ADAPTA BLUES

"Adaptation to climate change through management and restoration of European estuarine ecosystems".

E.2: Review of European Case Studies for Coastal Nature-based Solutions for Climate Adaptation

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Prepared by	Reviewed by	Approved by
Roberta P. L. de Moraes, Max Ricker, Inés E. Mazarrasa, Borja G. Reguero	José A. Juanes	

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1 INTRODUCTION

Climate change and poor management of natural resources are compounding and increasingly impacting societies around the world. Coastal populations are particularly at risk of climate impacts and urgently need improved adaptation approaches to meet such challenges (Wong et al. 2014). Coastal areas face increasing flood risks resulting from climate change impacts such as Sea Level Rise (SLR) and increasing frequency and severity of extreme weather (Morim et al. 2019; Li et al., n.d.; Reguero, Losada, and Méndez 2019). These areas tend to be particularly exposed and vulnerable to flood risks as they often have high population density and high concentration of economic activities situated in low-lying zones with large exposure to the impacts of waves, extreme sea levels, runoff, subsidence and other hazards (Lee, Choi, and Woo 2021; Creel 2003). It has been estimated that 41% of the global population live on the coast and more than 60% of the world's megacities are located in the coastal zone(Martínez et al. 2007). The proportion of coastal inhabitants is estimated to grow, with approximately 355 million more people expected to inhabit coastal areas by 2035 (Maul and Duedall 2019). This problem is acutely present in Europe, where nearly half of the population lives less than 50 km from the sea (Eurostat 2011). Estimates show that coastal flooding will increase in most European countries and that damages in Europe alone could reach nearly €1 trillion per year by 2100 if no action is taken to adapt to climate change (European Environment Agency 2019; Vousdoukas et al. 2018).

The projected climate change and coastal urbanization scenarios call for urgent solutions for coastal communities to adapt and manage these risks in a sustainable way (Hinkel et al. 2014; Reguero et al. 2015). The current conventional risk management approach of 'grey' coastal engineering is unlikely to keep pace with the dynamic hydrometeorological conditions and withstand the increasingly severe storms predicted under climate change (Kumar et al. 2020; Esteves 2014). Moreover, the maintenance costs of such structures are becoming impracticable (Morris et al. 2018). In this context, Nature Based Solutions (NbS) emerge as a framework of strategies to sustainably address risks while also enhancing biodiversity outcomes (EC 2021). NbS include actions to protect, sustainably manage and restore natural or modified ecosystems that provide critical ecosystem services for human well-being and biodiversity (Cohen-Shacham et al. 2016).

Coastal and estuarine ecosystems such as dunes, seagrass meadows, saltmarshes and biogenic reefs (e.g. oyster and coral reefs) are able to protect coastal areas from erosion and flooding by dampening wave energy and providing natural elevated barriers to flood waters (Gedan et al. 2011; Hanley et al. 2014; Ondiviela et al. 2014; Kobayashi, Raichle, and Asano 1993; Narayan et al. 2016; Lo et al. 2017). Unlike 'grey' engineering in which structures are designed to withstand a certain water level, NbS are long-term alternatives to varying conditions as they are able to respond to climate stressors and adapt to external factors. Vegetated ecosystems, for example, are able to maintain pace with SLR through soil vertical accretion or through migration inland, if no artificial barriers are in place (Duarte et al. 2013; Kirwan and Megonigal 2013; Potouroglou et al. 2017). The adaptability of ecosystems to changing conditions (up to a certain point) enhances the long-term sustainability of nature-based coastal protection and can reduce the long-term maintenance costs (Temmerman et al. 2013; Kirwan and Megonigal 2013; Duarte et al. 2013). These ecosystems furthermore offer an additional wealth of co-benefits, including carbon capture, improved well-being in urban areas, enhancement of biodiversity, fisheries support, water quality improvement and recreational and tourism benefits (Somarakis, Stagakis, and Chrysoulakis 2019; Barbier et al. 2011; Serrano et al. 2019; Nellemann et al. 2009).

In Europe, there is a heightened need for investment in NbS given historic environmental degradation and a growing risk to climate hazards. European coastal ecosystems have been historically threatened and/or modified by human activities, such as land reclamation and dredging (Airoldi and Beck 2007). It is estimated that two-thirds of European coastal wetlands that existed at the beginning of the 20th century have been lost (Airoldi and Beck 2007). The destruction of these coastal ecosystems leads to the loss of ecosystem services, including the defensive services against coastal hazards (Vo et al. 2012). The conservation or restoration of ecosystems as a NbS approach in coastal areas provides an opportunity to restore and maintain biodiversity and all other critical coastal ecosystem services these provide to society (Faivre et al. 2017).

The European Commission (EC) is investing in expanding the implementation of NbS to address these challenges in Europe (EC 2015). For example, the Green Infrastructure Strategy, incorporated in the EU Biodiversity Strategy for 2030, aims to enhance the integration of nature and natural processes into spatial planning and territorial development (EC 2020). The EU Strategy on Adaptation to Climate Change also encourages the application of blue-green infrastructure and ecosystem-based approaches (EC 2013). The Floods Directive (2007/60/EC) aims to restore or establish habitats, including wetlands, which can support water quality improvement and reduce flooding risk and damage (European Environment Agency 2007, 20). NbS are also aligned and can contribute to the goals of other European directives that specifically address the conservation of natural ecosystems and species such as the implementation of the EU Habitats Directive (92/43/EEC) and EU Birds Directive (2009/147/EC), particularly by enhancing the restoration and conservation of estuarine habitats (Esteves 2014).

Despite extensive research about the potential of NbS for coastal adaptation and supportive policy frameworks in place in Europe, its application is still scarce. Traditional engineered 'grey' structures are still the primary design for coastal defences (Morris et al. 2018). A major barrier for the wider implementation of NbS is the difficulty to predict its long-term effectiveness. There is a lack of standardized methods to assess efficacy of NbS, especially when compared to traditional engineering approaches (Temmerman et al. 2013; Narayan et al. 2016; Morris et al. 2018). This is partially because the effectiveness of NbS is highly context-specific to local site conditions, which can make it difficult to generalize effectiveness and to replicate NbS pilots in other locations (Arkema et al. 2017).

The EU LIFE Adapta Blues project seeks to further mainstream the implementation of NbS in Europe, particularly in coastal and estuarine zones. As part of this project, this study aims to address some of the barriers to the upscaling of coastal NbS in order to support the replication and improvement of future nature-based projects in coastal and estuarine areas. For this purpose, we reviewed 59 case studies extracted from NbS platforms, including projects created in previous EU-funded projects, in order to capitalize previous efforts. We catalogue and assess the status of coastal NbS in Europe and the patterns of implementation to identify the prevailing characteristics amongst the projects, including financing, associated co-benefits and monitoring aspects. We also performed a qualitative analysis to understand the main motivation that drive investments in and implementation of NbS in Europe over traditional coastal protection measures. These results and key findings are presented in this white paper in order to reach a wide audience of practitioners operating in the coastal adaptation space. The key findings presented here and in a peer-reviewed sister publication to this White Paper can be used to support the EU LIFE program’s strategic planning for mainstreaming coastal NbS through future projects as it gains a better understanding of the status of coastal NbS in Europe and how to better select and plan NbS interventions for specific contexts.

