Nature-based solutions in Europe:
Policy, knowledge and practice for climate change adaptation and disaster risk reduction

European Environment Agency

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Luxembourg: Publications Office of the European Union, 2021

ISBN 978-92-9480-362-7
ISSN 1977-8449
doi: 10.2800/919315

European Environment Agency
Kongens Nytorv 6
1050 Copenhagen K
Denmark

Tel.: +45 33 36 71 00
Internet: eea.europa.eu
Enquiries: eea.europa.eu/enquiries

Contents

Acknowledgements

Coordinators

Sergio Castellari (EEA), Emiliano Ramieri (European Topic Centre on Climate Change Impacts, Vulnerability and Adaptation, ETC/CCA and Thetis)

Lead authors

Sergio Castellari (EEA), Marianne Zandersen (ETC/CCA; Aarhus University and Aarhus University Interdisciplinary Centre for Climate Change, iClimate), McKenna Davis (European Topic Centre on Biological Diversity, ETC/BD, and Ecologic Institute), Clara Veerkamp (ETC/CCA and PBL Netherlands Environmental Assessment Agency), Johannes Förster (ETC/CCA and Helmholtz Centre for Environmental Research — UFZ), Mika Marttunen (ETC/CCA and Finnish Environment Institute, SYKE), Jaroslav Mysiak (ETC/CCA and Euro-Mediterranean Centre on Climate Change, CMCC and Ca' Foscari University Venice), Marie Vandewalle (ETC/CCA and Helmholtz Centre for Environmental Research — UFZ), Silvia Medri (ETC/CCA and CMCC), José Ramón Picatoste (EEA)

Authors and contributors by chapter

Executive summary

Author: Sergio Castellari (EEA)
Contributors: Ybele Hoogeveen (EEA), Marianne Zandersen (ETC/CCA, Aarhus University and iClimate), Clara Veerkamp (ETC/CCA and PBL), Johannes Förster (ETC/CCA and Helmholtz Centre for Environmental Research — UFZ)

Chapter 1: Introduction

Authors: Sergio Castellari (EEA), Marianne Zandersen (ETC/CCA, Aarhus University and iClimate), Marie Vandewalle (ETC/CCA and Helmholtz Centre for Environmental Research — UFZ)
Contributor: McKenna Davis (ETC/BD and Ecologic Institute)

Chapter 2: Global and European policy framework

Authors: Sergio Castellari (EEA), McKenna Davis (ETC/BD and Ecologic Institute)

Chapter 3: Knowledge base on nature-based solutions for climate change adaptation and disaster risk reduction

Authors: Johannes Förster (ETC/CCA and Helmholtz Centre for Environmental Research — UFZ), Clara Veerkamp (ETC/CCA and PBL)
Contributors: Claire Jacobs (ETC/CCA and Wageningen Environmental Research, WENR), Annemarie Bastrup-Birk (EEA), Jelle van Minnen (ETC/CCA and PBL), Daniella Möller (EEA), Marianne Zandersen (ETC/CCA, Aarhus University and iClimate), Silvia Torresan (ETC/CCA and CMCC)

Chapter 4: An analysis of practical uses of nature-based solutions for climate change adaptation and disaster risk reduction in Europe

Authors: Marianne Zandersen (ETC/CCA, Aarhus University and iClimate), Mika Marttunen (ETC/CCA, Finnish Environment Institute, SYKE)
Contributor: Johannes Förster (ETC/CCA and Helmholtz Centre for Environmental Research — UFZ)

Chapter 5: Financing nature-based solutions

Author: Jaroslav Mysiak (ETC/CCA, CMCC and Ca' Foscari University Venice)
Contributors: Elisa Calliari (CMCC and University College London), Andrea Staccione (CMCC and Ca' Foscari University Venice), Francesca Larosa (CMCC and Ca' Foscari University Venice)

Chapter 6: Conclusions

Author: Sergio Castellari (EEA)
Contributors: Marianne Zandersen (ETC/CCA, Aarhus University and iClimate), Clara Veerkamp (ETC/CCA and PBL), Johannes Förster (ETC/CCA and Helmholtz Centre for Environmental Research — UFZ), Ybele Hoogeveen (EEA), Emiliano Ramieri (ETC/CCA and Thetis)

Annex 1: Link to EEA activity

Author: Sergio Castellari (EEA)

Annex 3: The selected cases of nature-based solutions in Europe

Authors: Mika Marttunen (ETC/CCA, SYKE), Marianne Zandersen (ETC/CCA, Aarhus University and iClimate),

Annex 4: Description of the example cases of nature-based solutions in Europe

Authors: Mika Marttunen (ETC/CCA, SYKE), Marianne Zandersen (ETC/CCA, Aarhus University and iClimate)
Contributor: Johannes Förster (ETC/CCA and Helmholtz Centre for Environmental Research — UFZ)

Annex 5: Knowledge platforms addressing Nature-based Solutions for climate change adaptation and disaster risk reduction at European and National Level

Authors: Silvia Medri (ETC/CCA, CMCC), José Ramón Picatoste (EEA)

Annex 6: Glossary

Author: Sergio Castellari (EEA)

Members of the Advisory Group

Hugo Carrão (European Topic Centre on Urban, Land and Soil Systems, ETC/ULS, and space4environment sàrl), Jérôme Duvernoy (Ministère de la Transition écologique), Helena Hanson (Lund University), Mike Harley (Climate Resilience Ltd), Veronica Lo (Swedish University of Agricultural Sciences), Elena Lopez-Gunn (Icatalist), Farrokh Nadim (Norwegian Geotechnical Institute), Fabrice Renaud (University of Glasgow), Fernando Santos (Universidad Rey Juan Carlos), Zita Sebesvari (United Nations University and PEDRR), Karen Sudmeier-Rieux (United Nations Environment Programme, UNEP), Dava Vackaru (CzechGlobe), Zoran Vojinovic (Delft Institute for Water Education)

The authors would like to thank all those who contributed positively to this report with their critical and constructive comments and observations, which contributed to the final version of the report. In particular, we acknowledge the following experts from the EEA: Trine Christiansen, Gorm Dige, Markus Erhard, Hans-Martin Fussel, Eva Jensen, Blaz Kurnik and Wouter Vanneuville. We also acknowledge the following experts from European Commission: Alfred De Jager (Joint Research Centre, JRC), Luc Feyen (JRC), Tiago Freitas (Directorate-General for Research and Innovation), Peter Löffler (Directorate-General for Climate Action), Jelena Milos (Directorate-General for European Civil Protection and Humanitarian Aid Operations), Laura Palomo-Rios (Executive Agency for Small and Medium-sized Enterprises), Marine Robuchon (JRC), Luisa Sousa (JRC), Michalis Vousdoukas (JRC) and Karin Zaunberger (Directorate-General for the Environment)

Furthermore, the authors would like to thank the experts who provided useful review, input and feedback to the collection of information presented in Chapter 4 and Annexes 4 and 5:

- Chapter 4:
  - Stephan Brenneisen (Zurich University of Applied Sciences, ZHAW)
- Annex 4:
  - Idoia Arauzo González (Working Community of the Pyrenees), Christoffer Bonthron (Tullstorp Stream Economic Association), Hanna Bornholdt (Freie und Hansestadt Hamburg), Michela Cariglia (blue economy expert, ARTI Puglia adviser), Nicola del Seppia (Northern Apennines District River Basin Authority), Christian Dupraz (French National Institute for Agriculture, Food and Environment, INRAE), Elena López-Gunn (Icatalist), Guillaume Piton (INRAE), Maria Del Carmen Gonzalez Sanchis (Universitat Politécnica de València), Boris Radić (University of Belgrade), Christian Schröder (Greifswald Mire Centre), Georgios Sylaios (Democritus University of Thrace), Anders Solheim (Norwegian Technical Geotechnical Institute, NGI), Jean-Marc Tacnet (INRAE), Franziska Tanneberger (Greifswald Mire Centre), Laura Vay (Icatalist).
- Annex 5:
  - Julia Barrott (Stockholm Environment Institute), Floris Cornelis Boogaard (Hanze University of Applied Sciences), Harriet Bulkeley (University of Durham), Francisco Ríos Díaz (JRC), Marie Fischborn (International Union for Conservation of Nature, IUCN), Nikolaos Nikolaidis (Technical University of Crete), Nathalie Seddon (University of Oxford), Brian Mac Sharry (EEA), Bregje K. van Wesenbeeck (Deltares) and the national reference centres for climate change impacts, vulnerability and adaptation in Albania, Austria, Bosnia and Herzegovina, Bulgaria, Cyprus, Czechia, France, Ireland, Italy, Montenegro, Norway, Poland and Slovenia.

The authors would also like to thank Joost Knoop (ETC/CCA and PBL), Wolfgang Lexer (ETC/CCA and Environment Agency Austria, EAA), Guido Rianna (ETC/CCA and CMCC), Roger Street (ETC/CCA and CMCC) for their key contributions in 2019 to the development of the scoping paper 'Ecosystem-based approaches for climate change adaptation and disaster risk reduction — Exploring the knowledge base, policies and practices'.

The EEA acknowledges comments and additional input received on the draft report from the following national reference centres within the European Environment Information and Observation Network (Eionet): Czechia, France, Germany, Greece, Italy, the Netherlands, Norway, Poland, Spain, Sweden, Turkey. These suggestions were taken on board in the final version of the report as far as possible.

Special thanks to André Jol (EEA).

Key messages

- Nature-based solutions for climate change adaptation and disaster risk reduction are actions that work with and enhance nature to restore and protect ecosystems and to help society adapt to the impacts of climate change and slow further warming, while providing multiple additional benefits (environmental, social and economic).
- Nature-based solutions for climate change adaptation and disaster risk reduction is an 'umbrella concept' encompassing other established approaches, e.g. the ecosystem approach and ecosystem-based approaches, sustainable management, ecosystem-based management, sustainable forest management, green infrastructure and blue-green infrastructure, ecosystem-based adaptation, natural water retention measures and ecosystem-based disaster risk reduction.
- The concept of nature-based solutions for climate change adaptation and disaster risk reduction is increasingly embedded in global and EU policy frameworks for sustainable development. However, better coherence across policy domains, prioritisation at EU level and more project design is still needed.
- An EU-wide mapping of existing and potential new or restorative nature-based solutions can help identify priority areas based on desired services, increasing the consideration of trade-offs between climate change and biodiversity aims.
- Agreed standards, quantitative targets, measurable indicators and evaluation tools for nature-based solutions at EU level can help to assess progress, effectiveness and multiple benefits.
- As nature-based solutions depend on healthy ecosystems, which are vulnerable to climate change, their potential to address climate change adaptation and disaster risk reduction may be reduced in the future.
- Stakeholder involvement, dialogue and co-design of tools and measures are key to increase awareness, to tackle potential stakeholders' conflicts more effectively and to create social acceptance and demand for nature-based solutions. About half of the European cases analysed strongly emphasise stakeholder involvement.

Executive summary

Climate change, biodiversity loss and degradation of ecosystems are interdependent and pose significant societal challenges, threatening economic and social stability, public health and well-being. The World Economic Forum considers extreme weather- and climate-related events and biodiversity loss to be among the five most imminent global risks (WEF, 2020). Fighting climate change and preventing ecosystem degradation and biodiversity loss are highly interdependent, requiring increased coherency between their respective policy agendas and actions.

Extreme weather- and climate-related events and biodiversity loss to be among the five most imminent global risks

Ecosystem preservation and restoration can contribute to resilience to climate change and to climate change mitigation. Working with nature and enhancing crucial ecosystem services is at the centre of nature-based solutions to climate change adaptation and disaster risk reduction. Such solutions reduce social and environmental vulnerabilities and can bring multiple co-benefits such as mitigating climate change, improving human health and well-being, and providing jobs and business opportunities.

Nature-based solutions for climate change adaptation and disaster risk reduction can be considered an 'umbrella concept' encompassing a range of established nature-based approaches, which aim to increase resilience to climate change (see Figure ES.1).

This report shows that nature-based solutions and related concepts are increasingly integrated in the global and EU policy frameworks that are relevant for resilience to climate change, biodiversity conservation and restoration and related areas (see Chapter 2). However, the concept is not yet sufficiently embedded.

As a key pillar of the European Green Deal (EC, 2019c), the new EU biodiversity strategy for 2030 (EC, 2020e) includes an EU nature restoration plan among its objectives, which has the potential to strongly support the uptake of restorative nature-based solutions in Europe. Furthermore, the European Commission will launch a new EU strategy on adaptation to climate change in early 2021. The strategy's blueprint document (EC, 2020a) highlights the value of nature-based solutions as multipurpose, no-regret solutions that are expected to be key in the new strategy.

The scientific evidence base (see Chapter 3) related to nature-based solutions for climate change adaptation and disaster risk reduction is rapidly expanding in Europe, in large part due to the significant number of Horizon 2020-funded research projects. We conducted a scientific literature review to analyse key options for nature-based solutions and their multiple benefits, as well as their potential trade-offs and limitations for relevant sectors in Europe (water, forests and forestry, agriculture, urban and coastal areas). This analysis confirms that the nature-based solutions approach to climate change adaptation and disaster risk reduction is a valid and effective socio-economic option for these sectors, increasing resilience to climate change while providing many societal benefits. Further implementation of nature-based solutions to climate change adaptation and disaster risk reduction needs to be accompanied by developing technical standards, collaborative governance, capacity building and sufficient funding. More information is needed on the synergies and trade-offs, which can arise when combining nature-based solutions to climate change adaptation and disaster risk reduction with grey infrastructures (i.e. hybrid measures). Indicators would need to be standardised to allow for cross-site comparison of effectiveness of nature-based solutions.

Figure ES.1 Overview of nature-based concepts to climate change adaptation and disaster risk reduction and their related EU policy sectors

Biodiversity	Forests	Land use and forestry	Water	Agriculture	Climate change adaptation	Disaster risk reduction
· Biodiversity Strategy for 2030 · Strategy on Green Infrastructure	Forest Strategy	LULUCF Regulation	· Water Directive · Floods directive	Common Agricultural Policy	Strategy on adaptation to climate change	Action Plan on the SFDRR 2015-2030
EA/EbAp Ecosystem Approach/ Ecosystem-based Approaches **GI/BGI** Green Infrastructure and Blue-Green Infrastructure **SM/EbM** Sustainable Management and Ecosystem-based Management	**SFM** Sustainable Forest Management **SM/EbM** Sustainable Management and Ecosystem-based Management	**SFM** Sustainable Forest Management **SM** Sustainable Management	**NWRM** Natural Water Retention Measure	**NWRM** Natural Water Retention Measure	**GI/BGI** Green Infrastructure and Blue-Green Infrastructure **SM/EbM** Sustainable Management and Ecosystem-based Management	**Eco-DRR** Ecosystem-based Disaster Risk Reduction

Climate Change Adaptation and Disaster Risk Reduction

'Umbrella concept'
NbS
Nature-based Solutions

Note: CAP, common agricultural policy; LULUCF, Land use, land use change and forestry; SFDRR 2015-2030, Sendai Framework for Disaster Risk Reduction 2015-2030.

Source: EEA.

Another review of around 100 European cases (see Chapter 4) of implemented nature-based solutions, collected from European knowledge platforms, was conducted to identify examples of innovative methods and good practice and to extract lessons learnt (see chapter 4). The analysis finds that the design of nature-based solutions projects should build on forward-looking studies of projected climate change impacts and socio-economic developments and include evaluations, for example multi-criteria analysis, and consideration of trade-offs. The effectiveness of nature-based solutions is highly dependent on the local context. Involving local stakeholders from the outset in the planning and design phases is crucial for ensuring social acceptance and ultimately for the full delivery of multiple benefits. The social acceptability of implementing such solutions can also be improved by making nature-based solutions aesthetically appealing to citizens. Agreed standards, quantitative targets and measurable indicators are key to monitoring and evaluating the progress, effectiveness and return on investment of implementing nature-based solutions.

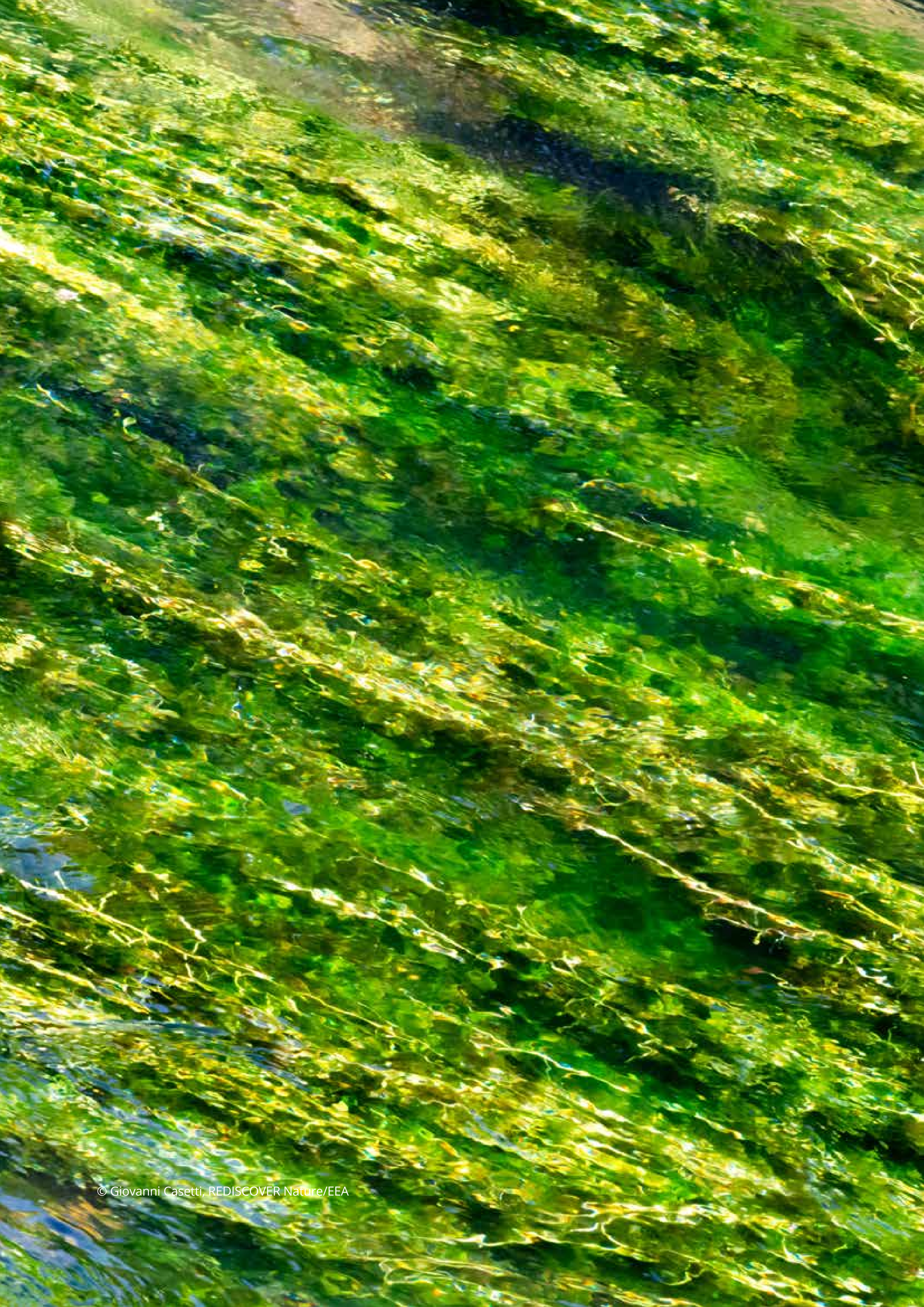
A variety of economic and financial instruments described in Chapter 5 can be applied to nature-based solutions. These include incentives, tradable environmental schemes, innovative risk-financing schemes and green investments. Ecosystem-linked insurance schemes have received a lot of attention recently (EC, 2015; NAIAD, 2020), and the United Nations Framework Convention on Climate Change Forum of the Standing Committee on Finance chose this topic for the 2021 forum meeting (UNFCCC, 2020). The early operational schemes address flood management, forest-based landslide risk prevention and nature-based fire management. The Natural Capital Financing Facility provides support for pioneering conservation and nature-based solutions projects (EIB, 2019). Innovative sustainable business models have been designed to promote nature-based solutions (Toxopeus and Polzin, 2017; Perrin, 2018; Somarakis et al., 2019). A sizeable part of the EU cohesion policy, common agricultural policy and LIFE programme funds can be used for implementing nature-based solutions.

Innovative sustainable business models have been designed to promote nature-based solutions

There are ample opportunities for mainstreaming nature-based solutions into diverse sectors across Europe

European knowledge platforms, including the European Climate Adaptation Platform, Climate-ADAPT, can support policymakers, scientists and practitioners in knowledge sharing and capacity building to develop nature-based solutions to climate change adaptation and disaster risk reduction.

This report finds that there are ample opportunities for mainstreaming nature-based solutions into diverse sectors across Europe (i.e. making them part of everyday practice), which can support the transformative change needed to address the interdependent climate and biodiversity challenges.



1 Introduction

1.1 Rationale and aim

Human society is facing urgent and interdependent global crises of climate change and biodiversity loss, which are causing and will continue to cause further impacts worldwide (IPCC, 2018, 2019; IPBES, 2019). Extreme events (see Annex 2), such as heat waves, heavy precipitation, river floods, windstorms, landslides, droughts, forest fires, avalanches, hail and storm surges, and slow-onset events (e.g. coastal erosion, prolonged wet periods, prolonged dry periods, biological colonisation) can have significant negative impacts on the economy and human health and well-being, both directly and indirectly (IPCC, 2018; IPBES, 2019). Most climate change impacts are expected to increase in the coming decades across Europe, based on projected changes in climate and socio-economic developments (EEA, 2017b; Feyen et al., 2020). With accelerating climate change, multiple hazards are increasing in severity and frequency in Europe (EEA, 2020b). At the same time, global biodiversity is declining and ecosystems are being degraded due to increased human activities (IPCC, 2018, 2019; IPBES, 2019), which undermine the provisioning of ecosystem services, critical for human health and well-being. The decline in the quality and quantity of ecosystem services in turn exacerbates climate change, which is already the third largest global driver of biodiversity loss (IPBES, 2019).

The decline in the quality and quantity of ecosystem services in turn exacerbates climate change

Extreme weather and climate, biodiversity loss and natural hazards have been identified among the five most likely global risks in the World Economic Forum's *The global risks report 2020* (WEF, 2020). On the other hand, biodiversity and ecosystem services are able to provide ways to support efficient climate change adaptation (CCA) and disaster risk reduction (DRR) in various sectors of our society. Working with and enhancing nature involves applying nature-based solutions (NbS), which, by restoring and sustainably managing the ecosystems and the environment, can reduce biodiversity loss and degradation of ecosystems, as well climate change impacts and risk of disasters.

Recently, at the European scale, research and innovation initiatives have been launched to address challenges and options for NbS, in relation to climate change adaptation and disaster risk reduction, including several Horizon 2020 research projects. Faivre et al. (2017) show that NbS for CCA and DRR can provide multiple benefits (e.g. protection of ecosystems, climate change mitigation, human health and well-being) and can be cost-effective measures.

This report aims to provide up-to-date information on how NbS can provide multi-benefit measures for climate change adaptation and disaster risk reduction in Europe and can be regarded as low or no regret options delivering a high cost-benefit ratio and return on investment. This report also shows how NbS are highlighted in global and European policy forums and how NbS are applied in Europe to reduce climate change impacts and extreme weather- and climate-related events. The report considers NbS as an 'umbrella concept' (see Section 1.2 for a definition).

The target audiences of this report are decision-makers and stakeholders at European, national and subnational levels and sectoral experts keen to enlarge their knowledge of various aspects of NbS.

1.2 Nature-based solutions for climate change adaptation and disaster risk reduction

A number of related terms have been developed over the last few decades in policy and sectoral discourses and in the scientific literature to describe approaches that work with nature and use nature as a tool to help address diverse societal challenges. The approaches relating to NbS have developed from a variety of backgrounds, including scientific research and practice and policy contexts, and can be categorised as follows:

- ecosystem approach (EA) and ecosystem-based approaches (EbAp);
- ecosystem protection and restoration approaches: sustainable forest management (SFM), sustainable management (SM), ecosystem-based management (EbM);

- infrastructure-related approaches: green infrastructure (GI), blue-green infrastructure (BGI);
- issue-specific ecosystem-related approaches:
  - climate change adaptation: ecosystem-based adaptation (EbA);
  - flooding: natural water retention measures (NWRM);
  - disaster risk reduction: ecosystem-based disaster risk reduction (Eco-DRR) (See also Box 1.1);
  - climate mitigation: sustainable climate actions (SCA), natural climate solutions (NCS) (See Box 1.2).

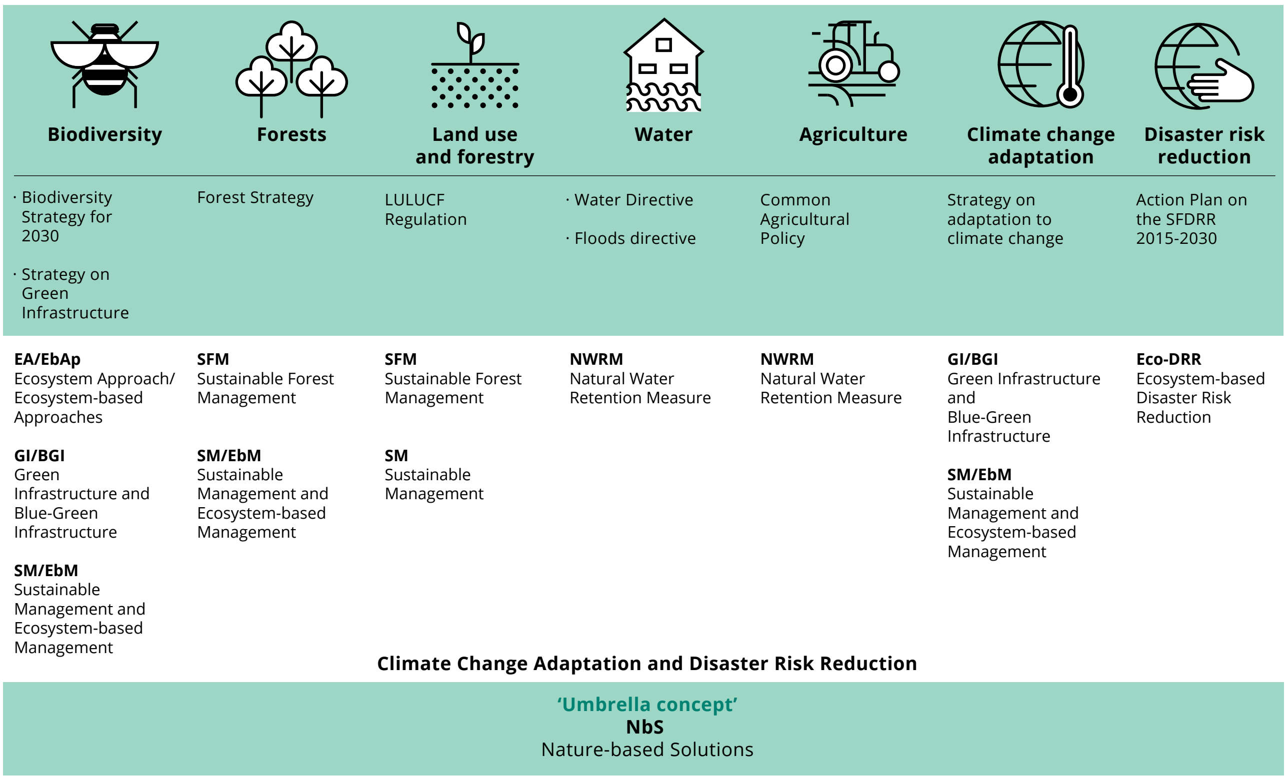
These share a focus on biodiversity and ecosystem services and aim to address societal challenges, recognising the fundamental role that ecosystems play in supporting human safety and well being.

Definitions of existing ecosystem-based initiatives at EU level are provided on the OPPLA platform (OPPLA, 2020a), i.e. the EU repository of nature-based solutions. The Esmeralda Glossary for ecosystem mapping and assessment terminology also lists NbS-related terms and definitions (Potschin-Young et al., 2018).

In this report, we focus on climate change adaptation and disaster risk reduction and we acknowledge **NbS for CCA and DRR** as an **'umbrella concept'** to describe the various policy areas working with nature to solve different but interlinked societal challenges related to climate change adaptation and disaster risk reduction (see Box 1.1). Hence, this report uses the broad term NbS when referring in general to the cluster of related approaches applying NbS for CCA and DRR and the individual terms when referring to specific approaches.

Figure 1.1 illustrates the predominant links between these different concepts and policy areas in the scope of this report. In practice, the different policy areas address more concepts, e.g. the EU Floods Directive (EU, 2007a) also address SM and EbM, and the EU action plan on the Sendai Framework for Disaster Risk Reduction (EC, 2016a) addresses all terms (see Table 2.4). The different concepts used in this report are described below, and Chapter 2 assesses in detail how and to what extent the policies refer explicitly to these terms.

Figure 1.1 Overview of nature-based concepts for climate change adaptation and disaster risk reduction and their related EU policy sectors



Note: LULUCF, Land use, land use change and forestry; SFDRR 2015-2030, Sendai Framework for Disaster Risk Reduction 2015-2030.

Source: EEA.

1.2.1 Nature-based solutions

The European Commission's definition of **NbS** recognises them as: solutions to societal challenges that are inspired and supported by nature, which are cost-effective, simultaneously provide environmental, social and economic benefits and help build resilience. Such solutions bring more, and more diverse, nature and natural features and processes into cities, landscapes and seascapes, through locally adapted, resource-efficient and systemic interventions. Nature-based solutions must benefit biodiversity and support the delivery of a range of ecosystem services (EC, 2020g; Faivre et al., 2017).

NbS encompass a wide range of actions, such as the protection and management of natural and semi-natural ecosystems, the incorporation of BGI in urban areas and the application of ecosystem-based principles to agricultural systems (Seddon et al., 2020b). The concept is grounded in the ecosystem approach: the knowledge that healthy natural and managed ecosystems produce a diverse range of services on which human well-being depends, from storing carbon, controlling floods and stabilising shorelines and slopes to providing clean air and water, food, fuel, medicines and genetic resources. People and society are seen as being not only passive beneficiaries of nature's benefits, but as key players who can proactively protect, manage or restore natural ecosystems as a purposeful and significant contribution to addressing major societal challenges (Cohen-Shacham et al., 2016). The concept of NbS emerged in the 2000s as a way to promote nature to help meet challenges associated with climate change, and it was supported and broadened by the International Union for Conservation of Nature (IUCN) (Cohen-Shacham et al., 2016) and later by the European Commission (Bourguignon, 2017).

The term NbS used in this report focuses on the aspects relating to climate change adaptation and disaster risk reduction. In this way, NbS increase resilience and reduce social and environmental vulnerability; generate multiple socio-economic benefits and contribute to achieving climate change adaptation objectives and several multilateral environmental agreements and sectoral policy objectives; restore, maintain and improve ecosystem health; enhance governance of natural resources with respect to the use of biodiversity and ecosystem services; and empower people and provide jobs and business opportunities.

1.2.2 Ecosystem approach and ecosystem-based approaches

The **ecosystem approach** is a strategy for the integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable way. An ecosystem approach applies appropriate scientific methods focused on levels of biological organisation, which encompass the essential structure, processes, functions and interactions among organisms and their environment. It recognises that humans, with their cultural diversity, are an integral component of many ecosystems. The ecosystem approach was endorsed at the Fifth Conference of the Parties (COP 5) of the Convention on Biological Diversity (CBD) in 2000 and is the primary framework for action under the convention (CBD, 2000).

The ecosystem approach also encompasses the term **ecosystem-based approaches** for generic use**.** The concept of ecosystem-based approaches was introduced by the CBD as a refinement in the context of biodiversity and climate change. After introducing the term initially, the CBD expanded its definition of ecosystem-based approaches to include other similar concepts (CBD, 2004b). The ecosystem approach or ecosystem-based approaches started from an ecological point of view and has moved from a focus on conservation issues towards a more holistic approach, including fostering public participation and integration of socio-economic needs (FAO, 2003).

1.2.3 Green infrastructure and blue-green infrastructure

GI, encompassing **BGI**, is defined by the European Commission (EC, 2020f) as being a strategically planned network of natural and semi-natural areas with other environmental features, designed and managed to deliver a wide range of ecosystem services such as water purification, air quality, space for recreation and climate change mitigation and adaptation. GI incorporates green spaces (or blue, if aquatic ecosystems are concerned) and other physical features in terrestrial (including coastal) and marine areas. This is often called BGI. On land, GI is present in rural and urban settings (EC, 2020f). The Commission has recently clarified the definitions of these three components in a guidance document (EC, 2019b) in recognition of their multiple scales and aspects, which can be challenging to capture.

Specifically for climate change adaptation and disaster risk reduction, GI solutions can boost disaster resilience through, for instance, functional floodplains, riparian woodland, protection of forests in mountainous areas, barrier beaches, coastal wetlands and urban GI to counteract the urban heat island effect while also helping reduce vulnerability to risks by supporting local livelihoods and economies (EC, 2013c).

1.2.4 Ecosystem-based adaptation

The term **EbA** was officially defined during the CBD's COP 10 in 2010 in Nagoya (CBD, 2010) and described by the Second Ad Hoc Technical Expert Group on Biodiversity and Climate Change under the CBD as using 'biodiversity and ecosystem services in an overall adaptation strategy. It includes the sustainable management, conservation and restoration of ecosystems to provide services that help people adapt to the adverse effects of climate change' and states that EbA 'can be cost-effective and generate social, economic and cultural co-benefits and contribute to the conservation of biodiversity' (CBD Secretariat, 2009). The EU refers directly to this definition in existing ecosystem-based initiatives. Friends of Ecosystem-based Adaptation (FEBA) proposed a set of five criteria to help sharpen the understanding of what qualifies as EbA and to avoid incorrect repackaging of business-as-usual conservation or development approaches (Bertram et al., 2018): (1) reduces social and environmental vulnerabilities; (2) generates societal benefits in the context of climate change; (3) restores, maintains or improves ecosystem health; (4) is supported by policies at multiple levels; and (5) supports equitable governance and enhances capacities.

1.2.5 Ecosystem-based disaster risk reduction

Eco-DRR is a concept that emerged through the Partnership for Environment and Disaster Risk Reduction (PEDRR), established in 2008. Eco-DRR operates in line with the Sendai Framework for Disaster Risk Reduction 2015-2030 (UNDRR, 2015), which encourages 'ecosystem-based approaches ... to build resilience and reduce disaster risk'. Eco-DRR adopts 'sustainable management, conservation and restoration of ecosystems to reduce disaster risk, with the aim to achieve sustainable and resilient development' (Estrella et al., 2013). Well-managed ecosystems, such as wetlands, forests and coastal systems, act as natural infrastructure that reduces physical exposure to multiple hazards and increases socio-economic resilience by sustaining local livelihoods and providing essential natural resources such as food, water and building materials (PEDRR, 2020).

Estrella and Saalismaa (2013), who first defined and coined the term Eco-DRR, provide an overview of important linkages between the environment and disasters and the role of ecosystems in DRR.

Although disasters can have adverse impacts on ecosystems with long-term implications for populations, depending on the related ecosystem services, environmental degradation in itself is a major driver of disaster risk. This report focuses on the latter aspect.

Environmental degradation in itself is a major driver of disaster risk

1.2.6 Natural water retention measures

NWRM, as defined by the European Commission (EC, 2014), are multifunctional measures that aim to protect water resources and address water-related challenges by restoring or maintaining ecosystems as well as natural features and characteristics of water bodies using natural means and processes (EC, 2014). Applying NWRM means enhancing the retention capacity of aquifers, soil, and aquatic and water-dependent ecosystems with a view to improving their status. NWRM support GI by improving the qualitative and quantitative status of water bodies and reducing vulnerability to floods and droughts. NWRM have been classified into two types (EC, 2014):

1. direct modification in ecosystems — e.g. restoration and maintenance of rivers, basins, ponds and wetlands; floodplain reconnection and restoration; restoration of lakes and aquifers);

2. changes in and adaptation of land use and water management practices in agriculture, forestry and urban settings — e.g. restoring and maintaining meadows and pastures, buffer strips and shelter belts, soil conservation practices; afforestation of headwater areas/mountainous areas/reservoir catchments, targeted planting to catch precipitation, land use conversion to improve water quality; green roofs; urban rainwater harvesting; sustainable urban drainage systems.

1.2.7 Sustainable management and ecosystem-based management

SM and **EbM** refer to the sustainable management of ecosystems, water, forests and natural resources. By making use of EbAp, SM and EbM are able to build resilience in ecosystems. They are based on 12 guiding principles for achieving sustainable management (CBD, 2000; CBD Secretariat, 2004). Sustainable management and EbM involve integrated, holistic approaches to management that consider the interdependence of human activities, ecosystems and human well-being, taking a long-term outlook across different spatial scales. EbM furthermore focuses on evaluating ecosystem services before management decisions are made (EEA, 2016a). The term **SFM** is also found under the umbrella of sustainable management and EbM. SFM was developed in line with the Rio forest principles, which are a means of applying the ecosystem approach for forests (FAO, 2003). No globally agreed definition of SFM has yet been reached, but this report applies Forest Europe's 2003 definition: 'stewardship and use of forest lands in a way and at a rate that maintains their biodiversity, productivity, regeneration capacity, vitality and their potential to fulfil, now and in the future, relevant ecological, economic and social functions, at local, national and global levels and that does not cause damage to other ecosystems' (Helsinki, 1993).

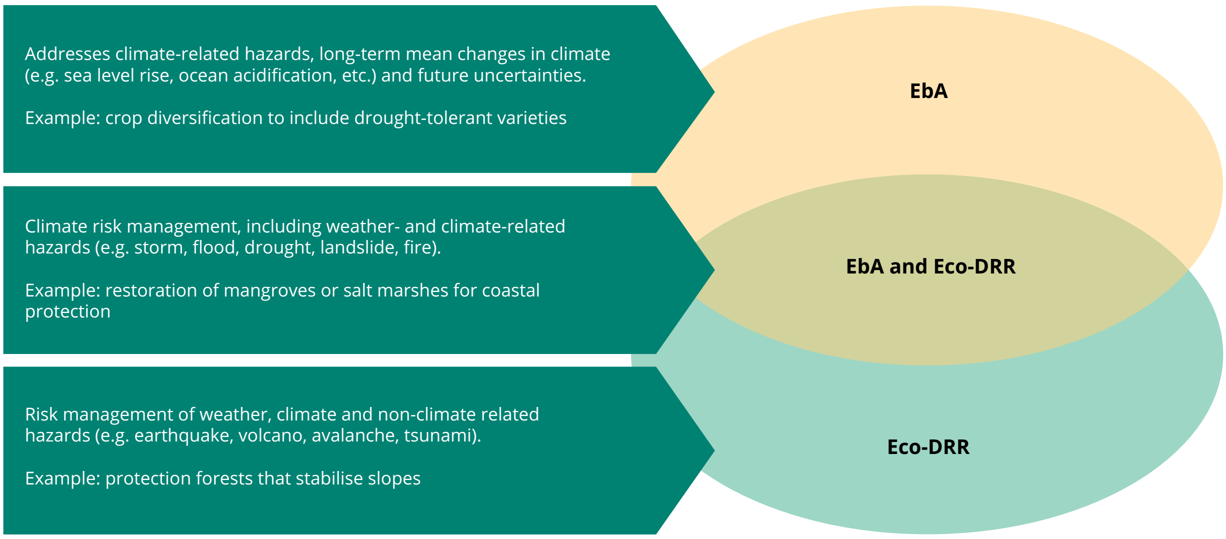
Box 1.1 Nature-based solutions, ecosystem-based adaptation and ecosystem-based disaster risk reduction as ways of enhancing synergy between climate change adaptation and disaster risk reduction

Climate change adaptation (CCA) and disaster risk reduction (DRR) offer complementary approaches for managing the risks associated with extreme weather- and climate-related events. Although climate change adaptation and disaster risk reduction focus on the shared goal of reducing vulnerability and enhancing resilience, they operate at different spatial and temporal scales, they are governed by different policy, institutional and legal frameworks and they involve different communities (Salvaterra et al., 2016; EEA, 2017a).

As a consequence of these potentially complementary relationships, benefits can be obtained from closer policy coordination and collaboration for climate change adaptation and disaster risk reduction. This was emphasised in an EEA report (EEA, 2017a), which uses a number of European case studies to highlight varying degrees of integration of climate change adaptation with disaster risk reduction and identifies nature-based solutions among good practices for integrating climate change adaptation and disaster risk reduction.

The EU-funded Placard project, which developed a platform for dialogue, knowledge exchange and collaboration between the climate change adaptation and disaster risk reduction communities, explored the different uses of terminology, norms and practices between the two communities and made recommendations for integrating ecosystem-based approaches within climate change adaptation and disaster risk reduction science, policy and practice (see Figure 1.2).

Figure 1.2 Linkages between ecosystem-based adaptation and ecosystem-based DRR and CCA and DRR



Source: EEA (2017a). Adapted from Salvaterra et al. (2016) and amended from Doswald et al. (2014) and CBD (2016).

Box 1.2 Sustainable climate actions and natural climate solutions

Two terms have recently emerged in the literature and policy documents, referring to nature-based solutions and the ecosystem approach/ecosystem-based approaches, but they focus predominantly on the potential for climate change mitigation and are therefore not addressed in this report:

- **Sustainable climate action (SCA)** is defined as a transition 'employing nature-based solutions, alongside a rapid phase-out of fossil fuel use, to reduce the scale and impacts of climate change, while providing positive benefits for biodiversity and other sustainable development goals.' (CBD Secretariat, 2020a).
- **Natural climate solutions (NCS)** refer explicitly to conservation and management actions that reduce greenhouse gas emissions from ecosystems and harness their potential to store carbon (Griscom et al., 2017). In a follow-up study it is clarified that natural climate solutions are also referred to as nature-based solutions (Griscom et al., 2020).

In a follow-up study it is clarified that natural climate solutions are also referred to as nature-based solutions

1.3 Nature-based solutions and societal challenges

Although the terms referring to NbS used in international and European policies vary (see Chapter 2), the common idea is that nature can be used as a valuable tool to strengthen the resilience of ecosystems, protect biodiversity and reduce the risk of extreme weather- and climate-related disasters. Furthermore, NbS can help address broader societal challenges, including social and economic challenges within the paradigm of sustainable development.

Table 1.1 lists various societal challenges (identified under the United Nations Sustainable Development Goals, SDGs) in which the cluster of NbS approaches can provide benefits in terms of climate change adaptation and disaster risk reduction. These societal challenges have been selected based on a review of the SDGs, a review of NbS frameworks (Kabisch et al., 2017a), an Eklipse Expert Working Group report to support planning and evaluation of NbS projects (Raymond et al., 2017b), the Urban Nature Atlas of the Naturvation project (Naturvation, 2020) and the European research programme Horizon 2020 outline of the societal challenges (EC, 2020g).

NbS and related approaches to climate change adaptation and disaster risk reduction are highly relevant for supporting the pathway towards sustainable development and the implementation of the SDGs (IUCN French Committee, 2019a).

