS are adapted to dry Mediterranean conditions to minimise irrigation needs?
SN34	KN22	Implementation	Maintenance plans for native Mediterranean urban trees and gardens - proper pruning, watering etc.	1	Yes	N/A
SN35	KN31	Implementation	What crops or plants might be suitable for phytoremediation of waste water effluent including salt water?	1	Yes	*What crops or plants might be suitable for phytoremediation of wastewater including saltwater?
SN36	KN15	Implementation	Which native plants are suitable for urban gardens or road sides, and where can people buy them? (commercial garden centres do not usually provide Malta-grown species)	1	Yes	*Which native plants are suitable for urban gardens and roadsides, and where can people buy them?
SN37	N/A	Implementation	What estuarine vegetation communities might be suitable for phytoremediation of saltwater effluent from a marine research centre?	0	No	No
SN38	N/A	Implementation	Which trees are suitable for urban streets?	0	No. Merged with SN36	N/A
SN39	KN26	Implementation	A design of a tree pit for roadsides, including specifications for paving, lining of pit etc.	0	Yes	N/A
SN40	N/A	Implementation	Leaching of contaminants from NbS (use of fertilizers and/or pesticides in NbS can lead to the leaching of these contaminants)	0	No	N/A
SN41	N/A	Implementation	Organic waste treatment on site: The organic waste collection recently applied to homes, is not valid for companies. We would like to study the feasibility to have composters on site or look forward other solutions. Have example can help to study the project applicability in our premises.	0	No	N/A
SN42	KN45	Implementation	People appreciate ’colour’ in urban gardens and streets - which plants, trees and bushes can be used to add ’colour’ to urban streetscapes and public areas?	0	Yes	N/A
SN43	KN44	NbS options	How can ecosystem services support urban areas?	3	Yes	N/A
SN44	KN01	NbS options	Need for a more precise definition: what exactly are NbS and what are they expected to do in my city?	3	Yes	*Need for a more precise definition: what exactly are NbS?
SN45	KN28	NbS options	What technologies and methods are suitable for the local context, especially in terms of sustainable urban drainage systems?	3	Yes	*What technologies and methods are suitable for sustainable urban drainage systems?
SN46	KN04	NbS options	How can new and existing buildings be modified to accommodate green infrastructure?	2	Yes	*How can new or existing buildings and built-up areas be modified to accommodate green infrastructure?
SN47	KN08	NbS options		2	Yes	N/A

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Table A2 (*continued*)

Submitted Need ID	Knowledge Need ID	Category	Knowledge Need	Votes	Scored	Modifications
			What solutions can be implemented for dense urban areas having a high incidence of the built environment with cultural heritage value?			
SN48	KN27	NbS options	Plastic recycling: The plastic recycling is a challenge because when its send to recycling, needs to be separated per type. Locally are not available recycling plant, and this force to look foreign companies for their treatment. In addition, for some kind of plastic (like PS) it`s hard to find companies able to perform their treatment.	1	Yes	*Are there NbS that can help with management of plastic waste?
SN49	KN43	NbS options	Do any commercial nature-based live feed algal cultures exist? (Cultures fertilised through phytoremediation)	1	Yes	*Do any commercial nature-based algal cultures exist for waste water management?
SN50	KN46	NbS options	How can we replace the present anthropocentric management system into an ecocentric system?	1	Yes	N/A
SN51	KN09	NbS options	How do we integrate NbS with current road infrastructure?	1	Yes	N/A
SN52	KN47	NbS options	May a system be developed to alert personnel when something hazardous has been discarded in our water system?	1	Yes	N/A
SN53	N/A	NbS options	What are the opportunities and issues of retro-fitting of buildings and dense built-up areas for GI? Do examples from similar locations elsewhere exist?	1	Not scored. Merged with SN46.	N/A
SN54	KN10	NbS options	What kind of smaller changes can be done in larger companies to make a difference with regards to climate change?	1	Yes	*What NbS can companies implement to mitigate climate change?
SN55	N/A	NbS options	Reuse activity: Most part of our waste can be easily reuse instead to send it for recycling/ landfill	0	No	N/A
SN56	N/A	NbS options	Are there any sustainable vegetable-based NbS fish feeds available or is there any research on this issue?	0	No	N/A
SN57	N/A	NbS options	Do any nature-based dietary enhancements for fish husbandry exist?	0	No	N/A
SN58	N/A	NbS options	Do any nature-based solutions or related studies exist to control and/or treat fish pathogens?	0	No	N/A
SN59	N/A	NbS options	How can aerial pollution from the surrounding industrial activities and vehicular traffic be eliminated?	0	No	N/A
SN60	N/A	NbS options	How can the accessibility of Għar Dalam site and surroundings be improved with minimal impact on the natural environment?	0	No	N/A
SN61	N/A	NbS options	How can the biodiversity of the site and its surroundings be increased?	0	No	N/A
SN62	KN32	NbS options	How can we best harmonise environmental protection with a sustainable agriculture?	0	Yes	*What NbS are available for use in agriculture and pastoralism?
SN63	N/A	NbS options	Targeting NbS to specific urban problems: · which NbS is more likely to solve my problem?	0	No	N/A
SN64	N/A	NbS options	What are the best management practices that will contribute to an increased level of social, economic and environmental development at Għar Dalam?	0	No	N/A
SN65	KN41	Societal engagement	As part of an organisation's CSR, how can companies influence people to be more aware of the current issues revolving [around] nature-based solutions?	2	Yes	*How can companies influence people to be more aware of nature-based solutions?
SN66	KN11	Societal engagement	Social acceptance and clear definition of beneficiaries: · who's going to benefit from NbS? · are people ok with this?	2	Yes	N/A
SN67	KN29	Societal engagement	What can a highly regulated industry such as the pharmaceutical industry do to contribute to nature-based solutions?	1	Yes	*What can industry do to contribute to nature-based solutions?
SN68	KN12	Societal engagement	How can we re-evaluate the role of farmers as guardians of our open spaces and of our rural areas?	1	Yes	*How can we re-evaluate the role of farmers and shepherds as guardians of rural areas?
SN69	KN39	Societal engagement	How effective will be the development and implementation of NbS through co-production processes? If yes, how can we ensure the choice of the best possible combination of stakeholders in order to achieve the knowledge based outputs that will target the specific urban challenges we aim to deal? Importance of clear roles between the stakeholders.	1	Yes	*How effective is development and implementation of NbS through co-production?
SN70	N/A	Societal engagement	How can a city interact or collaborate with citizen-led or citizen initiated NbS such as urban	0	No	N/A

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Table A2 (*continued*)

Submitted Need ID	Knowledge Need ID	Category	Knowledge Need	Votes	Scored	Modifications
			agriculture? How a city can interact effectively with citizens for any urban infrastructure project? Is there a standard planning process that needs to be followed? (consultation, participatory workshops, hearings etc)			
SN71	N/A	Societal engagement	What would the general public think of government appropriation of private land in order to create such spaces if need be?	0	No	N/A

Appendix B. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.envsci.2020.10.003.

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