2 REVIEW OF CASE STUDIES

In total, 59 case studies of NbS addressing climate change hazards in coastal and estuarine areas in Europe were selected between July and November 2020. The work was carried out by searching in seven NbS platforms (section 2.1.1 to 2.1.6): EcoShape, OPPLA, OURCOAST, The River Restoration Centre (the RRC), RESTORE (RiverWiki), NATURVATION and Climate-ADAPT. Complementarily, Google Scholar was employed to gather more detailed information about the case studies listed in the NbS databases. The number of case studies selected was limited by information availability.

All the case studies included in this analysis addressed coastal adaptation to hydrometeorological hazards, either directly or indirectly. Each identified project meets at least one of the four criteria, as follows:

1. Ecosystem was used as an integral part of the design rationale.
2. Ecosystem restoration activities were included in the project, such as the removal of engineered solutions or the combination of traditional engineering with the use of ecosystems (defined here as a hybrid solution).
3. The project resulted in the creation of new habitats that could provide flood or erosion benefits as well as other ecosystem services.

2.1 Data sources

2.1.1 OPPLA

The OPPLA platform has more than 60 contributors and it is a joint output of the OPERAs and OpenNESS projects (OPPLA 2021a). It contains an assortment of NbS case studies from all over the world, although around 80% of its case studies are located in Europe (OPPLA 2021b). The platform adopts a clear approach to knowledge sharing to a wide audience, including a user-friendly interactive map, an enquiry service and a standardized structure for each case study to facilitate comprehension. It also includes keywords that facilitate the search for similar case studies within the platform. Yet, the search filters are limited to scale and type of case study, which might prevent the user from finding a case study of interest. It is essential to simplify the search mechanism in order to encourage the use of the platform.

2.1.2 OURCOAST – ICZM in Europe

Dedicated to the dissemination of sustainable practices, the OURCOAST was a three-year programme centred on Integrated Coastal Zone Management (ICZM) in Europe (EC 2012). Focus was given to the necessity of adaptation to climate change by highlighting implemented communication systems and effective planning instruments. Most of the case studies presented in this platform contained lessons learned and costs associated to each project (e.g., EU OURCOAST-Project 2015). OURCOAST encompasses a diversity of policy-making initiatives from a number of European countries; however, the interactive database was terminated, and the remaining content is not readily accessible.

2.1.3 NATURVATION

Focused on building expertise around NbS in urban areas, the NATURVATION platform was developed by 14 different institution in Europe during four years (NATURVATION 2017a). It contains a resourceful interactive map with practical search filters such as key challenges, project coast and urban setting (NATURVATION 2017b). However, the platform is restricted in number of fields and sections, resulting in limited information about its case studies. Additionally, by the time of our search, there had been no further update in the platform since their data collection, which took place between June and August 2017. The case studies in NATURVATION have recently been moved to the Urban Nature Atlas platform (NATURVATION 2021), which was not assed in this study.

2.1.4 Climate ADAPT

The Climate ADAPT database arose from a cooperation between the European Commission (EC) and the European Environment Agency (EEA) (Climate-ADAPT 2020). The project was focused on sharing expertise related to adaptation policies aiming to tackle the adverse effects of climate change (European Environment Agency 2018). The resulting platform is complete and robust, comprising of standardized case studies descriptions with a variety of filtering options such as type of climate impact and funding. It is up to date and indicates the point of contact for each project; yet, it lacks on quantitative data reporting the effectiveness of solutions.

2.1.5 EcoShape – Building with Nature

The EcoShape consortium is formed by 15 parties engaged in promoting Building with Nature (EcoShape 2020). It aims to provide guidelines for the reproduction of NbS principles through the implementation of pilot projects along with the results of monitoring campaigns of such projects. The EcoShape platforms contains holistic information about each project covering each project phase: initiation, planning and design, construction, operation and maintenance and lessons learned (e.g., EcoShape 2016).

Despite its content richness, the EcoShape platform is more tailored to skilled practitioners. The filters available in the database search are limited to landscape type and technology readiness levels, which may prevent an unexperienced user from accessing a project of interest. Similarly, the categories of lessons learned are not standardized amongst the case studies and tend to be very site specific and little is known about generic lessons learned that could be applicable to other areas.

2.1.6 The River Restoration Centre (the RRC) and RESTORE

The River Restoration Centre (the RRC) is the UK's expert centre in river restoration, habitat improvement and catchment management (the RRC 2014a). The historic data available at the RRC's website (i.e., the interactive map) is part of the National River Restoration Inventory (NRRI) and its main objective is to disseminate expertise around river restoration and to provide site-specific technical advice (the RRC 2018). Although the platform is no longer up to date, it contains a number of useful filters and comprehensive data in PDF format about each case study, including a dedicated section to effectiveness and project's costs.

In the addition to the historic data, the EU LIFE+ RESTORE project has delivered the RiverWiki platform (the RRC 2014b), which is also part of the NRRI (the RRC 2018). The interface of this platform is user-friendly, and it still receives submissions of projects, which are published after the RRC's review. The RiverWiki is a global database that also contains the historic projects from the RRC. Although the search filters are broad, it can also be complex for unexperienced users with little technical knowledge to find projects of interest.

2.2 Database structure

A database containing 31 fields was proposed to gather relevant information about NbS case studies in Europe. Each field presented in **Figure 2-1** was selected with the aim to identify implementation patterns that could support replication of the selected case studies. The full database including all case studies presented in this report are available in **Annex 1 – Database.**

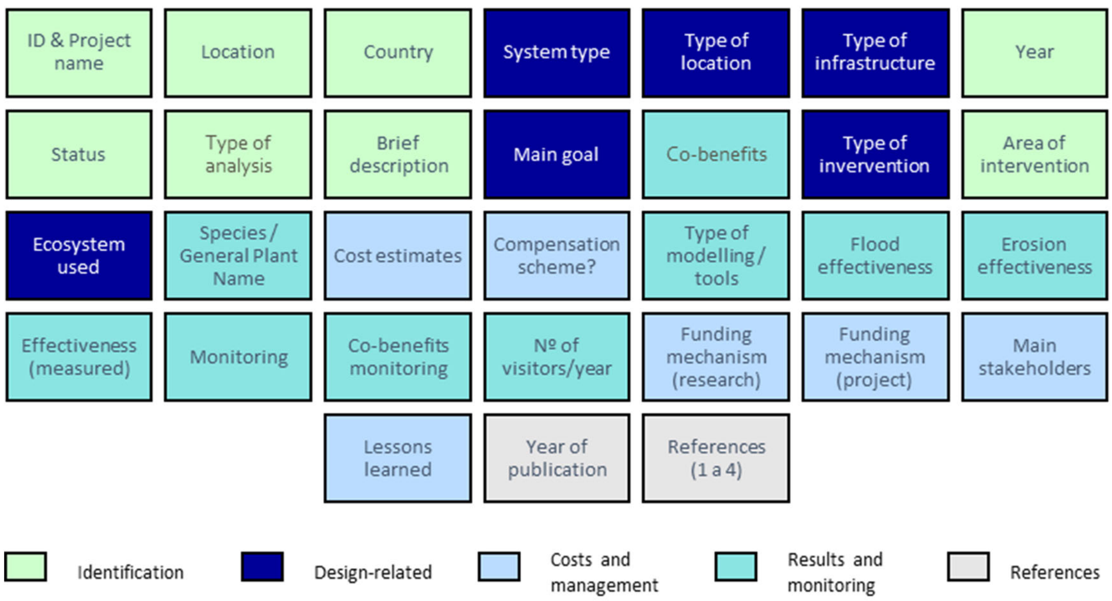

Figure 2-1. Variables assembled for the assessment of possible implementation patterns in NbS case studies