Two sets of societal challenges identified under the SDGs with regard to climate change adaptation and disaster risk reduction are proposed in Table 1.1:

1. a set of 'core' challenges that are of relevance to climate change adaptation and disaster risk reduction;
2. a set of 'other' challenges, in which NbS provide multiple benefits in relation to mitigating climate change, environmental quality, health and sustainable economic development.

These societal challenges help us to approach decision-making with 'value-focused' thinking (Keeney, 2008), which is a creative method of decision-making that perceives the process as more of an opportunity to create something new rather than as a problem to be solved. In the context of this report, societal challenges underpinned by the SDGs are objectives for planning, in which the best combination of NbS and related concepts is identified in each case to improve the achievement of a specific objective. Using value-focused thinking can help find new, innovative solutions with multiple benefits and can help bring about transformative change (see Box 1.3).

Nature can be used as a valuable tool to strengthen the resilience of ecosystems, protect biodiversity and reduce the risk of extreme weather- and climate-related disasters

Table 1.1 Societal challenges and nature-based solutions for climate change adaptation and disaster risk reduction

Core societal challenges (CSCs) for CCA and DRR where NbS can provide direct benefits			
CSC no	**Challenges**	**Relevant SDG**	**Relevance of NbS and related concepts for CCA and DRR**
CSC 1	Improving society's resilience to extreme weather- and climate-related events	SDG 13	Increases resilience to abrupt natural hazards and slow-onset events including heat waves, heavy precipitation, droughts, flooding, sea level rise, wildfires, landslides and avalanches, windstorms and storm surges
CSC 2	Food security, sustainable agriculture and forestry	SDG 2, SDG 15	Protects, restores and promotes sustainable use of terrestrial ecosystems including sustainable management of forests, combats desertification, halts and reverses land degradation and loss of biodiversity
CSC 3	Preserving habitat, reducing biodiversity loss and increasing green and blue spaces	SDG 14, SDG 15	Reduces or prevents loss of natural capital/biodiversity and the ecosystem services it provides (clean air, water and soil); enhances coastal resilience and marine protection; increases natural insurance value, thus improving ecological resilience
CSC 4	Water management	SDG 6	Improves water quality and quantity and reduces water stress
CSC 5	Social justice, cohesion and equity, and reducing risk for groups of society highly vulnerable to climate change	SDG 10	Improves liveability, health and well-being for an ageing population and deprived communities to counteract growing inequalities and enhance social cohesion
CSC 6	Public health and well-being (related to climate change impacts)	SDG 3	Reduces mortality and morbidity directly or indirectly due to adverse heat and flood events; reduces stress and anxiety
CSC 7	Make cities and human settlements inclusive, safe, resilient and sustainable	SDG 11	Regenerates urban and rural areas; promotes sustainable land use and liveable urban development, including urban green and blue spaces and urban agriculture
Other societal challenges (OSCs) where NbS can provide multiple benefits			
OSC no	**Challenges**	**Relevant SDG**	**Sub-topics**
OSC 1	Environmental quality, including air quality and waste management	SDG 12	Regulate chemicals and micro-pollutants in water bodies, reduce eutrophication of water bodies, abate urban air pollution problems (e.g. traffic emission, industry) and restore polluted soils (e.g. heavy metal in former brownfield sites)
OSC 2	Public health and well-being (in addition to public health and well-being related to climate change)	SDG 3	Improve mental well-being (thinking, attentiveness, concentration and sociability, stress, depression, etc.); develop and maintain immune defences (against asthma, allergies, diabetes, intestinal disease, cancer, etc.); enhance physical health (exercise and sport)
OSC 3	Sustainable economic development and decent employment (including green jobs)	SDG 8	Promote inclusive and sustainable economic growth (potential for new economic opportunities) through full and productive employment and decent work for all (potential for green jobs)
OSC 4	Climate change mitigation	SDG 13	Sequestering carbon and reducing greenhouse gas emissions

Source: EEA.

Box 1.3 Nature-based solutions and transformative change

The complexity of tackling the climate change and biodiversity loss crises together requires a broad transformative change: 'Goals for conserving and sustainably using nature and achieving sustainability cannot be met by current trajectories, and goals for 2030 and beyond may only be achieved through transformative changes across economic, social, political and technological factors' (IPBES, 2019). One promising path to transformative change, which is increasingly explored both in research and in practice, involves working with and enhancing nature (Seddon et al., 2020b). In practice, this involves applying approaches that use nature, which in this report are referred to under the umbrella concept of nature-based solutions.

The EU and its Member States acknowledge in the official contribution to the development of the post-2020 Global Biodiversity Framework (CBD, 2020) that 'nature-based solutions with safeguards can deliver multiple and cost-effective benefits in addition to climate change mitigation and adaptation and disaster risk reduction, including benefits to human health, food and water security, land degradation neutrality, sustainable development and poverty eradication, gender equality and women's empowerment, respect for human rights and respect for the rights of indigenous peoples and local communities.' The EU and the Member States also stress that 'stepping up action for climate change at all levels and within and across all sectors requires scaling up of biodiversity conservation and ecosystem restoration, investing in nature-based solutions.'

Society is at a strategic point in time at which nature-based solutions and related concepts can play a key role in addressing the combined climate and biodiversity crises while contributing to accelerating transformative change.

Horizon Europe's proposed research and innovation mission on climate adaptation and societal transformation (Hedegaard et al., 2020) embraces an ambitious agenda for transformational adaptation and resilience building. It embraces a model of innovation designed to generate options in the face of uncertainty and diversity, and it tests integrated and exponential solutions to address the complex, multifaceted nature of the changes. The proposed mission promotes nature-based solutions and green-blue multipurpose infrastructure investments in ecosystems. It draws up a research and innovation agenda addressing incentives and financial schemes encouraging cooperation among landowners and a high degree of ecological connectivity, knowledge transfer and evidence within and across context-specific domains, demonstrable performance and efficiency of nature-based solutions at large scales, and connections between ecosystem quality and human health. The mission will support efforts to meet the EU's commitments under the biodiversity strategy for 2030.

1.4 Structure of the report

This report consists of six chapters addressing the following often interconnected elements:

1. Chapter 1 introduces the background, terminology and societal challenges relevant to NbS for CCA and DRR.
2. Chapter 2 explores how NbS are mainstreamed across the relevant policy frameworks at international and EU levels that drive climate change adaptation and disaster risk reduction, biodiversity and ecosystem conservation and restoration.
3. Chapter 3 presents the main elements of the increased knowledge base and highlights the opportunities for, limitations of and lessons learned from NbS for CCA and DRR in addressing the different risks in selected sectors and thematic areas.
4. Chapter 4 describes solutions and practical measures through analysis of a wide range of European NbS case studies, highlights how applying NbS for CCA and DRR addresses the key societal challenges, and presents examples of innovative measures/methods used in different sectors and thematic areas and identifying lessons learned.
5. Chapter 5 describes the relevant financing instruments for NbS for CCA and DRR in Europe.
6. Chapter 6 presents the conclusions.

In addition, there are six annexes:

1. Annex 1 describes past EEA activity relevant to this report.
2. Annex 2 provides an overview of key climate hazards identified for Europe.
3. Annex 3 Annex 3 presents the distribution of the selected cases of NbS in Europe by country and sector/thematic area.
4. Annex 4 provides a description of the 11 example cases of NbS in Europe
5. Annex 5 presents the relevant web platforms in Europe for NbS for CCA and DRR.
6. Annex 6 provides a glossary.

The report reviews various types of literature, such as EEA reports and information from EEA member countries, the scientific literature and outcomes from European research projects and other initiatives, the European web platforms relevant to NbS for CCA and DRR, and a large amount of European case studies. The European Environment Information and Observation Network (Eionet) contributed to this report by reviewing the draft report in August and September 2020.

2 Global and European policy frameworks

Key messages

- **Global and EU policy frameworks on sustainable development, disaster risk, climate and environment are increasingly embedding nature-based solutions for climate change adaptation and disaster risk reduction throughout their objectives, actions and instruments.**
- **The United Nations 2030 agenda for sustainable development is linked directly and indirectly to nature and can promote nature-based solutions across different sectors and policy areas and scale up their implementation as a means of contributing to transformative change.**
- **Strengthening the coherence between relevant EU policies can increase the level of ambition and support for nature-based solutions and encourage new, innovative applications for climate change adaptation and disaster risk reduction.**
- **Nature-based solutions for climate change adaptation and disaster risk reduction at the EU level can benefit from the use of agreed standards, quantitative targets (e.g. on application, coverage, quality) and measurable indicators to assess progress, effectiveness and the benefits.**

This chapter thus examines whether and how global and EU policy frameworks address the various nature-based solutions (NbS) options (see Section 1.2) as tools for climate change adaptation (CCA) and disaster risk reduction (DRR). A review of seven international policies and their respective conclusions, decisions and resolutions as well as 15 EU polices form the basis of the analysis. The findings serve as an entry point for increasing the potential contributions of individual policies and improving synergies across policies for implementing, operationalising and mainstreaming NbS for CCA and DRR. In this context, factors such as the level and form of support and how binding policies are, the type of obligations and the impact on multi-level governance play a critical role.

2.1 Approach

A 'policy' in this study is understood as a set of ideas or plans that is used as a basis for making decisions in politics and also usually includes instruments for its implementation; these can be a regulation, strategy, action plan, agenda or global agreement, decision, resolution or framework. The most relevant global and EU policies for enhancing the implementation and degree of support for NbS and related concepts were identified from a desk-based review, in-house expertise and research project findings (Davis et al., 2018; Knoblauch et al., 2019). The policies reviewed are outlined in Table 2.1.

Table 2.1 Global and EU policies included in the review

Policy area	Global policy	EU policy
Cross-cutting	• 2030 Agenda for sustainable development, Sustainable Development Goals (2015) • United Nations (UN) Convention to Combat Desertification (1996) ([a])	• European Green Deal (2019) • Bioeconomy strategy (2012) and its update (2018)
Biodiversity (including forestry)	• UN Convention on Biological Diversity (1993) ([a]) • Ramsar Convention (1975) ([a])	• Biodiversity strategy for 2030 (2020) • Green infrastructure strategy (2013) • Habitats Directive (1992) • Birds Directive (1979/2009) • EU forest strategy (2013) • LULUCF Regulation (2018)
Climate	• Sendai Framework for Disaster Risk Reduction 2015-2030 (2015) • UN Framework Convention on Climate Change (1994) ([a]), Paris Agreement (2015)	• Action plan on the Sendai Framework for Disaster Risk Reduction (2016) • Strategy on adaptation to climate change (2013, 2021)
Water and agriculture		• Farm-to-fork strategy (2020) • Floods Directive (2007) • Water Framework Directive (2000) • Common agricultural policy (2013) • Nitrates Directive (1991)
Urban	• New urban agenda – Habitat III (2016)	• Urban agenda for the EU (i.e. Pact of Amsterdam, 2016)

Note: ([a]) The original agreements/treaties, as well as relevant subsequent conclusions, resolutions and decisions, were reviewed. LULUCF, Land use, land use change and forestry.

Source: EEA.

The selected policies were first reviewed for their explicit inclusion of NbS, ecosystem-based approaches or related terminology and for any implicit references to the use of nature, ecosystems and biodiversity. The explicit search terms used are as follows (see Section 1.2 for definitions):

- umbrella concept:
  - nature-based solutions (NbS);
- approaches applying NbS concepts:
  - ecosystem approach (EA) and ecosystem-based approaches (EbAp);
  - sustainable management (SM), ecosystem-based management (EbM), sustainable forest management (SFM);
  - green infrastructure (GI) and blue-green infrastructure (BGI);
  - ecosystem-based adaptation (EbA);
  - natural water retention measures (NWRM);
  - ecosystem-based disaster risk reduction (Eco-DRR).

In a second step, references to climate change adaptation and/or disaster risk reduction were assessed. This was determined based on an initial key term search (i.e. risk, adaptation) as well as a thorough review of the documents to identify linkages with these concepts even in cases in which other terms were used.

Lastly, the extent to which a policy supports the deployment of NbS for CCA and DRR was assessed using expert judgement and on the basis of the review. Four levels of support were identified, as outlined in Table 2.2. The key considerations were the following: (1) Are NbS terms used 'explicitly' or 'implicitly' in the policy text (and related documents, for global policies)?; (2) Are these concepts linked in the policy to climate change adaptation and/or disaster risk reduction?; and (3) How strongly are NbS terms and related concepts for climate change adaptation and disaster risk reduction embedded in the policies and their objectives, actions instruments? These variables form the basis for determining the level of support of individual policies for NbS for CCA and DRR.

On this basis, three EU policies were found to offer 'low support' and were excluded from the remainder of the study (i.e. Birds Directive, Habitats Directive, Nitrates Directive). The remaining EU and global policies, which were determined to have strong explicit, strong implicit or medium support for NbS for CCA and DRR, are elucidated in more detail in the following sections.

Table 2.2 Levels of support of nature-based solutions for climate change adaptation and disaster risk reduction in policies

Level of support	Description
Strong explicit support	Explicit mention of NbS in connection with CCA and/or DRR; strong embedding throughout the policy, including in objectives, actions and instruments
Strong implicit support	Strong framing of nature, biodiversity and ecosystems as a means to address CCA and/or DRR challenges but no explicit mention of NbS; strong embedding throughout the policy, including in objectives, actions and instruments
Medium support	NbS are mentioned explicitly or implicitly, but they are not a prominent feature in the policy and/or linkages to CCA and DRR are weak or missing
Low support	NbS are neither a prominent feature of nor relevant for or mirrored in policy measure design and supported actions, particularly with regard to CCA and DRR

Source: Adapted from Davis et al. (2018).

2.2 Global policy framework

The use of NbS for CCA and DRR and their support for implementation have been promoted within major global agreements and in general in the international policy arena for issues such as climate, biodiversity, environment and disaster risk. In 2015 and 2016, four major global policy agreements were adopted at the United Nations (UN) level: the first was the Sendai Framework for Disaster Risk Reduction (SFDRR) 2015-2030, adopted in March 2015 (UNDRR, 2015); the second was the endorsement in October 2015 by the UN General Assembly of the 17 Sustainable Development Goals (SDGs) (UN, 2015); the third was the Paris Agreement on climate change, adopted in December 2015 (UNFCCC, 2015); and the fourth was the new urban agenda, adopted in October 2016 and endorsed by the UN in December 2016 (UN, 2017). In 2018, the Parties to the UN Convention on Biological Diversity (CBD) adopted, through Decision 14/5 (CBD, 2018a), the voluntary guidelines for the design and effective implementation of ecosystem-based approaches to climate change adaptation and disaster risk reduction (CBD Secretariat, 2019).

Other relevant conventions, frameworks and initiatives that are key for NbS for CCA and DRR and sustainable development include the UN Convention to Combat Desertification (UNCCD), the Ramsar Convention on Wetlands and the Global Platform for Disaster Risk Reduction. All of these global policy agreements recognise at different levels the role that ecosystems play in promoting sustainable development and in building resilience against disasters and climate change (see Table 2.1).

Global policy agreements recognise at different levels the role that ecosystems play in promoting sustainable development

Table 2.3 Explicit use of nature-based solution terms, references to climate change adaptation and disaster risk reduction, and level of support

Global policy	NbS-related terms							Reference to DRR	Reference to CCA	Level of support
	NbS	EA/EbAp	GI/BGI	EbA	SM/EBM/ SFM	NWRM	Eco-DRR			
SFDRR 2015-2030		✓		✓			✓	✓	✓	Strong explicit
SDGs					✓			✓	✓	Medium
UNFCCC ([a])	✓		✓	✓	✓	✓	✓	✓	✓	Strong explicit
CBD ([a])	✓	✓	✓	✓	✓	✓	✓	✓	✓	Strong explicit
UNCCD ([a])	✓			✓	✓		✓	✓	✓	Medium
New urban agenda	✓ ([b])	✓	✓	✓	✓			✓	✓	Strong explicit
Ramsar Convention ([a])		✓		✓	✓		✓	✓	✓	Medium

Note: ([a]) The original agreements/treaties, as well as relevant subsequent conclusions, resolutions and decisions, were reviewed.
([b]) Uses the term 'nature-based innovation'.

Source: EEA.

Table 2.3 outlines the explicit use of NbS terms within these policies and related decisions, resolutions and conclusions (see table note). The table further highlights whether or not the policies reference climate change adaptation and disaster risk reduction and their level of support for NbS terms for CCA and DRR. The most frequently used terms across the seven policies are EbA (all seven policies) and SM/EbM/SFM (six), followed closely by Eco-DRR (five) and NbS and EbAp (four). GI/BGI appear in three policies, while NWRM appear in two.

All of the policies reviewed were characterised as having strong explicit (four) or medium (three) support for NbS terms and consideration of disaster risk reduction and climate change adaptation. All of the policies and the way in which they support these concepts are outlined in more detail below.

2.2.1 Sendai Framework for Disaster Risk Reduction 2015-2030

The SFDRR recognises the role of ecosystems and environment as a cross-cutting issue in disaster risk reduction, emphasising that ecosystems need to be taken into account in undertaking risk assessments (priority action 1), in risk governance (priority action 2) and in investing in resilience (priority action 3) (UNDRR, 2015). The SFDRR clearly refers to climate change adaptation and disaster risk reduction and supports the uptake of EbAp, EbA and Eco-DRR, as shown in the following articles:

1. 'to enable policy and planning for the implementation ecosystem-based approaches' in order 'to build resilience and reduce disaster risk' in transboundary cooperation for 'shared resources, such as within river basins and along coastlines' (Article 28, 'Global and regional levels', paragraph (d), under priority action 2);

2. 'to strengthen the sustainable use and management of ecosystems and implement integrated environmental and natural resource management approaches that incorporate disaster risk reduction' (Article 30, 'National and local levels', paragraph (n), under priority action 3).

The Framework also recognises that both EbA and eco-DRR are part of a multidisciplinary, cross-cutting approach and that effective cooperation between them can yield more robust results in terms of increased resilience (UNDRR, 2015). The SFDRR was thus assessed as providing strong explicit support, particularly for EbAp, EbA and eco-DRR.

2.2.2 2030 Agenda for sustainable development and Sustainable Development Goals

Although NbS terms addressing global challenges are directly connected to the SDGs, the Goals refer explicitly only to the sustainable management of ecosystems and to both climate change adaptation and disaster risk reduction. Assessed as offering a medium level of support, the SDGs also address the biological diversity of ecosystems, the services they provide, and the adaptive capacity and resilience they offer society, specifically:

- SDG 6 (Clean water and sanitation) aims to protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes by 2020.
- SDG 12 (Responsible consumption and production) aims to achieve the sustainable management and efficient use of natural resources by 2030.
- SDG 13 (Climate action) explicitly addresses the challenge of combatting climate change by also increasing the resilience and adaptive capacity of society and ecosystems.
- SDG 14 (Life below water) and SDG 15 (Life on land) address the need to protect and restore marine and terrestrial ecosystems, to combat desertification and to halt land degradation and biodiversity loss.

It is recognised that climate change adaptation and disaster risk reduction — including tools delivering solutions through investment in innovative ways of harnessing nature's benefits for people, such as NbS — contribute to or are integrated in all of the SDGs (UNFCCC Secretariat, 2017). The 2030 agenda for sustainable development and the SDGs thus offer a medium level of support for NbS for CCA and DRR, with direct references to SM, EbM and SFM.

Climate change adaptation and disaster risk reduction contribute to or are integrated in all of the SDGs

Box 2.1 Focus on nature-based solutions at the UN Climate Action Summit, 23 September 2019, New York

The UN Climate Action Summit aimed to mobilise political and economic commitments at the highest levels to advance climate action to achieve an effective implementation of the Paris Agreement and the 2030 agenda for sustainable development. Among the 12 themes, theme 4, 'Unlocking the potential of nature in climate action', highlighted new initiatives to demonstrate that nature-based solutions are realistic and economically adequate options for climate action, providing over 30 % of mitigation potential and offering scalable solutions to increase resilience and adaptation.

A 'Nature-Based Solutions Coalition' for the summit was jointly led by China and New Zealand and facilitated by the UN Environment Programme and Convention on Biological Diversity and supported by several countries, including EU Member States, the European Commission, organisations, business leaders and stakeholders. Initial commitments had already been put forward from a coalition of food and agribusiness companies on halting deforestation, preserving biodiversity, restoring high-value natural ecosystems and encouraging regenerative agriculture and from another coalition of countries on preserving and restoring ecosystems and pursuing reforestation.

The 'Nature-Based Solutions for Climate Manifesto' (NbS for Climate Coalition, 2019) was launched at this summit with the support of more than 70 governments, the European Commission, private sector, civil society and international organisations and set ambitious priorities for unlocking the potential of nature-based solutions for climate action in the short term.

2.2.3 United Nations Framework Convention on Climate Change

The recent outcomes from the UNFCCC, including related decisions, technical papers and the Paris Agreement (UNFCCC, 2015), have supported the uptake of EbAp, EbA and SM and clearly addressed both climate change adaptation and disaster risk reduction. It is therefore evaluated as offering strong explicit support. Historically, the Cancun Agreements (UNFCCC, 2010) addressed the risks and impacts of slow-onset events along with those of extreme events including loss of biodiversity, land and forest degradation, and the Cancun Adaptation Framework promoted further action on climate change adaptation. In addition, the importance of EbAp in relation to addressing slow-onset events is evident from a UNFCCC technical paper (UNFCCC, 2012) prepared by the Secretariat. This paper recognises the role of EbAp as being particularly appropriate for slow-onset events and processes (including loss of biodiversity, land and forest degradation), because they involve long-term strategies for building resilience. The technical paper also outlines measures and tools for responding to slow-onset events, many of which are EbAp.

In 2015, the Paris Agreement was adopted at the 21st Conference of the Parties (COP 21) and recognised the need to protect the integrity of ecosystems and biodiversity for climate change adaptation and mitigation. The Agreement established a long-term global goal for climate change adaptation (Article 7) and confirmed that the 'Loss and damage initiative' is key to addressing the Agreement's aims (Article 8). These and other articles include several references to climate change adaptation, disaster risk reduction and adaptive capacity aiming to build the resilience of ecosystems through sustainable management of natural resources (UNFCCC, 2015).

Many of the nationally determined contributions (NDCs) submitted to the UNFCCC in 2019 include NbS: 104 of the 168 NDCs include NbS in their adaptation section, 77 in both their adaptation and mitigation sections and 27 as part only of their mitigation plans. Hence, 131 Parties (66 % of all signatories to the Paris Agreement) have highlighted NbS in one form or another (Seddon et al., 2020a). Despite the large number of Parties, these national intentions to deliver NbS for CCA show large differences in the level of ambition, depending on the regions, habitat types and the countries' level of economic development; a few include measurable evidence-based targets (Seddon et al., 2020a).

National intentions to deliver NbS for CCA show large differences in the level of ambition

At COP 25 (2019), a high-level leadership dialogue including heads of UN agencies discussed how to halt global deforestation by supporting countries to reduce their deforestation rates and improve forest management. The UNFCCC also has a 'Database on ecosystem-based approaches to adaptation' (now included in the Adaptation Knowledge Portal), which provides examples of how EbAp have contributed to sectoral development (e.g. through disaster risk reduction and biodiversity conservation). In preparation for COP 26 (postponed to 2021 due to the COVID-19, or coronavirus disease 2019, pandemic), the Parties that already have NDCs are expected to revise and increase their commitments' level of ambition, given that the initial NDCs are not sufficient to meet the goals of the Paris Agreement.

Overall, the UNFCCC policy documents (including the Paris Agreement) thus show strong explicit support for NbS for CCA and DRR, with direct references to all of the search terms except NbS.

2.2.4 United Nations Convention on Biological Diversity

The outputs from the CBD have shown strong explicit support for NbS during the last two decades and have recently included voluntary guidelines for the design and effective implementation of EbAp for CCA and DRR, which also refer to GI and NbS.

At COP 7 (2004), the Parties identified the 'ecosystem approach' (already endorsed through Decision 5/6 at COP 5 in 2000 (CBD, 2000)) as a tool to facilitate climate change adaptation and mitigation while also contributing to biodiversity conservation and sustainable use (Decision 7/11 (CBD, 2004b)). It was also agreed that the priority should be on facilitating implementation by making the ecosystem approach the primary framework for action under the Convention. Furthermore, at COP 7, the CBD invited the UNFCCC and UNCCD to collaborate through a joint liaison group (Decision 7/15 (CBD, 2004a)).

EbAp for CCA were highlighted at COP 10 (2010) for sustainable management, conservation and restoration of ecosystems, as part of an overall adaptation strategy (Decision 10/33 (CBD, 2010)). The strategic plan for biodiversity 2011-2020 was also adopted at COP 10, including (1) 20 Aichi biodiversity targets mostly to be achieved by 2020 (Aichi targets 10, 13 and 15 addressing issues such as biodiversity loss, sustainable use and improvement of biodiversity by safeguarding ecosystems, species and genetic diversity), and (2) a 2050 vision of the strategic plan for biodiversity 2011-2020, 'Living in harmony with nature', which stresses the role of biodiversity for human-well-being.

In 2014 at COP 12, the Parties acknowledged through Decision 12/20 on biodiversity and climate change and disaster risk reduction (CBD, 2014) that, while biodiversity and ecosystems are vulnerable to climate change, their conservation, sustainable use and restoration can play a significant role in climate change adaptation and mitigation, combating desertification and disaster risk reduction.

In 2016, COP 13 recognised the political, economic and social value of EbAp and encouraged the Parties to integrate EbAp with climate change adaptation and mitigation and disaster risk reduction into their strategic planning across sectors (Decision 13/4 (CBD, 2016)).

In 2018, the Parties at COP 14 adopted the 'Voluntary guidelines for the design and effective implementation of ecosystem-based approaches to climate change adaptation and disaster risk reduction' (Decision 14/5 (CBD, 2018a)), including agreed principles and safeguards to promote more integration of biodiversity, ecosystems, climate change adaptation and disaster risk reduction among the Parties

(CBD Secretariat, 2019). Furthermore, in Decision 14/34 (CBD, 2018b), a comprehensive participatory process for preparing a 'post-2020 global biodiversity framework' was adopted by the Parties. The new post-2020 global biodiversity framework needs to take stock of shortcomings and to identify innovative ways to advance the implementation of the Convention, in full alignment with the 2030 agenda for sustainable development and the SDGs.

In 2019, the CBD Parties were invited to submit possible targets and indicators for the post-2020 global biodiversity framework related to the interlinkages and interdependencies between biodiversity and climate change. Their views were compiled by the CBD Secretariat and made available for upcoming meetings (CBD, 2020). The updated zero draft of the post-2020 global biodiversity framework (CBD Secretariat, 2020b) includes among the 2030 targets a specific one related to NbS and EbAp for CCA, DRR and climate change mitigation as effective ways of ensuring resilience and minimising any negative impacts on biodiversity.

At COP 15 (originally planned for October 2020 in Kunming, China, but postponed to 2021 due to COVID-19 pandemic), the CBD will adopt the post-2020 global biodiversity framework, aiming to achieve the 2050 vision 'Living in harmony with nature'.

In the context of the Convention, the concept of 'transformative, systemic change across multiple sectors and actors' has emerged in recent years as an effective way to avoid the catastrophic biodiversity losses predicted for the near future and to fully achieve the vision of the SDGs (CBD Secretariat, 2017). There is a need (1) to identify the barriers to, and opportunities for, the transformative change (including changes in institutions and behaviours) needed to address the drivers of biodiversity loss, and (2) to ensure that the CBD through the post-2020 global biodiversity framework can leverage such changes (CBD Secretariat, 2017) and achieve the 2050 vision for biodiversity (CBD, 2018c).

Overall, given the longstanding integration and explicit references to NbS, the CBD policy documents are assessed as offering strong explicit support for NbS for CCA and DRR.

CBD policy documents are assessed as offering strong explicit support for NbS

2.2.5 United Nations Convention to Combat Desertification

The UNCCD is a legally binding international agreement linking environment and development to sustainable land management (UNCCD, 1994). UNCCD decisions address issues such as climate change adaptation and the sustainable management of land and water resources but have not — until recently — explicitly referred to EbA, Eco-DRR or NbS. This development started with Decision 3/COP 8 (UNCCD, 2007) at COP 8 (2007), i.e. the UNCCD's 10-year strategic plan and framework (2008-2018), which recognised the role of ecosystem services (especially in dryland ecosystems) in mitigating drought and preventing desertification. It further highlights the synergies between desertification/ land degradation and drought issues and climate change adaptation and biodiversity conservation.

Then in 2015 at COP 21, the Parties adopted the 'land degradation neutrality (LDN) target' (target 15.3 of SDG 15 'Life on land'), i.e. the amount of healthy and productive land should remain stable starting in 2030, and also agreed to develop indicators for measuring progress in achieving land degradation neutrality and for enhancing the land's resilience to climate change and halting biodiversity loss linked to ecosystem degradation. Subsequently, the UNCCD 2018-2030 Strategic Framework, the most comprehensive global commitment to addressing the land degradation neutrality concept was adopted at COP 13 (2017) through Decision 7/COP 13 (UNCCD, 2017), promoting the sustainable management of land and water resources (introduction and strategic objective 1) and addressing climate change adaptation for drought to enhance the resilience of vulnerable populations and ecosystems (strategic objective 3).

The Delhi Declaration: Investing in land and unlocking opportunities was adopted at COP 14 (2019), addressing — among other objectives — ecosystem restoration and sustainable management (UNCCD, 2019b). Furthermore, Decision 19/COP 14 (UNCCD, 2019a) requests coordination among all Rio conventions and relevant partners to 'ensure coherence and alignment in the way ecosystem-based adaptation, ecosystem-based disaster risk reduction, nature-based solutions and sustainable land management are categorised through the UNCCD science-policy instruments and the UNCCD Knowledge Hub'. However, the Delhi Declaration demonstrates that all three Rio conventions fully support NbS.

In conclusion, the UNCCD policy documents are assessed as offering a medium level of support for NbS for CCA and DRR, as they only directly address NbS, EbA, SM/EBM/SFM and eco-DRR.

2.2.6 New urban agenda — Habitat III

The new urban agenda, endorsed in December 2016 by the UN General Assembly, set global standards of achievement in environmentally sustainable and resilient urban development (UN, 2017). The agenda clearly supports climate change adaptation (Articles 13(g), 63, 79, 80, 101, 125, 143) and disaster risk reduction (Articles 13(g), 65, 77, 101, 165) and promotes the uptake of NbS, SM/EbM/SFM, EbAp and EbA in several articles (65, 69, 71, 77, 80, 101).

In conclusion, the agenda offers strong explicit support for NbS for CCA and DRR and makes direct references to NbS, EbAp, EbA and SM/EbM/SFM.

2.2.7 Ramsar Convention (Convention on Wetlands)

The Ramsar Convention provides the framework for national and international cooperation on the conservation and 'wise use' of wetlands and their resources and addresses the concept of working with nature in general terms (Ramsar, 1994). The concept of 'wise use of wetlands' is key to the Ramsar Convention's work. The Parties at COP 3 (1987) adopted an initial definition of 'wise use'. New key Ramsar definitions were adopted at COP 9 (2005) in Resolution IX.1, Annex A (Ramsar, 2005). The definition of 'wise use' was updated to refer explicitly to EbAp: 'Wise use of wetlands is the maintenance of their ecological character, achieved through the implementation of ecosystem approaches, within the context of sustainable development' (Ramsar, 2005).

Over the last decade or so, a few Ramsar Convention resolutions have begun to make more reference to climate change adaptation and disaster risk reduction and to promote the uptake of EbAp, EbA, Eco-DRR by enhancing the conservation and restoration of peatlands. For example, the Parties at COP 10 (2008) adopted Resolution X.24 (Ramsar, 2008), affirming the role of healthy wetlands in increasing resilience to climate change and extreme weather events and ensuring that responses to climate change would not lead to serious damage to the ecological character of wetlands. Then the Parties at COP 12 (2015) approved Resolution XII.13 (Ramsar, 2015), which in paragraphs 13, 17, 20 and 25 recognised the relevant role of healthy and well-managed wetland ecosystems in reducing disaster risk and encouraged countries to mainstream disaster risk reduction measures in wetland management plans and to integrate wetland EbM (including EbAp and EbA) with climate change adaptation and disaster risk reduction strategies and plans. Finally, the Parties at COP 13 (2018) adopted Resolution XIII.13 (Ramsar, 2018), which addressed peatland conservation and restoration of peatlands for climate change adaptation, disaster risk reduction and enhancing biodiversity to contribute to achieving the SDGs.

Given these considerations, the Ramsar Convention was assessed as offering an increasing level of support over the last decade for NbS for CCA and DRR. It refers directly to EbAp, EbA, SM/EbM/SFM and Eco-DRR and thus offers a medium level of support.

2.3 EU policy framework

As with the global policy framework, EU policies support to varying degrees the uptake and implementation of NbS for CCA and DRR. To assess the type and level of support, we assessed 15 EU policies (see Table 2.1) spanning biodiversity (including forests), climate, urban, water and agriculture policy areas and two with a cross-cutting focus. The 12 policies found to offer medium or strong explicit/implicit support are discussed in this chapter. The explicit use of NbS terms within these policies is outlined in Table 2.4, as is whether or not the policies reference climate change adaptation and disaster risk reduction and their level of support for NbS for CCA and DRR.

EU policies support to varying degrees the uptake and implementation of NbS

The most frequently used term is SM and EbM (10 of 13 policies), followed closely by NbS (8 of 13 policies) and GI/BGI (7 of 13 policies). EbAp (3 of 13 policies), EbA, NWRM and Eco-DRR (each mentioned in 2 of 13 policies) were used less frequently.

The use of terms can clearly be linked to the evolution of the dominant EU discourse and introduction of dedicated policies. The bioeconomy strategy in 2012 (EC, 2012), for example, did not mention NbS and only included GI once. Its update in 2018 (EC, 2018a) included NbS, BGI, EbAp and SM. Similarly, newer policies such as the EU biodiversity strategy for 2030 (EC, 2020e) and the EU action plan on the Sendai Framework for DRR (EC, 2016a) include numerous key terms, while the older Habitats and Birds Directives do not use these terms explicitly, despite the relevance of such concepts for these directives' policy ambitions.

Regarding the degree of support, the majority of the policies reviewed were characterised as offering strong explicit (six) or medium (seven) support for NbS in the context of DRR and CCA. It is relevant to highlight that the new EU Adaptation Strategy (EC, 2021a) moves away from its emphasis only on GI in 2013 to include stronger explicit support for NbS alongside GI/BGI. Strong implicit support was found only in the case of the Floods Directive and, unsurprisingly, older directives, including the Nitrates, Birds and Habitats Directives, offered low levels of support, as did the newer farm-to-fork strategy. The policies found to offer a high or medium level of support are outlined in more detail below.

The majority of the policies reviewed were characterised as offering strong explicit (six) or medium (seven) support for NbS

Table 2.4 Explicit use of nature-based solutions terms, references to climate change adaptation and disaster risk reduction, and level of support

EU policy	NbS-related terms							Reference to DRR	Reference to CCA	Level of support
	NbS	EA/EbAp	GI/BGI	EbA	SM/EbM/ SFM	NWRM	Eco-DRR			
European Green Deal	✓							✓	✓	Strong explicit
Bioeconomy strategy (update)	✓	✓	✓		✓				✓	Medium
Biodiversity strategy for 2030	✓		✓		✓			✓	✓	Strong explicit
Green infrastructure strategy	✓	✓	✓	✓			✓	✓	✓	Strong explicit
Forest Strategy			✓		✓				✓	Medium
LULUCF Regulation					✓			✓	✓	Medium
Action plan on the Sendai Framework	✓	✓	✓	✓	✓	✓	✓	✓	✓	Strong explicit
Adaptation strategy	✓		✓		✓			✓	✓	Strong explicit
Floods Directive					✓	✓		✓	✓	Strong implicit
Water Framework Directive					✓				✓	Medium
Urban agenda	✓		✓					✓	✓	Medium
Farm-to-fork strategy	✓				✓				✓	Medium
Common agricultural policy					✓			✓	✓	Medium

Note: LULUCF, Land use, land use change and forestry.

Source: EEA.

2.3.1 European Green Deal

Although the European Green Deal provides a roadmap of actions and anticipated law and strategies and action plans across different policy areas, only the Communication on the Deal itself is considered in this review (EC, 2019c). The Green Deal exhibits strong explicit support for NbS for both CCA and DRR, placing NbS at the centre of the work on climate adaptation and mitigation and highlighting the role of NbS in ensuring healthy and resilient seas and oceans. Specifically, it 'aims to protect, conserve and enhance the EU's natural capital, and protect the health and well-being of citizens from environment-related risks and impacts'. The value of ecosystems and their ability to provide essential services, including mitigating natural disasters and regulating the climate, are outlined. The EU biodiversity strategy for 2030, the farm-to-fork strategy for a fair, healthy and environmentally friendly food system and the new EU strategy on adaptation to climate change (see below) will be central in this regard. The intention to adopt a more ambitious EU strategy on adaptation to climate change is also outlined in the Green Deal, citing the need to 'strengthen efforts on climate-proofing, resilience building, prevention and preparedness' and ensure public and private investment in NbS.

2.3.2 Bioeconomy strategy

Mitigating and adapting to climate change is one of the five objectives of the EU bioeconomy strategy. The focus of this objective in practice and throughout the strategy is, however, on mitigation. The original bioeconomy strategy (EC, 2012) only explicitly mentions GI once. It highlights the need to 'work on land as a resource to develop the full range of ecosystem services, from crops to fresh water to climate change mitigation and adaptation, and taking into account landscape level effects and connectivity, to transition towards more sustainable production'. Its update (EC and Generaldirektion Forschung und Innovation, 2018) increases the consideration of NbS and explicitly outlines them as a tool to rehabilitate urban brownfield sites, apply nature-based remediation solutions, and stimulate GI to reduce the urban pressure on agricultural and forest land as well as to solve complex soil pollution. In its second objective, the strategy calls for timely action to 'avoid ecosystem degradation, restore and enhance ecosystem functions, which can increase food and water security, and contribute substantially to the adaptation and mitigation of climate change'. The link to disaster risk reduction is largely absent, indicating a medium level of support for NbS for CCA and DRR.

2.3.3 Biodiversity strategy for 2030

The EU biodiversity strategy for 2030 (EC, 2020e) aims to ensure that ecosystems are healthy, resilient to climate change and rich in biodiversity and that they deliver the range of services essential to the prosperity and well-being of citizens. NbS are highlighted as essential for emission reduction and climate adaptation. In particular, ecosystem restoration is seen as a key instrument and will be subject to legally binding EU nature restoration targets in 2021 to restore degraded ecosystems, in particular those with the most potential to

capture and store carbon and to prevent and reduce the impact of natural disasters. Sustainable management also features prominently, highlighting the importance of sustainable forest, nutrient, water resource and soil management. Applying EbM approaches is encouraged for the conservation of marine resources. GI is spotlighted in the urban context: 'planting trees and deploying green infrastructure will help us to cool urban areas and mitigate the impact of natural disasters'. Here, setting up an EU Urban Greening Platform is envisaged under a new 'Green City Accord', encouraging all the mayors of European cities with more than 20 000 inhabitants to establish urban greening plans by 2021. The strategy recognises the value of investing in natural capital as a means to achieve these ambitions and to recover from the COVID-19 crisis. One goal is to unlock at least EUR 20 billion a year for spending on nature, coming from, for example, Invest EU (NbS for a green recovery), 25 % of the EU budget dedicated to climate action (largely through ecosystem restoration) and public authorities (e.g. green public procurement). Given these considerations, the EU biodiversity strategy for 2030 is assessed as showing strong explicit support for NbS for CCA and DRR.

EU biodiversity strategy for 2030, ecosystem restoration is seen as a key instrument

2.3.4 Strategy on green infrastructure

Creating new and restoring degraded ecosystems as part of Europe's GI network is essential to enhance the delivery of ecosystem services at landscape level, provide healthy habitats for species and improve the connectivity between areas in urban and rural landscapes throughout Europe (Naumann and Davis, 2020). The EU strategy on green infrastructure recognises this potential and explicitly refers to green infrastructure and nature-based solutions as well as to ecosystem-based approaches to adaptation and disaster risk reduction, thus showing strong explicit support for NbS for CCA and DRR (EC, 2013c). The strategy emphasises the importance of investing in GI solutions that boost disaster risk reduction and help societies to adapt to the impacts of climate change as a means to reduce negative effects and support local economies, green growth and sustainable livelihoods. Specifically, Eco-DRR and GI are outlined as providing 'many benefits for innovative risk management approaches and adapting to climate change-related risks'. As cities and local authorities are the first to deal with the immediate consequences of such disasters, the strategy highlights their critical role in implementing prevention measures such as GI. The strategy also includes specific examples of GI, such as functional floodplains, riparian woodland, protecting forests in mountainous areas, barrier beaches and coastal wetlands that can be used in combination with infrastructure for disaster reduction, such as river protection works. The intention to promote GI through regional or cohesion, climate change and environmental policies, disaster risk management, health and consumer policies, and the common agricultural policy is outlined.

2.3.5 Forest strategy

Promoting nature-based solutions and ecosystem-based approaches in rural areas can be accomplished in part through promoting multifunctional agroforestry, woody landscape features or food forests as part of a larger GI network (Naumann and Davis, 2020). The EU forest strategy (EC, 2013a) mentions SFM as a strong underlying objective, aiming to maintain or enhance the delivery of ecosystem services and provide other societal benefits, such as jobs. The strategy also mentions financing instruments to support 'sustainable forest management' and sets out objectives for both Member States and the Commission. It has a focus on enhancing, restoring and maintaining forest ecosystems' resilience and adaptive capacity to fulfil, now and in the future, relevant ecological, economic and social functions and not to cause damage to other ecosystems. The strategy further outlines the need to create new woodland and agroforestry ecosystems. However, as there are no references made to disaster risk reduction, the strategy is assessed as offering medium support for NbS for CCA and DRR.

It should be noted that a post-2020 EU forest strategy, which is aligned with the European Green Deal and ensures the multifunctionality of forests, is expected in 2021. The new EU forest strategy, like the other strategies and policies under the European Green Deal, is likely to opt for a holistic integrated approach. This means an approach that coordinates and acts upon integrating the multiple functions of forest ecosystems and the benefits of forest ecosystem services for society and people's well-being, as well as making close links between the management and use of forest resources throughout the forest value chain. Aspects of increased protection of biodiversity in forests, resilience to climate change impacts and restoration of degraded forests are expected to be included. Approaches to management that integrate these aspects, such as the closer-to-nature approach to forestry will have a larger role to play. This will support a more precise implementation of the SFM concept to achieve integrated multifunctional forest management objectives with the minimum necessary human intervention, combining conservation with productivity.

2.3.6 Regulation on land use, land use change and forestry

The EU Regulation on land use, land use change and forestry (LULUCF Regulation) requires that Member States offset greenhouse gas emissions from the land use sector for the period from 2021 to 2030 and contribute to enhancing sinks in forests and soils (EU, 2018). The policy also provides incentives for improving land management, not least to deliver on EU climate targets. Projects including agroecology, agroforestry, the protection of wetlands and the restoration of degraded lands are provided as examples of how the LULUCF sector can enhance its contributions to climate mitigation and adaptation and strengthen the productivity and resilience of the sector. Sustainable management practices are also explicitly outlined as a valuable investment to 'reduce the risks associated with natural disturbances'. However, safeguards against the negative impacts on biodiversity and nature protection (e.g. regarding old growth forests) are not outlined (Böttcher et al., 2019). Consequently, the LULUCF Regulation is assessed as showing medium support for NbS for CCA and DRR.