The variables of interest were categorized into five different groups, as presented in **Figure 2-1**. The first group ('Identification') includes descriptive fields gathered to differentiate and specify each case study, including location, which is relevant to determine spatial disparities. 'Design-related' variables were employed to assess possible implementation patterns associated with the focus of the case studies (e.g., type of infrastructure and coastal challenge addressed), and the options available within each category are listed in **Table 2-1.** 'Costs and management' parameters summarize relevant administrative features such as source of funding and cost estimates, while the 'Results and monitoring' category was assembled to guide the evaluation of the NbS' implementation status. Data on project's costs can be helpful to other practitioners to estimate their own budgets and sharing knowledge on NbS outcomes may support replication in similar sites. Details about sources and references were also kept in a different category for organization purposes ('References').

Table 2-1. *Options available within each design-related category (see Figure 2.1)*

Design-related variables	Options
System type	Estuarine; Coastal; River basin
Type of location	Urban; Rural / suburban
Type of infrastructure	Green; Hybrid
Coastal challenge addressed	Reduce flooding; Reduce erosion; Biodiversity restoration / conservation; Reduce flooding and erosion
Type of intervention	Ecosystem creation; Ecosystem restoration; Managed realignment
Ecosystem used	Natural embankments; Wetlands; Salt marshes; Oyster reefs; Beach and dune systems

In order to be included in the database, the case study description must provide information about all the design-related variables as they depict the focus of the case study. Each design-related variable contained at least two classes, as presented in **Table 2-1**. Estuarine, coastal and river basin were the type of locations considered in this study**.** The latest was incorporated to specify case studies that encompassed a larger area than the estuarine zone, while some others would cover only the coastal zone (e.g., beaches and sand dunes systems). The type of location is described as urban, and rural / suburban, which refers to low-density or uninhabited areas identified through satellite imagery. The type of infrastructure was categorized as green, when no construction or realignment of engineered coastal defences was implemented; or hybrid, when ecosystem services were combined with 'hard' engineered structures.

Funding was classified in public, private, Private-Public Partnership (PPP) or other types of funding. The latter class includes trust funds of distinct structures (i.e., public, private, mixed funds), charity, and taxation schemes. A number of different funding sources to NbS was identified, and each source contributed to one or more projects. In other words, a single sponsor might have contributed to various projects. In this manner, the number of contributions exceeds the amount of funding sources.

NbS have the potential to yield a number of co-benefits besides the coastal protection features they may provide. The term co-benefits is often used to refer to social, environmental and economic benefits derived from NbS implementation (Raymond et al. 2017). Aiming to understand the wider benefits associated with our case study selection, the co-benefits were registered whenever reported. They were divided into 13 categories in total, which were grouped into four main classes – environmental, social, economic, and coastal protection (**Figure 2-2**). Sustainability was considered an intrinsic value to NbS; thus, it was not listed as a co-benefit. The cost reduction category relates to the actual savings in initial investments and maintenance costs when compared to traditional solutions. In a few cases, the improvement of navigation and the creation of areas for residential developments were mentioned as a co-benefit. Regarding our case study selection, coastal protection may also have been considered as co-benefit when the challenge addressed was: 1) biodiversity restoration / conservation; 2) only reduce flooding, thus reduce erosion was deemed as a co-benefit; and 3) only reduce erosion and reduce flooding was listed as a co-benefit.

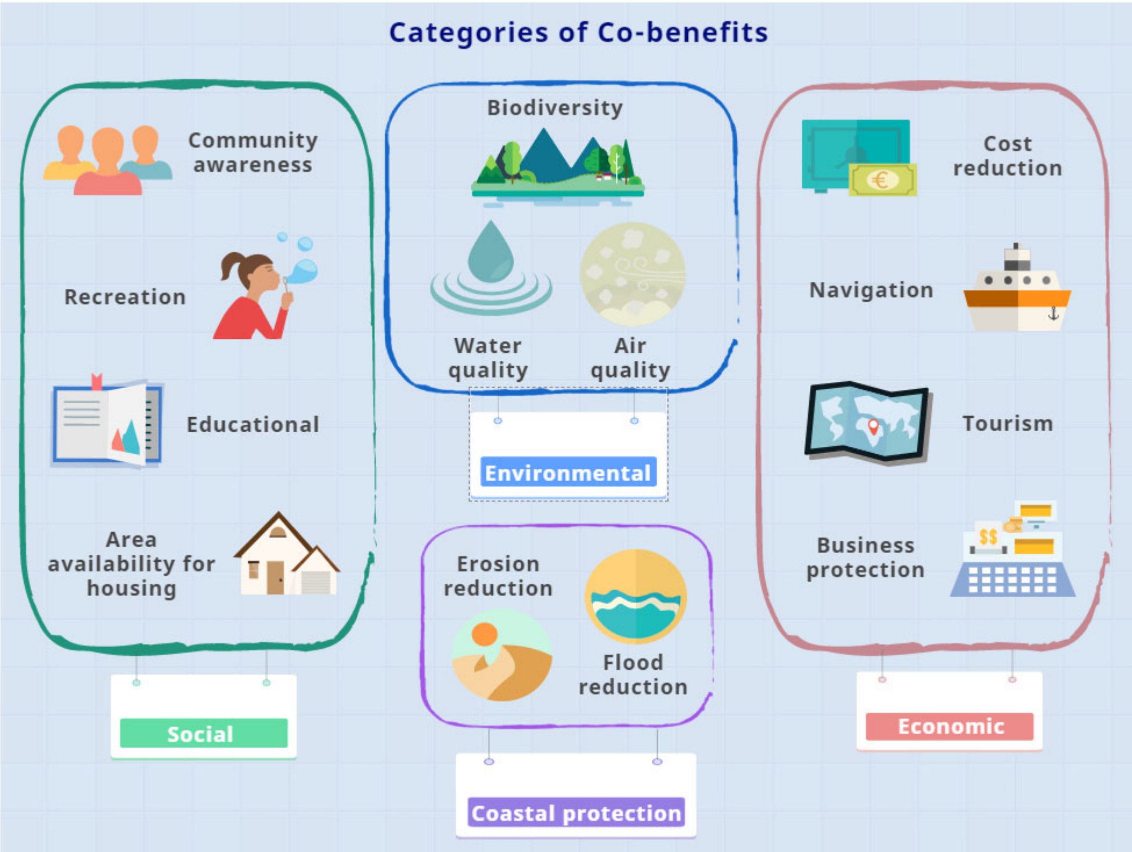

Figure 2-2. *Categories of co-benefits identified amongst 59 NbS project in Europe.*

Another relevant information assessed was the case study motivation, i.e., the reason why NbS was preferred over a traditional approach. At least one motivation was identified per case study and it was established as the goal that would have not been achieved without the NbS component when comparing to a traditional approach. For example, if the case study goals were environmental compensation and flood protection, the main motivation is registered as environmental compensation because this would not have been achieved by implementing a traditional coastal protection scheme. Whenever other reasons for choosing a NbS were mentioned, they were classified as additional reasons following the same categories as the main motivation. **Table 2-2** presents the seven categories of motivations employed in this study.

Table 2-2. *Description of motivation categories.*

Nº	Motivation category	Description
1	Sustainability and coastal resilience	Aims at restoration of lost habitats and prevention against future losses by adopting a sustainable solution that may include community involvement.
2	Policy-making context	Includes national, regional and/or local policies promoting restoration projects employing NbS principles. Additionally, projects may have been triggered due to its location in conservation units.
3	Recreation and tourism	Restoration or creation of natural areas for tourism and/or recreational purposes.
4	Cost-benefit relationship	Cost-benefit analysis were performed and concluded that the traditional coastal defence was no longer economically viable.
5	Environmental compensation	Legally required environmental compensation for habitat losses
6	Coastal defence improvement	Improvements were required for safety reasons including a high probability of damage to existing assets (e.g., business, houses) and possible failure of existing coastal defences. This category also includes preserving/providing economic growth opportunities.
7	Development of expertise and knowledge sharing	Encompasses pilot projects as well as larger implementations aiming to create a better understanding of NbS and to share the acquired knowledge.

Lessons learned were listed when reported and classified into 10 categories which were created aiming to group the experiences resulting from the implementation of each case study. The categories include (1) communication, (2) cost-benefit analysis, (3) funding and costs, (4) planning, design & construction, (5) permitting and legal requirements, (6) biological and ecological, (7) physical, (8) monitoring and maintenance, (9) management, and (10) stakeholder engagement (**Table 2-3**).

***Table 2-3.** Description of each lesson learned category.*

Nº	Lesson learned category	Description
1	Stakeholder engagement	Includes consequences of stakeholder disengagement such as resistance to project and adverse human impacts (e.g., vandalism and unwanted visitors). It also contains lessons learned on management of expectations and participative planning.
2	Communication	Information availability, level of awareness, and well-defined communication plan.
3	Cost-benefit analysis	Cost comparison with traditional solutions or with no intervention. It also includes valuation of co-benefits.
4	Funding and costs	Cost management and cost estimates strategies to guarantee funding throughout the project.
5	Planning, design & construction	Conclusions about preliminary and predictive assessments, benchmarking, modelling, and incorporation of maintenance costs and program.
6	Permitting and legal requirements	Considers legal aspects during the planning phase to avoid underestimation of the necessary time to receive permits.
7	Biological and ecological	Knowledge gained about ecosystem behaviour, evolution, and ecological feedback after implementation.
8	Physical	Experiences on sedimentation, erosion and accretion rates, and impacts of waves and tides after implementation.
9	Monitoring and maintenance	Associated with resources for monitoring and maintenance, and adequate planning to implement it after the project is concluded.
10	Management	Comprises experiences of risk and project management, and composition of project team.

2.3 Structure of expert interviews

In order to best capture the full range of existing coastal NbS work in Europe, we have interviewed five experts in the field to further discuss some questions that should lay out important context about the potential for NbS in coastal and estuarine areas. A short biography of each expert who donated their time to contribute to the EU LIFE Adapta Blues project is presented in **Table 2-4.**

***Table 2-4**. Participants of expert interviews.*

Interviewees	Institution	Short bio
Fabrice Renaud	University of Glasgow	Fabrice Renaud is a Professor of Environmental Risk and Community Resilience at the University of Glasgow's School of Interdisciplinary Studies. He is also the Research Director for the National Centre for Resilience in Scotland. Prior to joining the University of Glasgow, he was the head of the Environmental Vulnerability and Ecosystem Services

Interviewees	Institution	Short bio
		section of the United Nations University Institute for Environment and Human Security (UNU-EHS) where he worked for 13 years.
Nico Stelljes	Ecologic Institute	Dr. Stelljes is a member of the Ecologic Institute in Germany working as the Coordinator Coastal and Marine Studies. His research interests include regional adaptation to climate change, integrated coastal zone management (ICZM), and the dissemination of scientific knowledge. Dr. Stelljes has been involved in several projects in the field such as "Innovation in the provision of climate services" (INNOVA) and “Resilience-Increasing Strategies for Coasts – toolkit” (RISC-KIT).
Alfonso Pino Maeso; and Francisco Heras	Spanish Office for Climate Change / *Oficina Española de Cambio Climático* (OECC)	Mr. Maeso and Mr. Heras are technical advisors at the OECC, created in 2001 for the development of climate change policies. The OECC responsibilities include: to develop research activities on climate change and observation of the climate system; to formulate mitigation policies and measures to tackle climate change causes; and to propose actions to favour the development and sustainable management of carbon sinks.
Nigel Pontee	Jacobs Engineering	Dr. Pontee has 26 years of experience in coastal geomorphology and more than 90 publications in his field. He is currently the Global Practice Leader of Coastal Planning & Engineering at Jacobs. Nigel has expanded his research and work interests by getting involved with NbS over the last 5 years.
Lourdes Lázaro Marín	International Union for Conservation of Nature (IUCN)	Ms. Lázaro Marin holds a bachelor’s degree in Journalism and a masters in Environment, Science and Society. Currently working at the Corporate Development Department of the IUCN Centre for Mediterranean Cooperation, Lourdes has more than 20 years of experience working as a communication advisor. She is specialized in the field of accelerating climate change mitigation and adaptation, focusing on communication methods.

We compiled the general aspects and outcomes of the interviews (section 3.5), which were guided by the following questions:

1. How can coastal and estuarine NbS be applied in Europe? At what scales, ecosystem types, and contexts are they currently applied or could be applied in the future?

2. What are the main limiting factors to the replication and scaling up of coastal and estuarine NbS in Europe? What types of example cases are needed to guide European stakeholders to develop and implement more coastal and estuarine NbS?

3 KEY FINDINGS

3.1 Case study characteristics

Most case studies were located in the United Kingdom (53%) and the Netherlands (20%), and each one of the other European countries represented 5% or less of the case study selection (**Figure 3-1**). Data on NbS projects were not evenly distributed across European countries, which does not necessarily indicate the absence of NbS projects, but most likely a bias towards countries dedicating more resources to sharing NbS best practices. It is unclear how skewed the spatial distribution of NbS is in Europe as its concept might be incorporated in different projects, but the ecosystem-based approach and its benefits were not highlighted.