Sustainable management practices 'reduce the risks associated with natural disturbances'.

2.3.7 Action plan on the Sendai Framework for Disaster Risk Reduction 2015-2030

The action plan on the Sendai Framework for Disaster Risk Reduction 2015-2030 (EC, 2016a) was the only policy at EU level reviewed that explicitly uses all NbS-related key terms. It exhibits strong explicit support for NbS for CCA and DRR, as it clearly supports the use of EbAp to contribute to the conservation, enhancement and restoration of biodiversity, ecosystems and ecosystems services in urban, rural, coastal and natural areas. It frames such solutions as a 'positive and cost-efficient way of supporting climate change adaptation and disaster risk reduction, while often providing significant co-benefits in terms of climate change mitigation or human health, safety and well-being'. In this way, the action plan calls for a need to strengthen the links between disaster risk management, climate change adaptation and biodiversity strategies and to reinforce the links between disaster risk management, climate change adaptation and urban policies and initiatives.

Specifically, key area 2 aims to strengthen the links between disaster risk management, climate change adaptation and biodiversity strategies. Key area 3 aims to promote risk-informed investments to foster and implement EbAp to disaster risk reduction. Finally, the action plan encourages the use of NbS as a systemic approach for urban and territorial resilience. Through building the resilience of people, ecosystems, infrastructure, policies and planning processes, and taking into account climate-related risks and the need for adaptation, the implementation of the Sendai Framework also forms part of the EU's contribution to the 2030 agenda for sustainable development.

2.3.8 Strategy on adaptation to climate change

The first EU strategy on adaptation to climate change was launched in 2013 (EC, 2013b) and explicitly encourages implementing GI and applying EbAp approaches as part of a coordinated European approach to climate adaptation (Mysiak et al., 2018). The Strategy underwent a positive evaluation in 2018, demonstrating steady progress on all of its actions.

A new, more ambitious EU Strategy on Adaptation to Climate Change was launched in February 2021 (EC, 2021a). This strategy is a key priority in the European Green Deal and aims to make the EU climate-resilient by 2050 by increasing society's adaptive capacity and minimising vulnerability. The strategy recognises CCA as a crucial component to achieving the Paris Agreement's global adaptation goal and aims to make 'adaptation action smarter, more systemic, and faster'. The strategy explicitly recognises BGI, SM/EbM and NbS, not least for CCA and DRR. The strategy has thus been assessed as providing strong explicit support for NbS.

NbS for adaptation, including coastal protection, are identified as a priority due to their cost-efficiency and ability to provide multiple benefits. Relevant EU funding and investment programmes are called on to consider NbS for adaptation and provide incentives to Member States to achieve climate resilience. Increased action is proposed to better understand, monitor and evaluate climate change impacts on ecosystems and to develop robust ecosystem management measures to reduce climate change risks. In particular, 'biodiversity-friendly afforestation, reforestation and closer-to-nature-forestry practices' are needed for the agriculture and forestry sectors. Finally, the strategy supports tool and method development to assess the vulnerability, resilience and cost-efficiency and effectiveness of NBS, taking into account projected changes in climate.

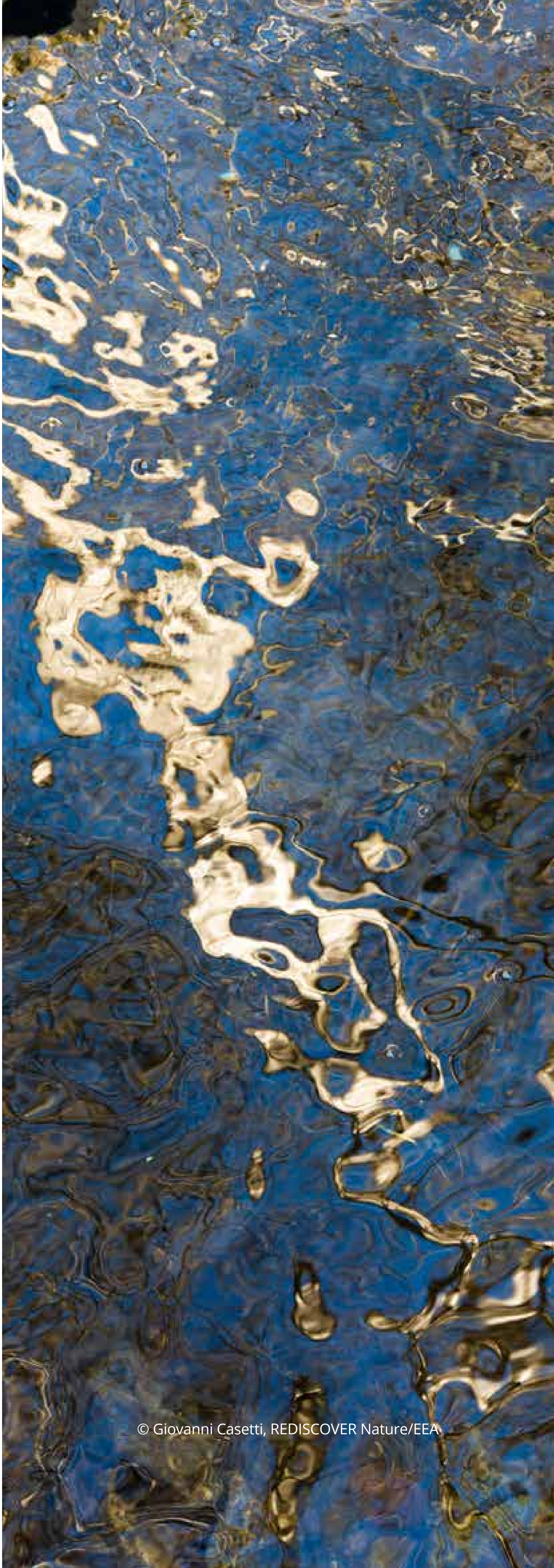
2.3.9 Floods Directive

The EU Floods Directive (EU, 2007b), while not explicitly referring to climate change adaptation or disaster risk reduction, aims to prevent adverse impacts of flooding on 'human health and life, the environment, cultural heritage, economic activity and infrastructure' and is thus assessed as offering strong implicit support for NbS for CCA and DRR. The Directive recognises the value of NbS for use within natural, rural and urban areas to mitigate catchment flood risk, not least as a potential approach to water retention that can be used in flood risk management plans. Such plans are to take into account the characteristics of the particular catchment area and include promoting sustainable land use practices, improving water retention and allowing controlled flooding of certain areas in the case of a flood event (Article 7). However, while several public authorities at local and regional level have made use of this opportunity and implemented NbS (e.g. relocating dykes, using floodplain forests) to cope with floods in a sustainable way, they still represent only a small percentage of authorities. Only a limited number of flood risk management plans use GI as a flood protection measure (ECA, 2018; Schwarz et al., 2018). The Directive also takes into account future changes in the risk of flooding as a result of climate change (in contrast to the Water Framework Directive. Relevant aspects such as areas that have the potential to retain flood water, such as natural floodplains, are to be taken into account in decision-making processes and in the flood risk management plans. However, only minimal guidance is available on the role of measures in combination with climate change or — where relevant — land use and land cover changes.

2.3.10 Water Framework Directive

The term NbS is not mentioned by the EU Water Framework Directive (WFD) (EU, 2000). However, this fact has to be interpreted against the background that the WFD was developed before the concept of NbS became popular. In contrast, sustainable water management is explicitly mentioned and is also one of the Directive's main objectives. NbS, such as targeted land protection, revegetation, riparian restoration, improved agricultural practices and wetland restoration and creation, are already being applied, although not labelled as such (Trémolet, 2019). Thus, the WFD is assessed as showing medium support for NbS as a tool to achieve good ecological status or potential of (ground)water bodies in natural, rural and urban areas. It also provides a strong argument for applying NbS by outlining the need to protect, enhance and restore functioning ecosystems and water bodies to deliver multiple ecosystem services (Trémolet, 2019). For drought resilience, however, the WFD and the river basin management plans are still limited in their recognition of the capacity of NbS to contribute to adaptation and disaster risk reduction goals. The WFD promotes further integration of protection and sustainable management of water into other EU policy areas such as energy, transport, agriculture, fisheries, regional policy, spatial planning and tourism.

Sustainable water management is explicitly mentioned and is also one of the Directive's main objectives



2.3.11 Urban agenda for the EU

Urban areas offer great potential to contribute to the protection of species and habitats as well as climate change adaptation and disaster risk reduction through the implementation of biodiverse NbS (e.g. urban allotments and gardens, green parks, pollinator sites, green corridors, wetland restoration, sustainable urban drainage systems or green walls and roofs) to bring more and more diverse nature into cities (Naumann and Davis, 2020). The urban agenda for the EU (EC, 2016b) makes explicit reference to NbS and GI, not least in the context of CCA and DRR. Adaptation to climate change, including GI solutions, is a priority theme whose objective is to 'anticipate the adverse effects of climate change and take appropriate action to prevent or minimise the damage it can cause to urban areas'. The focus is on vulnerability assessments, climate resilience and risk management (including the social dimension of climate change adaptation strategies). A further priority theme is the 'sustainable use of land and nature-based solutions', whose objective is to 'ensure that the changes in urban areas (growing, shrinking and regeneration) are respectful of the environment, improving quality of life'. The focus is on urban sprawl, development of brownfield sites and renaturalising or 'greening' urban areas. The partnership formed under the NbS theme also aims to identify best practices for funding schemes (Trémolet, 2019). Given the flexibility awarded to Member States in choosing priority themes (i.e. potentially neglecting greening entirely), the urban agenda's level of support for NbS for CCA and DRR can be considered medium. However, considering the COVID-19 pandemic has clearly raised the awareness of the role of urban BGI for human mental and physical health, an increase in the level of support can be expected, also taking into account the job provision potential of urban NbS.

Urban areas offer great potential to contribute to the protection of species and habitats

2.3.12 Farm-to-fork strategy

The farm-to-fork strategy is a key component of the European Green Deal, aiming to 'make food systems fair, healthy and environmentally-friendly' (EC, 2020d). In this context, NbS are explicitly recognised for their ability to help deliver better climate and environmental results and increase climate resilience. Total funding of EUR 10 billion is proposed for research and innovation on food, the bioeconomy, natural resources, agriculture, fisheries, aquaculture and the environment, as well as on the use of digital technologies and NbS for agri-food systems. The strategy also promotes sustainable management in the context of fish and seafood resources and coastal management. The level of support is therefore considered medium, although the strategy has only limited links to climate change adaptation and lacks ties to disaster risk reduction.

2.3.13 Common agricultural policy

The common agricultural policy (CAP) is highly relevant, given the impacts of agriculture on biodiversity (EEA, 2020d) and climate. All CAP subsidies are subject to cross-compliance with environmental legislation. Specific environmental investments currently include mandatory greening measures under the 'first pillar' (e.g. crop diversification and maintenance of permanent grassland and 'ecological focus areas' on arable land) and voluntary measures under the 'second pillar' (e.g. agri-environment schemes, organic farming and agroforestry). The second pillar's expenditure is tied to the EU's rural development policy (ENRD, 2020) and corresponding national rural development plans, with climate change adaptation, risk prevention, and preservation of agriculture- and forestry-related ecosystems explicit priorities (EU, 2014). Despite its relevance, the CAP is assessed as providing only medium support for NbS for CCA and DRR, largely because of its expenditure pattern (EC, 2021a, 2021b) and the limited effectiveness of the greening measures thus far (ECA, 2017, 2020). In line with the European Green Deal, the environmental ambitions for the CAP spending period 2021-2027 will be raised, but the greening architecture itself is unlikely to undergo major changes.

2.4 Gaps, barriers and opportunities

In the last decade, global and EU policies on sustainable development, disaster risk, climate and environmental issues have increasingly embedded NbS for CCA and DRR throughout their objectives, actions and instruments (Davis et al., 2018; Knoblauch et al., 2019). Policies have begun to reflect the growing recognition that, while ecosystems and their services are vulnerable to climate change, they can also serve to protect society from climate change impacts. These climate and biodiversity crises are interdependent, as they share multiple drivers; accordingly, they are increasingly being addressed in unison (Seddon et al., 2019). The Intergovernmental Panel on Climate Change (IPCC) and the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) recognise this need (IPCC, 2018; IPBES, 2019), as does the European Commission in its ambitious European Green Deal and its associated strategies.

Climate and biodiversity crises are increasingly being addressed in unison

The global and EU policies reviewed in this study were found to have almost equal numbers of policies providing medium or strong explicit support for NbS for CCA and DRR, although their use of key terms differs. At the global level, EbA and SM/EbM are most frequently used, followed by Eco-DRR. SM/EbM were frequently used at the EU level, followed by NbS and GI/BGI. Eco-DRR was, in contrast, only mentioned in two EU policies (green infrastructure strategy and action plan on the Sendai Framework for DRR 2015-2030). Although it is unsurprising that climate policies at both global and EU levels exhibit strong explicit support for NbS, given its known value for climate change adaptation and climate-related disaster risk reduction, it is nevertheless noteworthy given the historically slow recognition and uptake of NbS as a tool outside biodiversity/restoration discussions and within the climate discourse. These synergies in terms of using NbS as a tool to achieve multiple policy objectives in parallel are only now beginning to draw momentum within, for example, the UNFCCC conferences, the SDGs and the European Green Deal (Seddon et al., 2019).

Despite the large number of policies assessed as showing strong potential support, the degree and type of support varies widely in practice and leaves several important gaps. At both EU and global levels, a persistent weakness in policy frameworks is the lack of coherence among policies (Somarakis et al., 2019) and fragmented governance arrangements (Trémolet, 2019). This can challenge the collaboration, synergies and degree of joint financing across multiple agendas. At the EU level, further alignment of sectoral planning instruments and mainstreaming of NbS is needed to reduce the burden of conflicting requirements and facilitate cross-sectoral collaboration for implementing multifunctional solutions (Somarakis et al., 2019). With regard to the current EU adaptation strategy, for example, national adaptation strategies could strengthen coherence with national disaster risk management plans and use NbS as a tool to foster synergies.

A persistent weakness in policy frameworks is the lack of coherence among policies

Nevertheless, some positive steps are already being taken in this regard, such as integrating NbS into countries' nationally determined contributions as part of the UNFCCC to address climate change mitigation and adaptation. This shift also highlights the value of nature and capitalises on synergies with the CBD and its post-2020 global biodiversity framework (Seddon et al., 2020a). There is, nevertheless, significant potential to further increase this integration and the pursuant actions and levels of ambition across the parties to the conventions.

Furthermore, quantitative and measurable indicators for monitoring and evaluating the progress and effectiveness of agendas for NbS are lacking across policy arenas (Somarakis et al., 2019). Streamlining the currently fragmented indicators that do exist and encouraging the adoption of a (flexible) standard or safeguards could foster more effective design and implementation (Cohen-Shacham et al., 2019) and help to understand and value the co-benefits of NbS for CCA and DRR as well as the potential trade-offs. With the aim of supporting stakeholders in the design and application of NbS, the International Union for Conservation of Nature (IUCN) launched the IUCN Global standard for nature-based solutions at a high-level virtual event on 23 July 2020. This standard includes guidance (with eight criteria and 28 indicators) and a self-assessment tool, and it provides a common understanding and consensus on NbS to accelerate the scaling up of proven and workable models of NbS for both mitigation and adaptation (IUCN, 2020).

Despite the publication of this global standard for NbS, at the global level, mandatory requirements for including or designing NbS for CCA and DRR still do not exist in the current multilateral agreements (e.g. Paris Agreement, SFDRR and SDGs) or in the conventions (e.g. CBD and UNCCD). Similarly, at the EU level, existing shortcomings in the design and thus the application of the policies for supporting NbS in practice can be linked to the largely non-binding nature of the policies (Davis et al., 2018). Although ambitious objectives are outlined and information and guidance is provided, the policies reviewed largely lack the teeth necessary to result in action. The EU Green Infrastructure Strategy, for example, outlines the intention to promote GI through various sectoral policies, but a roadmap and measurable targets for achieving this mainstreaming are lacking. The strategy thus serves more to provide information about funding sources and the multiple benefits of GI than drive implementation. Similarly, the strength of the EU Urban Agenda is questionable as Member States can choose which priority themes to focus on and are only encouraged to get involved in voluntary partnerships to devise and implement action plans. As adopting conducive national and local policies is central to facilitating the uptake of NbS (Trémolet, 2019), the lack of EU requirements for mainstreaming GI and monitoring its implementation is a critical gap.

On the other hand, the European Climate Law proposal, presented in 2020, can play a role in getting the EU and its Member States to increase ambition and policy coherence on climate change adaptation and, in particular, on NbS for CCA and DRR. In particular, the new EU Adaptation Strategy (EC, 2021a) and the EU Biodiversity Strategy 2030 (EC, 2020e) can play a key role here.

Adequate funding is needed to support such efforts to implement plans in practice, increase knowledge and the evidence base, and foster wider support for and awareness of potential applications that address multiple societal challenges in parallel (Trémolet, 2019). Enhanced funding and novel collaborative initiatives towards a green recovery are outlined at the EU level, for example in the EU biodiversity strategy for 2030 and the European Green Deal. Sustainable finance will be key to supporting the delivery of these objectives by channelling private investment towards a sustainable, climate-resilient economy. Furthermore, existing policies such as the CAP can strengthen the baseline requirements for spending and dedicate increased funds to rural development plans to increase the uptake of nature-based farming practices (e.g. agro-ecological agronomic practices and agroforestry), green infrastructure (e.g. hedgerows, buffer strips, fallow land, extensive pasture) and biodiversity-friendly practices (ECA, 2020; EC and Alliance Environment, 2020; Naumann and Davis, 2020).

Finally, a mapping of priority areas for NbS and restoration through NbS is deemed critical to identifying the links, synergies and trade-offs between climate change adaptation and mitigation and biodiversity (EEA, 2020a). These areas should be monitored in the long term, including regarding ecosystem capacity and the potential to deliver the desired ecosystem services and keeping in mind distributional issues and equity of access to the benefits. The anticipated EU nature restoration plan and proposed EU nature restoration targets in the EU biodiversity strategy for 2030 will provide a solid foundation for addressing this gap in the European context.

Thus, although current EU and global policy mixes provide a strong starting point, there is significant potential to strengthen the level of ambition and degree of support across sectoral policies to create new and optimise existing NbS for CCA and DRR and encourage innovation in this regard. At the global level, NbS can be further enhanced to provide an integrated approach to reducing trade-offs and promoting synergies among the SDGs (Seddon et al., 2019, 2020a). At the EU level, the many initiatives promised as part of the European Green Deal are a strong response to global discourse and have the potential to encourage the use of NbS as a tool to achieve sustainability, biodiversity and climate-related objectives in parallel. A step in this direction is the Horizon 2020 call in support of the European Green Deal, which will mobilise EUR 1 billion funding for research and innovation activities

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aiming to deliver high-impact results in the short to medium term. Key areas relevant to NbS include restoring biodiversity and ecosystem services, climate-resilient innovation packages for EU regions, and preventing and fighting extreme wildfires. Furthermore, the European Green Deal's 'do no harm' oath could serve to boost policies fostering the deployment of NbS, as they are a means to fulfil this requirement by definition; they could also be used in recovery planning to 'build back better' and I prioritising 'green over grey' solutions.

Horizon 2020 call in support of the European Green Deal, which will mobilise EUR 1 billion funding for research and innovation activities

Established policies could also be strengthened. The Floods Directive, for example, could be broadened to more explicitly encourage the use of NbS for different types of flooding contexts and situations and promote the integration of these solutions into national policy instruments. To achieve the desired impacts and be effective, however, clear objectives, measures, commitment and enforcement mechanisms are necessary, as are adequate financing and monitoring.

3 Knowledge base on nature-based solutions for climate change adaptation and disaster risk reduction

Key messages

- **Multiple climate hazards are occurring across societal sectors and ecosystems. They require nature-based solutions that work across ecosystems and provide integrated responses across sectors.**
- **Nature-based solutions for climate change adaptation and disaster risk reduction involve various levels of intervention: (1) conservation and restoration of ecosystems; (2) sustainable management and climate-proofing of ecosystems; and (3) creation of new, engineered ecosystems for reducing the impacts of climate change.**
- **Nature-based solutions are multifunctional, providing many environmental, socio-economic and cultural benefits. In addition to increasing resilience to climate change, they support biodiversity conservation, human health and well-being, climate change mitigation, recreation and tourism, and job creation.**
- **Well-designed nature-based solutions for climate change adaptation and disaster risk reduction that are based on participatory approaches and address multiple stakeholders' needs can be more cost-effective than grey solutions for reducing the impacts of climate change.**
- **Climate change impacts may reach a magnitude that exceeds ecosystems' capacity to adapt, causing ecosystem degradation and reducing the potential of nature-based solutions to address climate change adaptation and disaster risk reduction.**
- **Appropriate indicators, evaluation tools and integrated assessment methods are needed to allow better evaluation of the net effectiveness of nature-based solutions.**

In Europe, initiatives on research and innovation have been launched to address the climate change and biodiversity loss crises and assess options for nature-based solutions (NbS) to climate change adaptation (CCA) and disaster risk reduction (DRR), for example through several Horizon 2020 research projects (Faivre et al., 2017; McVittie et al., 2018).

This chapter provides an overview of the scientific knowledge base on relevant extreme weather- and climate-related hazards (hereafter climate hazards ([1]) (see Section 3.1), options for NbS for CCA and DRR (see Section 3.2), their multiple benefits (see Section 3.3), opportunities (see Section 3.4) and limitations for implementation (see Section 3.5). This is followed by NbS

([1]) The terms extreme weather- and climate-related event or extreme natural event, natural hazard and disaster can be mistakenly misused among the general public. In simple terms, an extreme natural event is an abnormally severe natural event, a natural hazard is an extreme natural event that could threaten people, and a disaster is an extreme natural event that does affect people.

options for sectors and thematic areas of societal importance: water management (see Section 3.6), forests and forestry (see Section 3.7), agriculture (see Section 3.8), urban areas (see Section 3.9) and coastal areas (see Section 3.10). The selection of these sectors and thematic areas is based on a review of projects on NbS for CCA and DRR across Europe by McVittie et al. (2018). For each sector and thematic area, we provide an overview of key NbS options and focus in particular on the multiple benefits of NbS as well as the potential trade-offs. We then discuss challenges and opportunities for implementing NbS and conclude the chapter with the need for future research on NbS (see Section 3.11).

3.1 Climate hazards for selected European sectors and thematic areas

Climate hazards are causing significant impacts in Europe and have been addressed in multiple assessments (Forzieri et al., 2016; Alfieri et al., 2018; Spinoni et al., 2018; Vousdoukas et al., 2018, 2020). Key climate hazards observed in Europe (see Figure 3.1) include heat waves, droughts, forest fires, heavy precipitation and river floods, windstorms, hail and storm surges, landslides and avalanches (see Annex 2 and data and maps in EEA indicators for key variables online (EEA, 2020c). With accelerating climate change, multiple hazards are projected to increase in severity and/or frequency in the coming years, causing substantial damage to Europe's society and economy (Kovats and Valentini, 2014; Forzieri et al., 2016; EEA, 2017a; Spinoni et al., 2018; Vousdoukas et al., 2020). Recently, the European Parliament declared a global 'climate and environmental emergency' (EP, 2019).

Recently, the European Parliament declared a global 'climate and environmental emergency'

Water management (see Section 3.6): climate change affects the seasonal variability of droughts and precipitation, challenging (fresh)water management across Europe, in particular for forestry and agriculture but also for rural and urban areas. The risk of droughts is projected to increase in many parts of Europe with the strongest increase projected for southern Europe, causing water scarcity and a deterioration in water quality (Kovats and Valentini, 2014; EEA, 2017a; Spinoni et al., 2018). Furthermore, the frequency and intensity of extreme rainfall events have increased especially in northern and north-eastern Europe, leading to an increased risk of floods and landslides and affecting water quality (Kovats and Valentini, 2014; EEA, 2017b; Debele et al., 2019). Heavy precipitation events are projected to increase in both frequency and intensity (Kovats and Valentini, 2014; Rajczak and Schär, 2017).

Forests and the forestry sector (see Section 3.7): the southern and central European regions are affected by droughts, which limits tree growth and increases tree mortality and vulnerability to pest outbreaks and dieback as well as the likelihood of forest fires (Kovats and Valentini, 2014; EEA, 2017b). Europe, and particularly southern Europe, will face more frequent fires and longer fire seasons. In Scandinavia, extreme fire events are also likely to increase (Krikken et al., 2019).

Agricultural sector (see Section 3.8): this sector is affected by climate change in a number of ways, including heat stress on livestock and crops, variations in patterns of outbreaks of pests and diseases, and reduced water availability (Spinoni et al., 2018; EEA, 2019a). Climate projections expect these impacts to be more severe in the future, especially in southern Europe. In contrast, agricultural areas in northern Europe are affected by flooding, causing reductions in yields (e.g. due to crop damage, loss of agricultural soil, limited access to grazing land), transport disruption and loss of assets (EEA, 2019a).

Urban areas (see Section 3.9): the damage caused by floods represents the largest share of climate impacts on Europe's economy (EEA, 2020e). Floods also create human and ecosystem health issues in urban areas, such as introducing *Enterococcus faecalis* contamination into rivers and lakes or discharging untreated water into the environment, when the capacity of sewerage systems is overloaded, increasing the risk of human exposure to infectious disease agents (EEA, 2017b). Furthermore, people are also vulnerable to heat waves, causing heat-related health issues (EEA, 2020e). Climate projections indicate an increase in temperature across the whole of Europe, leading to more frequent and intense heat waves, particularly during the summer in southern Europe (Kovats and Valentini, 2014) and central Europe (Smid et al., 2019). Cities located in these regions are particularly vulnerable to heat waves, while northern and north-eastern cities are exposed to higher risks of flooding due to intense rainfall events.

Coastal areas (see Section 3.10): these areas are particularly vulnerable to extreme storm surges and sea level rise, causing loss of land, coastal erosion, inundation and salt water intrusion (Kovats and Valentini, 2014; EEA, 2017b; Vousdoukas et al., 2020). Extreme sea level events and storm surges are expected to increase at most locations along Europe's coastlines, causing significant damage in low-lying coastal areas in northern and western Europe (EEA, 2017b).

Figure 3.1 **Key climate hazards to European sectors and thematic areas and examples of potential options for nature-based solutions to address climate hazards**

	Water management	Forests and forestry	Agriculture	Urban areas	Coastal areas
Key climate hazards	Water scarcity and water quality deterioration due to **droughts** Floods and landslides due to **heavy precipitation**	Limiting tree growth, increasing tree mortality and risk of pest outbreaks due to **droughts** and **forest fires** **Landslides** and **soil loss** due extreme rainfall events	Crop and livestock loss due to **heat stress**, increased risk to **pest and disease outbreak**, and water scarcity Damage to yield, transportation and asset loss due to **flooding**	Heat stress due to **heatwaves** Urban flooding due to **heavy precipitation**	Loss of land due to **rising sea level** and **coastal erosion** Loss of life due to **storm surges and inundation**
NbS options	Large-scale measures, e.g. river, floodplain restoration Small-scale measures, e.g. urban rainwater harvesting	Protection of intact forest Restoration of degraded forests Sustainable forest management, e.g. tree diversification, selective logging	Improved soil and water farm management Crop type diversification and rotation Agroforestry	Parks, urban forest, street trees Green buildings, e.g. green roofs and walls NbS for water management, e.g. bioswales, detention ponds	Rehabilitation and restoration of coastal habitats Near-shore enhancement of coastal morphology Hybrid solutions

Source: EEA.

3.2 Climate change adaptation, disaster risk reduction and nature-based solutions

There is growing scientific evidence for the relevance of ecosystems and their services for climate change adaptation and disaster risk reduction (McVittie et al., 2018; Cohen-Shacham et al., 2019; Morecroft et al., 2019). This is substantiated by the increasing number of scientific publications on NbS (Hanson et al., 2020; Ruangpan et al., 2020).

Climate change adaptation and disaster risk reduction can be achieved by building resilience to climate hazards through (1) reducing exposure, (2) reducing sensitivity and (3) increasing adaptive capacity (Adger et al., 2005; Seddon et al., 2020a). Exposure to climate change impacts and related climate hazards can be reduced by, for example, enhancing the ability of ecosystems to act as a buffer for extreme events. The water storage capacity of rivers can be enhanced through river protection and restoration, which reduces flood risks further downstream (see Section 3.6). Creating green spaces in cities can moderate the impacts of heat waves (see Section 3.9). Moreover, the sensitivity of a community or sector to climate change impacts can be reduced by, for example, diversifying land use to allow it to cope better with climate variability and future uncertainties. This can include using more drought-resistant tree species and crops in forestry and agriculture to allow the sectors to cope better with climate variabilities and diversifying income options (see Sections 3.7 and 3.8). Integrating such knowledge on NbS for CCA and DRR into local management practices and sectoral adaptation strategies can enhance the adaptive capacity of individuals, communities and economic sectors (Seddon et al., 2020b).

Options for NbS that reduce exposure and sensitivity to climate hazards and enhance adaptive capacity for addressing such hazards involve various levels of intervention: (1) conservation and restoration (including rewilding) of natural ecosystems in locations where they provide ecosystem services critical for adaptation and DRR; (2) sustainable management and climate-proofing of managed ecosystems to provide multiple ecosystem services (e.g. diversifying agricultural landscapes and forests); (3) creating new, engineered ecosystems for particular adaptation needs (e.g. green roofs or hybrid solutions for coast management) (Eggermont et al., 2015) (see Figure 3.1).

NbS provide options for climate change adaptation and disaster risk reduction in particular for sectors that depend on ecosystems and natural resources (e.g. water) such as forests and forestry and agriculture (McVittie et al., 2018) (see Table 3.1 and Sections A4.6 and A4.7). It has been demonstrated that NbS are also effective in cities, providing benefits for climate change adaptation and disaster risk reduction, while also providing other important societal benefits (Kabisch et al., 2016) (see Section A4.9). Furthermore, coastal areas exposed to sea level rise and storm surges benefit from enhancing and maintaining coastal ecosystems to increase coastal protection (Morris et al., 2018) (see Section A4.11). The conservation and restoration of ecosystems in locations that are critical for climate change adaptation and disaster risk reduction is an integral part of designing and implementing NbS (Eggermont et al., 2015).

Biodiversity is fundamental for providing the ecosystem services that underpin human well-being and economic development (IPBES, 2019). NbS take into account the interdependence of humans and biodiversity, and therefore biodiversity is at the core of NbS (Folke et al., 2016; Nesshöver et al., 2017; McVittie et al., 2018). For effective design and implementation of NbS it is critical to understand how biodiversity (comprising species and ecosystems) provides ecosystem services across the landscape and how these can benefit strategic and cross-sectoral planning for climate change adaptation and disaster risk reduction.

Responding to climate hazards requires a systems approach, taking into account the ecological, societal and economic impacts and their respective adaptation needs. The impacts of climate hazards occur across regions and ecosystems and across sectoral and societal boundaries. Because of accelerating climate change, assumptions about the risks of extreme weather- and climate-related hazards cannot rely on past experience alone (UNDRR, 2019). Taking the approach of addressing single hazards is also inadequate for preparing for, anticipating and adapting to ongoing and future changes. Instead, we need systemic approaches that consider people and the economy as part of nature (UNDRR, 2019). This requires approaches that are transdisciplinary, span sectors and integrate knowledge from science and practitioners. Therefore, it is important to recognise that society and its sectors are interconnected with ecosystems and landscapes from local to global scales (Morecroft et al., 2019). Given that NbS account for this interconnectedness of humans and ecosystems, they are particularly suited to addressing society's needs with regard to climate change adaptation and disaster risk reduction. However, this needs ecosystems to be intact if they are to deliver the desired NbS, which is why reducing multiple stressors on ecosystems (e.g. pollution and overuse) and ensuring their conservation and sustainable management is important.

We need systemic approaches that consider people and the economy as part of nature

Table 3.1 Examples of nature-based solutions for climate change adaptation and disaster risk reduction

Category	Broad measure	Example measures		Impact addressed
Agriculture	Agricultural habitats	· Agro-forestry and crop diversification · Buffer strips and hedgerows · Improved water retention in agricultural areas · Meadows and pastures		· Floods · Flash floods · Drought
	Agricultural management	· Crop rotation · Low till agriculture · No till agriculture · Green cover		
Forestry	Forest planting	· Reforestation · Afforestation · Forests in riparian buffers · Land use conversion · Maintenance of forest cover in headwater areas		· Climate change mitigation · Land slides · Floods · Heat waves
	Forest management	· Water sensitive forest management · Coarse woody debris · Continuous cover forestry		
Coastal		· Beach nourishment · Coastal managed realignment · Dune reinforcement and strengthening · Cliff stabilisation		· Sea level rise · Storm surges · Land slides
Urban	Green infrastructure	· Green roofs · Rain gardens · Soakaways · Swales	· Urban greenspace · Urban forest parks · Urban trees and forests	· Heat waves · Flash floods · Floods
	Blue infrastructure	· Basins and ponds · Channels and rills · Detention basins · Filter strips · Infiltration basins · Permeable surfaces	· Retention ponds · Sediment capture ponds · SUDS · Temporary flood water storage	
Water management	River restoration	· Elimination of riverbank protection · Natural bank stabilisation · Re-meandering · Reconnection of oxbow lakes and similar features · River restoration and rehabilitation · Riverbed material re-naturalisation · Stream bed re-naturalisation		· Floods · Flash floods
	Floodplain restoration Groundwater restoration Lake restoration Wetland restoration			

Note: The measures were identified in a review of 125 applications of NbS in Europe (McVittie et al., 2018).

Source: McVittie et al. (2018). Reproduced with permission from Elsevier.


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Climate change adaptation and disaster risk reduction are closely interlinked with NbS addressing multiple objectives across sectors (see Table 3.1). For example, mitigating the impacts of floods and droughts can involve measures to retain water on agricultural land (e.g. buffer strips and hedgerows), restore rivers to enhance their water retention capacity, and enhance permeability in urban areas to reduce rainwater run-off (Berland et al., 2017). Each of these measures can contribute to the multiple objectives of achieving adaptation, disaster risk reduction and mitigation.

3.3 Multiple benefits of nature-based solutions for climate change adaptation and disaster risk reduction

For the effective design and successful implementation of NbS it is critical to ensure that the measures are adequate for addressing the hazards while also delivering other societal benefits. Demonstrating multiple benefits for society and sectors is important to justify and legitimise investment in climate change adaptation and disaster risk reduction. From the perspective of decision making, adaptation options need to be effective and efficient and address equity and legitimacy in order to be sustainable in the long term, taking into account uncertainty in the impacts of future events (Adger et al., 2005). If well designed, NbS for CCA and DRR can provide sustainable, cost-effective and multipurpose options that can act as alternatives to or in synergy with built and grey infrastructure (McVittie et al., 2018).

Adaptation options need to be effective and efficient and address equity and legitimacy

NbS are characterised by their multifunctionality i.e. producing multiple benefits simultaneously, including environmental, socio-cultural and economic benefits (Raymond et al., 2017b; Calliari et al., 2019). NbS designed to address CCA and DRR are able to provide crucial benefits, including reducing damage from heavy precipitation and flooding, alleviating the impact of drought and mitigating heat. In addition, NbS have been shown to address other societal challenges such as conservation of biodiversity, human health and climate change mitigation (Figure 3.2). For example, restoring the floodplains along various Dutch rivers (the 'Room for the river' programme) provides enhanced flood protection for 4 million people while addressing other objectives and challenges such as improving environmental quality and enhancing recreation facilities. Engaging different stakeholders in the design process, assessing NbS in relation to their multiple benefits and addressing the socio-institutional barriers is key to enhancing society's acceptance of these solutions and finding the best option (Pagano et al., 2019).

Strategically integrating ecosystems and their services into spatial planning is a cost-effective option for climate change adaptation and sustainable development (IPBES, 2019) while also providing multiple benefits in addressing other societal challenges. Furthermore, demonstrating the benefits can help to ensure stakeholders' support and acceptance, secure funding and enhance the mainstreaming of NbS across various policy areas (McVittie et al., 2018).

Figure 3.2 Multiple benefits of nature-based solutions for addressing climate hazards across selected sectors and thematic areas

	NbS options	NbS benefits	Climate impacts addressed
Water management (Section 3.6)	Restoration of rivers and floodplains River buffers (e.g. vegetation strips) Water sensitive forest management	Regulation of water flows Reduction of floods and soil erosion Recreation and aesthetic appreciation Biodiversity Water quality	Droughts Floods
Forests and forestry (Section 3.7)	Protection and restoration of forests Sustainable forest management Integration of trees/forest into the landscape	Regulation of water flows Reduction of floods Control of disease and pests Slope stabilisation Carbon sequestration Biodiversity Recreation and aesthetic appreciation	Droughts Floods Fires
Agriculture (Section 3.8)	Improved soil and water management Crop type diversification and rotation Agroforestry	Retention of water and soil retention Mitigation of heat stress Control of disease and pests Carbon sequestration Soil fertility Biodiversity	Droughts Floods Heat stress
Urban areas (Section 3.9)	Parks, forest, street trees Green buildings (e.g. green roofs, green walls) NbS for water management (e.g. bioswales, detention ponds)	Cooling air temperature Regulation of water runoff Carbon sequestration Biodiversity Human health and well-being Water quality	Floods Heat stress
Coastal areas (Section 3.10)	Rehabilitation and restoration of coastal habitats Barrier islands, beach nourishment Hybrid solutions (e.g. green dykes, vegetated levees)	Reduction coastal flooding Stabilisation of coast Carbon sequestration Biodiversity Recreation	Sea level rise Storm surges Coastal erosion

Source: EEA.

3.3.1 Key environmental benefits

NbS for CCA and DRR help to address the risk of flooding and water scarcity (drought) by regulating water flows. Increasing green spaces can increase water infiltration into the soil, enhance evapotranspiration and provide storage areas for rainwater, which can alter the magnitude and timing of water run-off and flooding during heavy precipitation events, while contributing to maintaining water flow during drought periods (Sutherland et al., 2014; EC, 2015). For example river catchment restoration, including revitalising wetlands and riverbanks, reforesting floodplains and reversing the canalisation of rivers, has been shown to enhance the natural water storage capacity and reduce peak run-off, which prevents floods and provides multiple additional benefits such as biodiversity protection, carbon storage and recreation opportunities (EC, 2015; Morecroft et al., 2019). Smaller interventions, such as creating hedges, tree lines or grass strips alongside agricultural fields, have also been demonstrated to enhance water infiltration rates and reduce surface run-off (Carroll et al., 2006). In addition, these interventions increase nutrient uptake from run-off water, improving the quality of nearby water bodies (EC, 2015). Agricultural management practices, such as mulching and the use of cover crops, also increase infiltration rates and the water content in agricultural soils, alleviate drought stress and reduce soil compaction and erosion risk (see Section 3.8). Furthermore, crop diversification and rotation can improve yield stability during droughts (Isbell et al., 2017). In cities, public and private green space (e.g. green roofs, urban parks) can increase water storage capacities, reducing surface run-off and flood events (Pregnolato et al., 2016; Zölch et al., 2017). Green space simultaneously provides other benefits, such as carbon storage and sequestration, improved air quality, cooling and habitat conservation (Escobedo et al., 2011; Roy et al., 2012; Francis and Jensen, 2017). Creating new green space for stormwater management (e.g. constructed wetlands, bioswales) has been shown to enhance flood protection while providing additional benefits such as biodiversity protection, recreation and water purification (Liquete et al., 2016; Raymond et al., 2017a; Filazzola et al., 2019).

Crop diversification and rotation can improve yield stability during droughts

NbS measures to stabilise slopes and coastal habitats are key in addressing the risk of landslides and coastal erosion (Sutherland et al., 2014; EC, 2015). Retaining and restoring forest cover, especially on steep slopes, reduces the risk of soil erosion while also encouraging maintenance or growth of vegetation (EC, 2015). Protecting coastal habitats (e.g. intertidal mudflats, saltmarshes, dunes and seagrass beds) can stabilise shorelines against coastal erosion (Gedan et al., 2011) while providing opportunities for recreation, water purification and biodiversity conservation (Sutherland et al., 2014; EC, 2015; Raymond et al., 2017a). Applying soil conservation measures (e.g. cover crops, reduced tillage) on agricultural land has been shown to reduce soil loss and support agricultural productivity while also benefiting groundwater recharge, soil fertility and disease regulation (Sutherland et al., 2014).

Grass surfaces exposed to the sun can be much cooler than concrete surfaces

Another key environmental benefit of NbS for CCA and DRR is its potential to contribute to reducing the risk of heat waves and heat stress in humans, crops and animals (e.g. livestock) through enhancing temperature regulation and thermal comfort. For example, grass surfaces exposed to the sun can be much cooler than concrete surfaces, and trees can reduce air temperatures through evapotranspiration and providing shade or regulate the microclimate by providing shelter from wind (Calfapietra, 2020). These cooling effects can also reduce buildings' energy consumption during summer (i.e. air conditioning), reducing CO_2 emissions and contributing to climate change mitigation (Hunter Block et al., 2012; Bulkeley, 2020b). Compared with bare roofs, green roofs not only help insulate buildings, which has benefits in terms of reduced energy costs (Akbari, 2002; Demuzere et al., 2014; Francis and Jensen, 2017), but also increase biodiversity significantly (Filazzola et al., 2019). At the same time, urban parks and forests can provide additional benefits such as improved air quality, biodiversity conservation and recreation opportunities, which are important for human health (Konijnendijk et al., 2013; Keeler et al., 2019). Cooling effects also occur in non-urban areas, such as cropland and grazing land, where trees can provide shade for livestock and crops and reduce heat stress while also enriching soils, controlling erosion, sequestering carbon and enhancing groundwater recharge (Griscom et al., 2017).

37 % of the global climate change mitigation needed up to 2030 to keep climate warming below 2° C

In forests and forestry and other land use sectors, NbS can help regulate diseases and pests affecting crops, trees, livestock and people. For example, maintaining and enhancing tree species diversity can reduce disease transmission (Sutherland et al., 2014). Mixed crop-livestock farming systems and crop diversification can enhance biological control of pests through species interactions (although not guaranteeing a reduction in all pests and diseases) (Ratnadass et al., 2012) while simultaneously improving soil fertility and biodiversity. Another important benefit of NbS is their potential for carbon sequestration and thus climate change mitigation: conserving and restoring natural habitats and improving land management could contribute to about 37 % of the global climate change mitigation needed up to 2030 to keep climate warming below 2° C (Griscom et al., 2017).