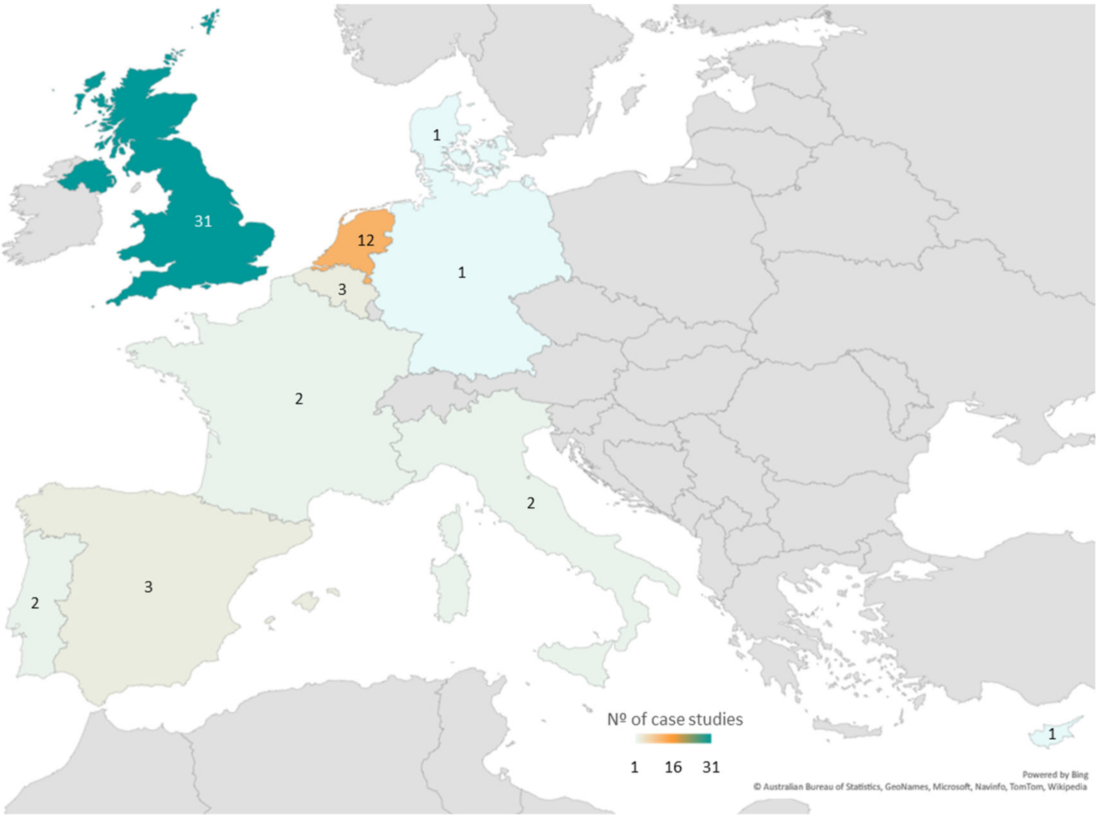

***Figure 3-1**. Distribution of case studies across countries. Transational project between Belgium and the Netherlands is not indicated in the map.*

Based on the case studies selection, the majority of projects (64%) are focused in coastal areas (**Figure 3.1**). Hybrid solutions are more common than solely green alternatives, and they are usually applied to address coastal protection issues (i.e., flooding and erosion) (**Figure 3.1**). Yet, case studies aiming at biodiversity restoration and conservation also presented coastal protection co-benefits, and it was presented as the main challenge addressed in one-thirds of the case studies. The spatial distribution of NbS projects between urban and rural / suburban areas appeared to be balanced in our results (**Figure 3.1**).

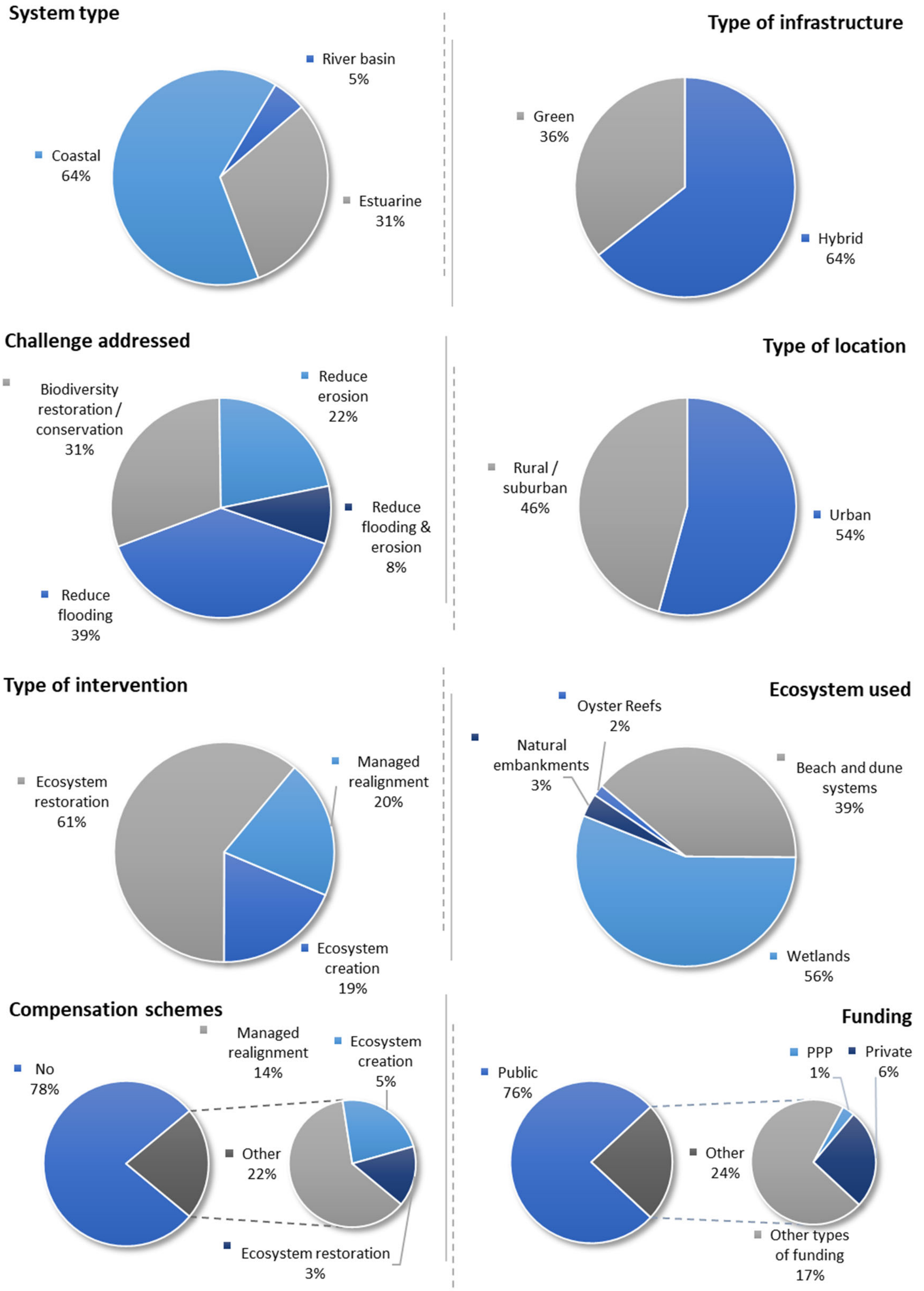

Figure 3-2. *Key characteristics of 59 NbS case studies implemented in Europe*

Ecosystem restoration was the most common type of intervention across the case studies with diverse geographical representation. Although managed realignment (also cited as depoldering in our search) was ranked second, case studies employing this type of intervention were only found in the UK and in one cross-border project between Belgium and the Netherlands (the Hedwige and Prosper Polders at the Scheldt Estuary). The least used method (19%), ecosystem creation, was found in the UK, the Netherlands and Germany only. Around 22% of the case studies were identified as compensation schemes, from which 14% were managed realignment schemes. In fact, this type of intervention was used as an environmental compensation tool in 26% of the case studies in the UK. Supported by governmental policies, managed realignment became a common coastal management solution in the UK as one of the official policy alternatives available in Shoreline Management Plans (SMPs) within the country (Doody 2013). This type of intervention mainly consists of the partial or total removal of a sea defence to allow the natural flooding of the area and the migration or return of coastal ecosystems landwards (MacDonald et al. 2020). They are usually implemented due to a combination of needs to improve coastal defence as a consequence of climate change stressors and to reduce/compensate coastal habitat losses (see, for example, McAlinden, 2015, cited in Giuliani and Bellucci 2019).

Wetlands, beach and dune systems, natural embankments, and oyster reefs were the ecosystems identified amongst the selected case studies. Wetlands accounted for 56% of the case studies, from which 32% were salt marshes and 24% were generally presented as wetlands. The predominance of tidal marshes in ecosystem-based solutions is consistent with the findings of Temmerman et al. (2013). Beach and dune systems were the second most mentioned ecosystem, including major ground-breaking projects such as the Sand Motor Delfland. Although there is a number of studies analysing the potential of oyster reefs, such as the Native Oyster Reef Restoration Ireland (NORRI)[1], it was the least represented ecosystem in NbS projects along with natural embankments. The latest is exemplified by the 'River as a Tidal Park' case study at the Rotterdam region (DE URBANISTEN 2014).

It is common to observe NbS projects receiving funds from more than one source. Amongst the 59 case studies, 130 contributions from 72 distinct funding sources were identified; yet, it is believed that not all sponsors were acknowledged through our search. A preliminary evaluation of the funding sources of the case studies indicated a foremost amount of public funds, representing 77% of the total contributions. Amid public contributions, around 85% were sponsored by local, regional, or national governments, whereas 15% of cases studies were funded by EU programmes. Other types of funding were employed in 17% of the cases, while private funding was scarce (6%). Public and Private Partnership (PPP) schemes were even more uncommon, which is a probable indicator of obstacles hampering the application of such

[1] http://norri.ie/

schemes that combine private and public funding. Other types of funding were only found in the UK and the Netherlands, representing 22% and 8% of the total contributions in each country, respectively.

Completed or partially implemented projects represented 54 out of 59 of our selection, thus the evaluation of monitoring status was based in 54 cases. Although project monitoring has been widely mentioned (81% of the completed/partially implemented case studies), it is uncommon to encounter quantitative effectiveness data of NbS against flood and/or erosion. Most of monitoring results were related to biodiversity benefits and little was found on coastal protection. This is also clear by the scarcity of monitoring results from case studies that suggested field measurements after implementation: only 17 out of 54 cases provided detailed data demonstrating efficacy, such as accretion rates or performance of NbS after a storm surge.

3.2 Motivation for NbS implementation

Improving existing coastal defences dominated the motivation for NbS implementation amongst case studies, also frequently cited as a relevant additional motivation (**Figure 3-3**). Although developing expertise on NbS was not mentioned as an extra incentive, it was the second most mentioned motivation. Maximising the sustainability of projects was a major additional motivation (39%), and still highly present as a main motivation (15%). Although environmental compensation triggered the implementation of 15% of the cases, it was only encountered in three countries (United Kingdom, the Netherlands and France). A favourable policy framework was not widely mentioned as a main motivation or additional reason for NbS implementation (8% and 9%, respectively). Recreation and tourism ranked last amongst the motivation categories but were often cited as an additional reason for project execution (**Figure 3-3**).

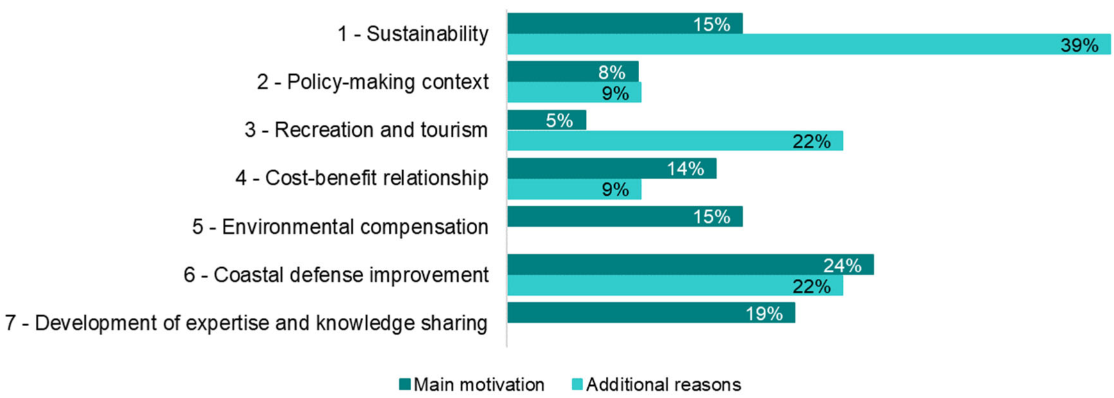

Figure 3-3. *Motivation for the implementation of NbS projects per category in terms of percentage*

3.3 Co-benefits

In total, 156 co-benefits were identified (**Figure 3-4**). Environmental benefits are dominated by the biodiversity category, incorporating benefits such as providing nesting, breeding, and roosting sites for birds, and nursery areas for fishes, through the protection and/or creation of coastal habitats. For instance, monitoring results from the first managed realignment case study in Scotland (UK), the Nigg Bay Coastal Realignment Project, indicated a significant surge of wintering waterbirds at the newly created saltmarsh area (85% increase of wader species and 62% of wildfowl species) (Elliott 2015). Other environmental benefits include water quality improvement, such as the oxygen level increase in the salt marsh restoration in Lippenbroek (BE), and air quality enhancement. The latter is less common, and it was only mentioned once in the transnational depoldering project 'Hedwige and Prosper Polders', which was caused by fewer suspended solids from former agricultural land. In total, 30% of the reported co-benefits were environmental related.