3.3.2 Key social and cultural benefits

NbS can provide multiple social and cultural benefits. Maintaining, restoring or creating new (semi-)natural ecosystems in or near cities and communities can enhance the physical and mental health of people. Studies show a positive relationship between access to green space and human health (WHO Europe, 2016; van den Bosch and Ode Sang, 2017; Kabisch et al., 2017b). Urban parks, for example, can contribute directly to public health and well-being by, for example, increasing opportunities for physical activities (e.g. running, biking, walking) and social interactions, reducing stress, mental health disorders and heat-related mortality (Konijnendijk et al., 2013; Demuzere et al., 2014; Maia da Rocha et al., 2017; van den Bosch and Ode Sang, 2017). Creating new green space, for example redevelopment from brown sites and planting street trees, can also enhance social equality when planned in communities with low socio-economic status, which often lack green space in their immediate neighbourhood (Ferguson et al., 2018; Song et al., 2019). However, green regeneration may be a catalyst for gentrification (Ali et al., 2020). Urban trees are highly appreciated for their aesthetic appearance, creating a sense of place and identity (Roy et al., 2012) while at the same time reducing air and noise pollution, contributing to people's health and well-being, and promoting biodiversity. In addition, the rehabilitation and restoration of rivers and floodplains can create additional social benefits, such as creating space for people to relax, interact with nature and/or sun-bathe or to go fishing (Polizzi et al., 2015; Vermaat et al., 2016).

3.3.3 Key economic benefits

NbS are reported to provide cost-efficient and low-cost solutions to many climate change-related impacts and offer key advances over engineered 'grey' solutions because they generate multiple benefits, including economic ones (McVittie et al., 2018; Feyen et al., 2020; Seddon et al., 2020b). For example, the rehabilitation and restoration of eight rivers and floodplains across Europe reduced flood damage to crops and forests and increased agricultural production, carbon sequestration and recreation, with a net societal economic benefit over unrestored rivers of EUR 1 400 ± 600 ha/year (Vermaat et al., 2016). In Germany, an outlook study estimated that floodplain restoration of the River Elbe and its tributaries could enhance flood protection, reduce nutrient loads and improve biodiversity and the landscape, estimated to have a total economic benefit of EUR 1.2 billion and a cost-benefit ratio of 1:3 (Grossmann et al., 2010). Across Europe, enhancing floodwater retention areas of rivers is a solution that can reduce economic damage and the exposure of the population to flooding by up to 70 % while enhancing ecosystem quality, with a cost-benefit ratio superior to that of built infrastructure for flood mitigation (Feyen et al., 2020). The development of green areas in cities has been shown to increase the economic value of surrounding areas, as measured by the increase in the price of houses close to nature (Brander and Koetse, 2011; Bockarjova et al., 2020). The benefits of NbS such as (constructed) wetlands, retention ponds or raingardens can reduce water treatment costs associated with excessive run-off water entering the sewage treatment systems (Raymond et al., 2017a). A case study from Lisbon estimated a net economic benefit of USD 4.48 for every USD 1 invested in urban trees due to the multiple benefits provided by trees, including energy savings, carbon sequestration, reducing stormwater run-off, improving air quality and increasing property values (Soares et al., 2011).The potential of urban green spaces to reduce outdoor temperatures can also be translated into avoided costs, such as reduced energy demand for heating and cooling of buildings (Demuzere et al., 2014). McDonald et al. (2020), for example, studied the economic value of urban trees in US cities, and estimated a total annual economic value of USD 1.3-2.9 billion or an annual value of USD 21-49 per capita due to the trees' potential to reduce heat-related impacts (i.e. mortality, morbidity and the electricity consumption of buildings).

Enhancing floodwater retention areas of rivers can reduce economic damage and the exposure of the population to flooding by up to 70 %

3.4 Opportunities for implementing nature-based solutions for climate change adaptation and disaster risk reduction

Evidence from case studies across Europe indicates that the multiple benefits can justify investment in NbS for CCA and DRR (McVittie et al., 2018). Uncertainties around future climate change will always remain a challenge in planning for adaptation — no matter whether it is for green or grey infrastructure. The consequences of large-scale ecosystem degradation already occur today and threaten social and economic development and restrict future options for adaptation (IPCC, 2018; IPBES, 2019; Turner et al., 2020). Hence, choosing NbS with multiple benefits for sustainable development can be a prudent and far-sighted approach. As ecosystems provide benefits to multiple stakeholders, building on NbS for CCA and DRR can be regarded as a low-regret option for public and private investments. If NbS measures are well designed the multiple benefits can justify the investments in such options (Le Coent et al., forthcoming) and in many cases addressing multiple benefits early on in the development of NbS can also form the basis for designing the most suitable NbS (Giordano et al., 2020).

For NbS to be effective, the scale of implementation is critical, often requiring landscape approaches and the involvement of multiple stakeholders and landowners in particular (McVittie et al., 2018). Hence, participatory approaches are critical for developing effective NbS (Nesshöver et al., 2017). Participation and the inclusion of stakeholders' perspectives from an early stage of the design of NbS is fundamental not only for ensuring their effectiveness in delivering multiple benefits but also for ensuring their public acceptance. NbS need to be designed in an inclusive and equitable way to ensure their successful implementation and the delivery of multiple benefits for a diverse range of societal objectives.

Participatory approaches are critical for developing effective NbS

To address this challenge, science-policy platforms have been created to promote policy coherence on NbS and to facilitate capacity building and co-design to ensure the successful policy uptake and implementation of NbS (see Annex 5). Furthermore, evidence-based standards and guidelines have been developed to ensure the effective design and implementation of NbS measures and actions. This includes guidelines for the design and effective implementation of ecosystem-based approaches to CCA and DRR, the *Guidebook for monitoring and evaluating ecosystem-based adaptation interventions and the IUCN Global standard for nature-based solutions (Cohen-Shacham et al., 2019; GIZ et al., 2020; IUCN, 2020).*

3.5 Limitations of nature-based solutions for climate change adaptation and disaster risk reduction

While NbS can help to mitigate the impacts of climate hazards and provide benefits for adaptation, there are also limits to which ecosystems can cope with these hazards. Biodiversity is underpinning NbS, and therefore the effectiveness of such approaches is determined by the resilience of species and ecosystems to the impacts of climate- and weather-related hazards (Morecroft et al., 2019; Turner et al., 2020). Ongoing climate change might lead to more extreme climate- and weather-related hazards that exceed the capacity of species and ecosystems to adapt, causing ecosystem degradation (Morecroft et al., 2019).

Apart from climate-related challenges, other natural, environmental, biological and technological drivers and hazards, which are exacerbated by climate change, affect ecosystems and their services (Oliver and Morecroft, 2014; UNDRR, 2019). Interactions between and feedback from these drivers (e.g. unsustainable land use and climate change) can push ecosystems across thresholds whereby they change to different ecological states, undermining their ability to provide ecosystem services (Turner et al., 2020). However, the short- and long-term consequences of interactions between and feedback from multiple drivers of change (e.g. climate change interacting with other drivers such as land use change) and the response of ecosystems are not well understood (Turner et al., 2020). Nevertheless, NbS measures that involve ecosystem conservation, restoration and adaptation are found to reduce the vulnerability not only of people but also of ecosystems themselves (Morecroft et al., 2019).

The effectiveness of NbS depends not only on the specific intervention itself but also on the local context, including climatic, ecological and socio-economic factors and the vulnerability of communities, cities and sectors to climate change and ecosystem degradation (Debele et al., 2019). Then, the feasibility of NbS and the trade-offs and potential negative consequences (so-called disservices) have to be assessed. For example, the opportunity costs of land users can be considerable because of changes in management practices and the related loss of income sources; some more engineered ecosystem-based adaptation measures may lead to a loss of or damage to natural habitats; the benefits of NbS may only occur after a considerable time (e.g. it may take decades for ecosystem restoration to deliver the desired benefits) (McVittie et al., 2018); and intended solutions may have negative consequences for some stakeholders, such as displacement of residents or an increased risk of pollen related allergies (Keeler et al., 2019). Such disservices are highly context dependent; however, they are often not addressed when assessing the benefits of NbS (Haase et al., 2014a; Kabisch et al., 2016; Veerkamp et al., forthcoming). Moreover, public green and blue areas may be distributed unevenly within or around a city, and minority groups or low-income neighbourhoods may have less access to such areas than high-income neighbourhoods, raising the issue of social equity and environmental justice in the distribution of public green and blue areas (Kabisch and Haase, 2014; de Sousa Silva et al., 2018). However, if well designed, the multiple benefits of NbS outweigh the disservices (Feyen et al., 2020).

If well designed, the multiple benefits of NbS outweigh the disservices

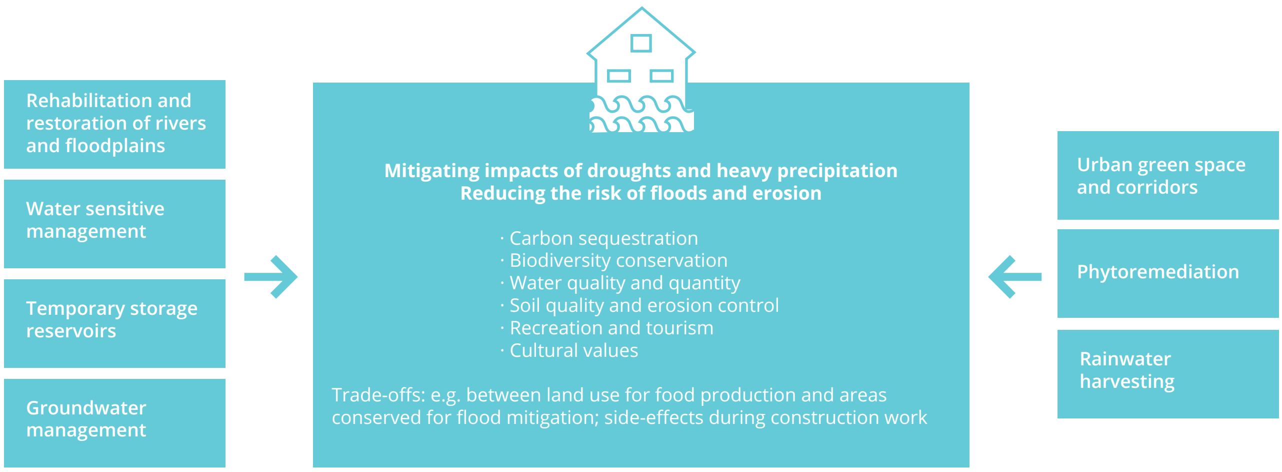
Furthermore, identifying and implementing adaptation measures such as NbS requires long-term planning, which involves uncertainties and risks. There are, for example, uncertainties concerning future climate change impacts, the effectiveness of adaptation measures and societal needs for adaptation. Hence, measures for CCA and DRR may not be sufficient (lack of effectiveness), may be designed beyond what is required (lack of efficiency) or may even be harmful, which can increase vulnerability and/or undermine capacities or opportunities for adaptation (Magnan and Mainguy, 2014). NbS are seen as reducing such risks, as they involve conserving, restoring and sustainably managing already existing ecosystems and their services for society.

Although there is increasing evidence of the success of NbS for CCA and DRR, quantifying their effectiveness in biophysical, social and economic terms is a complex task, and quantitative data are still scarce (Doswald et al., 2014; EC, 2015; McVittie et al., 2018; Seddon et al., 2020b). There is heterogeneity in the methods used to assess and evaluate the effectiveness of NbS, and impact indicators are highly diverse, which makes comparison of the different options (including comparing them against alternative grey options) difficult and hampers the development of a common evidence and knowledge base for NbS (Raymond et al., 2017b; McVittie et al., 2018; Veerkamp et al., forthcoming).

3.6 Water management and nature-based solutions for climate change adaptation and disaster risk reduction

Addressing the impacts of climate change on freshwater management requires an integrated perspective of water management (Granit et al., 2017). There are several examples of NbS for addressing different types of climate hazards related to water, which are categorised here according to their spatial scales: large-scale NbS and small-scale NbS (see Figure 3.3).

Figure 3.3 Key nature-based solutions for addressing climate change impacts on water management and their multiple benefits and trade-offs



Source: EEA.

Large-scale nature-based solutions

Large-scale NbS are realised across landscapes and intersect with different ecosystems (e.g. rivers, floodplains, forest) (Ruangpan et al., 2020). These types of NbS require integrated planning strategies and strong collaboration between different actors (e.g. water basin authorities across provinces, regions or countries). Examples of large-scale NbS include the rehabilitation and restoration of rivers and floodplains (e.g. channel re-profiling, sediment dredging, changing the natural forms of rivers, extending floodplains) and the establishment and restoration of river buffers (i.e. strips of grass, shrubs and trees adjacent to the river ecosystem) (see Section A4.1). These NbS are mainly designed to reduce flood risk. Restored floodplains can hold excess water, while vegetation in the buffers can decrease the speed of flow and trap sediments (Reberski et al., 2017; Bridgewater, 2018). Floodplains and buffer areas also provide protection against drought and water scarcity by retaining and slowly releasing water discharges and enhancing groundwater recharge (Reberski et al., 2017) (see Image 3.1 and Section A4.2). If established near agricultural areas, vegetation buffers along rivers can mitigate the run-off of pollutants from fields, improving water quality (Reberski et al., 2017; Bridgewater, 2018). The temporary flooding of agricultural land can act as a storage reservoir to capture peak flows during extreme rainfall events, avoiding flood damage downstream (Climate-ADAPT, 2020d).

Vegetation buffers along rivers can mitigate the run-off of pollutants from fields

Water-sensitive forest management (e.g. reducing the density of trees in a stand, shortening the cutting cycles, planting hardwood species, afforestation; see also Section 3.7.1) can enhance water flow regulation, reduce surface run-off during heavy rainfall events and mitigate water scarcity during drought events (Reberski et al., 2017; Fondazione Nordest, 2019). Moreover, trees trap sediments and pollutants from other upslope land use activities, avoiding water pollution downstream and reducing the water temperature due to shading (Reberski et al., 2017). In addition, groundwater management options include injecting surface waters into the groundwater system through wells, managed aquifer recharge, forested infiltration areas or filling recharge basins that allow surface waters to slowly percolate downwards into the groundwater, increasing groundwater availability. These NbS allow the maintenance of high groundwater tables that can serve agriculture and natural vegetation and prevent saltwater intrusion in coastal regions.

Image 3.1 Rehabilitation of the Serchio river basin (Italy) to reduce the risk of floods and droughts in a Mediterranean catchment, while increasing biodiversity and improving water quality (the photo shows the Fossa Nuova channel)

© Anders Solheim

Note: See Section A4.2.

Small-scale nature-based solutions

Small-scale NbS are usually realised within a specific place (e.g. single building or street). Rainwater harvesting measures (e.g. ponds, swales, rain gardens, green roofs linked to storage cisterns) are examples of small-scale NbS that are used in both agricultural areas and urban environments to mitigate both flooding and water scarcity (Berland et al., 2017; Frantzeskaki, 2019; UNaLab, 2019). Water-sensitive urban planning and designing buildings to reduce water run-off, attenuating flood peaks and enhancing groundwater recharge, is another example of small-scale NbS; it includes permeable paving of footpaths, car-parking areas and playgrounds, linked to underground storage tanks, infiltration basins, retention ponds, rain gardens, porous asphalt, constructed wetlands and vertical greening (see Section 3.9). The filtering capacity of such permeable paving can also help to improve groundwater quality (Berland et al., 2017; Depietri and McPhearson, 2017; UNaLab, 2019). In urban and peri-urban environments phytoremediation measures (e.g. riparian vegetation, retention ponds and constructed wetlands) play an important role in waste treatment, for example purifying the water before it is discharged into rivers (Wild, 2020a). In addition, such NbS also support flood control during heavy precipitation events (Bridgewater, 2018; Wild, 2020a). Lastly, urban green spaces e.g. parks, green corridors, trees) allow water to percolate into soil, and reduce peak discharges during heavy rainfall events (Berland et al., 2017; Du et al., 2019; UNaLab, 2019) (see Section 3.9).

Urban green spaces allow water to percolate into soil, and reduce peak discharges during heavy rainfall events

3.6.1 Multiple benefits and trade-offs

NbS for water management offer multiple benefits related to water quantity, quality and related risks, while also offering relevant benefits, which go beyond CCA and DRR (see Figure 3.3). For example, floodplains, buffer strips and water-sensitive managed forests improve habitat quality and diversity, thus enhancing biodiversity and landscape connectivity (Reberski et al., 2017; Frantzeskaki, 2019). Moreover, urban NbS (e.g. rain gardens, green roofs, constructed wetlands and ponds) support biodiversity (Song et al., 2019). Large-scale NbS can also enable natural processes that are beneficial for the maintenance of safe physical environments, such as hydrogeological stability to protect against erosion and landslides (Reberski et al., 2017; EEA, 2019b) (see Section A4.11). Similarly, NbS enhancing groundwater management can promote soil compaction and reduce peat oxidation (Climate-ADAPT, 2020a). NbS for water management can also improve the aesthetic and recreational value, for example by providing opportunities for hiking, walking or relaxing along water bodies, or promote social cohesion, social inclusion and a sense of place within urban areas (Song et al., 2019). Measures designed to manage water flows in urban areas (e.g. rain gardens, green roofs, green facades, constructed wetlands and green spaces and corridors) can also contribute to enhanced quality of life by reducing air and noise pollution and the heat island effect. Some of these measures, especially those related to green roofs and green facades, can also promote food production and reduce the energy consumption of buildings due to the reduced need for cooling or heating (Frantzeskaki, 2019; UNaLab, 2019).

However, there are also trade-offs, for example the construction work related to implementing the NbS may negatively affect water quality and the river ecosystem. Trade-offs can also occur when, for example, enhanced green spaces connectivity triggers the dispersal of unwanted organisms (e.g. mosquitoes) with negative impacts on both local ecosystems and human health (Somarakis et al., 2019). Trade-offs can also be due to conflicts between different sectors, for example if agricultural areas are temporarily used as reservoirs for flood expansion. Restoration (or creation of new floodplains) can lead to unwanted negative consequences and disservices if they are not planned carefully (Schaubroeck, 2017). For example, in the case of heavily polluted surface waters, the reconnection of floodplains with rivers can contribute to the wide-scale diffusion of pollutants to soils, agricultural areas and groundwater.

3.6.2 Opportunities for implementation

NbS for water management contribute to a variety of social, environmental and economic needs (Cohen-Shacham et al., 2016). They can support surface water and groundwater water protection, contributing to achieving good qualitative and quantitative environmental and ecological status of water bodies (EU, 2000; Wild, 2020a). The extension of buffer zones and the establishment of water-sensitive forests and NbS for urban areas reduce pollution, supporting related policies including the Urban Waste Water Treatment Directive, the Nitrates Directive and the Groundwater Directive (EC, 2008). This supports habitat quality and biodiversity conservation, which can have positive effects for developing businesses and jobs, in particular those related to recreation and tourism. This is also of relevance for achieving policy targets in relation to the Water Framework Directive, the Floods Directive, the Habitats and Birds Directives and the new biodiversity strategy for 2030 as well as the overarching targets of the European Green Deal (EC, 2019c) (see Chapter 2).

NbS supports habitat quality and biodiversity conservation, which can have positive effects for developing businesses and jobs

3.6.3 Limitations

Limitations are mainly due to lack of knowledge regarding the effectiveness of NbS and insufficient planning or design of the solutions. Selecting the wrong plant species might not lead to the provision of the desired benefits (e.g. not providing sufficient erosion control or causing allergic reactions in people) (Solcerova et al., 2017; Vaz Monteiro et al., 2017; Peng et al., 2019). Moreover, the evidence base on the effectiveness of large-scale NbS for flood mitigation and coastal resilience is rather limited, stressing the need for more research in particular on networks of both small-scale and large-scale NbS (Vojinovic, 2020). Further barriers to implementing NbS involving river and floodplain restoration include complex planning processes, competition for land and insufficient space available for the interventions (e.g. sometimes the artificially created river margins do not enable natural restoration of the river) (Climate-ADAPT, 2020c). Water management through NbS in urban areas requires a lot of space compared with traditional grey strategies, and this can lead to high opportunity costs, as land values are high. Particularly in these cases, including the economic and social values of multiple benefits, which are typically substantial, then becomes essential when assessing the cost advantages of NbS over grey solutions (Le Coent et al., forthcoming).

Budget constraints can also be a barrier for implementation. Furthermore, stakeholders' involvement and conflicts (e.g. housing vs greening strategies) pose additional difficulties for implementation. Only a few case studies have critically evaluated how science-policy processes can reduce the communication gaps between researchers, engineers, politicians, managers and stakeholders (Fletcher et al., 2015; Prudencio and Null, 2018).

3.7 Forests and forestry and nature-based solutions for climate change adaptation and disaster risk reduction

Trees and forests provide NbS for CCA and DRR to the forestry sector and beyond. For example, healthy, tree-based landscapes provide protection against increasingly erratic weather events, droughts, fires, floods and landslides (Martin et al., 2016) (see Sections A4.4 and A4.11). Forests can reduce the impact of heat waves, as they provide shade and cool the surroundings through transpiration (Krofcheck et al., 2019). Planting and keeping trees next to farmland can protect crops from erosion due to heavy rain. Forests can contribute to alleviating inland floods because they absorb water like a sponge and play an important role in carbon sequestration for climate change mitigation (Watson et al., 2018).

Forests themselves are also under threat because of climate change. The increasing rate of change in climatic conditions may limit the capacity of trees and forests to adapt to new growing conditions or to move to more suitable areas (EEA, 2017b; Morecroft et al., 2019). The increased intensity and frequency of extreme climatic events, such as droughts and storms, trigger severe disturbances, such as fires, insect infestations, disease outbreaks, and competition from exotic/invasive plant species (Seidl et al., 2017) (see Image3.2). These disturbances may result in forest degradation, deforestation and loss of biodiversity (Ciccarese et al., 2012).

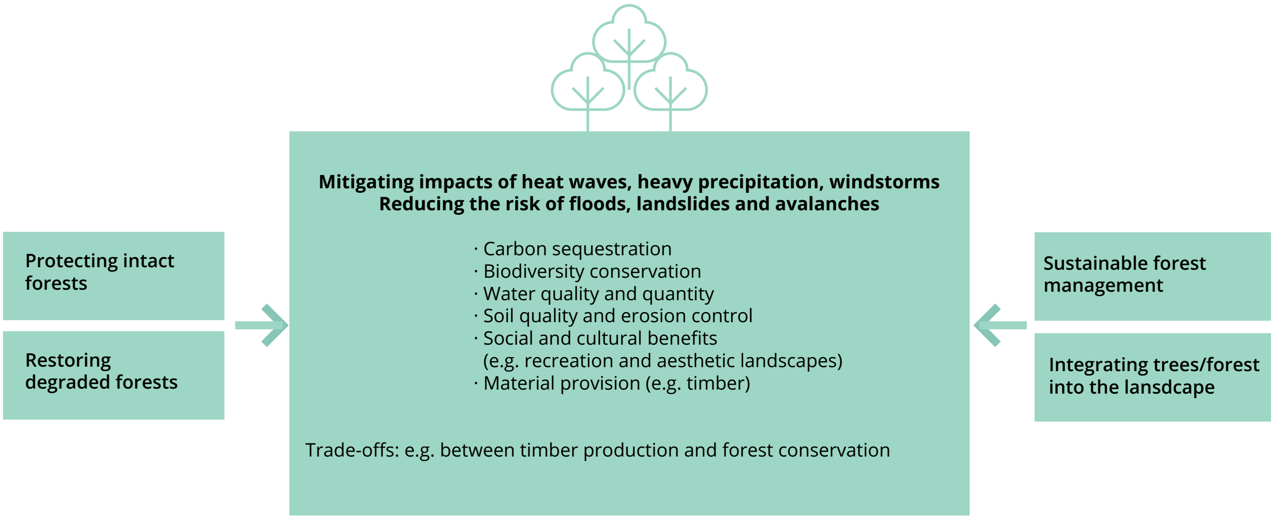
Four actions can regain the ecological, social, climatic and economic benefits of forests: (1) protecting primary and old-growth forests; (2) restoring degraded forest ecosystems; (3) managing forests sustainably; and (4) integrating trees and forests into other sectors and ecosystems (e.g. in agriculture and urban planning) (see Figure 3.4).

Natural forest ecosystems, including old-growth forests, host rich and complex biodiversity, due to the heterogeneity and diversity of stand structures and species composition. This complexity and diversity make natural forests more stable and resilient to diverse and unexpected disturbances. Natural undisturbed forests in Europe cover less than 4 % of the total forest area (Forest Europe, 2015). The protection and recovery of these remaining natural forests is indispensable for addressing climate change, because the unmanaged forest can develop into various states (Watson et al., 2018).

Natural undisturbed forests in Europe cover less than 4 % of the total forest area

Image 3.2 **Dieback of coniferous forest affected by droughts and insect infestation at Bieleboh mountain in eastern Germany (regrowth of deciduous tree species allows more diversity of tree species, helping to reduce the risk of future diebacks)**

Figure 3.4 Key nature-based solutions for addressing climate change impacts in the forests and forestry sector and their multiple benefits and trade-offs



Source: EEA.

Planting new forests, restoring degraded forests and enriching existing forests helps to re-establish the multiple functions of forests and in that way contribute to CCA and DRR. Studies demonstrate that the sustainable restoration of degraded forest ecosystems can be cost-effective (de Groot et al., 2013; Verdone and Seidl, 2017; Mansourian et al., 2019). A study in Czechia demonstrated that the restoration of degraded forests generated benefits exceeding the investment costs in the long term, saving EUR 1.5-2.5 billion per year (Jongepierová-Hlobilová, 2012).

More than 95 % of Europe's forests are under some form of management: most of them are classified as semi-natural forests, being planted or seeded. Sustainable forest management (see Box 3.1) provides options to cope with the adverse effects of extreme climatic events and natural disasters (Millar and Stephenson, 2015; Morecroft et al., 2019). Silvicultural practices, for example tending, thinning, stand conversion and tree species enrichment, alter the stand structures and tree species composition and can help adapt to and reduce the risks from climate change and hazards (EC, 2015).

More than 95 % of Europe's forests are under some form of management

Box 3.1 Definition of sustainable forest management

Forests in Europe are generally managed in accordance with the principles of sustainable forest management. Forest management has shifted emphasis from timber production towards considering the delivery of other products and services from forest ecosystems. Sustainably managed forests and trees make vital contributions to both people and the planet in the form of protecting biodiversity, responding to climate change and providing a broad range of ecosystem services. The latest report on global forest resources from the Food and Agriculture Organization of the United Nations defines sustainable forest management as a 'dynamic and evolving concept, which aims to maintain and enhance the economic, social and environmental values of all types of forests, for the benefit of present and future generations' and states that 'managing forests sustainably means optimising their benefits, including timber and contributions to food security, to meet society's needs in a way that conserves and maintains forest ecosystems for the benefit of present and future generations' (FAO, 2020).

Integrating trees into the management practices of other sectors, such as agriculture (agroforestry) and urban areas, can also support CCA and DRR in these sectors. Likewise, planting trees in urban and peri-urban spaces can reduce flood risk, stabilise steep slopes and provide cooling for humans and animals (Carinanos et al., 2018) (see Section 3.9).

3.7.1 Multiple benefits and trade-offs

The four forest actions demonstrate solutions that are applicable at tree, stand and landscape level and across different sectors. Protecting, restoring and sustainably managing forests entails maintaining a plethora of forest ecosystem products and services (Hoffmann and Sgrò, 2011; EEA, 2016a; Watson et al., 2018). Well-managed forests offer multiple benefits, such as biodiversity protection, improved water quality and supply, water regulation, control of soil erosion and maintenance of attractive landscapes and recreational areas (Fernandes and Guiomar, 2018). Agroforestry systems (see Box 3.2) have also been proven to substantially contribute to climate change adaptation by increasing resilience to climate and weather extremes and improving soil conditions (Schoeneberger et al., 2012; Torralba et al., 2016). Urban and peri-urban forests improve air quality, enhance biodiversity, and improve the health and well-being of citizens (Albert et al., 2019; Ferreira et al., 2020).

The level of provision of forest services varies depending on the management practice and the maturity of a forest. Thus, the degree to which the benefits listed are achieved depends on whether the design of the proposed NbS involves trade-offs with ecosystem services. While timber extraction provides monetary returns, it may lead to trade-offs with biodiversity, recreation opportunities and carbon storage. An essential requirement for the development of NbS is to reduce systemic trade-offs and to increase synergies (Eggermont et al., 2015; Maes and Jacobs, 2017).

3.7.2 Opportunities for implementation

Forest management should aim to enhance ecological and societal resilience to climate change, while such NbS interventions can potentially also generate jobs and considerable socio-economic benefits in the forestry sector (Maes and Jacobs, 2017). To this end, NbS need to include sustainable, locally adapted and biodiversity-enhancing practices stemming from both innovative and existing practices based on traditional and local knowledge. For example, agroforestry is gaining interest in Europe and has the potential to increase the resilience of the production system to climate change as well as sequestering carbon (see Box 3.2).

3.7.3 Limitations

The rotation cycle of managed forests varies from several decades to more than 100 years. This creates considerable uncertainty around the timing and severity of climate change and disaster impacts, the consequences of management changes and the responses of the forest ecosystems to both. The effectiveness of a forest NbS is challenging to measure, as climate change adaptation may not happen until decades after the implementation of an NbS (Morecroft et al., 2019). However, similar uncertainties are also involved in the planning and construction of grey infrastructure.

Forest managers are used to considering long timeframes and are aware of the pressures and risks caused by climate change and the increasing frequency of disaster events. They employ a wide range of practical options, but there are few straightforward recommendations of use for making management decisions (Jandl et al., 2019). Ownership structures across the landscape and the multiple uses of forest services can make it challenging to unite the various stakeholders and actors in a concerted effort to achieve CCA and DRR (von Geibler et al., 2010; EIP-AGRI Focus Group, 2019; Ferreira et al., 2020). An increasing number of non-expert owners of small forest properties may find it unexpectedly challenging to make decisions on forest management with long-term implications.

Recent EU strategies entail the massive replanting of trees and forests to address the climate and biodiversity crises. However, the documentation of the efficiency of such measures is inadequate. This needs further research (e.g. the potential for restoring and rewilding of forests and peatlands for mitigation and adaptation).

Box 3.2 Agroforestry

Agroforestry is part of traditional land use systems across Europe, which often have high nature and cultural values. Such systems are unique as land management practices that simultaneously offer biophysical, ecological and socio-economic services, including climate-smart solutions (Fagerholm et al., 2016; Hernández-Morcillo et al., 2018). Agroforestry refers to multipurpose land use, i.e. the integration of trees and shrubs with crops and/or livestock on the same unit of land (see Image3.3 and Figure 3.5). While contemporary agroforestry is not widespread in Europe, traditional examples include systems in which trees are integrated into arable systems on the field boundaries (e.g. windbreaks, hedgerows) and where intercropping and grazing is combined with high-value tree crops such as olives and apples (Mottershead and Maréchal, 2017). Modern agroforestry systems combine biomass production for non-food uses with food production using, for example, poplar or black locust with different types of agricultural crops (Torralba et al., 2016).

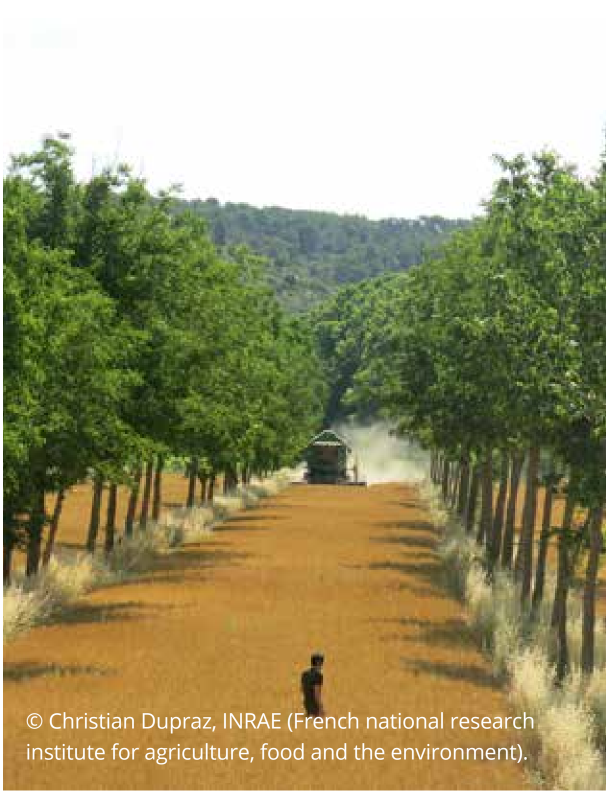
The multiple benefits of agroforestry systems include higher carbon sequestration and higher biodiversity levels than conventional agricultural systems (but lower than that of many natural forests), and they enable wildlife corridors and protect livestock (Fagerholm et al., 2016; Kay et al., 2020). Economically, by their nature, agroforestry systems increase economic resilience because they are a means of reducing reliance on a single source of income.

Agroforestry systems are also proven to substantially contribute to climate change adaptation (see Section A4.5). Hernández-Morcillo et al. (2018) and Kay et al. (2020) list a number of agroforestry solutions for enhancing resilience to climate change and reducing threats. The combination of trees, crops and livestock helps:

1. mitigate erosion by creating permanent soil cover;
2. minimise damage from flooding and enhance water storage, with considerable benefits in warm and dry regions;
3. bring nutrients from deeper soil layers or fix nitrogen in the case of leguminous trees, thus maintaining soil fertility;
4. secure yields and economic income under different climatic conditions due to the range of intercrops, yielding marketable produce, and crop-rotation;
5. reduce the impacts of extreme weather events by using multifunctional windbreaks and hedgerows with trees and shrubs.

Compared with current agricultural systems, the food or fodder production of most agroforestry systems is lower because there is less space for crops and more competition for light (Burgess and Rosati, 2018; Dupraz et al., 2018). This may, however, be different under more limited conditions (e.g. droughts) as agroforestry systems are more climate resilient; agroforestry can maintain and, in some cases, enhance yields in drier, more variable climates (Seddon et al., 2020b). Another challenge of agroforestry systems is their complexity (e.g. the combination of long-lived perennial trees and shrubs with other crops and/or livestock), which can make their management difficult and time consuming (e.g. because less machinery can be used).

Image 3.3 Barley and walnut agroforestry plot (Restinclières, Occitanie, France)



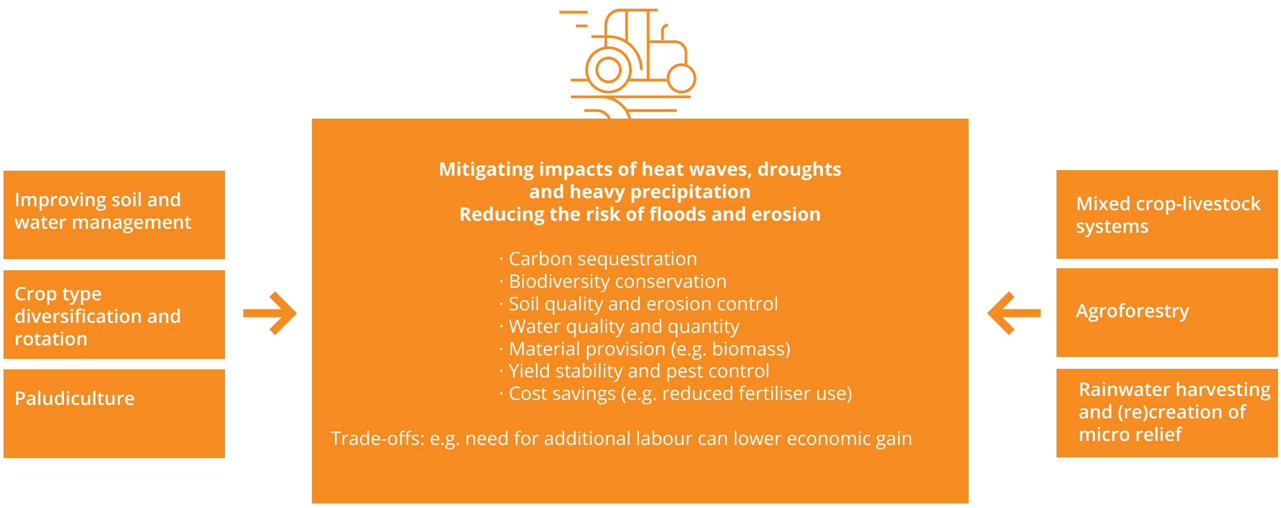
Note: See Section A4.5.

3.8 Agriculture and nature-based solutions for climate change adaptation and disaster risk reduction

Various farming systems across Europe use NbS. A key principle is that ecologically based diversification reduces vulnerability to hazards, while at the same time it can increase productivity. Examples are integrated crop-livestock systems, soil organic matter management, mixed cropping, crop rotations, biological control of pests and agroforestry. Resilience to climate disasters is closely linked to farms with increased levels of biodiversity (Altieri et al., 2015). An agro-ecological approach supports biodiversity, which has growing importance in the European debate on agri-food systems (Wezel et al., 2018). The EU biodiversity strategy for 2030 aims to increase biodiversity features on agricultural land, referring to agro-ecology as an option (EC, 2020e). There are, however, gaps in our knowledge of its performance (HLPE, 2019) and not enough is known about its use in European farming systems (Wezel and Bellon, 2018). Thus far, agro-ecology is not explicitly part of EU funding schemes under the common agricultural policy (CAP), but it is beginning to be recognised as a viable way to improve environmental performance (Paracchini and Bertaglia, 2018). Case studies of policies supporting agro-ecology have been done in France and Germany (Mottershead and Maréchal, 2017) and in Czechia, where the second pillar of the CAP is used to encourage investment in agro-ecology-related measures (Wezel et al., 2018).

Ecologically based diversification reduces vulnerability to hazards, while at the same time it can increase productivity

Figure 3.5 Key nature-based solutions for addressing climate change impacts on agriculture and their benefits and trade-offs



Source: EEA.

Adaptation measures occur at a variety of levels, including at national, regional and farm levels. An overview of the options and the multiple benefits for climate change mitigation is provided in the 2019 EEA report *Climate change adaptation in the agriculture sector in Europe* (EEA, 2019a). Based on this, a number of NbS options are set out in Box 3.3.

Box 3.3 Nature-based solutions for a resilient European agriculture

- Improved soil and water management: cover crops, no tillage or minimum tillage, high nature value farmland, improved irrigation efficiency.
- Crop type diversification and rotation: crop diversification and rotation, use of adapted crops (e.g. crops demanding less water), diversification of farm income sources.
- Agroforestry (see Box 3.2).
- Mixed crop-livestock systems: livestock breeding, improved pasture management, improved livestock rearing conditions, silvo-pastoral practices.
- Water harvesting: rainwater harvesting, re-creating micro-relief to allow rainwater to infiltrate to the groundwater.

Sources: EEA (2019a).

Conservation agriculture

Conservation agriculture promotes minimum soil disturbance, maintenance of permanent soil cover and biodiversity. This leads to an improved soil structure, reduced use of fertilisers and lower CO_2 emissions). Such practices improve the ability of crops to adapt to climate change and variability (Vignola et al., 2015), and they can perform as well as high-input systems. Conservation agriculture is not widely adopted in Europe; however, the area is growing, because of increasing environmental awareness. In Norway and Germany, for example, the adoption of conservation agriculture has been encouraged and subsidised to mitigate soil erosion.

Conservation agriculture is not widely adopted in Europe; however, the area is growing

Mulching and use of cover crops

Cover crops (grass or legumes in rotation between regular crops) can help alleviate drought stress by increasing water infiltration rates and soil moisture. They can also improve soil quality by increasing soil organic matter and reducing erosion (Bergtold et al., 2017). Cover crops help reduce the effects of extreme radiation, extreme rainfall and strong winds (Vignola et al., 2015). Cover crops can also lead to savings in input costs by adding or recovering nutrients and can generate revenue when sold as biofuel feedstocks (EEA, 2019a). Cover crops can have both positive and negative impacts on yields (Blanco-Canqui et al., 2015; Bergtold et al., 2017), but they help to promote the long-term sustainability of the farm, even if the immediate net returns are not positive.

Minimum tillage

No tillage or minimum tillage contributes to more productive soils, as carbon storage in the upper soil layers can increase. No tillage may be viewed as a method for reducing soil erosion and ensuring food security, while an increase in soil organic carbon storage is a co-benefit for society (Ogle et al., 2019). A case study in the United Kingdom showed that soil organic matter increased by around 75 % on a farm using a minimum tillage system (FiBL, 2020). In general, there are uncertainties over the effectiveness of this option and its suitability depends on soil type, as some soils do not respond well (e.g. heavy clay). No tillage can also lead to an increasing need for pesticides or alternative forms of pest control.

Crop diversification and rotation

Diversification of crop varieties can ensure crops' resistance to extreme weather events (Ratnadass et al., 2012; Vignola et al., 2015). Diversification strategies can include mixed cultivation, intercropping and maintaining local genetic diversity of crops to spread risks. Diverse systems are more resilient to natural disasters than monocultures (Dooley and et al., 2018) and exhibit greater yield stability (Altieri et al., 2015). Renard and Tilman (2019) showed that diversification leads to increased national harvest stability and greater resilience in the long term. The effects on soil nutrients and carbon remain poorly understood (Isbell et al., 2017), but diversification may result in a slight gain of soil carbon (EEA, 2019a). The variety of diversification approaches, however, make it difficult to compare effects (Beillouin et al., 2019; Hufnagel et al., 2020).

Paludiculture

Paludiculture is a 'wet agriculture' practice on peatlands for producing biomass, for example for bioenergy or building materials. In northern, eastern and central European countries, peat soils drained for agriculture are a considerable source of greenhouse gas emissions (Buschmann et al., 2020). Across the EU, drained peatlands comprise 2.5 % of agricultural land but are responsible for 25 % of agricultural greenhouse gas emissions. Wet peatlands do not release CO_2, can sequester carbon, help to improve water quality, provide habitat for rare and threatened species and can be used to produce biomass in paludiculture (Tanneberger et al., 2020). Therefore, restoring peatlands and implementing paludiculture benefits both climate change mitigation (less greenhouse gas emissions) and adaptation (reduced risks of floods as well as droughts), and it increases biodiversity compared with conventional agriculture (see Image 3.4 and Section A4.7).

Wet peatlands do not release CO_2, can sequester carbon

Image 3.4 Paludiculture in north-east Germany on a rewetted fen (left) and with a cattail or bulrush (Typha) plantation (right)

Note: Restoring peatlands and using them for 'wet agriculture' practices reduces greenhouse gas emissions and benefits adaptation by reducing the risks of floods and droughts while providing alternative sources of income.

Mixed crop-livestock systems

Mixed crop-livestock systems can use resources more efficiently by using crops and grassland to feed animals and fertilising fields with their manure. In this way mixed crop-livestock systems improve nutrient cycling while reducing chemical inputs. The number of mixed farms has declined across Europe (Martin et al., 2016) because of intensification and CAP regulations. Currently over 70 % of the EU's livestock is raised on very large farms (Sharma, 2019) which can lead to loss of biodiversity. Successful implementation of mixed crop-livestock systems over Europe are reported by the EIP-AGRI Focus Group (2017). Leterme et al. (2019) showed that mixed-crop livestock farms have improved environmental performance but may have drawbacks, including increased workload and reduced productivity and economic performance.