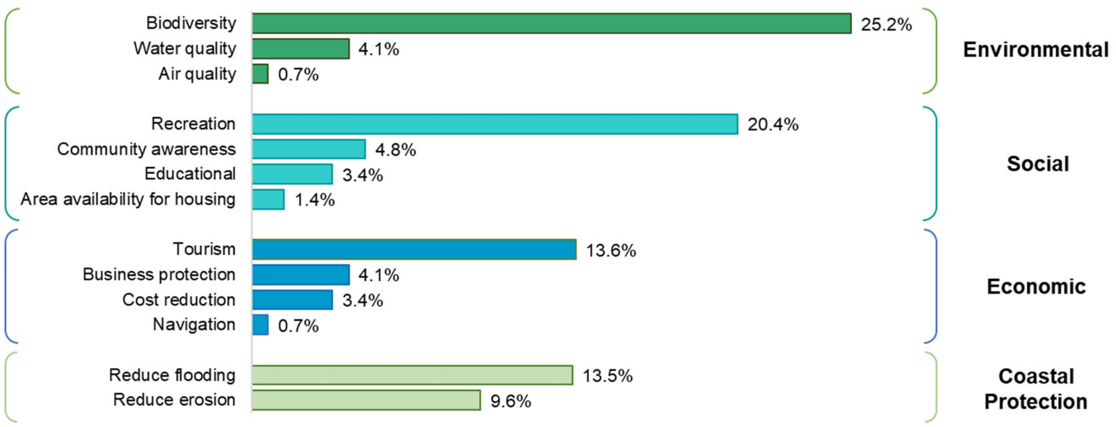

Figure 3-4. *Frequency of co-benefits reported within 59 NbS case studies examined, per class and category.*

Recreation, community awareness, educational (i.e., learning outcomes for the community and/or visitors), and area availability for housing were grouped as social benefits (30% of total informed co-benefits) (**Figure 3-4**). The latter is likely to arise from revitalization projects, such as the Managed Realignment in Perkpolder (NL), and it can arguably be considered an economic benefit if new constructions are not related to social housing.

Economic co-benefits are of great importance as they are likely to support investments in NbS, representing 21.8% of the total reported co-benefits. Tourism was the most highlighted amongst the economic benefits, followed by business protection (i.e., businesses' constructions were at risk prior to project implementation), and cost reduction in comparison with traditional solutions (**Figure 3-4**). Improved navigation resulting from sustainable dredging was mentioned only once in the Pevensey Sea Defences scheme, where the blockage of the Sovereign Harbour entrance was avoided by the nature-based approach. Reduce flooding (10.9%) and reduce erosion (7.5%) were also present as co-benefits (see section 2.2 for details).

3.4 Lessons learned

An initial screening of the lessons learned from the selected case studies indicated 155 records (**Figure 3-5**). Stakeholder engagement was consistently indicated as essential for the success of projects. An example of positive outcomes due to stakeholder engagement is the habitat re-creation at Blackwater Estuary (Abbott's Hall Farm). One of the key success factors of the project was early identification and adequate communication with stakeholders, which included a consultation process through personal meetings (EU OURCOAST-Project 2015b). On the other hand, delays were observed in the creation of a depoldered area between Belgium and the Netherlands as part of the Sigma Plan due to the disapproval of landowners, indicating the need for stakeholder engagement and communication. The latter was included in a separated lesson learned category which was cited in 11.6% of the reports (**Figure 3-5**).

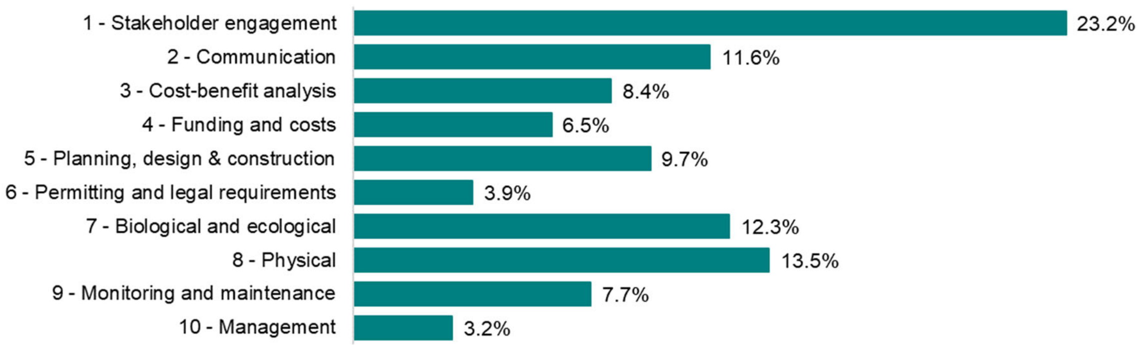

Figure 3-5. *Percentage of reported lessons learned per category defined for the project sample (n = 59)*

The knowledge regarding technical aspects of the site was pointed out as crucial, before and after implementation, in order to secure adequate selection of adaptation measures and monitoring of effectiveness, respectively. These aspects include biological, ecological, and physical site-specific features. For instance, the assessment of erosion rates and topographic surveys prior to the implementation of the Alkborough Flats Managed Realignment allowed the identification of post-implementation accretion rates. Monitoring results indicated that accretion rates are stable and most of the area lays at 3.1 m or more (RiverWiki 2020).

A number of projects identified the importance of cost-benefits analysis, such as the adaptive restoration of the former saltworks in Camargue (France); yet, the need to conduct such analysis was infrequently mentioned. Other occasionally reported lessons learned included meeting permitting and legal requirements and timetables, and the importance of guaranteeing funding during the implementation to assure monitoring and maintenance (**Figure 3-5**). We suppose that the need for project management experience and multidisciplinary team involvement was the least reported lesson learned because it was considered as a premise in the implementation of NbS.

3.5 Outcomes of expert interviews

Experts provided insights on key considerations for replication of NbS and commented on the uses and limitations of a database of European coastal NbS. The interviews with experts confirmed that there are important generic lessons for replication which can be learned from such a database. Generic lessons on costs, type of intervention, motivations for implementation, co-benefits captured, and success factors can provide insights on how to frame a project proposal to be more competitive for funding and public support, as well as key processes which need to be included in planning and implementation. Coastal ecosystems can provide coastal protection and services in erosion control, carbon sequestration and other services. There is experience with coastal restoration and ecosystem protection, but the diversity of landscape is large. Experiences have provided better results in protected areas given the legal frameworks, public land ownership and lack of threats and conflicting interests in coastal resources. However, the interviews also suggest that NbS planning should be designed for context-specific needs, as coastal systems are highly diverse. NbS projects should have better defined objectives and values. Further research is also required to demonstrate where the European coast's physical characteristics are conducive to replication of various types of NbS, to gather more knowledge on their economics, and to demonstrate the performance and benefits of these solutions.

Importantly with any NbS, the interviews highlighted that they are often not a standalone solution for flooding and that typically they should be applied in tandem with additional measures. Differences between European Countries is also large, both in experience and uptake. Wetlands, deltas and other low-lying areas can be potential sites for the application of NbS in Europe, leveraging experiences in managed realignments, wetland restoration, beach and dune restoration and management of deltaic areas. The scale required for assessing a site context was also discussed: although protecting the coastline is a local need, upstream processes have a direct impact on the coastal conditions and site suitability for NbS and therefore should always be included in a site scoping. However, estuarine zones are dynamic areas and are challenged by factors such as availability of space, conflicting uses, water management, and urbanization. These factors should also be accounted for while assessing the feasibility of NbS. In this context, NbS tend to be more achievable in open, public land areas where tourism values and other environmental services may be higher and offer a higher potential for yielding benefits. There are also other opportunities such as leveraging compensatory habitat under EU legislation to also improve flood defence as co-benefit. Currently, ecosystem services assessments are developed but are not necessarily captured in the formal assessment for decision procedures in coastal protection.

Although a considerable amount of resources has been invested in NbS research over the last few years (Faivre et al. 2017), a number of limiting factors associated with NbS implementation were also raised during the expert interviews (**Table 3-1**). Most of these factors are aligned with limitations and concerns raised in the broader NbS literature (e.g., van Wesenbeeck et al. 2017; Morris et al. 2018; Kumar et al. 2020; Faivre et al. 2017). Addressing these limiting factors should be a priority in order to support replication and scaling up of NbS.

Table 3-1. *Summary of NbS limiting factors for NbS replication and scaling up identified through expert interviews*

Type	Summary of challenges and limiting factors
Technical	• Diversity of coastline types, including different biological conditions and climatic aspects. • To adapt successful solutions to local characteristics of other sites.
Public perception	• Lack of trust in NbS when compared to traditional engineering solutions. • Empirical data is required to prove/demonstrate NbS effectiveness against severe coastal hazards. • Nature has often been perceived as a limitation instead of a protective element.
Financial	• Increase funding availability of NbS implementation. For instance, beach nourishment could be applied in more places, but it may require significant funding.
Space	• More complex to implement in urban areas due to space limitations. • Retreat/realignment of the coastline is often unfeasible in high density areas.
Geography	• Constraints associated with local geography such as tidal levels and topography. • Sediment sources might not be available (e.g., beach nourishments). • Little information on areas more suitable to receive NbS. • New important opportunities to explore in areas with ports.
Stakeholder engagement	• Changes in land use may generate resistance against NbS projects depending on ownership. • Communication with local community is vital to minimize trade-offs.
Diversity of contexts	• Definition of issue addressed by NbS should be clear and specific not to raise unrealistic expectations. • Economic activities and social context vary largely between countries. • Language barrier (need to translate project data to other languages). • Differences between legal frameworks.

Type	Summary of challenges and limiting factors
Assessment of benefits	• Evaluation of benefits does not account for all ecosystem services. • Assessment might identify benefits that are not appealing for stakeholders.

The interviews also highlighted that, in regard to the general public perception of and demand for NbS, mistrust is still present when compared to traditional approaches and nature is often seeing as a barrier to economic growth. Therefore, enhanced communication between stakeholders is required along with the promotion of benefits from NbS in alignment with communities' needs (e.g., tourism, generation of green jobs, and/or climate mitigation). Additionally, all stakeholders should obtain information on empirical evidence on NbS effectiveness. Future projects should involve the beneficiaries to demonstrate how coastal NbS can help communities. There should be a clear and open communication between project owners and the local community in order to reduce trade-offs and potentialize synergies amongst each one's interests. It is also essential to increase the involvement of civil society and the outreach on the private sector, elucidating the opportunity to protect assets by efficiently employing ecosystems. Finally, the outcome of the interviews also point out the value of user-friendly tools to disseminate scientific knowledge on NbS is one alternative to increase engagement; however, the information should also be broadly accessible and understandable., including in multiple languages to avoid language barriers and misbalances in access to the information and lesson sharing.

Two important opportunities for NbS projects are in using recovery funds to support NbS and restoration activities, as well as for NbS space in port development and infrastructure.

4 THE WAY FOWARD

The European Union (EU) has been leading a series of initiatives to create more resilient societies through sustainable solutions. Horizon 2020, LIFE+ Climate Action and COST actions are some of the funding mechanisms available to achieve EU's sustainability goals (EC 2021). Most of the integrative databases used in this study are results of such investments and they play a critical role to disseminate knowledge on NbS; however, there is room for improvement to facilitate the public's access to evidence-based data.

Although the information provided in the integrative platforms is highly useful, some tend to focus on major projects that achieved extraordinary results, resulting in a slight bias and not entirely accurate representation of NbS projects. To address this issue, we recommend the interconnection of EU platforms aiming to centralize information in one hub. RiverWiki, an outcome of the EU LIFE+ RESTORE project, is an example of a platform presenting a wider variety of projects. In this platform the users are allowed to submit their own case studies, which must be approved by an authorized member of the platform. This approach enabled a miscellaneous collection of local scale case studies. Another useful resource that should be promoted is the 'Community' section included in OPPLA. Users are allowed to network with other members of the community and ask questions about NbS, sharing experiences and knowledge. The creation of user-friendly filters is also recommended to facilitate the access to projects of interest. We recommend that the EU interconnect its platforms in a central hub and adopt these features and recommendations in order to allow easy access to information and accounts for holistic content, including community type, costs, and scale.

We additionally suggest that the key characteristics encountered amongst our sample are further analysed in other case studies to confirm the identified patterns. A relevant aspect is the main motivation of projects, which can allow a better understanding of what practitioners are seeking when applying NbS. It seems that most of them are motivated by the need to improve coastal defences (i.e., adapt to climate change) while adopting a sustainable approach. This highlights a willingness to adopt NbS even though there are uncertainties about its long-term effectiveness. It is likely that traditional 'hard' engineering structures will not be able to cope with the consequences of climate change, thus we suggest that more attention is given to hybrid solutions in order to make a smoother transition from 'grey' to 'green' solutions. This approach is likely to strengthen a more positive perception about NbS. Yet, it is important to highlight that in some cases it is unlikely that the traditional engineering approach will be fully removed, especially while long-term results of NbS effectiveness are not available. This stresses the importance of monitoring and the adequate reporting of results. Most of the projects we identified mentioned effectiveness but were lacking on quantitative data about effectiveness.

In terms of implementation, sharing data on the initial site conditions in order to enable replication in similar areas is recommended. Nevertheless, replication will not be possible in all cases as the ecological, geographic, and social context are likely to be dissimilar and they must be considered. It was possible to identify a number of sponsors of NbS case studies. Yet, besides the projects funded by the EU, the process to acquire funding from local and regional governments was not easy to identify nor even mentioned in most of the reviewed cases. Although this is not the case of projects funded by the EU, most of them seem to be of a large-scale. Also, where trust funds were employed, the information about the fund was not easily accessible.

In summary, we recommend that the EU next:

- Interconnect its NbS project records and write-ups in a central, maintained hub to facilitate access to information and a holistic overview of NbS efforts in Europe;
- Further research the initial site conditions in successful NbS cases in order to gain insight on which site contexts are conducive to NbS implementation; and
- Monitor more NbS projects and work to quantify the successes of efforts rather than just reporting qualitative successes.

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ANNEX 1 – DATABASE

The database file was delivered separately in a spreadsheet file (.xlsx).