(Rain)water harvesting and (re)creation of micro-relief

(Rain)water harvesting and (re)creation of micro-relief increases the resilience of a farm to water scarcity and droughts. It offers a promising contribution to enhancing the availability and quality of water (Sonneveld et al., 2018). For rain-fed crops, rainwater harvesting increases production per unit of area and input (EEA, 2019a). Improved rainwater harvesting and storage can also result in energy savings. Water harvesting can be implemented at various scales: rainwater harvesting on the farm, constructing floodplains near agricultural land and groundwater recharge in dry areas (see Section A4.6). Rainwater harvesting can reduce groundwater levels and stream flows, but farmers can incur significant costs.

3.8.1 Multiple benefits and trade-offs

In general, NbS in agriculture promote diversification to reduce vulnerability and spread the risks posed by climate variability and extreme weather. Improved soil and water management practices can improve soil structure and increase its water-holding capacity, lower CO_2 emissions and reduce the use of fertilisers. This is important, as mineral fertilisers are widely used in EU agriculture. Europe is dependent on imported phosphorus, but there is a limitation on its use, being a non-renewable resource. Cover crops lead to improved carbon sequestration, and reducing tillage can enhance the ability of soils and biomass to operate as carbon stock reserves. Mixed crop-livestock farming systems can lead to improved soil fertility and increased biodiversity. They enhance the biological control of pests through species interaction. A co-benefit is that such systems promote rural development through diversified jobs and linking farming, food and tourism (EIP-AGRI Focus Group, 2017). As a trade-off, despite improved environmental performance, they can have drawbacks in terms of reduced productivity. Rainwater harvesting can increase crop yield and improve resilience to water scarcity and droughts. It can result in energy savings because of the reduced need for pumping. As a trade-off, however, it can incur significant costs for farmers, groundwater levels and lead to loss of (productive) land.

In general, it is difficult to assess the effects of NbS and make comparisons, because of unique local circumstances and the different combinations of options applied. In addition (quantified) evidence for the impacts is poorly documented in Europe, as shown by D'Annolfo et al. (2017).

Rainwater harvesting can increase crop yield and improve resilience to water scarcity and droughts

3.8.2 Opportunities for implementation

Implementation of NbS requires a comprehensive approach that starts with the valuation of the desired ecosystem services to be provided. Stakeholder involvement and funding schemes are also important elements for successful implementation (Sonneveld et al., 2018). Opportunities are offered by EU policies and programmes. The EU strategy on adaptation to climate change and the CAP support adaptation actions in agriculture. The proposed new CAP for 2021-2027 promotes the implementation of measures for both mitigation and adaptation at farm level and offers opportunities for investment (EEA, 2019a).

3.8.3 Limitations

A number of factors limit the effectiveness of NbS for agriculture and may even put them at risk. Despite potential positive effects, diversification measures are not always implemented because of a lack of the required investment, expertise and research evidence (Meynard et al., 2018; Hufnagel et al., 2020). Some examples are:

- A barrier to introducing mixed crop-livestock systems is their low short-term profitability at farm level (EIP-AGRI Focus Group, 2017).
- Morel et al. (2020) identified that major barriers to crop diversification are related to a lack of technical knowledge and references and also to a lack of crop varieties adapted to the local context and fears of increased complexity.
- Lack of proper community involvement can act as a barrier. In most NbS success stories described by Sonneveld et al. (2018), communities were involved from the beginning, which gave them a sense of ownership. An example from

the Netherlands shows how a small-scale cooperative mixed farm was initiated by a group of local residents to produce 'nature-driven food' and provide the farmer with a stable income, avoiding the risk of financial breakdown (Farming Communities, 2020).

3.9 Urban areas and nature-based solutions for climate change adaptation and disaster risk reduction

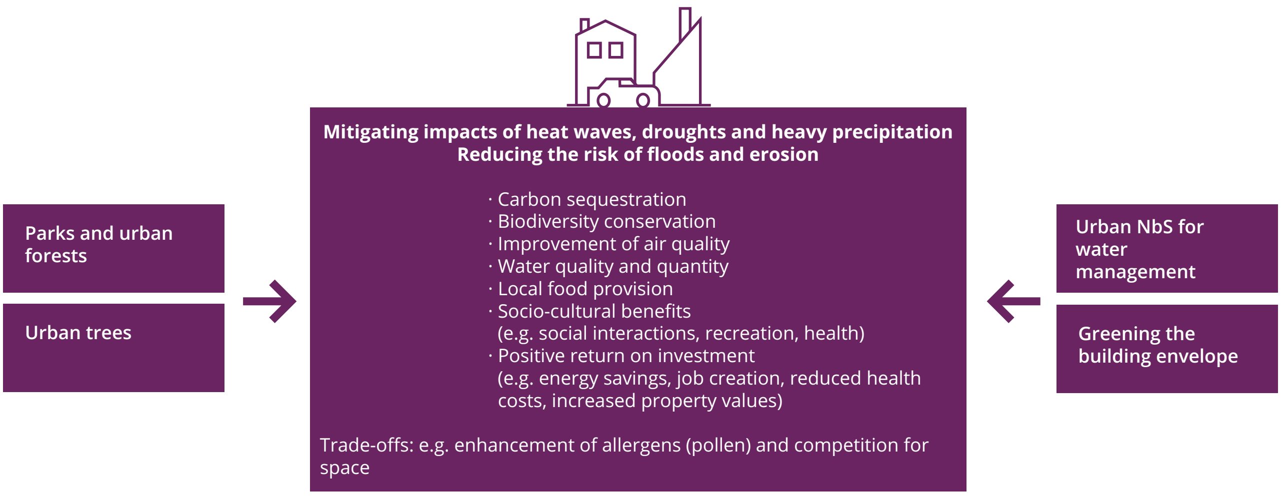
Key NbS options for resilient European cities involve maintaining, restoring and creating new parks and urban forests, planting individual urban trees, improving urban water management and greening buildings (see Figure 3.6). NbS emerge as being effective in addressing high temperatures and flooding in cities and may simultaneously address multiple hazards and provide multiple benefits to the environment and society (EEA, 2020e). The scale of urban NbS ranges from individual small-scale NbS on buildings or streets to large-scale, systemic implementations of NbS across an urban area, connecting to peri-urban areas and the wider landscape (see Section A4.9).

Parks and urban forests

Among the different types of urban NbS, parks and urban forests are recognised for their capacity to reduce air and surface temperatures, provided that the right species are chosen (Roy et al., 2012; Calfapietra, 2020; EEA, 2020e). For example, grass surfaces exposed to the sun can be 2-4 °C cooler than concrete surfaces, and trees lower air temperatures by 5-7 °C due to shading and evapotranspiration (Armson et al., 2012). Urban parks are on average 0.94 °C cooler during the day than built-up areas, with larger parks and those with trees having a more substantial cooling effect (Bowler et al., 2010a). Beside mitigating the urban heat island effect and heat stress, urban parks and forests can also regulate storm water and thus mitigate flood hazards by intercepting rainfall, which subsequently evaporates, infiltrates the ground or is otherwise delayed in contributing to run-off (Berland et al., 2017). For example, while urban landscapes with 50-90 % impervious cover lose 40-83 % of rainfall to surface run-off, a forested landscape typically loses about 13 % of rainfall to run-off following similar precipitation events (Pataki et al., 2011).

Urban parks are on average 0.94 °C cooler during the day than built-up areas

Figure 3.6 Key nature-based solutions for addressing climate change impacts in urban areas and their multiple benefits and trade-offs



Source: EEA.

Urban trees

Trees and other woody plants along streets and in public squares and car parks can contribute to reducing stormwater run-off during heavy rainfall events. The structure, in terms of the number, density, sizes and species composition, health and spatial configuration of street trees, largely determines the stormwater benefits. A study on street trees estimated that a tree can intercept 6.7 m^3 water per year, which can help to reduce the frequency and severity of combined sewage water overflow events (Berland and Hopton, 2014). Similar results have been found in other studies (Berland et al., 2017). The stormwater benefits from urban trees can be translated into economic terms; for example, a study from Lisbon estimated an economic benefit of USD 47.80 per tree thanks to its ability to reduce stormwater run-off (Soares et al., 2011). Urban trees also contribute to improving the microclimate by providing shade, reducing air temperature, reducing heat island effects, modifying the microclimate and reducing wind speed, followed by reducing solar radiation, relative humidity, glare and reflection (Bowler et al., 2010b; Roy et al., 2012; Calfapietra, 2020).

Nature-based solutions for urban water management

NbS for addressing water management within cities include river restoration, bioswales, retention and detention basins (or bioretention cells/filters), (constructed) wetlands, rain gardens, permeable pavements, riparian vegetation strips and green roofs (see also Section 3.6). Removing excess asphalt and concrete in private and public urban spaces can offer opportunities to implement many such NbS, including reopening channelised watercourses and restoring riverbanks. Flowing freshwater also adds to the cooling effects of cities and provides habitat for species (e.g. birds, fish). NbS for urban water management aim to control surface run-off volumes and timing and hence reduce the risk of flooding during heavy rainfall events (Vojinovic, 2020). This approach is largely in contrast to conventional grey, engineered, infrastructure which often routes run-off to the sewerage system, which may overflow during extreme precipitation events, or directly to streams and rivers, exacerbating pollutant inputs and hydrological disturbance and resulting in a degradation of the ecosystem's structure and function (Roy et al., 2008). Combining the sewerage infrastructure with NbS, such as bioswales, street trees or rain gardens, can enhance the interception, evaporation and infiltration of storm water before it reaches sewerage systems, thus decreasing the volume of (waste) water needing to be treated (Wild, 2020a). The effectiveness of NbS for urban water management depends on the type and design of the NbS and the local conditions. Small-scale NbS have been found to reduce run-off by 30-65 % for porous pavements, up to 100 % for rain gardens or up to 56 % for infiltration trenches (Ruangpan et al., 2020).

Street trees or rain gardens decreasing the volume of (waste) water needing to be treated

Greening the building envelope

Without compromising the need for space in dense urban areas, greening the building envelope (e.g. green roofs, green walls or facades) can provide effective local benefits for CCA and DRR in terms of water and heat management (see Image 3.5). In terms of water management, green roofs can retain greater amounts of water than conventional roofs and delay water run-off (Oberndorfer et al., 2007; Pataki et al., 2011). A heavy rain event of short duration (e.g. 30 min) may even be completely retained by a dry green roof (Richter and Dickhaut, 2018) and in general reduce run-off volume by up to 70 % and peak flow volume by up to 96 % (Ruangpan et al., 2020). In terms of heat management, vegetated roofs are effective in reducing air temperature and in improving indoor thermal comfort and reducing energy demand (EEA, 2020e). For example, green roofs and facades have been found to reduce the energy demand for air-conditioning by up to 40-60 % in a Mediterranean climate (Alexandri and Jones, 2008; Mazzali et al., 2012) and can cool surrounding streets by between 0.03 °C and 3 °C (Francis and Jensen, 2017) (see Section A4.10). Moreover, greened surfaces, whether on buildings or on the ground, have a higher albedo (20-30 %) than artificial hard surfaces (5 %), contributing to reducing the urban heat island effect by reflecting more light (Perini and Rosasco, 2013). Although the installation, maintenance and disposal of greening systems may appear costly at first, the costs compared with the overall construction costs are small (0.4 % of overall construction costs for multistorey residential buildings) and life-cycle costs over 40 years have been found to be similar to those of black roofs (Dickhaut et al., 2017).

A heavy rain event of short duration (e.g. 30 min) may even be completely retained by a dry green roof

Image 3.5 Heat mitigation by green roofs in Hamburg, Germany

Note: On a hot summer, day green roofs can be 30 °C cooler than conventional roofs (Hamburg Agency for Environment and Energy in Wilhelmsburg, Germany). See Section A4.10.

3.9.1 Multiple benefits and trade-offs

Urban NbS offer multiple benefits beyond CCA and DRR, addressing air quality, health and well-being, carbon sequestration, energy savings, local food production, biodiversity and improvement in the quality and quantity of water resources (see Figure 3.6). Many of these benefits from urban NbS provide quantifiable direct and indirect economic benefits to society, businesses and communities, such as job creation, reduced costs of mental and physical health care, savings in energy costs, avoided damage costs or increased property values. However, it has proved a challenge to create a market of private investors and insurers willing to invest in NbS, as many of the benefits take time to manifest (Whiteoak, 2020). However, the investments in labour intensive NbS could make a significant contribution to reducing unemployment resulting from measures implemented to address the COVID-19 pandemic (see Section 3.9.2).

Air quality and human health is positively affected by plants, and in particular trees, through the removal of pollutants (e.g. ozone, fine particulate matter, nitrogen oxides and sulphur dioxide) (Grantz et al., 2003; Nowak et al., 2014; Calfapietra, 2020). Green walls and roofs can be valid options in very dense areas where the use of trees is not optimal, and street trees have, for instance, been associated with a lower prevalence of early childhood asthma (Calfapietra, 2020).

Plants and trees can, however, also emit pollen and biogenic volatile organic compounds with negative health effects; but by choosing the right species, it is possible to maximise the services provided and minimise disservices (Calfapietra, 2020).

Access to parks and urban forests has positive physical and mental health benefits

Physical and mental health and well-being can be considerably enhanced by having access to green and blue spaces (Calfapietra, 2020). Access to parks and urban forests has positive physical and mental health benefits (Chiesura, 2004; Haase et al., 2014b) and the COVID-19 lock-downs across Europe have highlighted the vital importance of local parks, pocket parks and urban forests as an essential element of people's quality of life (Kleinschroth and Kowarik, 2020) and as infrastructure promoting resilience during a time of crisis (Venter et al., 2020). Furthermore, evidence suggests that access to vegetation and nature has a mitigating effect on violent crime (Shepley et al., 2019). Urban parks, well-designed green streets and even green roofs can play a crucial role in promoting more sustainable commuting modes and in connecting neighbourhoods, thus creating opportunities for a more healthy lifestyle (Adkins et al., 2012). Moreover, there is a growing evidence base for the potential for urban NbS to contribute to the storage and sequestration of carbon (Nowak et al., 2013; Merriman et al., 2017; Bulkeley, 2020a), although urban vegetation is not capable of completely offsetting anthropogenic carbon emissions (Velasco and Roth, 2010; Baró et al., 2014).

Biodiverse and healthy ecosystems are key to NbS in urban and peri-urban areas so that they can tackle societal, economic and environmental challenges. Biodiverse and healthy ecosystems are essential to ensure climate change resilience and to enable ecosystems to deliver critical ecosystem services and benefits to their full potential (Naumann and Davis, 2020). Urban NbS significantly improve biodiversity over conventional infrastructure and sometimes can even match their natural counterparts (Baldock et al., 2015; Filazzola et al., 2019). However, this requires space for nature. Urban biodiversity can be improved through the creation of new ecosystems, for example on walls and roofs (Perini and Rosasco, 2013). Urban parks, pocket parks, urban trees, vegetated roadsides, wetland detention basins, yards and gardens are other features essential for supporting biodiversity and urban wildlife. Restoring degraded urban habitats, for example rivers and riverbanks, provides new habitats and green infrastructure corridors for biodiversity (Vojinovic, 2020). Natural protected areas on the outskirts of cities can improve the connectivity between areas within urban and rural areas (Naumann and Davis, 2020), thus supporting the health and resilience of urban ecosystems.

NbS for water management can have significant benefits for water quality and water resource replenishment by increasing the amount of surface water supplies, recharging groundwater and improving water quality by removing pollutants from urban run-off and reducing the impacts of combined sewer overflows (Prudencio and Null, 2018; Wild, 2020a). Green roofs can deliver significant improvements in water quality (Czemiel Berndtsson, 2010), and rain gardens can be effective urban NbS in terms of groundwater recharge and removing nitrogen, depending on the type of rain garden (Nocco et al., 2016). Implementing a suite of sustainable urban drainage measures (e.g. combining rain gardens, bioswales and street trees) can also contribute significantly to stream restoration by reducing frequent disturbances from even small rain events that would otherwise regularly deliver water and pollutants to water courses (Walsh et al., 2005).

Urban NbS can, however, also provide disservices if not well designed, planned or properly maintained; for example, the choice of certain species may increase emissions of biogenic volatile organic compounds and pollen (Calfapietra, 2020), the prevalence of low and dense vegetation may create more unsafe environments (Kondo et al., 2015) or the use of irrigation water for urban green spaces might put additional pressure on cities' water supplies during droughts (Fam et al., 2008). Although the overall benefits of urban NbS can outweigh the disservices, it is important to mitigate negative effects to ensure public acceptance of urban NbS. Moreover, poor planning might lead to an uneven distribution of green areas, which may trigger social exclusion or segregation due to unequal access to nature, and central or easily accessible nature areas may be vulnerable to intensive recreational use. Urban NbS can also be subject to trade-offs with other activities, as space is scarce and competition is high. For instance, the emerging policies on solar photovoltaic panels on roofs may overrule plans for green roofs, even if a combination of both would be beneficial; or policies to create affordable housing centrally (e.g. on abandoned brownfield sites) may be at odds with creating a large urban park that provides a range of regulating and cultural ecosystem services to the city. Similarly, it would require a holistic and in-depth assessment to decide among the trade-offs between establishing an urban forest on contaminated land, providing the maximum level of benefits but no direct revenue streams, or having remediation paid for by new buildings on part of the area.

3.9.2 *Opportunities for implementation*

The benefits and opportunities achievable using NbS to address global and societal challenges have never been more relevant, important or urgently needed than now (Wild et al., 2020). In addition, a resilient recovery from COVID-19 offers a chance to 'build back better' and significantly increase investment in urban NbS. Scaling up and stepping up their implementation would provide jobs and business opportunities and foster transformative change in urban areas while significantly increasing the much-needed resilience of European cities to climate change and other unprecedented shocks. The COVID-19 pandemic could thus give an additional boost to NbS in cities (EEA, 2020e). In addition, the EU Green Deal mentions urban NbS explicitly in relation to addressing climate change impacts, and the EU biodiversity strategy for 2030 highlights NbS as a key instrument for climate adaptation and mitigation and for greening cities (Naumann and Davis, 2020).

3.9.3 *Limitations*

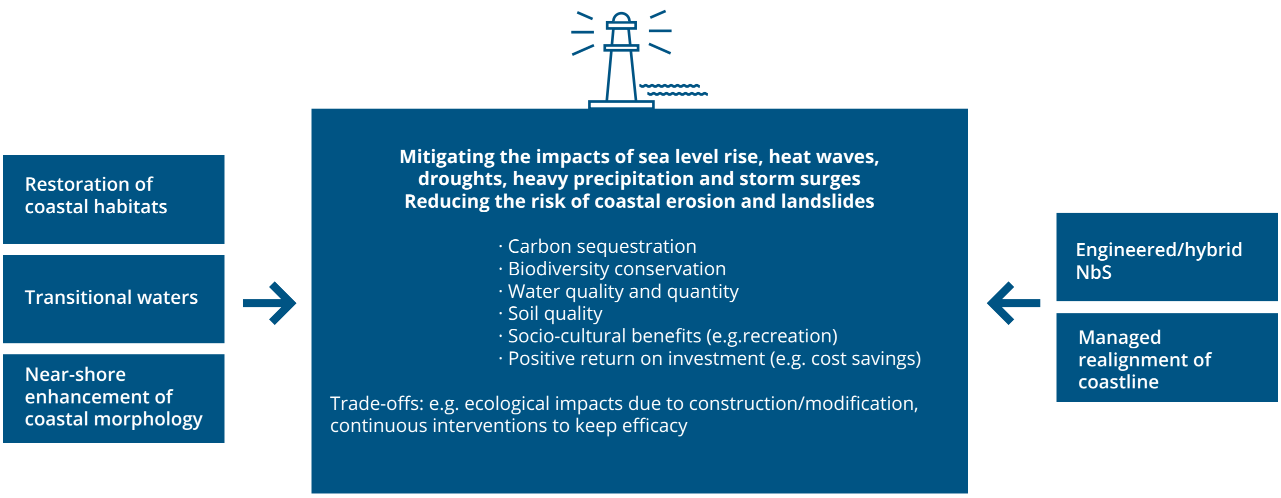
Especially within recent years, evidence on multiple benefits provided by NbS is starting to emerge (Veerkamp et al., forthcoming), and a growing number of cities are exploring NbS to address urban sustainability challenges (Naturvation, 2020). However, despite the growing attention from both scientists and policymakers, the evidence base is still scattered and the research effort is uneven, with a dominance of studies evaluating single or a few benefits only or focusing on certain types of NbS (i.e. urban parks and urban forests) rather than assessing the multiple benefits (including co-benefits and disservices) simultaneously (Keeler et al., 2019; Veerkamp et al., forthcoming). Moreover, there are many diverse assessment methods and impact indicators (Haase et al., 2014b), which might hinder comparability across studies and ranking the effectiveness of different NbS options or comparing them against a grey intervention (Veerkamp et al., forthcoming). The Eklipse impact evaluation framework, identifying 12 societal challenge areas, is one approach to assessing multiple benefits (and costs) of NbS in a holistic framework (Raymond et al., 2017b). An integrated NbS assessment framework, developed by 17 individual EU-funded NbS projects, expands on the Eklipse framework to provide much-needed guidance for practitioners on NbS impact assessment, by identifying and classifying NbS impact indicators for different areas of societal challenge and guiding users through the choice between the various assessment methods and contexts (Dumitru and Wendlin, 2020).

Data on and assessments of the relative performance of NbS, in particular cost-effectiveness compared with traditional grey infrastructures, are urgently needed (Wild, 2020b). Standardising the terminology might be helpful to create a more cohesive field of study of the benefits provided by urban NbS by using harmonised metrics/indicators quantified to a greater extent than today (Prudencio and Null, 2018). Quantifying the benefits would be beneficial to facilitate widespread uptake of NbS measures. Furthermore, insights from social researchers and political science is needed to complement the current assessments (Wild et al., 2020). Issues of scale limit the widespread implementation of urban NbS. For instance, most research on hydrometeorological risks and NbS has to date focused on small-scale NbS (Ruangpan et al., 2020). Future research is therefore needed to assess the effectiveness and efficiency of 'networks' of interconnected small-scale NbS and that of large-scale NbS, including hybrid combinations with grey infrastructure (Vojinovic, 2020). In addition, better evidence is needed on how NbS can create synergies between climate and biodiversity goals across different scales (Wild et al., 2020).

3.10 Coastal areas and nature-based solutions for climate change adaptation and disaster risk reduction

In recent decades, coastal protection has shifted from engineered solutions (i.e. hard or grey) to 'hybrid' and more environmentally friendly 'soft' nature-based solutions (Luo et al., 2015; Pontee et al., 2016). NbS for CCA and DRR are relevant for the management of inland areas, shorelines, urban coastlines and marine areas and are implemented in terrestrial coastal areas (i.e. rural and urban shorelines) and coastal water bodies (e.g. transitional waters, seas, oceans) (see Figure 3.7).

Figure 3.7 Key nature-based solutions for addressing climate change impacts in coastal areas and their multiple benefits and trade-offs



Source: EEA.

The conservation and rehabilitation of terrestrial coastal habitats has been shown to reduce the impact of coastal hazards including sea level rise, storm surges, drought and heat waves, coastal erosion and landslides (Thorslund et al., 2017; Morris et al., 2018; Vuik et al., 2019). Coastline vegetation, barrier islands, dunes and beaches serve as natural barriers to waves and are able to recover rapidly after a storm (Bridges et al., 2015). Vegetation can reduce the dryness in coastal areas (Di Pietro et al., 2009) while mitigating coastal erosion (Morris et al., 2018). Similarly, seafloor vegetation, such as seagrasses, can retain sediments and support erosion control (Gracia et al., 2018) (see Image 3.6). Coral reefs (e.g. in European overseas territories) provide substantial protection by dissipating up to 95 % of wave energy (Ferrario et al., 2014). Hence, the restoration of coastal habitats in transitional waters (e.g. seagrasses, wetlands, saltmarshes, coral reefs) as well as near-shore enhancement of coastal morphology (e.g. through protection of barrier islands, beach nourishment, dune reconstruction, cliff stabilisation) act as a natural defence against shoreline erosion and flooding (Charbonnel et al., 2011; Bridges et al., 2015; Taal et al., 2016).

Vegetation can reduce the dryness in coastal areas while mitigating coastal erosion

In the case of the managed realignment of coastal areas, built coastal structures (e.g. flood defences) are removed to give space to the coastal ecosystems (e.g. saltmarshes or salt meadows) that act as natural coastal protection. The restored coastal ecosystems provide a wide range of ecosystem services, including nutrient retention, carbon sequestration and water quality regulation and have a high potential for eco-tourism and recreation (MacDonald et al., 2020). These benefits can outweigh the monetary loss associated with the loss of agricultural land in the case of managed realignment (MacDonald et al., 2020). In certain regions, such as on the German Baltic coast, managed realignment is often a cheaper and more sustainable long-term coastal management option than 'holding the line' (Rupp-Armstrong and Nicholls, 2007).

Engineered NbS including hybrid solutions are another option for CCA and DRR in coastal areas, where natural solutions are combined with built structures. Examples include the use of green dykes, wooded (e.g. bamboo) fences and vegetated levees, which are combined with structural measures (e.g. dykes) to enhance resilience and resistance against climate hazards (e.g. storm surges, coastal erosion and landslides) (IUCN French Committee, 2019b). For example, Artecology ([2]) have developed innovative systems of seawalls in which timber and concrete groynes, stone-filled gabions and metal sheet piling were implemented, recreating the intertidal coastal habitat by using cavities in seawalls on defended and urbanised shorelines (Hall et al., 2019)

Moreover, LIFE Vimine ([3]) used small naturalistic engineering interventions with low environmental impact (e.g. branches tied together and wrapped with nets of plant material) to protect sandbanks and saltmarshes from erosion in the Venice lagoon. Similarly, gabions filled with oyster shells are widely used to provide protection from hydrodynamic and morphological hazards (Smaal et al., 2019). Another example of a hybrid solution in coastal areas is the Sand Motor carried out by the Dutch authorities with the aim of preserving and protecting Dutch coastlines against storm surge flooding while adapting to the changing climate and enhancing biodiversity (Taal et al., 2016). The managed realignment of coastal areas can also be characterised as a hybrid approach in cases in which hard infrastructure solutions (i.e. new dykes around settlements) are combined with the restoration of coastal ecosystems.

3.10.1 Multiple benefits and trade-offs

The rehabilitation of terrestrial coastal habitats and ecosystems in transitional waters provides key ecological benefits, as vegetation is responsible for about 60 % of wave attenuation during storms events (Cunniff and Schwartz, 2015). Vegetation acts as an inland barrier during severe storms, attenuating wave energy and reducing wind speed. In addition, it provides benefits in terms of recreation, water filtration and carbon sequestration (Renaud et al., 2013). For example, a case study of the coastal habitats in the United Kingdom showed that the average sequestration rate of carbon for dune habitats is 59.5 ± 25.8 g C/m^2 per year (Beaumont et al., 2014).

Vegetation is responsible for about 60 % of wave attenuation during storms events

([2]) https://www.artecology.space/climate-change-solutions
([3]) http://www.lifevimine.eu

Image 3.6 The Ugento case study, Italy: using beached leaves of Posidonia oceanica (Mediterranean tapeweed) to reconstitute and protect dunes that have degraded

Note: The seagrass supports erosion control and the restoration of typical dune vegetation and also provides habitat for a variety of organisms (see Section A4.9).

Terrestrial coastal vegetation restoration strengthens the stability of the coastal morphology: roots and reefs retain soil and stabilise sediments in shallow coastal areas. Accordingly, these solutions provide benefits for the physical coastal environment, enhancing erosion control and mitigating the shoreline retreat (Shepard et al., 2011).

Furthermore, NbS for terrestrial and marine coastal habitats provide a more durable and flexible protection compared with hardened shorelines, apart from reducing the extra cost incurred by artificial coastal protection. In addition, engineered NbS are more durable and resistant during surge sequences than artificial solutions, while also remaining affordable (Halide et al., 2004; Pontee et al., 2016). Near-shore enhancement of coastal morphology reduces the risks of storm surge events and of forming new inlets (NRC, 2014). Moreover, the construction and strengthening of vegetated dunes and the restoration of barrier islands ensures soil stability, greater dissipation of wave energy and resistance to erosion (Cunniff and Schwartz, 2015). Habitat and nutrient loss can be limited by increasing the vegetative supplies (e.g. the presence of seagrasses) or ecosystem restoration (e.g. of coral reefs) (Gracia et al., 2018).

The trade-offs of implementing NbS must be considered. Terrestrial and marine vegetation itself is also susceptible to hazards such as extreme storm surges (Cunniff and Schwartz, 2015). Moreover, it takes time for coastal forests to become truly effective. Nevertheless, it has been demonstrated that ecosystems also play a key role in rapid and intense hazard events (e.g. protection from mangroves during Super Storm Haiyan in the Philippines in 2013 (Long et al., 2016)). Other trade-offs can occur when artificial dunes become less resistant to erosion and storm surges, as the roots of newly planted species remain shallow. Specifically, beach nourishment, implemented by adding sand along the coastline, requires re-nourishment, which can cause significant impacts on beach ecosystems (e.g. impacts on microphytobenthos, vascular plants, terrestrial arthropods) (Cunniff and Schwartz, 2015).

3.10.2 Opportunities for implementation

Although public awareness has significantly increased, the implementation of NbS for coastal areas is still limited, and hard structures are still most frequently designed and implemented (Arkema et al., 2017). It has been estimated that the protection of European coastal areas (e.g. wetlands) could lead to a saving of about EUR 50 billion annually due to the reduction in associated disaster damage (EC, 2020e). Restored and properly protected coastal and marine ecosystems bring substantial health, social and economic benefits to coastal communities and to Europe as a whole. The implementation of NbS in coastal communities can also create opportunities for economic sectors such as ecotourism (Cisneros-Martínez et al., 2018). If coastal NbS are to be successful, collaborative adaptation action, engaging scientists, local governance and coastal communities (Coast-ADAPT), is required. The transformation to more sustainable coastal cities and communities is important for improving marine and coastal ecosystems and their benefits for human well-being, but only few such concepts have been implemented, for example as in Vlissingen (Netherlands), Ostend (Belgium) and Gravelines (France). Lastly, it should be noted that coastal NbS can contribute to achieving major policy goals, such as the EU's common fisheries policy, the Marine Strategy Framework Directive and the Birds and Habitats Directives.

The transformation to more sustainable coastal cities and communities is important for improving marine and coastal ecosystems

3.10.3 Limitations

Several factors may limit the effectiveness of NbS applied to coastal areas. These limitations are mainly related to a lack of knowledge of the benefits and limitations of NbS options and to poor planning of measures (Vousdoukas et al., 2017; Somarakis et al., 2019). Vegetation may only reduce the strength of storm surges by attenuating and dissipating waves over large areas, while it takes time to become effective and to recover after extreme events (Morris et al., 2018). Vegetation also cannot protect against sea level rise, and impermeable artificial structures are needed to prevent permanent coastal inundation. However, such structures can become NbS-friendly if vegetation is added to them (Vousdoukas et al., 2020). Climate change is also altering the habitat conditions for vegetation, and introducing invasive species can suppress native species (Morton, 2002; Cunniff and Schwartz, 2015).

Further research is needed to assess the scalability of NbS and whether the same benefits and effects achieved on a small scale can be achieved by implementing them across larger spatial scales (Cunniff and Schwartz, 2015). Other limitations are related to the fact that extreme weather events (e.g. heavy rain or storms) can destroy NbS or render them ineffective, requiring continual intervention to maintain their efficacy. For instance, dune restoration and terrestrial coastal vegetation require maintenance (e.g. adding sand, increasing the volume of sand and the elevation) to ensure the desired level of protection against hazards (NRC, 2014; Cunniff and Schwartz, 2015). However, this should not be considered an obstacle, as artificial measures and installing grey infrastructure also requires monitoring and periodical maintenance involving high and recurring costs. Nevertheless, environmentally friendly and engineered NbS can also be expensive, as they require equipment, material and technical interventions (Pontee et al., 2016; Hussain et al., 2019; Mustafa et al., 2019). So far the application of engineered NbS options has been mainly limited to single projects (Dadamo, 2015), and they have not been implemented on a large scale yet (Pontee et al., 2016).

Introducing invasive species can suppress native species

3.11 Knowledge gaps and research needs

Based on the analysis of the available knowledge base, the following main gaps in our knowledge of and need for research on NbS have been identified:

1. The impacts of extreme weather- and climate-related hazards occur across large scales and affect society and economic sectors irrespective of societal and sectoral boundaries. Hence, integrated and cross-sectoral research on and implementation of NbS is needed to maximise the benefits for society and the economy.

2. Given the multiple benefits that NbS can provide to society, there is a need for more strategic approaches to maximising benefits of NbS for multiple development goals including the Sustainable Development Goals.

3. There is a need to integrate and mainstream NbS for CCA and DRR into policies on multiple scales (upscaling) and to connect individual NbS measures over larger regions and sectors.

4. Integrating and mainstreaming NbS for CCA and DRR needs to be accompanied by technical standards, collaborative governance, capacity building and sufficient funding.

5. More information is needed on the synergies and trade-offs of combining NbS with grey infrastructure (i.e. hybrid measures).

6. Engaging the different stakeholders in the co-design and assessment of NbS is needed to enhance the social acceptability of these solutions and to tackle potential stakeholder conflicts in a better way.

7. NbS need to be aesthetically appealing to citizens to enhance their acceptance and their social and health benefits.

8. Adequate indicators and data on the effectiveness and multiple benefits of NbS for CCA and DRR are needed to guide the broader implementation of NbS.

9. Better quantification of the net effectiveness of NbS in terms of their environmental, socio-cultural and economic benefits (including potential negative consequences) is needed (e.g. multi-criteria analysis).

10. There is a need for more standardised indicators to enhance cross-site comparisons of NbS

11. More effective long-term strategies that address the risks of slow-onset events, such as increasing temperature and biodiversity loss, and their interaction with multiple drivers (e.g. land use change) and cascading tipping points related to ecosystem degradation is needed (e.g. in relation to public health, food and water security, ecosystem resilience).

4
An analysis of practical uses of nature-based solutions for climate change adaptation and disaster risk reduction in Europe

Key messages

- **The selected cases analysed in relevant European sectors (water management, forests and forestry, agriculture, including agroforestry, urban areas, coastal areas and mountains) confirm that nature-based solutions for climate change adaptation and disaster risk reduction have become more prominent in Europe, in particular at the urban level.**
- **The efficiency of such nature-based solutions is context specific in terms of time, space and local socio-ecological conditions and also depends on planning, financing and regulation regimes. In some cases, nature-based solutions are successfully combined with grey infrastructure to achieve planned outcomes (e.g. the necessary flood protection level).**
- **Quantitative estimates of cost-benefit ratios and monitoring of effectiveness can help to mainstream nature-based solutions for climate change adaptation and disaster risk reduction into regulations, norms and plans. Only about 15 % of the cases analysed show any monitoring of the results and these are often limited to the duration of the project.**
- **Stakeholder involvement (also in the early stages), dialogue and the co-design of tools and measures are key to increase awareness, to tackle potential stakeholder conflicts in a better way and to create demand for and social acceptance of nature-based solutions. About half of the cases analysed explicitly highlight stakeholder involvement as key.**

4.1 Introduction

Chapter 4 illustrates how the relevant sectors and thematic areas identified in this study, such as water management, forests and forestry, agriculture (including agroforestry), urban areas, coastal areas and mountains, address various societal challenges using nature-based solutions (NbS) for climate change adaptation (CCA) and disaster risk reduction (DRR). Among the 97 selected cases, five were part of multinational projects with demonstration locations in several countries. A total of 107 locations are thus represented by the 97 selected cases. The breakdown of cases by country and sector/thematic area is presented in Annex 3.

Based on these cases, the chapter provides an overview of the methods applied, measures implemented, innovative features of the projects and wider applications of the results and lessons learned. In addition to the general review, 11 example cases are presented in more detail in Annex 4. The two-phase process is described in Figure 4.1.

The cases selected for the general review were identified from the following knowledge platforms: Climate-ADAPT (European Climate Adaptation Platform); Natural Hazards — Nature-based Solutions; Naturvation (Nature-based Urban Innovation); NWRM (Natural Water Retention Measures);

OPPLA (NatureNetwork web platform for nature-based solutions); Panorama (a global project on mainstreaming ecosystem-based adaptation); PEDDR (Partnership for Environment and Disaster Risk Reduction); and weADAPT (a collaborative platform on climate change adaptation issues). The exercise reviewed completed and ongoing cases on the platforms and did not undertake a systematic review of the ongoing Horizon 2020 projects providing new NbS case studies. A review and analysis of those projects can be found in Wild et al. (2020). A few ongoing cases from outside the platforms reviewed complement the review.

Figure 4.1 The selection of cases for the general review and identification of example cases

PHASE 1: REVIEW OF 97 CASES

Mapped platforms

ClimatADAPT, NaturalHazard Nature-Based Solutions, Naturvation, NWRM, OPPLA, PANORAMA, PEDDR, WeAdapt

Selection criteria

- Linkage to NbS
- Societal challenges addressed
- Different thematic areas covered
- Geographical spread

Sectors and thematic areas

- Water management (24 cases)
- Forests and forestry (4 cases)
- Agriculture (7 cases)
- Agro-forestry (3 cases)
- Urban areas (43 cases)
- Coastal areas (8 cases)
- Mountains (8 cases)

Information collected

- Primary objectives and co-benefits
- NbS measures realised
- Stakeholder involvement
- Innovativeness and transferability
- Overall assessment of the attractiveness of the case

PHASE 2: SELECTION AND DESCRIPTION OF 11 EXAMPLE CASES

Selection criteria

- Multifunctionality
- Innovativeness
- Wide transferability of results
- Geographical spread

Sectors and thematic areas (Table 4.1)

- Water management (2 cases)
- Forests and forestry (1 cases)
- Agriculture (2 cases)
- Agro-forestry (1 cases)
- Urban areas (2 cases)
- Coastal areas (2 cases)
- Mountains (1 cases)

Described contents

- Site description and societal challenges addressed
- NbS evaluated/implemented
- Main results
- Effectiveness of NbS
- Innovatineness
- Transferability of results
- Lessons learned

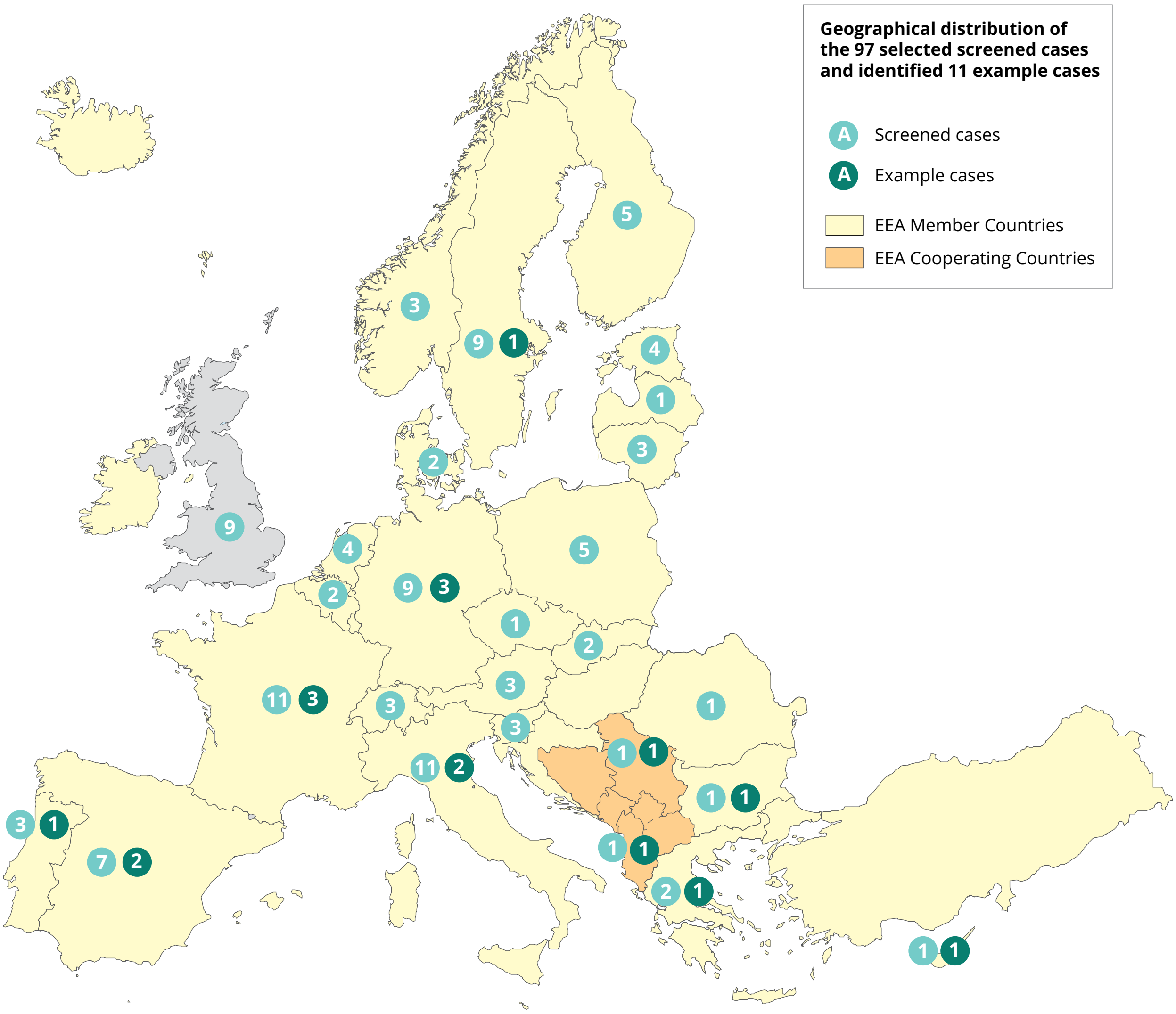
Source: EEA.

Relevant cases were assessed taking into account the following criteria: (1) the **type of measures realised**, as there are also cases on the platforms that do not include NbS; (2) the **societal challenges** that the case sought to address; and (3) the **innovativeness** of the case and the **wider applicability** of the results in Europe. The general review aimed to capture all sectors and thematic areas, ensure a geographical, topographical and climatic zone spread and represent different types of case implementation (e.g. concrete measures, planning and evaluation methods and policy-related cases) that address CCA and DRR. The general review did not intend to review the comprehensive list of European NbS cases but to illustrate the diversity of NbS cases for CCA and DRR that have been implemented in Europe during the last two decades.

The climate hazards and risks addressed by the NbS measures in the cases screened include floods and droughts, soil erosion (agriculture and agroforestry); coastal erosion and floods (coastal areas), wildfires, water quality and quantity (forestry); landslides, avalanches, flood risks (mountains); heavy precipitation, river floods, heat waves (urban areas); and quality and quantity of water and reducing water stress at catchment level (water management).

The numbers of cases in various sectors and thematic areas are presented in Map 4.1. The large share of urban cases is explained by the fact that a large part of the projects implemented in recent years have focused on addressing the impacts of climate change in urban areas using NbS, and these cases have been collected in the European knowledge platforms. Map 4.1 provides an overview of the geographical spread of the 97 cases selected. Of these, five cases were part of multinational projects with locations in several countries: (1) GreenRisk4Alps ([4]) case (Austria, France, Germany, Italy and Slovenia), (2) HERMES ([5]) case (Albania, Bulgaria, Cyprus and Greece), (3) LIFE Resilient Forests ([6]) case (Germany, Portugal and Spain), (4) MAREGOT case (France and Italy), and (5) PHUSICOS ([7]) case in the Pyrenees (France and Spain).

Map 4.1 Geographical distribution of the 97 selected cases screened and 11 identified example cases



Note: The 97 selected cases screened include five multinational cases (i.e. they are part of multinational projects with locations in several countries), of which three are also multinational example cases (included in the 11 identified example cases).

Source: EEA.

([4]) https://www.alpine-space.eu/projects/greenrisk4alps/en/home
([5]) https://cordis.europa.eu/project/id/511234
([6]) https://www.resilientforest.eu
([7]) https://phusicos.eu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Based on the information presented on the platforms, a summary review of the cases was made in terms of their costs, role of biodiversity issues, levels of stakeholder involvement and quantification of the impacts. The budgets of the cases varied significantly from tens of thousands of euros (Flood-breaking hedgerows in southern France) to EUR 260 million (Temporary floodwater storage in agricultural areas in the Middle Tisza river basin, Hungary). Biodiversity played an important role in most projects, as biodiversity or a nature quality element was explicitly articulated in approximately 70 % of the cases. We estimate that the level of stakeholder involvement was moderate or high in half of the cases. Impacts were more widely quantified in only 16 % of the cases.

Eleven of the 97 cases screened (example cases) were selected for a more in-depth analysis using the following criteria:

- **multifunctionality** — providing a solution to more than one challenge;
- **innovativeness** — including, for example, planning, measures, methods, co-creation, financing and governance;
- **wide transferability of results** — offering solutions to generic challenges;
- **geographical spread** — cases evenly distributed in different parts of Europe.

As NbS are multifunctional, the same measure also contributes to tackling a range of other societal challenges. Table 4.1 provides an evaluation of how the 11 example cases address the various societal challenges identified in Chapter 1. A ranking system has been used to characterise each example case within the given criteria categories, including scores of: 1 – low relevance; 2 - medium relevance; 3 - high relevance; or empty - not relevant.

Table 4.1 How the 11 example cases address the various societal challenges (identified in Chapter 1)

	Sector and thematic area	CSC1 — Improving societies' resilience to extreme weather- and climate-related events	CSC2 — Food security, sustainable agriculture and forestry	CSC3 — Preservation of habitat, reducing biodiversity loss and increasing green and blue spaces	CSC4 — Water management (Water quality and quantity, reducing water stress)	CSC5 — Social justice, cohesion and equity & reducing risk for groups of society highly vulnerable to climate change	CSC6 — Public health and well-being (related to climate change impacts)	CSC7—- Make cities and human settlements inclusive, safe, resilient and sustainable	OSC1 — Environmental quality, including air quality and waste management	OSC2 — Public health and well-being (mental well-being, immune, physical health)	OSC3 — Sustainable economic development and decent employment (including green jobs)	OSC4 — Climate change mitigation
Flash flood and wildfire hazard (Brague catchment, France) (see Section A4.1)	Water management	3		1	3		2	3				
Floods and drought risk (Serchio river basin, Italy) (see Section A4.2)	Water management	3		3	3		2	2		2	2	1
Coupling water, fire and climate resilience with biomass production (LIFE Resilient Forests; Germany, Portugal, Spain) (see Section A4.3)	Forestry	3		2	3	2	3				1	3
Agroforestry for climate resilience and productivity (Montpellier, France) (see Section A4.4)	Agroforestry	3	3	2	2							2
Adapting agriculture to wetter and dryer climates (Tullstorpsån, Sweden) (see Section A4.5)	Agriculture	3	3	1	3				2			
Rewetting peatlands for paludiculture (Germany) (see Section A4.6)	Agriculture	2		2	3				2			3
Blue-green corridors (Belgrade, Serbia) (see Section A4.7)	Urban	3	2	3	3	1	2	3	2	3	2	1
Green roof policy (Hamburg, Germany) (see Section A4.8)	Urban	3		3	3	2	2	3	3	3	2	1

	Sector and thematic area	CSC1 — Improving societies' resilience to extreme weather- and climate-related events	CSC2 — Food security, sustainable agriculture and forestry	CSC3 — Preservation of habitat, reducing biodiversity loss and increasing green and blue spaces	CSC4 — Water management (Water quality and quantity, reducing water stress)	CSC5 — Social justice, cohesion and equity & reducing risk for groups of society highly vulnerable to climate change	CSC6 — Public health and well-being (related to climate change impacts)	CSC7—- Make cities and human settlements inclusive, safe, resilient and sustainable	OSC1 — Environmental quality, including air quality and waste management	OSC2 — Public health and well-being (mental well-being, immune, physical health)	OSC3 — Sustainable economic development and decent employment (including green jobs)	OSC4 — Climate change mitigation
Using beached leaves of Posidonia to protect dunes (Ugento, Italy) (see Section A4.9)	Coastal	3		3			3	3	3	2	2	2
Coastal erosion (Hermes; Albania, Bulgaria, Cyprus, Greece) (see Section A4.10)	Coastal	3		3							2	
Landslides and flooding (Pyrenees, France, Spain) (see section A4.11)	Mountain	3			3						2	

Note: 1, low relevance; 2, medium relevance; 3, high relevance; no number, not relevant.

Source: EEA.

In the following sections, we present results of the 97 cases reviewed by sector and thematic area. The analysis of the 11 example cases is presented in Annex 4.

4.2 Review and examples of analysed cases

4.2.1 Water management cases

The **societal challenge** addressed by the majority of the 24 water management cases was flood and drought risk management (CSC1). The measures taken in the case studies had multiple benefits (e.g. improvement of water quality, protection of soil from erosion, habitat restoration and protection of and positive impacts on the recreational use landscape) and also supported the achievement of other societal challenges including CSC4 (water management) and OSC2 (food security, sustainable agriculture and forestry).

Most cases had connections to the agriculture, forestry or agroforestry sectors. Some of the cases identified as water management could also be classified as urban cases, making the distinction between these two sectors in some cases artificial. This is because flooding (and therefore water management) is the risk most frequently addressed in the urban cases.

The **scale** of the cases varied from small-scale experiments to regional-scale demonstrations. For example, in the Nummela case (Finland) a single wetland was built and monitored intensively, whereas in the largest scale projects a number of measures were either implemented in the catchment (Upper Vistula river basin, Poland; Catchment management approach to flash flood risks in Glasgow, United Kingdom; Flood and drought risk management in the Serchio river basin, Italy) or alternative management strategies were developed and their effectiveness in reducing floods was assessed using simulation models (Flash flood and wildfire hazards in **the** Brague catchment, France).

The cases included the following measures:

- **using existing ecosystems** — buffer strips and shelter belts, flood storage areas and reservoirs, re-opening connections to floodplains, preservation of woodlands, planting trees;
- **modifying ecosystems** — re-meandering, floodplain restoration, riverbed material renaturalisation, reconstruction of channels, opening an old dyke and building a new one further from the river, creating room for the river through long-term changes in land use planning;
- **creating new ecosystems** — retention ponds, wetlands, flood-breaking hedgerows.

Traditional flood protection structures are often already old. They may not meet current safety and flood protection requirements, taking into account, for example, the effects of climate change. NbS can help improve the efficiency of old grey measures. In the case of Elbe dyke relocation (Germany), sufficient flood protection was possible only by creating a floodplain and a new dyke.

Innovativeness relates to the planning processes and methods as well as to the measures implemented. As the implementation of NbS projects depends to a large extent on the attitude of stakeholders, great effort has also been made to engage them through novel ways. In two NAIAD cases (Romania and Slovenia), a participatory system dynamic model helped identify and describe the role of key variables and relationships within the system (Tacnet and Van Cauwenbergh, 2019). In catchment measures, land ownership issues are often difficult. In the Odense river restoration case (Denmark), the main barrier was the willingness of the landowners to participate in the project. However, the toolbox offered contained several measures (including land consolidation) that helped to overcome this problem and to establish voluntary agreements with and among the landowners. Novel assessment methods were applied in some cases to assess the flood risk and effectiveness of NbS measures. The Brague case (France) performed a comprehensive and in-depth analysis of a Mediterranean catchment to assess NbS benefits, disbenefits and multiple benefits and ways to optimise them (Le Coent et al., forthcoming). In the Serchio case (Italy), the most novel elements relate to the participatory process and to shared territorial planning strategies and to the identification of ecosystem services connected to the NbS (see Annex 4).

Planning NbS requires adequate meteo-hydrological information, which is not always freely available. In two cases (Thames, United Kingdom, and Glinščica, Slovenia), the problem was solved by a cheap monitoring network using FreeStation ([8]). FreeStation is designed to make reliable, detailed and local environmental data more accessible in areas that may have little local financial and technical capacity for the collection of such data. In the Thames case (United Kingdom), the EcoActuary ([9]) methodology was applied to plan and locate the best sites for investment. It is an open-access catastrophe model capable of assessing the impact of NbS on local and downstream assets at risk of flooding and the role of NbS in securing their economic value.

In general, the **transferability** of the measures applied in the cases is good. For example, flood-breaking hedgerows (France) can potentially be adapted to all river basins where flood events occur. A good indicator of transferability is actual replication elsewhere, such as in the case of Kristalbad (Netherlands), where the water machine concept was replicated from Sweden. The Amalvas and Žuvintas wetlands project (Lithuania) was expected to serve as an example of successful wetland restoration and more sustainable use that could be replicated in other parts of the country. In the water retention reservoir, Podutik (Slovenia) case, the concept of multifunctionality was transferred to the planning and construction of other flood reservoirs. Although the results of the Stevoort (Belgium) case were considered rather case specific and not easily transferred to other locations, the lessons learned were considered inspirational for similar cases elsewhere: that is, the need to confront the ecosystem services approach with local needs because habitats for NbS desired by locals do not always coincide with the areas with the highest ecosystem services potential. EcoActuary applied in the Thames case (United Kingdom) is a global model and thus applicable anywhere in the world on the basis of the data provided.

Annex 4 describes a case of flash flood and wildfire hazards in a Mediterranean catchment (Brague case in France; see Section A4.1) and a case of flood and drought risks in a Mediterranean basin (Serchio river basin in Italy; see Section A4.2)

4.2.2 Forests and forestry cases

The societal challenges addressed in the four forestry management cases screened include flood control and flood risk mitigation, drought risk mitigation and disaster risk and crisis management in relation to wildfires (CSC1 and CSC2).

The **scale** of forestry-related NbS range from interventions in individual forests and farms to regional and national forest management planning and implementation. For instance, in the LIFE+ Boscos-Menorca case (Spain), sustainable forest

([8]) http://www.freestation.org/
([9]) http://www.policysupport.org/ecoactuary

management plans were developed, piloted at farm level and upscaled to island level to increase the resilience of the island's forest ecosystems and to prevent forest fires. The Polish case of small-scale water retention measures was the first nationwide project to combine water retention in lowland forest ecosystems with protection against surface water run-off. The LIFE Resilient Forests projects (Germany, Portugal and Spain) moved from pilot-scale research to demonstration on experimental sites at sub-catchment scale and assessed the potential at catchment level in Germany and Portugal. A case in Finland evaluated the effectiveness of an existing forested wetland in improving and regulating stream water quality and peak flows.

The cases included the following **measures**:

- **using existing ecosystems** — protecting, connecting and restoring forest ecosystems, evaluating the effectiveness of improving and regulating water quality and flow, sustainable forest management, zoning;
- **modifying ecosystems** — reducing competition among trees, choice of species, rotation, planning thinning schedules and reducing scrub cover to reduce wildfire risks, favouring pasture (allowing cattle in), favouring regeneration through seeding, pruning, increasing landscape water storage capacity (hydrological restoration, e.g. wetland restoration and management including basins and ponds).

For three of the cases, training and education of farmers and landowners and drawing up pilot forest management plans for farms were central to implementing the NbS measures.

The **innovativeness** of the cases relates to the management processes and methods, the organisational aspects, modelling of the type and effectiveness of the measures and the implemented measures themselves.

Assessing the effectiveness of current ecosystems in countering societal challenges is fundamental to manage, modify or create new habitats in better ways. In the Finnish case, research work quantified by how much an existing forested wetland downstream from an urban area in the capital region improves and regulates stream water quality and flow. Initiatives to work with forested wetlands in Poland to store more water in the landscape and prevent the negative impacts of droughts and floods were streamlined and consolidated across the Polish forest management authority into a single project, 'Small water retention programme'. This programme could attract a substantial amount of funding from the EU Cohesion Fund and lead to a systemic, large-scale approach. Impacts of the project include a 27 % increase in landscape water storage capacity across the sites.

Two sustainable forest management cases aiming to reduce the risk of wildfires were carried out in innovative ways. The LIFE Resilient Forests case (see Annex 4) aims to demonstrate how combining multiple, often unlinked objectives, can create the economic basis for resilient forestry based on eco-hydrological forest management (see Box 4.1). The LIFE+ Bosco-Menorca case combined the 'what' (pilot testing sustainable forest management on farms, developing forest management guidelines, training and education of landowners and farmers) with the 'how' (improving governance integration across administrations, integrating climate change as a factor in the Balearic Islands' forestry plan and increased awareness through participatory meetings of stakeholders). Another important benefit has been the adjustment and introduction of measures financed through public subsidies for the agricultural sector that contribute to improving the adaptation of forest systems to climate change. Specifically, knowledge generated in cost-benefit studies of pilot farms has been leveraged to transfer it to all of the farms on the island as part of the Agricultural Biosphere Reserve Contract (a public subsidy that recognises the environmental services provided by farmers).

The **transferability** of the management approaches and methodological frameworks appears to be good. The approach of the LIFE Resilient Forests case can be replicated in particular in Mediterranean forests that are unmanaged, suffer from water scarcity and where the risk of wildfires is high (see Annex 4). In addition, the LIFE+ Bosco-Menorca findings and inclusive approach are transferable to Mediterranean forest ecosystems to increase forest resilience. Insights and lessons from these cases can be relevant if adapted to central and north European forest ecosystems, where the risk of wildfires increases with the more frequent occurrence of extreme drought events. Cost-benefit analyses of the altered forest management practices on the pilot farms were the basis for adjusting and introducing a payment for ecosystem services in the form of the Agricultural Biosphere Reserve Contract, which pays farmers for environmental services, notably sustainable and climate-resilient forest management.

The small water retention case in lowland forests in Poland was organised into a national programme. This facilitated a better transfer of projects nationally, and the approach of increasing water storage in the landscape is relevant to other lowland forest habitats in Europe. The methodology applied to gather evidence for the effectiveness of forested wetlands in improving water quality and reducing downstream flood risks in the Finnish case is will also be useful in other similar environments.

Box 4.1 Definition of sustainable forest management

Eco-hydrological forest management puts the water at the core of the management scheme, as it is a resource that has considerable effect on forest growth and development and therefore on the provisioning of other goods and services.

Eco-hydrological forest management balances the trade-offs between water and vegetation to produce forest goods and services, of which water could be one in the form of groundwater recharge, streamflow, watering vegetation, etc. It therefore means modifying the forest cover and/or species composition according to the local balance between water availability and consumption. In this sense, strategies such as canopy opening, pruning and species selection can be effective in combating water scarcity (by increasing soil and groundwater recharge) while also increasing climate change resilience and adaptation. Whenever these principles are taken into account and quantified in the planning stage of management, it is known as eco-hydrological forest management.

Annex 4 illustrates NbS in forestry through a case on coupling water, fire and climate resilience with biomass production in forestry to adapt watersheds to climate change in Germany, Portugal and Spain (LIFE Resilient Forests project; see Section A4.3).

4.2.3 Agriculture and agroforestry cases

The **societal** challenges addressed by the 10 cases include increasing the resilience of individual farming practices (CSC1, CSC2) by focusing on improving farm resilience to extreme weather- and climate-related events (drought, heat waves and flooding). Food security and sustainable agriculture are central themes across the cases: protecting, restoring and promoting sustainable use of terrestrial ecosystems and halting and reversing land degradation (soil erosion, soil structure) and biodiversity loss (CSC3). Water management — improving water quality and reducing water stress — is a challenge often tackled with the measures in combination (CSC4). Climate change mitigation by reducing greenhouse gas emissions on farms was also addressed (OSC4).

The **scale** of the cases ranges from measures at individual farm level (e.g. the measures to improve soil structure to increase climate resilience on a farm in Heilbronn, Germany) to cases that operate across many farmers or natural water retention measures at catchment scale on agricultural land. In two of the cases, collaboration among local farmers to address climate challenges proved to be key: the informal network of smallholder farmers in Roslagen (Sweden), who cultivate high-quality organic products and collaborate on using ecosystem approaches to adaptively respond to climate variability, and the 90 farmers in Tullstorpsån (Sweden), who collaborate on climate-proofing agriculture by increasing water storage in the landscape to counteract drought periods. Another two cases, both from the project 'Supporting Moldova's national climate change adaptation planning process', are building climate resilience and restoring reservoirs across the country with farmers to demonstrate climate-resilient farming. One case, restructuring the effluent web, operated at the drainage basin scale in the Venice lagoon (Italy), has the double aim of both reducing nutrient effluent coming into the Venice lagoon and reducing the incidence and intensity of flood events in the area.

Several of the cases have operated successfully over a longer period and continue to do so. For example, the agroforestry case in Montpellier (France), has operated for more than 20 years (see Annex 4), as have the cases of autonomous adaptation on the Herdade do Freixo do Meio farm in Alentejo (Portugal) and the Roslagen (Sweden) informal network of farmers applying ecosystem approaches. Other cases screened are either in the planning phase or have started recently, such as the Tullstorpsån 2.0 case (Sweden) (see Annex 4) and the Heilbronn (Germany) arable farm working to improve soil structure as part of the LIFE AgriAdapt project (2017-2019).

The cases included the following measures:

- **Using existing ecosystems** — ecosystem approaches to adapt agriculture to climate change: protecting trees in forests and wetlands, moisture conservation through using plants as shade providers, early spring harrowing to prevent capillary action and evaporation, conservation tillage, crop rotation, cover crops, protection of key species for pollination and pest control, polyculture. Soil structure improvements to increase farm resilience through crop management measures: growing different and versatile catch crop mixtures before spring crops and after early potatoes, crop and produce diversification.

- **Modifying ecosystems** — increase water storage capacity in the landscape for irrigation during drought periods while improving water quality: re-meandering river sections, introducing buffer strips and hedges, riverbed material renaturalisation, paludiculture, and wetland restoration and management (Image 4.1).

- **Creating new ecosystems** — combine crops and woody vegetation to increase resilience and farm productivity: planting walnut trees on wheat fields; recreating the multifunctional landscape, i.e. cork oak or holm oak trees combined with pastures and grazing sheep, goats, pigs or cows and with cereal or forage crops.

Image 4.1 Börringe mad, 20 ha constructed wetland at the village of Grönalun (Sweden)

Note: See Section A4.5.

The **innovativeness** in the cases relates to the type of measures and how they can achieve significant and synergistic multiple benefits. For instance, the Tullstorpsån (Sweden) and Venice lagoon (Italy) cases both implement measures that at the same time addressed eutrophication problems and water management (too much or too little), both working with natural water retention measures and renaturalisation of streams and rivers. The agroforestry case in Montpellier (France) not only created a more resilient production system but also increased the productivity by 40 %, thanks to the synergy between crops and trees and the innovative way of managing agroforestry (see Annex 4). The soil conservation case in Heilbronn (Germany) is expected to increase the production efficiency of the farm, reduce farming costs, improve soil conservation, reduce erosion, prevent pests and diseases, increase soil carbon sequestration, increase nitrogen content and avoid nutrient loss.

Other types of innovation relate to the soft power of awareness raising and courses. The Venice lagoon (Italy) case provides an example of how public acceptance of the measures can be achieved if the impacts are visible (decreases in flooding, nitrogen levels in drainage basin and Venice lagoon).
The Alentejo farm (Portugal) employing autonomous adaptation shows the importance of involving consumers. The farm established a community-supported form of agriculture, with, for example, direct delivery of produce to consumers, and it regularly opens for tourist visits and consumer courses, which has created a direct relationship and built trust with consumers that also secures sales.

A third type of innovation can be found in the power of farmer collaboration, as in the case of the Roslagen (Sweden) farmers, who exchanged new and old knowledge across farms, and those who worked as ambassadors for other farmers, as in the case of the climate-resilient pilot farms in Moldova, or those who collaborated on the planning and implementing of measures to improve the water storage capacity in the landscape, as in the case of Tullstorpsån (Sweden).

Transferability and upscaling are key components in several of the cases. In the two Moldovan cases, based on the results of the pilot project, plans are under way to expand the use of similar technologies to rural communities across the country. Here, scaling up water management projects is found to be an effective way of reducing climate vulnerability and ensuring the food security of rural communities and the entire country. Transferability of the various types of measures across Europe is highly relevant for areas that experience the same type of climate variability. Increasing occurrences of drought, which reduces crop productivity, can be alleviated by working across landowners to store more water in the landscape, as in Tullstorpsån (Sweden), and at the individual farm level by applying agroforestry and soil conservation practices, as in Montpellier (France), Alentejo (Portugal) or Heilbronn (Germany). Agro-ecological farming using the ecosystem approach to adapt to climate change can be transferable across agro-ecological zones when adapted to the local context. Peatlands are widely used in agriculture in central and northern Europe, and the results from the paludiculture case (Germany) can be used in other similar areas.

Annex 4 presents three detailed cases of NbS applied in agriculture and agroforestry. One is on growing wheat and walnut trees in Montpellier (France) to diversify agricultural activity and make the system more productive and resilient (see Section A4.4). The second case is from Sweden, adapting agriculture to more extreme climates through NbS (see Section A4.5), and the third case is from Germany on peatland restoration and paludiculture, combining climate mitigation and adaptation (see Section A4.6).

4.2.4 Urban cases

The main **societal challenge** addressed by the majority of the 43 urban NbS cases is flood-related risks, including erosion and landslides (geohydrological and hydrometeorological risks), and extreme temperatures, notably due to the urban heat island effect in urban areas (CSC1 and CSC7). Air pollution and carbon sequestration are also addressed by a few cases (OSC1 and OSC4).

The **scale** of implemented NbS range from the 'object level' (i.e. buildings, streets or car parks) and 'neighbourhood level' (i.e. with a larger contiguous imprint on the urban setting) to the city and peri-urban scale (i.e. at a systemic level with more pronounced impacts of NbS). Most of the measures involve creating new ecosystems in existing urban areas or on brownfield sites, i.e. former industrial areas such as in Luciline in Rouen (France).

At the object scale, cases involve NbS implementation such as green roofs and walls (Image 4.2), rain gardens, eco-streets/green roads, green playgrounds/school grounds, vegetation dells, green car parks and pocket parks. The majority of urban NbS cases in various platforms operate on this scale. While some cases focus on the implementation experiences of single-object NbS (e.g. the green roof of Aimé Césaire school complex in France, showcasing 2 700 m^2 of natural dunes and moors), others combine a wide range of possible NbS at the object scale. One case at urban street level is the eco-street design for decentralised ecological rainwater management found in Ober-Grafendorf, Lower Austria. The measure stores rainwater, makes it available to plants, filters out pollutants, and returns residual water to the groundwater. Evaporation of the water stored in the substrates and transpiration by plants creates a cooling effect.

Image 4.2 Green roof on the Hochbahn, Hamburg (Germany)


© Isadora Tast, BUKEA (German authority for the environment, climate, energy and agriculture), Hamburg

Note: See Section A4.8.

At the neighbourhood scale, NbS comprise creating tree corridors, rebuilding a stream in a central location, creating a system of small canals linked to a river, greening river banks and redesigning and redeveloping former industrial areas into climate-resilient neighbourhoods, such as the former national airport Fornebu (Norway), the old port area, Frihamnen, in Gothenburg (Sweden) and the former industrial area, Luciline, in Rouen (France).

At the city scale, examples include implementing green roofs at a systemic scale to the extent that green roofs are considered routine and developers do not object to installing them, as is the case in Basel (Switzerland), with 40-45 % of flat roofs greened today ([10]); another case is the restoration of blue-green corridors in Belgrade (Serbia) to alleviate erosion and torrential flooding at the city scale. City-wide programmes exist for (1) a specific type of NbS (often at the object scale, such as trees or green roofs), as in the case of the green roof programme in Hamburg (Germany), (2) a specific challenge (such as climate-proofing), as in the case of Bratislava (Slovakia), and (3) a holistic vision coupled with a public investment fund to create a climate-resilient, creative and diverse city with high-quality public transport and urban planning, as in the case of Amsterdam (Netherlands).

At the peri-urban scale, the creation of the 1 300 ha Confluence park on the outskirts of Prague (Czechia) is an example of combining river landscape restoration and drought and flood management with recreational opportunities. This project combines revitalisation of brownfield sites, agriculture and river banks with recreational purposes.

Innovativeness abounds in many different ways in the urban cases. One type of innovativeness can be found in **financial incentive schemes** (see Box 4.2) and in **regulation and public-private partnerships** to enhance the private uptake of urban NbS. The city of Hamburg (Germany) combines financial incentives for voluntary installations with regulation for compulsory installation of green roofs in new local plans. The city of Bologna (Italy) developed an instrument with which local enterprises and firms can decrease their carbon footprint by paying for local afforestation and, at the same time, generate environmental and social benefits for the community, while the city of Amsterdam (Netherlands) established a public green fund that has more than doubled private investment in greening the city.

Box 4.2 Examples of financing nature-based solutions in the urban cases screened

A wide variety of natured-based solution (NbS) financing mechanisms for urban areas exists. Below are examples from the cases screened:

- **Public green fund at city scale requiring at least 50 % private co-funding**. The case of Amsterdam's green agenda, with EUR 20 million public investment leading to an additional EUR 30 million private investment to create an urban green infrastructure to improve climate resilience, quality of life and the attractiveness of the city as a tourist destination.

- **Public co-funding of private implementation of NbS for climate resilience.** The case of Bratislava's adaptation programme, subsidising different forms of sustainable urban drainage systems, green roofs or rain gardens. The case of Hamburg's programme on green roofs, providing EUR 3 million for the period 2011-2024 for green roofs larger than 20 m^2 and up to EUR 100 000 per building. From 2020 onwards, the city of Hamburg is also offering financial support for green facades. Building owners can receive subsidies to cover up to 60 % of the installation costs of green roofs, both for refurbishment and for new buildings, and up to 40 % of the investment costs of green facades.

- **Deducting fees in return for private NbS investment**. The case of Hamburg's green roof programme, whereby the stormwater fee is reduced for those investing in green roofs.

- **Private investment in NbS for compensatory purpose**s. The case of GAIA — the Green Area Inner-city Agreement to finance tree planting in Bologna — whereby private companies fund urban afforestation in return for certificates off-setting their carbon footprint.

([10]) Personal communication from Stephan Brenneisen, Department of Environment and Natural Resources, Zurich University of Applied Sciences (March 2021)

Co-creation with local communities and/or across sector stakeholders that do not traditionally collaborate is key to innovative solutions. In the case of the Aimé Césaire school complex (France), the originality of the green roof results from its co-construction by architects, landscape designers and ecologists and from schoolchildren having full access to it, fostering education on coastal ecosystem restoration. In the case of Hamburg (Germany), a stakeholder group was established before 2014, including housing estate companies, construction firms, landscape architects and urban planners, which was involved in dialogue with other cities and in defining the incentive programme. The stakeholder group remains active and has biannual meetings to evaluation the strategy for green roofs.

Co-creation with local communities is key to innovative solutions.

Focusing on quality in urban NbS fosters a higher degree of multifunctionality in the solutions, than the 'standard' NbS. In the case of the Hamburg green roof programme, the city decided to have the financial incentive based on the surface and thickness of the green roofs instead of their water retention capacity, as is the case in most other city programmes. This decision pushed constructors to not only focus on water retention but also to consider other benefits that green roofs may bring in terms of biodiversity and use of space. The design of the green roof on the French Aimé Césaire school complex used ecological research to create a biodiverse, robust and easy-to-manage ecosystem.

The same NbS measure is multifunctional and hence provides multiple benefits, making investment in urban NbS particularly cost-effective, as space is costly and subject to high levels of competition. One of the benefits of NbS is job creation, which, if investment is scaled up and stepped up, can make a significant contribution to a resilient recovery from crises such as the COVID-19 pandemic.

Transferability of implemented measures is generally very good when practical measures and implementation approaches are tailored to local conditions and governance cultures. Many of the initiatives screened also serve as front-runners for other cities to follow suit. For example, the eco-street design in Ober-Grafendorf (Austria) won the Austrian Energy Global Award in the category 'water' and a Climate Star Award in 2016. The eco-street design has been tailored to other municipalities and large cities, including Vienna. The green roof programme in Hamburg (Germany) was part of the German federal lighthouse project in the national climate adaptation strategy and features in the future-proof toolkit created by the European Green Capital Network for best practices. Before getting started, Hamburg made use of extensive consultation and dialogue with other cities to avoid the pitfalls and develop a programme that best fits the city. In the case of Amsterdam (Netherlands), the holistic approach to innovation in governance by involving citizens and considering the economy, social inclusion and quality of life, while improving climate resilience, was recognised in its achieving the European Capital of Innovation Award in 2016.

Examples of redeveloping urban brownfield sites into climate-resilient neighbourhoods are found across Europe, as the cases in Fornebu (Norway), Frihamnen in Gothenburg (Sweden) and Luciline in Rouen (France), illustrate. The last received a climate adaptation award, and the official ecodistrict label contributes to spreading best practice.

Other cases feature unique approaches that can be sources of inspiration for other cities, such as Amsterdam's public green fund to enhance environmental and social benefits, the visions of a restored blue-green corridor in Belgrade (Serbia), the exceptionally high-quality green roof with access for schoolchildren on a French school in Nantes and the novel public-private partnership in Bologna (Italy) to plant urban trees.

Annex 4 illustrates the implementation of NbS in urban areas through a case on blue-green corridors in Belgrade (Serbia) (see Section A4.7) and a case on successfully implementing a green roof policy in Hamburg (Germany) combining regulation, stakeholder dialogue and science (see Section A4.8).

4.2.5 Coastal cases

The **societal challenge** addressed by the majority of the eight coastal cases was reducing either storm surge flooding or coastal erosion or both (CSC1). In addition, strengthening coastal biodiversity and ecosystem services (CSC3) and recreational use or tourism (OSC2) were important challenges. Increasing awareness of NbS and their effectiveness and multiple benefits was also mentioned as an important objective. In several cases, new spaces for leisure activities and new access routes and viewpoints (Medmerry, United Kingdom; Camargue, France) were built, which also improves opportunities for diversifying the local economy through tourism (OSC3).

There were large differences between cases in terms of both measures taken and scales. However, the measures and their effects are local and not as regionally cumulative as, for example, in water management cases. Some cases included large-scale hydraulic construction works (Camargue, France) or local ecosystem-based measures, such as construction and protection of wetlands to protect shorelines, restoration of sand habitats and dunes, improved seawater vegetation structure and shore-face improvements (realised in many places on the western and eastern coastline of Sweden — LIFECOASTadapt).

In the Medmerry case (United Kingdom), realignment of coastal flood defences was carried out and compensatory intertidal habitats were developed. In the Ugento case in Italy (see Section A4.9), the beached leaves of *Posidonia* from the mouths of the channels are used to reconstitute and protect degraded dune cords. The Hermes case in Albania, Bulgaria, Cyprus and Greece (see Section A4.10) is an example of soft NbS developing a unified and harmonised framework for mitigating coastal erosion to promote environmentally friendly technical works for coastal restoration (e.g. beach and dune stabilisation, beach nourishment). The Maregot case (France and Italy), in turn, is a strategic project that intends to initiate shared planning and identify optimal solutions to manage the morphological and hydrodynamic characteristics of the coast.

The **innovativeness** of the cases analysed provided a wide variety of examples of innovative solutions to combat coastal erosion, increase biodiversity and improve planning processes. In the Ugento case (Italy), using the biomass from *Posidonia* accumulations to protect beaches has been recognised as an alternative to waste management. The Camargue case (France) implemented an adaptive management approach to the rising sea level through a controlled, progressive retreat from the coastline in areas subject to erosion. In the Medmerry case (United Kingdom), forming specialist groups to manage complex issues, such as habitat management and archaeological findings that may affect construction timelines, was very important for addressing stakeholder concerns.

The innovative feature of the Hermes project is the joint coastal framework, including a novel modelling toolkit combining meteorological, hydrodynamic, wave and morphodynamic models that provide results that are useful when designing effective NbS. The Maregot project (France and Italy) developed an innovative cross-border methodology to define strategies and action plans in response to the needs of the areas. A cross-border approach is necessary because the natural dynamics of erosion phenomena transcend national administrative boundaries. Here, a methodology consisting of characterising morphological and geological features and collecting data from remote and proximal sensors, either on the sub-aerial or in the submerged cliff, has been proposed.

The **transferability** of the approaches or methodological frameworks was assessed as good in all cases. Coastal squeeze remains an issue for other managed realignment schemes, which can be subject to the same erosion processes as natural coastal wetlands. The same methodology of creating water banks can be applied to areas that are in danger of flooding. The methodological framework of the Hermes project could be expanded to any Mediterranean or Black Sea shoreline to assess, for example, the historical levels of coastal erosion to evaluate the vulnerability of coastal areas to erosion and climate change and to monitor and model processes from the open sea to the near-shore. The assessment of cliffs' instability to understand the dynamics of erosive phenomena and of coastlines realised in the Maregot project is an important challenge worldwide, mainly where coastal retreat implies an economic impact.

Annex 4 provides two detailed case descriptions on the use of NbS in coastal areas. One is using the beached leaves of *Posidonia* to protect dunes in Ugento (Italy) (see Section A4.9). The other is on developing a harmonised framework to mitigate coastal erosion in Albania, Bulgaria, Cyprus and Greece to help identify suitable sites for NbS and their technical design to protect the coastline (see Section A4.10).

4.2.6 Mountain cases

The **societal challenges** primarily addressed by the eight mountain cases were reducing soil erosion and floods (CSC1 and CSC6). Some cases also aimed to enhance ecosystem biodiversity, protect fish stocks and game populations and increase groundwater reserves to be used for various uses and for ecosystem services (CSC2, CSC3 and CSC4).

The selected projects differ greatly in terms of content and measures and can be divided into four categories based on their main objective:

- exploring NbS measures (Olympia case, Greece; three Phusicos cases, Austria, France, Norway and Spain);
- developing risk assessment methodologies (Engadin case, Switzerland; GreenRisk4ALPs, Austria, France, Germany, Italy and Slovenia);
- studying residents' risk perceptions (Tyrol case, Austria);
- developing a climate adaptation strategy (Grimsel area, Switzerland).

Forest protection or management was the focus in the majority of cases, as it can provide effective protection against surface run-off, erosion, rockfalls, landslides and avalanches. In the Olympia case (Greece), the temporary installation of structures using locally available timber aim to alleviate the environmental impacts of the previous significant wildfires, such as soil erosion and floods. The method was selected to avoid major landscape intervention and to preserve the ecological balance of the ecosystem. In the Pyrenees case (France and Spain) terracing with drainage and revegetation is one of the major measures to be implemented.

In the Gudbrandsdalen case (Norway, Phusicos project), the aim is to remove the existing, 'grey' flood protection along the riverbank and build a new green flood barrier further away from the river. In the higher and treeless mountain areas in the Kaunertal valley case (Austria, Phusicos project) various ways to accelerate vegetation development (e.g. the growth-promoting effects of bacteria) will be explored.

The Protect Bio method developed in the Engadin region case (Switzerland) aims to evaluate the forest's protective functions against natural hazards or the need for implementing technical protective measures (i.e. barriers or nets) to prevent damage from rockfalls. GreenRisk4ALPs major aim is to develop forest-based recommendations and guidelines to support risk management with respect to natural hazards and climate impacts in five countries.

In terms of **innovativeness**, the two selected Phusicos cases turned out to be very different. The Pyrenees case uses traditional old methods of erosion control and silviculture (see Image4.3 and Section A4.11). The Kaunertal valley case (Austria) uses cutting-edge science to identify microbes that help plants establish in areas of loose soil. Revegetation measures are well known for their effectiveness in reducing erosion and consolidating slopes. However, seed mixtures sown on unconsolidated slopes often do not establish long-lasting plant cover or do not have the desired effectiveness, forcing management measures to be repeated (Phusicos, 2019).

GreenRisk4ALPs introduces an innovative ecosystem-based risk mitigation concept and offers for the first time risk mitigation alternatives by relating natural hazard protection targets to the effectiveness and consequences of the mitigation measures. The Protect Bio method (the Engadin case, Switzerland) is a new method that can be used to assess whether forest can provide similar levels of safety to structural measures. The climate adaptation strategy for the Grimsel region is considered a success and a good practice example by the coordinators of the Swiss pilot programme for climate adaptation. It is among the minority of pilot projects that went beyond improving the knowledge base or developing support tools and proceeded to identify practical adaptation options, setting them out in a regionally anchored strategy and preparing its implementation in practice.

In terms of **transferability**, the methods and materials developed in the mountain cases and their experiences have wide application potential in European mountain areas. The construction method used in the Olympia case (Greece) is applicable in other regions experiencing wildfires on steep hills and having similar climate conditions and soil properties and characteristics. The Protect Bio method can be applied in other locations and also in the context of avalanches, rockfalls and mudflows. However, the available data may limit the use of the method. The revegetation methods developed in the Kaunertal valley case (Austria) have considerable upscaling potential, and the methods may also be of interest for other Phusicos sites, such as some of the sites in the Pyrenees.

Annex 4 describes a case from the Phusicos project on using NbS to mitigate the risks of floods, rockfalls, landslides, debris flows and avalanches in the Pyrenees (France and Spain) (see Section A4.11), learning from a 100-year-old technique of terracing with dry walls and revegetating.

Image 4.3 A vegetated and terraced wall on the slopes of Biescas (Spain) today, the result of implementing a nature-based solution more than 100 years ago (left), and a till slope in Santa Elena (Spain) with frequent rockfall problems (right). It will be terraced, drained and revegetated, inspired by the traditional approach taken at Biescas

Note: See Section A4.11.

5 Financing nature-based solutions

Key messages

- **Nature-based solutions build upon and emphasise the economic and social value embedded in biodiversity and ecosystem services.**
- **Nature-based solutions for climate change adaptation and disaster risk reduction may initially entail higher investment costs but provide higher and multiple long-term benefits or reduced costs over the investment's lifetime.**
- **Nature-based solutions can be financed by a combination of existing economic instruments, innovative investment and insurance schemes and by shifting to more sustainable corporate business models.**

5.1 Introduction

Ecosystems can help to mitigate natural hazard risks, for example by stabilising earth masses and controlling erosion, regulating water flow, or dissipating wind or wave energy. In doing so ecosystems contribute to reducing disaster risks, damage and losses. Ecosystems services have an economic value in the context of natural disaster risk reduction and climate change adaptation, even if no price is paid for their provision and/or maintenance. The failure to account for their true social value leads to market distortions and, ultimately, insufficient levels of protection with lasting, in some cases irreversible, damage. This chapter briefly introduces and discusses some economic, financial and business innovation instruments favouring the adoption of nature-based solutions (NbS).

Ecosystems services have an economic value in the context of natural disaster risk reduction and climate change adaptation

5.2 Economic policy instruments

Many economic and financial instruments that have been developed to stimulate environmental conservation and restoration can be applied to foster the adoption of NbS (Lago et al., 2015). These instruments are commonly embedded across EU environmental law in the form of incentives (e.g. subsidies and payments) or disincentives (e.g. taxes or charges). Other instruments include tradable environmental schemes and risk-financing schemes (e.g. insurance and deposit guarantee schemes). The Organisation for Economic Co-operation and Development (OECD) database of policy instruments for the environment and the Biofin ([11]) database of financial solutions contain several examples of innovative economic instruments and their practical implementation.

([11]) The Biodiversity Finance Initiative is a global partnership established by the United Nations Development Programme in 2012 to address the challenges of financing biodiversity and support investments in the management of ecosystems and biodiversity (https://biodiversityfinance.net/finance-solutions).

The choice of policy instruments and their combination plays an important role. For example, attenuation or detention of storm water can be achieved by increasing localised infiltration, as a part of sustainable urban drainage systems (Ossa-Moreno et al., 2017). The adoption of NbS interventions such as swales, water gardens and green roofs can be encouraged by stormwater utility charges or credits. In the former case, landowners or developers pay lower fees if they reduce the amount of concrete and paved areas (Tasca et al., 2018). In the latter case, landowners obtain credits for increasing natural water retention on their land and can sell these to developers, who are then obliged not to increase peak stormwater run-off. The incentives may also assume some form of ecosystem service payments, triggering a change in land management practices. The payments for ecosystem services may be negotiated under specific programmes or determined by auctions. Land conversion fees have also been introduced to discourage the loss of high nature value land (Prokop et al., 2011).

Taxes are compulsory, unrequited payments to government. Environmental tax reform aims to limit the environmental impacts of resource use and to decouple environmental pressures from economic growth. Environmental tax reform shifts the tax burden away from where it may have an adverse impact on economic competitiveness, such as labour and capital taxation, to areas where such impact is lower and to activities with proven negative environmental impacts (Ekins, 2009). There are more than 150 biodiversity-relevant taxes in the OECD countries, generating revenues of around USD 7.4 billion a year (OECD, 2018). The pesticide tax, for example, is applied in various EU countries (Böcker and Finger, 2016) and in some cases (e.g. in Denmark and France) the revenues are earmarked for environmental purposes and to compensate farmers.

Tradable environmental permits (Tietenberg, 2006; OECD, 2013) have been applied to control non-uniformly mixed air pollutants, such as sulphur and nitrogen oxides, and greenhouse gas emissions, to support the production of renewable energy sources (Jensen, 2003) and for waste management (Bailey, 2003), biodiversity conservation (Wissel and Wätzold, 2010; Drechsler and Hartig, 2011) and fisheries (Grainger and Costello, 2011). The tradable (land) development rights, more common in Anglo-Saxon countries, have been connected to soil and biodiversity protection and to spatial planning as a complementary instrument to zoning and compensation for land value losses from downzoned properties.

Biodiversity-relevant taxes in the OECD countries, generating revenues of around USD 7.4 billion a year

5.3 Insurance-related instruments

Insurance is the most common form of financial protection against the risk of contingent losses. The insured party or policyholder transfers the cost of potential loss to the insurer in exchange for monetary compensation known as a premium. By acquiring the costs of contingent losses from many policyholders, the insurer absorbs, pools and diversifies the individual risks, making them assessable and manageable. Risk-based pricing embedded in insurance and risk transfer schemes can provide incentives for investments in loss reduction. Insurance can also help dissuade policyholders from risky behaviour and incentivise risk reduction (Surminski, 2009; Warner et al., 2009).

Insurance can play an important role in mitigating disaster impacts through all aspects of the risk management cycle, including risk identification and modelling, risk awareness, damage prevention, risk transfer and recovery (Michel-Kerjan and Kunreuther, 2011; Surminski and Oramas-Dorta, 2014). Insurers can reward individual risk reduction measures by lowering the premiums and deductibles (e.g. part of an insurance claim not covered). They can also assist policyholders and build awareness of the role that ecosystem protection and restoration play in reducing disaster risks. The community resilience rating framework of the Zurich Flood Resilience Alliance, for example, highlights the role of natural capital among the resilience drivers (Campbell et al., 2019).

Insurers can reward individual risk reduction measures by lowering the premiums and deductibles

The European Commission's research and innovation policy agenda on NbS (EC, 2015) defines the 'insurance value of ecosystems' as the 'sustained capacity of ecosystems to maintain their functioning and production of benefits despite any disturbance' or, elsewhere in the same report, as the 'sustained capacity of ecosystems to reduce risks to human society' caused by natural hazards, climate variability and climate change. The NAIAD project (NAIAD, 2020) has coined the term 'natural assurance schemes' to denote strategies employing NbS that internalise the insurance capacity of ecosystems (Denjean et al., 2017). Consistently, the insurance value would reflect an ecosystem's capacity to 'remain in a given regime and retain its capacity to deliver vital ecosystem services in the face of disturbance and change'. A survey into perceptions of NbS (Marchal et al., 2019) revealed that insurers understand ecosystems' risk reduction role as a part of a resilience dividend (building resilience while generating multiple societal benefits).

One of the first examples of putting into practice the concept of the insurance value of ecosystems is the Mesoamerican reef insurance (Reguero et al., 2019), developed by The Nature Conservancy, Swiss Re, the Mexican state of Quintana Roo and the Cancún and Puerto Morelos Hotel Owners Association to insure around 60 km of coastal reef and beaches along the coastline of the Yucatan peninsula. The jointly created Coastal Zone Management Trust purchases parametric insurance to ensure that vital ecosystems are restored after being damaged by extreme storms. Parametric insurance is triggered when wind speeds exceed certain thresholds. The Trust is financed by the taxes collected from the tourism industry. The Mesoamerican Reef Rescue Initiative is aiming to develop similar insurance-based schemes in other countries (Watson Willis Towers and Mesoamerican Reef Fund, 2019). The same concept can be applied to floodplain restoration, forest-based landslide risk prevention or nature-based fire management (Reguero et al., 2020; Kousky and Light, 2019). The InsuResilience Initiative ([12]) developed a catalogue of ecosystem-based adaptation measures based on insurance or similar instruments (Beck et al., 2019). It also includes a proposal for a social enterprise supporting mangrove restoration and conservation to reduce the risks of property damage and enhance carbon sequestration. The concept, originally developed for the Philippines, may be implemented based on insurance incentives or as a resilience bond (see Section 5.4).

5.4 Debt and equity instruments

From an investment perspective, the instruments for financing NbS can be based on debt, equity or a combination thereof (EIB, 2019). Debt instruments, such as loans or bonds, are assets that yield the lender interest. Green loans are made available to finance eligible green projects. The green loan principles of the Loan Market Association specify under which conditions a project may access green loans (Loan Market Association, 2018). Bonds are fixed income instruments involving loans made by an investor (or creditor) to a borrower, such as companies or governments, to finance projects. Bonds specify the end date when the principal of the loan is due to be paid and include the terms of interest payments. Green bonds are bonds that have positive environmental and/or climate benefits. First introduced by the European Investment Bank in 2007, green bonds are expected to play an important role in financing the transition to a carbon-neutral and resilient Europe and the EU's next generation recovery plan. The EU Green Bond Standard, recommended by the High-Level Expert Group on Sustainable Finance, will provide transparency and certainty over the green credentials of investments.

Green loans are made available to finance eligible green projects

Catastrophe or CAT bonds are instruments used to obtain financial coverage for climate-related events. They are defined as fully collateralised instruments that pay off on the occurrence of a defined catastrophic event (Cummins, 2008). If the event occurs, investors will lose the capital invested, and the issuer will use that money to recover from the damage. A resilient impact bond is a bond through which an investor is remunerated based on how well resilience measures are implemented, according to pre-defined performance indices (Vaijhala and Rhodes, 2018). It aims to promote resilience and interventions to reinforce the financial infrastructure by turning an index that measures the resilience of an infrastructure into a financial tool.

Equity represents the shareholders' stake in the company in return for, for example, capital injection. Equity does not entail repayment of capital; investors may receive regular dividends and receive capital gains or make losses at sale. Debt instruments are predictable and do not involve transfer of ownership, but they may often require securities or third parties' guarantees. Equity instruments do not require securities and do not increase debts.

The Natural Capital Financing Facility (NCFF) was established by the European Investment Bank and the European Commission as a dedicated programme to support pioneering conservation and NbS projects (EIB, 2019). The NCFF includes (1) a finance facility offering direct or intermediated debt or investing in equity instruments/funds and (2) a technical assistance support facility providing grants for project preparation, implementation, monitoring and evaluation. Examples of projects ([13]) include green infrastructure (e.g. green roofs, ecosystem-based rainwater collection, flood protection and erosion control), payment for ecosystem services (e.g. programmes to protect and enhance forestry or to reduce water or soil pollution), biodiversity offsets (e.g. compensation pools for on- and off-site compensation projects), pro-biodiversity and adaptation businesses (e.g. sustainable forestry, eco-tourism) and NbS for adaptation to climate change. Among others, a project implemented by the Croatian Bank for Reconstruction and Development offers small loans to projects investing in NbS such as eco-tourism and sustainable agriculture (EIB, 2017).

([12]) The InsuResilience Global Partnership for Climate and Disaster Risk Finance and Insurance Solutions was launched at the 2017 United Nations Climate Conference in Bonn (https://www.insuresilience.org). The Global Innovation Lab for Climate Finance is another example of a public-private initiative (www.climatefinancelab.org) addressing innovative financial solutions for climate change and sustainable development.

([13]) For more examples, see https://www.eib.org/en/products/blending/ncff/project-examples/index.htm

5.5 Business model innovation

Private sector engagement in adaptation can catalyse major investments in building resilience. Sustainable business model innovation means that incentives and revenue mechanisms are reorganised to maximise sustainable solutions (Rashid et al., 2013). This can yield higher returns than other types of business innovation and provide additional benefit in terms of risk mitigation and resilience. Yet, business model innovation using NbS has not been explored in depth, despite the multiple benefits that these solutions provide and their positive performance demonstrated in various contexts.

Business model innovation using NbS has not been explored in depth

Business models describe how value is generated, retained and delivered. Value proposition is what customers value and what makes a product or service attractive to them. Value capture means how the company retains a proportion of the value created for its customers. In the context of NbS, business models describe how those who benefit from the restored or regenerated ecosystem services contribute to sustaining their costs. Sustainable business models (Lüdeke-Freund et al., 2018) engage multiple stakeholders to generate shared and long-term monetary and non-monetary value (Geissdoerfer et al., 2018). Their success depends on the network of interactions that stakeholders, partners and customers entail. This is the value network: a set of synergistic and multi-collaborative transactions that create economic and non-monetary benefits. These gains emerge because the technological, biophysical and economic components of NbS interact dynamically with one another. Examples of this open innovation are visible where NbS contribute to nature restoration, disaster risk reduction and tourism (as in the case of flood protection barriers). The installation of these innovations produces co-benefits that are financed, supported and exploited by a wide variety of stakeholders interacting in a complex but tight network. The ability of sustainable business models to enhance existing co-benefits is rooted in the idea of shared value (Porter and Kramer, 2006; Kramer and Pfitzer, 2016). This concept moves beyond trade-offs. It is not a simple mechanism for redistributing individual gains to society but rather the expansion of opportunities for society beyond the simple economic dimensions. Companies become enablers of opportunities for their growth and for society at large. In the context of NbS, sustainable business models become the vehicle to promote increased resilience, stronger social ties and economic benefits through nature.

Business models for NbS and the returns from investing in ecosystem services have received some attention (Toxopeus and Polzin, 2017; Perrin, 2018; Somarakis et al., 2019). Many of the business models put forward propose a hybrid (public-public; public-private, etc.) finance structure. The Naturvation Urban Nature Atlas (Toxopeus, 2019), for example, developed eight sustainable business models — risk reduction, green densification, local stewardship, green health, urban offsetting, vacant space, education and green heritage — with detailed descriptions of value proposition, delivery and capture and of the enabling conditions and risks.

Business model innovation calls for further efforts to generate financial returns while having positive impacts on society and biodiversity. Higher synergies between NbS and the circular economy would help to transform urban spaces, enhancing adaptation and closing the existing resource loop. Successful examples of these new typologies of business models include those embracing the 'use, reuse, share, repair' logic. Here, the public actor becomes the trigger of a virtuous circle, whereas the private actor assumes the maintenance of NbS, and profits are generated using the natural capital for complementary purposes (i.e. tourism). Disaster risk reduction and biodiversity restoration goals match the economic logic of return on investment. First and foremost, they help unleash a new wave of innovation, in which non-monetary benefits are an essential component of value creation.

5.6 European funds

The implementation of NbS has been supported by European funds. Substantial funding for such solutions stems from cohesion policy funds (EC, 2020c). A 2016 study estimated that over the period 2007-2013, around EUR 6.6 billion were invested in green infrastructure, with the highest contribution from the European Agricultural Fund for Rural Development (Trinomics, 2016). Over the period 2014-2020, Member States allocated over EUR 3.7 billion to protection and enhancement of biodiversity, nature protection and green infrastructure and to the protection, restoration and sustainable use of Natura 2000 sites. These investments exceed EUR 10 billion if interventions that indirectly favoured biodiversity protection are included, such as wastewater treatment, adaptation to climate change and management of climate risks and tourism in natural areas (EC, 2020b).

Over the period 2014-2020, Member States allocated over EUR 3.7 billion to protection and enhancement of biodiversity

The common agricultural policy (CAP) has tangible impacts on the agricultural landscape and habitats. The CAP 2014-2020 has been based on a two-pillar system, consisting of direct payments to farmers (pillar 1) and the rural development policy, including biodiversity-related management interventions (pillar 2). Parts of the direct payments are aligned with environmental and climate goals, and compliance with certain environmentally friendly farming practices. Pillar 2 promotes sustainable rural development, including sustainable management of natural resources. This also includes agri-environmental and climate measures, aimed, for example, at promoting organic agriculture and active management of habitats. A recent analysis showed a relatively modest reward from implementing environmental practices under the current CAP model (Scown et al., 2020). Despite its relevance, the CAP has been found to provide only medium support to NbS for climate change adaptation and disaster risk reduction, largely due to the limited effectiveness of the greening measures thus far (ECA, 2020). In line with the European Green Deal and the Sustainable Development Goals, the new CAP 2021-2027 is designed to further stimulate progress on the EU's climate, environmental and biodiversity goals.

The LIFE programme, created back in 1992, is the EU's funding instrument for the environment and climate action. In the period 2014-2020, the programme was endowed with than EUR 3.4 billion and included two sub-programmes. The environment sub-programme was aimed at nature conservation and biodiversity, resource efficiency and environmental governance. The climate action sub-programme addressed climate governance, mitigation and adaptation. The projects from both sub-programmes helped to develop green infrastructure and enhanced the delivery of ecosystem services and connectivity between protected areas and the restoration of degraded ecosystems, all of which have positive impacts in mitigating climate change. The Urban Adapt initiative ([14]), for example, implemented natural water retention measures for 800 m^3 storage capacity and 37 500 m^2 of green river borders. Earlier LIFE projects TRUST and AQUOR demonstrated the feasibility of recharging groundwater aquifers through forested infiltration areas, that is, by channelling surface waters during times of excess into designated areas planted with trees and shrubs (Mezzalira et al., 2014).

The Multiannual Financial Framework for 2021-2027 set the financial envelope of the new LIFE programme at EUR 5.4 billion in current prices, with 64.8 % allocated to the environment portfolio, mainly to support biodiversity project. The programme's two main fields of action will cover four sub programmes.

The environment field would include: 1) the Nature and Biodiversity sub-programme; and 2) the Circular Economy and Quality of Life sub-programme. The Climate Action field would include: 3) the Climate Change Mitigation and Adaptation sub-programme; and (4) the Clean Energy Transition sub-programme (EC, 2018b).

The LIFE programme will contribute to funding NbS via the Natural Capital Finance Facility (NCFF) (see Section 5.4), financing projects that generate a revenue stream from natural capital. The initial slow uptake of loans form the NCFF has been addressed by adjustments made as a follow-up to the mid-term evaluation of LIFE. In 2018, the NCFF financed transformational investment in transport, waste, energy efficiency, culture and urban rehabilitation schemes across Athens to the tune of EUR 55 million, unlocking urban regeneration and ensuring better management of climate risks (EC, 2019a). The LIFE programme will also support the Urban Greening Plans (UGP) introduced by the EU Biodiversity Strategy to 2030 to bring nature back to cities. These plans are expected to mobilise the necessary policy and regulatory reform and leverage financial tools (EC, 2020e). NbS and green infrastructure can also be funded though the European Fund for Strategic Investments (EFSI). The 2019 Review of progress on implementation of the EU green infrastructure strategy found that the opportunities embedded in the various EU financing instruments have not yet been fully exploited and there was a need to improve access to finance.

Sizeable resources have been invested in research and innovation on and using NbS under the Horizon 2020 EU Framework for Research and Innovation 2013-2020.The new Horizon Europe programme will continue putting emphasis on NbS, including through the new instruments dedicated to mission-oriented research and innovation. Inspired by a seminal report on problem-solving approaches to fuel innovation-led growth (Mazzucato, 2018), the European Commission appointed expert groups to develop recommendations for five thematic areas, among which was adaptation and societal transformation (Hedegaard et al., 2020). The recommendation for this mission area includes boosting nature-based solutions and green-blue multi-purpose infrastructure investments in ecosystems. Research and innovation will address the following: incentives and financial schemes encouraging cooperation among landowners and a high degree of ecological connectivity; transferability of knowledge and evidence within and across context-specific domains; demonstrated performance and efficiency of nature-based solutions at large scales; and connections between ecosystem quality and human health (Hedegaard et al., 2020).

([14]) www.urbanadapt.eu


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6 Conclusions

Climate change and the loss of biodiversity and associated ecosystem services pose a systemic global threat to human society. Working with nature to use natural processes to reduce the risk of weather- and climate-related natural hazards is key to designing and implementing efficient climate change adaptation (CCA) and disaster risk reduction (DRR) approaches. Nature-based solutions (NbS) recognise this key value of nature and protect, sustainably restore and manage ecosystems to reduce biodiversity loss and ecosystem degradation, while increasing societal resilience to climate change impacts.

NbS are considered an 'umbrella concept' that encompasses the following related approaches to CCA and DRR: ecosystem-based approaches, ecosystem-based adaptation, ecosystem-based disaster risk reduction, green infrastructure/blue-green infrastructure and sustainable management/ecosystem-based management/sustainable forest management. In this way, NbS can play a key role in addressing both the climate and the biodiversity crises while accelerating transformative societal change.

6.1 Global and EU policy frameworks

In the last decade, scientific communities and the global and EU policy initiatives dealing with sustainable development, disaster risk, climate and biodiversity issues have started to recognise the interdependency of climate change and biodiversity loss and the potential of NbS to address both challenges in parallel. The global and EU policy frameworks analysed in this study show various levels of explicit and implicit support for NbS for CCA and DRR.

At the global scale, the Parties to the Convention on Biological Diversity at COP 14 (CBD, 2018a) adopted voluntary guidelines for ecosystem-based approaches to CCA and DRR. Furthermore, at the global and EU levels the 2030 agenda for sustainable development (UN, 2015) and the European Green Deal (EC, 2019c) can be pivotal to further promote NbS across different sectors and thematic and policy areas and to scale up and increase their implementation.

A lack of coherence among EU and global sectoral policies (Somarakis et al., 2019), fragmented governance arrangements (Trémolet, 2019) and a lack of quantitative and measurable indicators for monitoring and evaluating progress hamper capitalising on potential synergies and joint financing across multiple agendas. There is thus a need to streamline current efforts, adopt and respect standards to support effective design and implementation (Cohen-Shacham et al., 2019) and disseminate knowledge of the value of NbS for CCA and DRR and potential associated trade-offs.

There is thus a need to streamline current efforts, adopt and respect standards to support effective design and implementation

Recently, the International Union for Conservation of Nature (IUCN) launched a global standard for NbS, which intends to accelerate the implementation and upscaling of proven and workable models of NbS for both mitigation and adaptation (IUCN, 2020). Still, mandatory requirements for the inclusion or design of NbS for CCA and DRR are missing in global and EU policies. Some relevant EU policies that encourage the use of NbS are non-binding in nature, e.g. the EU adaptation strategy, the EU green infrastructure strategy and the EU urban agenda (Davis et al., 2018).

European Green Deal includes EU biodiversity strategy for 2030 actions include a roadmap for planting at least 3 billion additional trees and restoring at least 25 000 km of rivers to a free-flowing state by 2030.

However, the European Green Deal includes an ambitious roadmap with relevant initiatives, such as the EU biodiversity strategy for 2030 (EC, 2020e) and its EU nature restoration plan. This plan will be a legal framework for nature restoration with binding targets to restore degraded ecosystems by 2030 and to manage them in a sustainable way. The proposed actions include a roadmap for planting at least 3 billion additional trees and restoring at least 25 000 km of rivers to a free-flowing state by 2030. These EU initiatives put Europe's biodiversity on the path to recovery and can encourage further use of NbS to increase the climate resilience of society and ecosystems. The Green Deal roadmap also includes a new EU strategy on adaptation to climate change (EC, 2021a). This new strategy identifies NbS for CCA and DRR among its priorities for supporting more systemic adaptation and highlights the role as well of BGI and SM/EbM. Furthermore, increased action is proposed to better understand, monitor and evaluate the climate change impacts on ecosystems and to develop robust ecosystem management measures for reducing climate change risks.

New EU strategy on adaptation to climate change increased action is proposed to better understand, monitor and evaluate the climate change impacts on ecosystems and to develop robust ecosystem management measures for reducing climate change risks

6.2 Improving the knowledge base

The scientific evidence base on the relevance and effectiveness of NbS for CCA and DRR and other societal challenges is rapidly expanding. NbS that address climate hazards involve different levels of intervention: (1) conservation and restoration (including rewilding) of ecosystems; (2) sustainable management and climate-proofing of ecosystems; and (3) creation of new, engineered ecosystem solutions (blue-green or hybrid solutions).

A key advantage of NbS for CCA and DRR over grey solutions is their multifunctionality, i.e. producing multiple benefits simultaneously, including environmental, socio-cultural and economic advantages (Raymond et al., 2017b; Calliari et al., 2019). They increase the resilience of society to climate change (e.g. reducing damage from heavy precipitation and flooding, alleviating the impacts of droughts and mitigating heat) while also contributing to conserving biodiversity, mitigating climate change, protecting and improving human health and well-being and offering recreational opportunities. However, the effectiveness of NbS can be limited by the vulnerability to climate change of species and ecosystems themselves (Morecroft et al., 2019; Turner et al., 2020).

The scientific evidence base on the relevance and effectiveness of NbS for CCA and DRR and other societal challenges is rapidly expanding

This study has identified knowledge gaps that will need particular attention:

- better assessment and quantification of the effectiveness of NbS in environmental, socio-cultural and economic terms, including potential negative consequences (e.g. through multi-criteria decision analysis);
- including more strategic approaches towards realising multiple development goals, including the Sustainable Development Goals;
- understanding the synergies and trade-offs between NbS and grey infrastructure and designing hybrid measures;
- building solid evidence for the multiple benefits from NbS to society, which can help to secure funding and enhance the mainstreaming of NbS across various policy areas.

The recent Horizon 2020 call in support of the European Green Deal, mobilising EUR 1 billion funding for research and innovation to address the climate change and biodiversity crises, includes key areas relevant to NbS.

6.3 Challenges for the implementation

The analysis of 97 European case studies, based on information derived from knowledge platforms, pointed to the need for better quantification of the effectiveness of NbS at the local level, for example in municipalities wishing to adopt NbS. This could be supported by standardised performance indicators and local long-term monitoring, for which indicator check lists have already been developed in some projects (e.g. Phusicos, 2020). Such more rigorous assessments of the effectiveness of NbS across various scales could also help to identify synergies in combining NbS with conventional engineering (grey) approaches.

Analysis of 97 European case studies pointed to the need for better quantification of the effectiveness of NbS at the local level

Engaging stakeholders in the co-design and assessment of NbS is key for increasing social acceptance of and demand for NbS and for tackling potential stakeholder conflicts in better ways. For example, a dedicated communications officer, public information and a continuous stakeholder consultation group can help to ensure successful implementation and deal with perceived disservices from NbS. Creating a sense of ownership of NbS measures has often proved to be essential for avoiding local opposition.

Transnational cooperation and knowledge transfer can also help to foster local innovations. Bottom-up collaboration among stakeholders is key to innovate and implement large-scale NbS. Multi-criteria decision analysis (MCDA) is widely used in environmental planning and natural resources management to systematically evaluate alternatives from ecological, social and economic perspectives and to engage stakeholders in the planning processes. Among the cases analysed, however, there were none that applied MCDA in identifying and assessing the impacts of NbS. One case (the Phusicos project) includes a comprehensive framework for NbS assessment, which presents an MCDA-based approach (Autuori et al., 2019). Making the multiple benefits of NbS more visible, and valuing them in economic terms, is key to promoting their uptake. There is a need to better exploit the potential of MCDA in these and similar cases.

In many of the cases studied, cities employ financial incentives or tax rebates to push the implementation of NbS on private property, as this also provides public goods and benefits. Combined with regulation, such stimuli have been proven to accelerate the uptake of NbS.

The timescales for implementing NbS are frequently a challenge. Such solutions may initially entail higher investment costs, but they generally provide higher and multiple long-term benefits or reduced costs over the investment's lifetime. If the financial system and investment practices cannot adapt to longer timescales and include multiple benefits, NbS may not be considered on a par with conventional approaches.

Managing stakeholders' expectations can also be a challenge, because NbS may take several years to reach an optimal level of performance. However, making NbS aesthetically appealing to citizens will enhance their acceptance as well as their social and health benefits (Frantzeskaki, 2019).

6.4 Financing the implementation

NbS have been financed across Europe by a combination of instruments, including innovative risk-financing and investment schemes. Economic and financial instruments, such as incentives (e.g. subsidies and payments), disincentives (e.g. taxes or charges), tradable environmental schemes and risk-financing schemes (e.g. insurance and deposit guarantee schemes), have been developed to stimulate environmental conservation and restoration and can be used to foster the implementation of NbS for CCA and DRR.

NbS have been financed across Europe by a combination of instruments, including innovative risk-financing and investment schemes

The European Commission's research and innovation policy agenda on NbS (EC, 2015) defined the 'insurance value of ecosystems' as the 'sustained capacity of ecosystems to reduce risks to human society' caused by natural hazards, climate variability and climate change. The Horizon 2020 NAIAD project (NAIAD, 2020) coined the term 'natural assurance schemes' as strategies employing NbS that internalise the insurance capacity of ecosystems (Denjean et al., 2017). A survey has also shown that insurers in Europe are more aware now of ecosystems' role in reducing risk as a way of building resilience while generating multiple societal benefits (Marchal et al., 2019).

The European Investment Bank and the European Commission established the Natural Capital Financing Facility (NCFF) to support pioneering conservation and NbS projects (EIB, 2019). The projects to be supported include green infrastructure, payment for ecosystem services, biodiversity offsets (e.g. compensation pools for on- and off-site compensation projects), pro-biodiversity and adaptation businesses (e.g. sustainable forestry, eco-tourism) and NbS for adaptation to climate change.

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Innovative business models addressing NbS are receiving increased attention in Europe (Toxopeus and Polzin, 2017; Perrin, 2018; Somarakis et al., 2019). Eight sustainable business models (risk reduction, green densification, local stewardship, green health, urban offsetting, vacant space, education and green heritage) have been developed by the Horizon 2020 project Naturvation (Toxopeus, 2019), along with detailed explanations of value proposition, delivery and capture.

Moreover, many EU funds related to the cohesion policy, common agricultural policy and LIFE programme have been allocated to support the realisation of NbS for CCA and DRR.

6.5 Knowledge platforms

The 12 European knowledge platforms we analysed that are most relevant for NbS for CCA and DRR (see Annex 5) play a valuable role as an interface for enhancing networking and knowledge exchange between science, policy and practice (Karali et al., 2020; Almassy et al., 2018; Boogaard et al., 2020). There is still room to improve the interlinkages between platforms and the networking among their managers, providers and users (Adams et al., 2020; Barrott, et al., 2020; Boogaard et al., 2020). Seven of the platforms focus on either one specific approach or two NbS approaches, while five cover multiple NbS-related concepts, with only two platforms addressing all NbS approaches. Most of the European knowledge platforms analysed address multiple societal challenges.

Based on this analysis, knowledge platforms could be further developed to:

- capture the emerging knowledge from the next cycle of European research programmes;
- adjust the information to the needs of target users and evolving adaptation policies (Almassy et al., 2018; Boogaard et al., 2020);
- prove to be effective in supporting the implementation of NbS for CCA and DRR, including monitoring and evaluating the expected results;
- maintain the platforms beyond projects' lifetimes.

Only a few examples of national knowledge platforms tackling NbS for CCA and DRR have been identified, suggesting room for improvement in knowledge exchange and capacity building at country level.

In conclusion, the European Green Deal and the design of its supporting policies and initiatives can improve policy coherence across sectors and the integration of NbS and, along with other programmes (e.g. Horizon Europe, LIFE), can enhance further research and implementation of NbS in Europe. This indicates that there is ample opportunity to mainstream NbS for CCA and DRR into sectors across Europe, which can support the transformative change needed to address the climate change and biodiversity challenges.

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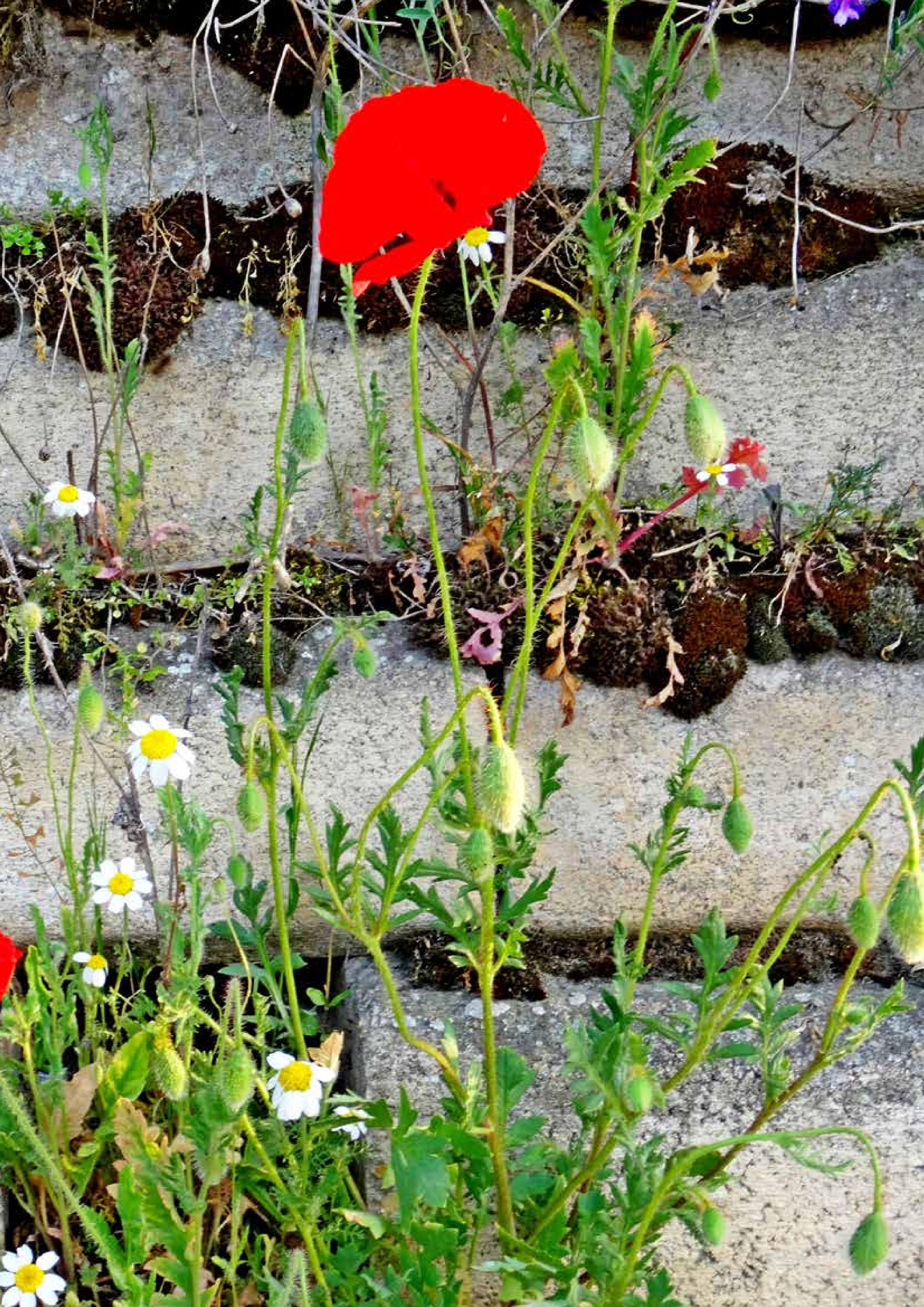

Abbreviations and symbols

BGI	Blue-green infrastructure
BISE	Biodiversity Information System for Europe
CAP	Common agricultural policy
CBD	Convention on Biological Diversity
CCA	Climate change adaptation
Climate-ADAPT	European Climate Adaptation Platform
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent
COP	Conference of the Parties
Copernicus	EU Earth observation programme
DRM	Disaster risk management
DRMKC	Disaster Risk Management Knowledge Centre
DRR	Disaster risk reduction
DSS	Decision support system
EA	Ecosystem approach
EbAp	Ecosystem-based approaches
EbA	Ecosystem-based adaptation
EbM	Ecosystem-based management
EC	European Commission
Eco-DRR	Ecosystem-based disaster risk reduction
EEA	European Environment Agency
EGTC	European Grouping of Territorial Cooperation
EIB	European Investment Bank
Eionet	European Environment Information and Observation Network

EIP-AGRI	Agricultural European Innovation Partnership
ETC/BD	European Topic Centre on Biological Diversity
ETC/CCA	European Topic Centre on Climate Change Impacts, Vulnerability and Adaptation
ETC/ULS	European Topic Centre on Urban, Land and Soil Systems
EU	European Union
EUR	Euro
FAO	Food and Agriculture Organization of the United Nations
FEBA	Friends of Ecosystem-based Adaptation
GHG	Greenhouse gas
GI	Green infrastructure
Horizon 2020	EU research and innovation programme
Interreg	EU instrument supporting cooperation across borders through project funding
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for Conservation of Nature
IWRM	Integrated water resources management
JRC	Joint Research Centre (of the European Commission)
LIFE+	EU funding instrument for the environment and climate action
LULUCF	Land use, land use change and forestry
MAES	Mapping and assessment of ecosystems and their services
MCDA	Multi-criteria decision analysis
NbS	Nature-based solutions
NCFF	Natural Capital Financing Facility
NCS	Natural climate solution
NWRM	Natural water retention measure
OECD	Organisation for Economic Co-operation and Development
PEDRR	Partnership for Environment and Disaster Risk Reduction
RCP	Representative Concentration Pathway
SDG	Sustainable Development Goal

SFDRR	Sendai Framework for Disaster Risk Reduction
SFM	Sustainable forest management
SM	Sustainable management
UHI	Urban heat island
UN	United Nations
UNDRR	United Nations Office for Disaster Risk Reduction
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
WFD	Water Framework Directive
WHO	World Health Organization

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Annex 1
Links to EEA activities

In recent years, the EEA has prepared various products on topics related to climate change adaptation (CCA), disaster risk reduction (DRR) and biodiversity, specifically including naturebased solutions (NbS) and green infrastructure (GI).

Climate change

The EEA report *National climate change vulnerability and risk assessments in Europe* (EEA, 2018a) provides a systematic review of national climate change impacts, vulnerability (CCIV) and risk assessments across Europe. The CCIV assessments cover 19 sectors and thematic areas, and water, agriculture, biodiversity, energy, forestry and human health are covered most frequently.

The EEA report on climate change, impacts and vulnerability in Europe (EEA, 2017b) presents trends in and projections for around 40 indicators, focusing on the impacts of climate change on various sectors, e.g. health, environment and economy. The report specifically addresses the climate change impacts and other pressures on ecosystems and their services.

Climate change adaptation and disaster risk reduction in Europe (EEA, 2017a) addresses the links between CCA and DRR thorough an analysis of the policies, knowledge base (including the impacts of weather- and climaterelated hazards on society and ecosystems) and practices. The report highlights how the negative climate change impacts can be mitigated by enhancing the use of NbS.

Biodiversity and ecosystem

The EEA contributes to the regular reporting on the mapping and assessment of ecosystems and their services (MAES), which presents the conditions of terrestrial, freshwater and marine ecosystems (EC, 2016a; Maes et al., 2018).

The EEA briefing *Building a coherent Trans-European Nature Network* (EEA, 2020a) built on a report developed by the EEA and the European Topic Centre on Urban, Land and Soil Systems (ETC/ULS and EEA, 2020), maps an EU GI network of protected Natura 2000 sites and unprotected natural and semi-natural terrestrial ecosystems (including agroforestry). This report demonstrates that the GI network has co-benefits for society and nature.

Forest and forestry

The EEA report on European forest ecosystems (EEA, 2016a) assess the current state of Europe's forest ecosystems and highlights the main environmental, economic and social pressures that challenge their sustainability. This report shows that ecosystem-based management and sustainable forest management are essential to protect, restore and maintain forests in a condition to meet the many demands from society, i.e. the whole range of forest ecosystem services, and able to be a component of successful NbS.

Nature-based solutions and green infrastructure

About 70-90 % of floodplains, part of Europe's natural capital, have been environmentally degraded. The report Floodplains: A natural system to preserve and restore (EEA, 2019b) shows that natural and restored floodplains provide an alternative to structural measures to reduce flood risk, based on GI or NbS.

The EEA contributed to the joint report Strategic green infrastructure and ecosystem restoration — Geospatial methods, data and tools (Estreguil et al., 2019), which provides guidance for the strategic design of a well-connected, multifunctional and cross-border GI network and identifies the knowledge gaps.

The EEA report on GI and flood management (EEA, 2017c) presents how this measure can be implemented on European floodplains. It demonstrates the scope of GI and its potential to provide flood protection in a cost-efficient way. It further contributes to building our knowledge and the evidence base on the multiple benefits of applying GI, which can support more efficient strategic or policy decision-making in the future.

The EEA report Exploring nature-based solutions: The role of green infrastructure in mitigating the impacts of weather- and climate change-related natural hazards (EEA, 2015) highlights how the GI network in Europe contributes to making ecosystems more resilient to the impacts of extreme events and natural hazards such as landslides, avalanches, floods and storm surges.

The EEA report Flood risks and environmental vulnerability — Exploring the synergies between floodplain restoration, water policies and thematic policies (EEA, 2016b) aims to support the implementation of the EU Floods Directive, looking in particular at synergies between water management, nature conservation and economic developments for CCA and DRR. For this purpose, it addresses the role of floodplains in flood protection, water management and nature protection.

Annex 2 Overview of the key climate hazards identified for Europe

Source: Adapted from EEA (2017a, p. 46).

Heat waves

Since 2003, Europe has experienced several extreme summer heat waves. Such heat waves are projected to occur as often as every 2 years in the second half of the 21st century, under a high emissions scenario (Representative Concentration Pathway 8.5, or RCP8.5). The impacts will be particularly strong in southern Europe.

Heavy precipitation

Heavy precipitation events have been increasing in northern and north-eastern Europe since the 1960s, whereas different indices show diverging trends for south-western and southern Europe. Heavy precipitation events are projected to become more frequent in most parts of Europe.

River floods

The number of very severe flood events in Europe has varied since 1980, but the economic losses have increased. It is not currently possible to differentiate the contribution due to increased heavy precipitation in parts of Europe compared with that due to better reporting and land use changes.

Windstorms

Observations of windstorm location, frequency and intensity showed considerable variability across Europe during the 20th century. Models project an eastward extension of the North Atlantic storm track towards central Europe, with an increase in the number of cyclones in central Europe and a decrease in the number in the Norwegian and Mediterranean Seas. For medicanes (also known as Mediterranean Sea hurricanes), a decreased frequency but increased intensity is projected in the Mediterranean area.

Landslides

Landslides are natural hazards that cause fatalities and significant economic losses in various parts of Europe. Projected increases in temperature and changes in precipitation patterns will affect rock slope stability and favour increases in the frequency of shallow landslides, especially in European mountains.

Droughts

The severity and frequency of droughts appear to have increased in parts of Europe, in particular in southern and south-eastern Europe. Droughts are projected to increase in frequency, duration and severity in most of Europe, with the strongest increase projected for southern Europe.

Forest fires

Forest fire risk depends on many factors, including climatic conditions, vegetation, forest management practices and other socio-economic factors. The burnt area in the Mediterranean region increased from 1980 to 2000; it has since decreased. Projected increases in heat waves and an expansion in the fire-prone area will increase the duration of fire seasons across Europe, in particular in southern Europe.

Avalanches

Observational data for the period between 1970 and 2015 show that avalanches cause on average 100 fatalities every winter in the Alps. Increased temperatures are expected to lead to decreases in the amount and duration of Alpine snow cover and in turn to decreased avalanche activity below about 1 500-2 000 m elevation in spring but increased avalanche activity above 2 000 m elevation, especially in winter.

Annex 3
The selected cases of nature-based solutions in Europe

Table A3.1 **The distribution of the 97 selected screened cases by country and sector/thematic area (five cases/ projects were implemented across several countries)**

	Water management	Forests and forestry	Agriculture	Agroforestry	Urban	Coastal	Mountains
Southern Europe/Mediterranean							
Albania						1	
Cyprus						1	
Greece						1	1
Italy	2		1		4	2	2
Portugal		1		1	1		
Serbia					1		
Slovenia	2						1
Spain		2			4		1
Western/central Europe							
Austria					1		2
Belgium	1				1		
France	3			1	3	2	2
Germany	1	1	2		3	1	1
Netherlands	1			1	1	1	
Poland	3	1			1		
Switzerland					1		2
Eastern Europe							
Bulgaria						1	
Czechia					1		
Romania	1						
Slovakia					2		
Northern Europe							
Denmark	1				1		
Estonia	2				2		
Finland	1	1			3		
Latvia	1						
Lithuania	2				1		
Norway					2		1
Sweden			2		6	1	
United Kingdom	2				6	1	

Note: The 97 selected screened cases include five multinational cases, i.e. part of multinational projects having demonstration locations in several countries (hence the Table sums to 107).

Source: EEA.

Annex 4 Descriptions of the example cases of nature-based solutions in Europe

A4.1 Brague case (France): flash flooding and wildfire hazards in a Mediterranean catchment

Websites

https://oppla.eu/casestudy/19924

https://oppla.eu/sites/default/files/uploads/2019-09-naiad-case-study-brague.pdf

Status

Complete (2016-2020).

Contact person

Jean-Marc Tacnet (French National Institute for Agriculture, Food and Environment, INRAE).

Site description and societal challenges addressed

The catchment (68 km^2, between Nice and Cannes) suffered from serious flash floods. Four people died in the 2015 flood (frequency 1/100 to 1/500), which caused losses worth more than EUR 200 million at the catchment scale. Flooding was exacerbated by flood-recruited large pieces of wood blocking bridges.

Nature-based solutions evaluated/implemented

The impacts of four flood alleviation strategies were assessed: two grey solutions and two levels of nature-based solutions (NbS) strategy. NbS combine retention measures that give room to the river by creating small natural water retention areas in the upper catchment and widening the river corridor in the lowlands, enhanced by floodplain reconnection. These were modelled at two levels of ambition, namely high and very high. The classic grey solutions considered were aimed at trapping large pieces of wood obstructing bridges and huge retention dams (see Figure A4.1) (Piton et al., forthcoming).

Main results

In rivers hit by large-scale Mediterranean thunderstorms, even a high level of ambition on retention measures in the upper and mid-catchment is insufficient to prevent flooding of downstream floodplains. Therefore, a sufficiently large corridor must be maintained so that such rivers can convey water down to the sea or to the downstream river system.

Effectiveness of nature-based solutions

NbS for water-related risks cannot be automatically assumed to be economically efficient. There is a need for economic evaluation to identify the most suitable strategy in a context of limited public funding. The largest share of the value of NbS comes from their co-benefits, which have significant implications for the funding of NbS and the need to maximise co-benefits in their design. In the Brague case, a reduction of 50 % in run-off hazard was able to reduce damage by 40-45 %. In addition, NbS solutions were found to have lower costs of implementation than grey solutions for the same level of risk reduction, reinforcing the evidence for the cost-effectiveness of NbS over grey solutions (Le Coent et al., forthcoming). However, the economic benefits arising from the reduced flood damage are not sufficient to fully cover the investment, maintenance and opportunity costs, which makes the inclusion of multiple benefits (economic, environmental, social) all the more important in assessing the total costs and benefits (Lopez-Gunn et al., 2020).

Innovativeness

The project used an integrated framework and methodology combining deterministic, quantitative approaches from the engineering sciences (e.g. hydraulics, hydrology, civil engineering, safety and reliability analysis) and decision-making science to assess the effectiveness of NbS and consider the physical effects as well as the economic and intangible NbS co-benefits.

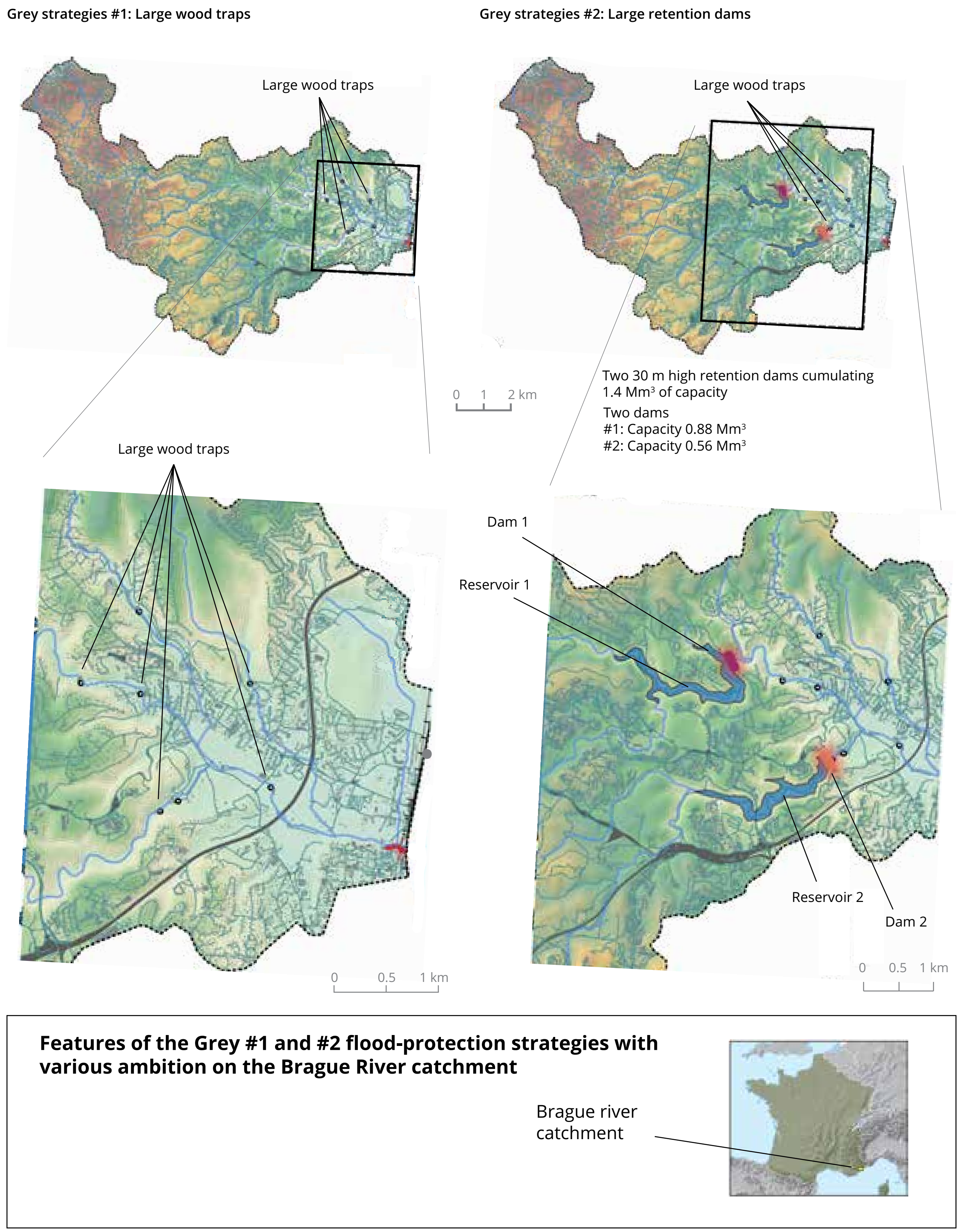
Transferability of results

- Effects of large pieces of wood on flood hazard and decision-making framework: global.
- Links between wildfire, urban sprawl and hydrology: Mediterranean region.
- Damage curves for flash flood damage evaluation: Mediterranean region.
- NbS co-benefit analysis: French coast for the study's results; Europe and North America for the generic co-benefit value transfer method.

Lessons learned

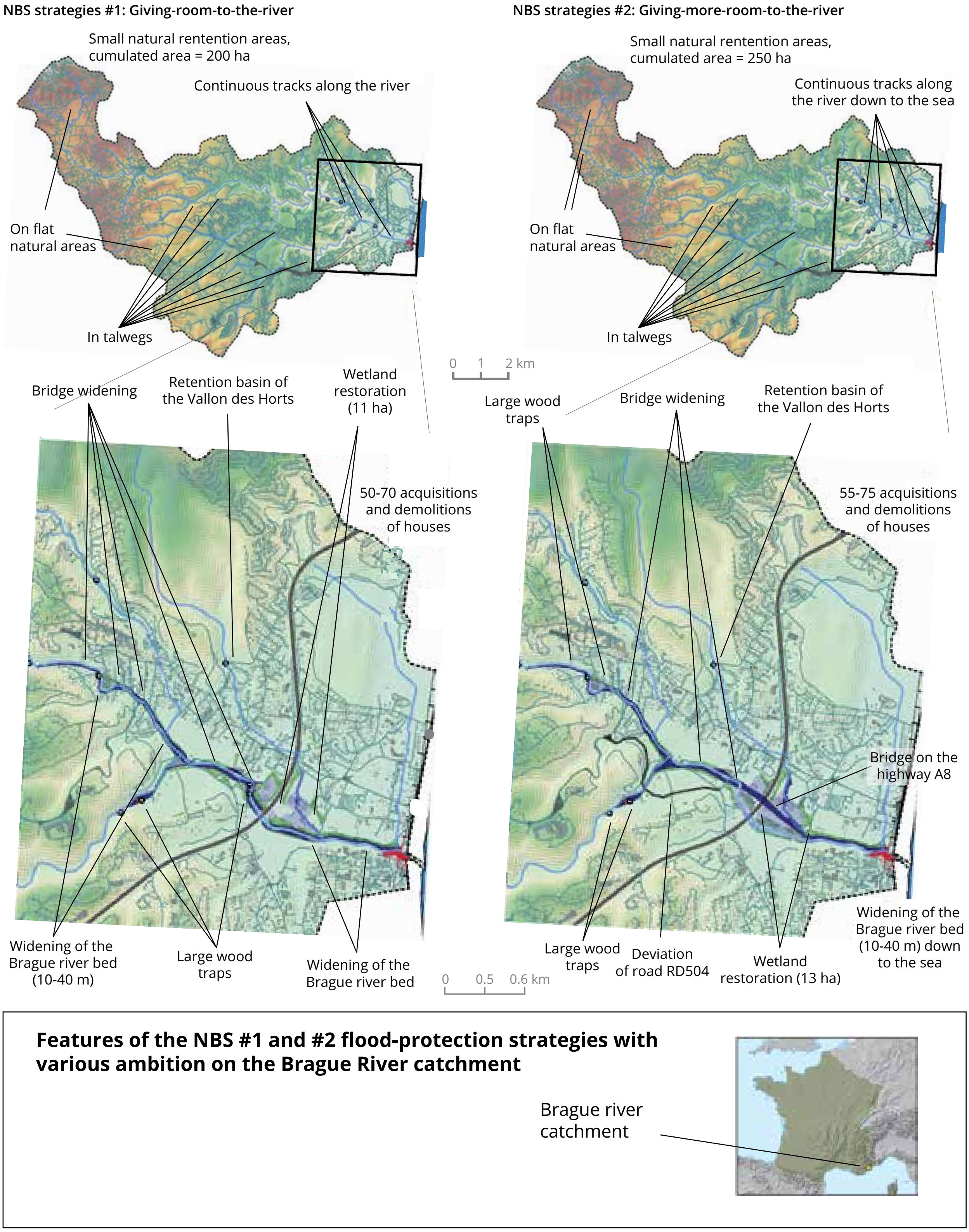
It is essential and effective to build and choose solutions that are grounded in strong physical evidence and accepted and understood by traditional (technical) flood risk managers, but also to consider other environmental and social features and to make the solutions acceptable to and likely to be implemented by stakeholders.

Figure A4.1 **Features of four flood-protection strategies with various levels of ambition in the Brague river catchment (south-east France): grey strategies (left-hand panel) were compared with NbS strategies (right-hand panel) in terms of efficacy of protection, environmental restoration capacity, citizen perception and cost-benefit ratio, showing better performance of and preference for NbS strategies**



Source: Le Coent et al. (forthcoming).

Figure A4.1 Features of four flood-protection strategies with various levels of ambition in the Brague river catchment (south-east France): grey strategies (left-hand panel) were compared with NbS strategies (right-hand panel) in terms of efficacy of protection, environmental restoration capacity, citizen perception and cost-benefit ratio, showing better performance of and preference for NbS strategies (cont.)



Source: Le Coent et al. (forthcoming).

A4.2 Serchio river basin case (Italy): floods and drought risks in a Mediterranean basin

Website

https://phusicos.eu

Status

Ongoing (2019-2022).

Contact person

Nicola del Seppia (Northern Apennines District River Basin Authority).

Site description and societal challenges addressed

Serchio river basin (about 1 500 km^2) is challenged by extreme drought and floods, seismic risks and water pollution. The sub-basin of Lake Massaciuccoli experienced a severe drought in 2017, the worst in the previous 40 years, which compromised crops on the farms in the basin. For this reason, measures to supply water have been put in place, combined with the implementation of various NbS to mitigate the effects of climate change, increase biodiversity and improve water quality.

Nature-based solutions evaluated/implemented

Various interventions were assessed, aimed primarily at slowing down erosion processes and soil loss and improving water quality, including the introduction of conservative agriculture, plant recomposition, and the creation of buffer strips and sediment containment basins. Moreover, maintenance plans, monitoring and planning strategies will be developed with the overall objective of developing an ecosystem-based management approach for reducing hydrogeological risk in the area of Lake Massaciuccoli.

Main results

The synergy of the measures envisaged will slow down soil consumption by improving environmental conditions and decreasing the hydraulic risk associated with the minor grid. Furthermore, with the implementation of a shared territorial management strategy for overcoming the problems related to drought and for mitigating flooding, it will also be possible to explore planning strategies with the overall objective of developing a management approach based on ecosystem services.

Effectiveness of nature-based solutions

NbS measures, designed to mitigate water-related risks such as drought and flood, will act directly on the causes in the case of Lake Massaciuccoli by improving the overall environmental status and mitigating the hydraulic risk; therefore, they will be considered efficient in this sense.

Innovativeness

The project's participatory design and implementation of the works within shared territorial planning strategies and the identification of ecosystem services connected to the NbS was innovative, as was the use of specific essences and plant species and more ecological agricultural approaches and techniques for implementation and maintenance. Previous experience of the adaptability of the ley species to specific conditions suggests that a mixture ensures better results in terms of adaptability to the environment and biodiversity. On the buffer strips, the plan is to start with a mixture consisting of *Festuca arundinacea* 40 %, *Lolium perenne* 50 %, *Trifolium repens* 5 % and *Trifolium subterraneum* 5 %.

Transferability of results

- Application of specific essences and plant species and their maintenance cycles: global
- Participatory processes and territorial planning: global
- Identification and definition of ecosystem services: global
- Remuneration systems for ecosystem services: regional
- NbS efficiency monitoring system: global
- NbS co-benefit analysis: regional.

Lessons learned

It is essential to build and choose natural solutions that produce short- and medium-term benefits; to set up well-structured participatory pathways to fully involve stakeholders in decision-making; and to stimulate the interest of citizens so that the measures implemented are accepted and understood.

A4.3 LIFE Resilient Forest case (Germany, Portugal and Spain): coupling water, fire and climate resilience with biomass production in forestry to adapt watersheds to climate change

Website

https://www.resilientforest.eu

Status

Ongoing (2018-2022).

Contact person

Maria Del Carmen Gonzalez Sanchis (Universitat Politécnica de València).

Site description and societal challenges addressed

Climate change affects forest ecosystems in different ways, e.g. by reducing plant growth or by making forests less resilient to disturbance (altered frequency and intensity of pest and disease outbreaks, droughts, wildfires and windstorms). Non-management is a model that has resulted in complex socio-economic changes in rural areas. However, it is not a sustainable solution, considering the risks of wildfires exacerbated by climate change. The project promotes a forest management approach at the watershed scale that improves forests' resilience to wildfires, water scarcity, environmental degradation and other effects induced by climate change and land use changes (forest encroachment). The aim is to develop a system able to introduce climate change adaptation strategies into forest management with a specific focus on the quantification and optimisation of ecosystem goods and services and upscalability within the project.

Nature-based solutions evaluated/implemented

The project demonstrates to what extent it is profitable to carry out forest management when accounting for additional forest products, e.g. the level of water collection, how management changes when combining additional goods and services (biomass production, fire risk reduction and climate resilience). In practice, the project works with an eco-hydrological-based forest management strategy that helps to reduce the impacts of climate change on Mediterranean forests to improve their adaptive capacity. The aim is to determine what type of forest management is optimal for maximising the profitability of ecosystem services.

Main results

The management scheme will be physically applied at one of three experimental sites and virtually applied at the other two. The Spanish experimental site, Serra village, located in the upper part of the Carraixet river catchment, is a semi-arid forest where water scarcity considerably limits forest growth and productivity, which results in marketable products that do not generate enough revenue to cope with the management costs, and therefore the forest remains unmanaged. The high frequency of lightning (one of the highest in Spain) also causes a high risk of wildfire that puts a significant part of the population in danger. The management approach trialled combined water production and fire risk reduction with increased revenue generation.

Based on the CAFE concept (carbon, aqua, fire and eco-resilience), the project has developed a decision support tool for multiple-criteria forest management. This tool determines the optimum activities to manage biomass production, CO_2 sequestration, fire risk, water provisioning, climatic resilience and biodiversity. The software provides key information for forest managers on how to manage resilient forests at catchment scale to meet multiple objectives with regard to management intensity, spatial distribution, and frequency and type of management (thinning/planting).

The project also plans to develop a complete monitoring system, including a life cycle assessment of the forest management approach, that will demonstrate the positive environmental impact of the project, as well as its socio-economic impact.

At first, the multi-criteria management approach will be applied at sub catchment level in Spain (415 ha), then at catchment level in Germany, Portugal and Spain (7 824 ha) and finally it will be further expanded to 350 000 ha within 5 years of the project's completion. Once the first forest working unit is managed, the results will be evaluated.

Effectiveness of nature-based solutions

The project relies on previous research from experimental approaches in previous research projects (CehyrfoMed, Hydrosil, SilvaMed) where this management approach was implemented and tested in terms of water production, climate resilience, wood production and fire risk. This project takes the pilot-scale research to a sub-catchment-scale demonstration and upscales the potential to catchment scale in Portugal and Germany.

Innovativeness

The project applies novel methods in forest management to couple water, fire and climate resilience with biomass production at different scales and countries. It combines genetic algorithms with forest management and eco-hydrological simulation, which means bringing together three different worlds to achieve one objective. It also quantifies other goods and services from forestry, not normally evaluated and thus changes the traditional qualitative narrative of co-benefits to a quantitative narrative. The project also increases the forest management possibilities and increases the evidence for the relevance of forests in the provisioning of goods and services.

Transferability of results

The forest management approach and the final software will be applicable to any climate or ecological region if the necessary input data are available.

Lessons learned

The dialogue with stakeholders from different countries and socio-ecological realities has improved the decision support system tool by increasing the scope of management goals and alternatives. For instance, plantation was not included in the tool from the outset, but this was incorporated after involving forest owners and realising the importance of this aspect.

A4.4 Agroforestry case (France): increasing resilience and productivity

Website

http://www1.montpellier.inra.fr/safe/english/agroforestry.php

https://climate-adapt.eea.europa.eu/metadata/case-studies/agroforestry-agriculture-of-the-future-the-case-of-montpellier

Status

Ongoing for 20 years.

Contact person

Christian Dupraz (French National Institute for Agriculture, Food, and Environment, INRAE).

Site description and societal challenges addressed

The agriculture sector in Montpellier is vulnerable to increasing temperatures and more frequent droughts. Conventional monoculture is recognised as more vulnerable than cultivating a mixture of crops or cultivating a mixture of trees and crops in agroforestry. This project addresses the impacts on agriculture of increasing temperatures or droughts, water and biotic stresses and more extreme events by implementing agroforestry in Montpellier for over 20 years. The implementation is accompanied by research as part of the EU SAFE (Silvoarable Agroforestry for Europe) project and supported by a French national scheme to plant half a million hectares of agroforestry over 25 years, based on results obtained by INRAE at Montpellier.

Nature-based solutions evaluated/implemented

Farms have adopted silvo-arable agroforestry, which combines widely spaced trees with arable crops. In practice, this has involved a combination of walnut trees and wheat.

Main results

Modern silvo-arable production systems are very efficient in terms of resource use and are able to capture more resources from the environment than pure crop or pure tree systems. Research by INRAE has shown that production from 1 ha of a walnut/wheat mix is the same as that from 1.4 ha with trees and crops separated. This 40 % increase in productivity is far more than that arising from any other innovation introduced by agronomists in the recent past. Trees provide shelter for crops and reduce damage due to high spring temperatures. Biodiversity is increased, as it creates a diverse habitat where wildlife can live. It also helps to control pests and enhances pollination. Farmers can diversify their products, increase their income and improve soil and water quality, reduce (wind) erosion and prevent damage due to flooding. Improving soil and water quality prevents erosion and maintains the land's productivity for future generations.

Effectiveness of nature-based solutions

Silvo-arable production systems are more efficient in their use of resources than separate crop and forest management because of the complementarity between crops and trees. For crops, trees offer a windbreak, shelter from the sun, rain and wind and keep the soil in place that stimulates soil microfauna and microflora. Nutrient leakage is recovered by the deep roots of trees, tree litter provides soil organic matter and planting valuable trees on arable land allows arable farming to be continued while offering farmers opportunities to diversify . From the forestry perspective, the spacious planting of high-value trees and their continuous care provide higher quality wood and the intercropping significantly reduces the maintenance costs of the plantation. It also protects against wildfires in risk areas. The silvo-arable production system has been proven to increase resilience and reduce vulnerability.

Innovativeness

The EU-funded SAFE project has reduced uncertainty concerning the validity of silvo-arable systems by monitoring and collating data from traditional and modern silvo-arable systems and experiments and modelling the outputs. The SAFE models allow optimum management schemes to be designed.

Transferability of results

The SAFE project provided models and databases for assessing the profitability of silvo-arable systems and suggested unified European policy guidelines for implementing agroforestry. The project has extrapolated plot-scale results to individual farms and sub-regions, and biophysical models have been constructed to simulate the dynamics of tree-crop systems in various soil and climatic conditions across Europe.

Lessons learned

Annual crops maintain an annual income for the farmer, while managed low-density tree stands provide capital for the future. However, agroforestry schemes are a long-term investment, which short-term investments hardly ever support, as they aim to make quick financial returns. Moreover, issues of European subsidy/grant schemes continue to exist that do not recognise the combination of forestry and agriculture. Modern silvo-arable production systems are very efficient in terms of resource use and could provide an innovative agricultural production system that would be both environmentally friendly and economically profitable. Growing high-quality tree crops in association with arable crops in European fields may improve the sustainability of farming systems, diversify farmers' incomes, provide new products for the wood industry and create novel high-value landscapes.

A4.5 Tullstorpsån 2.0 case (Sweden): adapting agriculture to wetter and drier climates

Website

https://www.tullstorpsan.se/english

Status

Ongoing (2019-2025).

Contact person

Christoffer Bonthron (Project Manager of the Tullstorp stream project).

Site description and societal challenges addressed

In recent years, Swedish agriculture has experienced extreme wet and dry seasons. To counter the problems of drought and associated crop losses, the Tullstorpsån 2.0 project aims to store water in multifunctional wetlands when there is excess water and to 'harvest' it from storage and use it in a recirculating irrigation system. The Tullstorpsån is a 30 km long stream where landowners, organised as the Tullstorpsån Economic Association, have worked since 2009 to restore the water course in a holistic way to improve biodiversity and water quality (Tullstorpsån 1.0). Between 2009 and 2019, 39 wetlands covering 169 ha and 10 km of the stream were restored. Another 3-4 years of restoration work are left in this first-generation project. Having experienced severe dry and wet conditions in recent years, landowners in the Tullstorpsån 1.0 project expanded the collaboration towards climate-proofing local agriculture using NbS. This will be carried out in Tullstorpsån 2.0, operating from 2019 to 2025.

Nature-based solutions evaluated/implemented

The Tullstorpsån 1.0 project measures include re-meandering, installing buffer strips and hedges, renaturalising riverbed material, restoring wetlands and adapting management
The focus of Tullstorpsån 2.0 is on a system combining multifunctional water reservoirs, recirculated irrigation and customised drainage to adapt agricultural production to extreme weather. Two pilot schemes are under way: one is a restoration of old sugar mill ponds that are fed with water from a drainage system, storm water and water from the Tullstorp stream; the second is a newly constructed water reservoir fed with water from a drainage system. These systems have the opportunity to simultaneously achieve ecological, economic and social benefits.

Main results

To date, the first-generation project has reduced the nitrogen content of the river by 30 % and the phosphorus content by 50 %. The second-generation project focusing on climate-proofing agriculture will still reduce nutrient loading but will not be positioned and optimally designed for nutrient purification, as the water flow service is prioritised. Tullstorpsån 2.0 will create approximately 12 ha of multifunctional wetlands with water from a closed drainage system in a catchment area of about 250 ha, of which 150 ha is arable land, whereby water from the Tullstorp stream will be pumped to the water reservoirs during winter and spring when the water level in the stream is high.

Effectiveness of nature-based solutions

Storing excess water during wet periods for use during dry periods with the added benefit of water purification is (expected to be) a highly effective and sustainable way of climate-proofing Swedish agriculture (see 'Main results'). The measures also improve biodiversity.

Innovativeness

The holistic approach to water in the agricultural landscape is a key defining element. It combines analysis of the entire drainage area and mapping of the available water with planning to optimally use the available water by combining three components into a circular system. The three components — multifunctional water reservoirs, recirculating irrigation and adapted drainage — contain a high degree of innovation through the benefits they bring to climate resilience and preservation of biodiversity. The advantage of this approach is that, in parallel with the climate benefit, the measures also contribute to environmental, economic and societal benefits. By adding more water areas to the landscape, agriculture can produce more food and new crops and improve its resilience to periods of more intense rainfall and drought. The project uses best possible technology with regard to energy consumption and water consumption for irrigation and drainage.

Transferability of results

The transferability of this type of action, albeit at an early stage of development, will be high, both within Sweden and across parts of northern Europe subject to the same climate challenges. Small rivers, streams and creeks within a catchment area can be used to set up a system for using water holistically while improving water quality. In order to move forward, the project is working to get the planned pilot projects in place and evaluate their effects. After this, the project aims to identify public funding to support their full-scale implementation.

Lessons learned

The major lesson from phase 1.0 is that during droughts the water reservoirs must be large and deep if any water is to be present when needed. Landowners are very positive about this type of measure, in which three benefits (ecological, economic and social) can be achieved at the same time. The challenge is the funding, as these measures are quite costly, and the funding system (in Sweden) is not yet open to irrigation and drainage projects but might be in the next generation of the Landsbygdsprogrammet (rural district programme).

A4.6 Paludiculture case (Germany): peatland restoration for climate change mitigation and adaptation

Website

https://www.moorwissen.de/en/paludikultur/paludikultur.php

Status

Ongoing for over 10 years.

Contact people

Christian Schröder and Franziska Tanneberger (Greifswald Mire Centre).

Site description and societal challenges addressed

In the federal state of Mecklenburg-West Pomerania 291 361 ha are peatlands. Currently, 57 % of the peatland area is used for agriculture (20 531 ha as arable land, 143 998 ha as permanent grassland) and therefore drained, causing greenhouse gas (GHG) emissions of 4.5 Mt CO_2 per year. This means that drainage-based agricultural use of peatlands is the largest single source of GHG emissions in the federal state of Mecklenburg-West Pomerania. Moreover, the lowering of the water table leads to a large loss of water, exacerbating climate change impacts, in particular droughts.

Climate-friendly, productive wet peatland utilisation is termed 'paludiculture', which ensures that both the productivity of the land and simultaneously the peat are preserved. Through the introduction of paludiculture, emission of up to 3 Mt CO_2e could be avoided annually, and the role of peatlands in the water cycle and the regional climate could be partly restored. Water discharge is buffered, which can reduce the risks of floods as well as droughts, and the higher evapotranspiration has a regional cooling effect. Thus, the restoration of water-saturated conditions by implementing paludiculture combines benefits for climate change mitigation and adaptation. Furthermore, paludiculture revitalises the regulatory functions of natural peatlands, in particular the mitigation of droughts and flood events and regional climate regulation. It also enhances nutrient retention, improving water quality, and has positive effects for biodiversity conservation. Taking all of these aspects into account the federal state Mecklenburg-West Pomerania has developed a technical strategy, for the implementation of paludiculture on agricultural land, recommending 12 actions to support the introduction of paludiculture.

Nature-based solutions evaluated/implemented

In order to preserve the peat layer, the water level has to be close to or above the surface throughout the year to guarantee saturation of the peat body. In addition, regular soil disturbance, e.g. by ploughing or by harvesting below-ground biomass, must be excluded. As alternative land uses, common reed (*Phagmites australis*), bulrush or cattail (*Typha* sp.), peatmoss (*Sphagnum* sp.) and many other crops could be cultivated for biomass production (e.g. for bioenergy and material use) or the sites could be used as wet grasslands. Methodologies to access the ecosystem services of peatland rewetting, in particular the option of issuing carbon credits from peatland restoration for the voluntary carbon market, are summarised by Joosten et al. (2015).

Main results

To date in Mecklenburg-West Pomerania, measures to stabilise the water level have been implemented on more than 26 000 ha. These restoration projects were driven by an interest in nature conservation, and most sites are not used for agriculture anymore. To address the mitigation and adaptation potential, while maintaining agricultural use, the regional government has decided to promote paludiculture. Considering that changing the land use on a large scale can lead to land use conflicts, a cross-sectoral spatial planning process was adopted to avoid undesirable trade-offs. For this purpose, the various types of paludiculture were divided into 'cropping paludiculture' and 'permanent grassland paludiculture', and a paludiculture land classification was developed.

As a result, any type of paludiculture can be carried out on 52 % (85 468 ha) of the peatlands used for agriculture. Depending on an administrative check, both cropping and permanent grassland paludiculture are possible on about 30 % (49 929 ha). On 17 % (28 827 ha), nature conservation restrictions allow only permanent grassland paludiculture. Currently, at one site biomass from wet peatlands is already used in a local heating plant and a pilot project for cultivating bulrush and common reed is running.

Effectiveness of nature-based solutions

The concept of paludiculture set out offers a nature-based solution for extending the agricultural use of peat soils under ongoing climate change. The soil is used as it was naturally formed in a saturated condition. In this way, soil regulatory functions benefiting climate change mitigation and adaptation are restored.

Innovativeness

In paludiculture, the drainage of peatlands is no longer needed. The innovative approach of wet agriculture preserves the soil carbon storage capacity (i.e. keeping C in), while the carbon taken up by the plants is used as agricultural goods (i.e. getting C out) and, ideally, a part of the carbon is removed from the atmosphere by peat formation (i.e. getting C in). Biomass produced from paludiculture can be used, for example, for local bioenergy production, and carbon credits can be generated based on the emissions avoided by peatland restoration.

Transferability of results

Worldwide emissions from drained peatlands and peat fires account for about 2 Gt CO_2e per year, which is equivalent to approximately 5 % of the total global anthropogenic emissions. In Germany, more than 90 % of the peatlands are drained. They account for 7 % of the agricultural land and cause 37 % of agricultural GHG emissions. Across the EU, drained peatlands comprise 2.5 % of agricultural land but are responsible for 25 % of agricultural GHG emissions (Tanneberger et al., 2020). Restoring peatlands and implementing paludiculture would therefore benefit both mitigation and adaptation to climate change and bring benefits for nature and people.

Lessons learned

As it is still associated with many risks and uncertainties for farmers, a large-scale transition to paludiculture is only feasible if the innovative wet use of peatland is eligible for payments under the EU common agricultural policy. Furthermore, a participatory planning procedure at national and local levels is recommended to avoid land use conflicts. Lastly, guidance and strategies for climate-friendly uses of wet peatland have to be developed to enhance implementation.

A4.7 Blue-green corridors case (Belgrade, Serbia): mitigating natural hazards and restoration of urbanised areas

Website

http://spatium.rs/index.php/home/article/view/99

Status

Ongoing since 10 years ago.

Contact person

Boris Radi**ć** (University of Belgrade).

Site description and societal challenges addressed

Belgrade, a city with almost 2 million inhabitants, covers a territory of 3 500 km^2. Increased soil sealing at the expense of forest vegetation and unsuitable agricultural measures have caused intense erosion and more frequent severe floods. The former surface run-off with a return period of 100 years (33.8 m^3/s probability of occurrence in 100 years) has become close to a return period of only 20 years. Several years of efforts by landscape planners to address this problem led to the adoption of the 'General regulation plan of Belgrade green urban areas' in 2019. This plan proposed to integrate basin management and their revitalisation as blue-green corridors, based on the specific landscape characteristics of the Belgrade region. At the national level, policies also push towards creating green infrastructure to connect the natural and cultural value of urban settlements, peri-urban mosaics and rural areas in the form of blue-green corridors in the previous spatial plan (2010-2020) and in the new spatial plan of the Republic of Serbia, which is currently in the adoption phase.

Nature-based solutions evaluated/implemented

The following NbS measures have been evaluated (Ristić et al., 2013): (1) increasing the current forest cover by 22 % to 7.62 ha; (2) reducing agricultural land use and converting to organic farming; (3) afforestation on degraded arable land with steep slopes; (4) re-grassing of degraded meadows; (5) establishing orchards on terraces and in gardens instead of on abandoned plough land; (6) protective forest belts along stream beds; (7) bans on clear-cutting; (8) bans on cutting on steep slopes; (9) bans on straight row farming down the slope; and (10) stopping uncontrolled urbanisation.

Main results

The restoration of blue-green corridors in Belgrade could have significant positive effects on the following:

- preventing or reducing the risk of torrential floods and destructive erosion processes;
- bringing people back into the city space and increasing sports and recreational facilities: 10 km of sealed walking and cycling paths, 1.7 km of unsealed forest paths, six open gyms and seven rest areas for sports and recreation;
- conserving and protecting biodiversity and helping protect and control the use of the natural and cultural value of the area, including a rare example of geodiversity (phonolite rocks), an area for birdwatching (40 bird species) and a Neolithic settlement;
- mitigating the effects of climate change (CO_2 sequestration, O_2 emission, reduced heat island effect).

Effectiveness of nature-based solutions

According to our modelling of the NbS measures evaluated, restoring blue-green corridors in the experimental watersheds of several urban watersheds (Kaljavi, Jelezovac, Rakovicki, Pariguz and Precica streams) will decrease the values of maximal discharges (p = 1 %) by about 50 %, and the volumes of direct run-off by about 40 % (Figure A4.2). The production and transport of eroded material will also be decreased by about 40 %.

Innovativeness

The city has applied a holistic approach to countering erosion processes and torrential floods, backed by research and models in ecological engineering and landscape planning, which recommend combining changes in agricultural practices, reductions in the area of farmland, reforestation, and regulating and banning unsustainable land use practices.

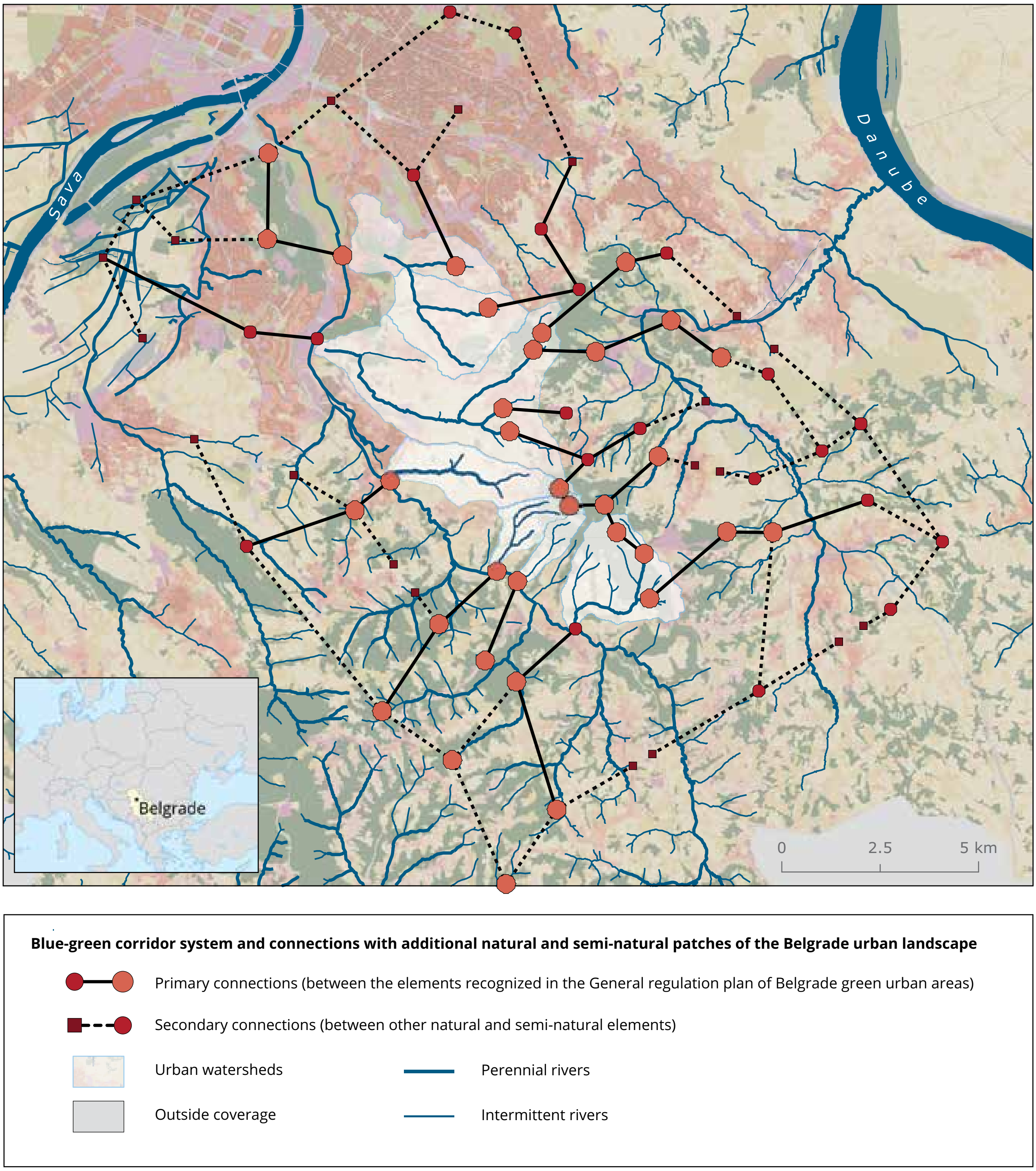
Transferability of results

The approach is transferable to most urban settings restoring and connecting blue-green infrastructure and changing land use practices to avoid environmental degradation and hazards.

Lessons learned

The Kaljavi and Jelezovac and other treated streams are located in the southern part of the Belgrade metropolitan area. Since the 1990s, land has been organised in many small private parcels with many different owners. The process of splitting the land was not synchronised with the cadastre resulting in virtual parcels with 10-20 owners. This has posed a real obstacle to implementing NbS measures. Generally, it has proven difficult to reserve space for implementing NbS measures in the light of rapid changes in the urban matrix. Investors in urbanisation have also not had sufficient understanding of the implementation of NbS. However, the city is currently making progress in the north.

Figure A4.2 **Blue-green corridor system and connection with other natural and semi-natural patches of the Belgrade urban landscape**



Source: © Boris Radić.

A4.8 Green roof case (Hamburg, Germany): combining regulation, dialogue, incentives and science

Website

https://www.hamburg.de/information-in-english

Status

Ongoing since 2014.

Contact person

Hanna Bornholdt (Freie und Hansestadt Hamburg).

Site description and societal challenges addressed

Hamburg, the second largest city in Germany, is home to 1.8 million people and expanding. Temperatures in the city are significantly higher today than 60 years ago and are projected to rise by on average from 2.8 °C to 4.7 °C by the end of the century. The urban heat island (UHI) effect is thought to add up an additional 5 °C to the average temperature increase in Hamburg. In addition, the distribution of rainfall is estimated to change significantly with more extreme weather events. The growing number of residents drives the need for additional housing, which exacerbates the climate impacts of excessive heat and flooding in Hamburg and the number of people affected. By promoting green roofs, the city aims to encourage space-efficient leisure areas, improve the city's rainwater retention capacity, increase biodiversity and reduce extreme temperature effects.

Nature-based solutions evaluated/implemented

Green roofs can provide part of a solution to the projected climate change impacts by mitigating increased temperatures (cooling the surroundings and increasing humidity), mitigating extreme rainfall events through water retention and evapotranspiration and insulating buildings (cooling in summer, insulating in winter), saving energy use in buildings. The goal has been up to 2019 to plant a total of 100 ha of green roofs in the metropolitan area and notably to have 20 % of green roofs on new buildings made available to residents or employees for recreation (sports fields, parks, community gardens).

Main results

Since 2014, 30 ha of green roofs have been implemented, reaching a total of 154 ha in the metropolitan area, of which 39 % is on housing, 35 % on industrial and business premises and 25 % on other buildings. Predominantly new buildings (75 %) have been installed with green roofs. The large area of underground car parks, which make intensive use of green roofs, is not included in the 154 ha. In addition, 20 ha of vegetation is planned on the lid of the A7 motorway passing through Hamburg, and another 1.85 ha on the Schnelsen motorway lid is under construction. Currently, there are 10 000 planning and building permissions for housing units processed every year and most of those with green roofs are under way.

New buildings and garages that impact nature and landscapes need to be compensated for, according to the German building law code and the Federal Nature Conservation Act. The installation of green roofs on the site can contribute to the required compensation and is a key driver in expanding green roofs. Furthermore, the city of Hamburg requires the installation of green roofs in new local plans but has so far not been able to alter the regulation of existing, 'old' local plans. For those areas, the Hamburg green roof programme offers an incentive. Since 2014 the programme has granted support for 6.25 ha of green roofs, of which 1 ha is intensive green roofs. The programme has been extended until 2024 and since 1 June 2020 also includes financial and practical support for green facades. The total city budget for green roofs over the period is EUR 3 million and another EUR 0.5 million for green facades. At least EUR 13.5 million has been invested in green roofs in Hamburg over the past 6 years, of which EUR 1.5 million is public funding.

Effectiveness of nature-based solutions

Tests of the retention capacity of four different types of green roofs were carried out on 220 m^2 and compared with a traditional gravel roof on three neighbouring apartment blocks in Am Weissenberge in Hamburg. The green roofs were fitted with rainwater storage below the substrate level combined with a throttle to allow increased retention and delayed release of water from the roofs, particularly useful during extreme precipitation events. Over 12 months, the green roofs reduced run-off by between 100 % and 76 % compared with 13 % for the gravel roof. A one in 8 years event that lasted for 2 hours led to practically no run-off during the event and the green roofs were able to retain the water during the following 24 hours (Richter and Dickhaut, 2019). Comparative studies of the life cycle costs of green roofs and black tar roofs in Hamburg have shown that the costs balance out after 40 years (Dickhaut et al., 2017). The study only included costs and not welfare benefits such as water retention impacts on the wider urban area, UHI reduction and aesthetics. A green roof can be 30 °C cooler than a conventional roof on a hot summer day. Hamburg is looking into quantifying the impacts of other benefits of green roofs, notably UHI reduction. The extreme warm temperatures of recent years have increased interest in gathering evidence for the multiple benefits of green roofs and green facades.

Innovativeness

Hamburg is the first German city to have developed a comprehensive green roof strategy. The green roof policy was based on four pillars: financial incentives, dialogue, regulation and science. Hamburg is working across departments and with the housing industry to make green roofs and green facades compulsory by law, but it is facing opposition from a political objective to increase affordable housing and an industry reluctant to accept further regulation. Since 2018, the standard green roof has been regulated at 12 cm substrate thickness for housing and offices, while green roofs on large industrial buildings 8 mm substrate thickness as a minimum. The city regularly reviews its green roof legislation in collaboration with stakeholders, in particular with regard to the ecological quality standards of the roofs.

The city took a systemic approach and has used a lot of NbS quality indicators and regulation, focusing on the surface and thickness of the green roofs instead of their water retention capacity (the traditional approach in other cities). This approach fosters roof solutions with a higher degree of multifunctionality. The city provides professional and practical guidance, using the latest science, to illustrate and communicate the benefits of green roofs.

Transferability of results

An evaluation of the instruments and processes initiated through the Hamburg green roof strategy shows that they are useful, practical and transferable building blocks for implementing green roof strategies in other cities (Richter and Dickhaut, 2018). The green roof strategy was supported by the federal government as a lighthouse project in the German climate adaptation strategy. The green roof strategy has also been included in the future-proof toolkit of the European Green Capital Network (a toolkit intended to share best practice). Hamburg is part of the Horizon 2020 project CLEVER Cities ([15]) and is one of three front-runner cities.

Lessons learned

- Communication and dialogue/involvement is key to changing practices and creating a demand for green roofs among residents and companies. This requires a dedicated full-time communication officer and structured co-creation processes. Co-creation was formalised in a stakeholder group consisting of housing estate companies, construction firms, landscape architects and urban planners. The group took part in dialogue with other cities, co-designed the incentive programme and continue to meet to evaluate of the green roof strategy biannually.
- The combination of regulation, dialogue, financial incentives and scientific advice and evaluation is key to successful urban NbS implementation.
- The green roof financial support programme is, in combination with public relations and dialogue, the most important feature in creating awareness. The main driving force for expanding green roofs in Hamburg is the demand for greening buildings with vegetation.
- There is still a considerable need to gather evidence for the effectiveness of green roofs, e.g. for water retention and temperature reduction. The lack of evidence means that the impact of green roofs is currently not recognised in the DIN norms for retaining and slowing down run-off from buildings.
- The objective of creating affordable housing is perceived by the housing sector to be at odds with green roofs, despite the evidence showing no life cycle increases in costs.
- The disservices of green roofs — e.g. the case of 2 500 pairs of seagulls breeding on a 7 ha green roof during spring or an increased hatch of insects — necessitate a lot of dialogue and awareness raising.

A4.9 Ugento case (Italy): using beached leaves of Posidonia (seagrass) to protect dunes

Website

https://www.interregtriton.eu

Status

Ongoing (2018-2020).

Contact person

Michela Cariglia (blue economy expert — ARTI Puglia adviser).

Site description and societal challenges addressed

The artificial channels in Ugento have been blocked by the leaves of *Posidonia oceanica* (the seagrass Mediterranean tapeweed) that beach along the Ugento coast. Approximately 35 000 m^3 of leaf biomass is estimated to accumulate in the mouths of the channels each year. The basins and canals receive an increasing nutrient load associated with agriculture and tourism in the surrounding area and are subject to eutrophication due to being blocked by *Posidonia* remains. The coastal area where

([15]) https://clevercities.eu

Posidonia remains accumulate is a low sandy coast. The beaches are bordered by a dune cordon, which has partly degraded as a result of natural and anthropogenic causes.

Nature-based solutions evaluated/implemented

The beached leaves of *Posidonia* from the mouths of the channels (Torre San Giovanni and Torre Mozza) are used to reconstitute and protect dune cords that have degraded. *Posidonia* leaves control erosion, restore typical dune vegetation and provide habitat for a variety of organisms. The changes in the dunes will be monitored through phytosociological surveys.

Main results

The reuse of the *Posidonia* leaf accumulations for reconstituting the dune cordons allows the beaches to be preserved in the wintertime and ensures the maintenance of the main local economic activity in summertime. Furthermore, in this way, it is possible to avoid perpetrating the old practice of disposing of very large quantities of material in landfill, saving unnecessary costs and reducing the waste impact. Incorporating these solutions into a rigorous legislative framework of activities necessary for the movement of the biomass appears to be a strategy for enhancing the ecological role of *Posidonia* leaves in avoiding or minimising any form of impact on the surrounding environment.

Effectiveness of nature-based solutions

Innovative methods for transporting the *Posidonia* leaves were developed between 2007 and 2013 along the shores of Ugento park. These integrated coastal management practices are able to maintain the physical and ecological processes regulating the morphology of the coast. This is important for maintaining tourism in the area.

Innovativeness

According to the current reference legislation for the management of *Posidonia* leaves, the biomass is considered urban solid waste. Using the biomass in the integrated management of the coastal environment has been recognised as an alternative to waste management. Managing the *Posidonia* accumulations in this way enables sand dunes at the beach to be reconstituted in the winter, promoting the main local economic activity in the summer and minimising the quantity of waste disposed in landfill.

Transferability of results

The results and methodologies defined in Ugento as 'coastal design thinking' are transferable in similar situations with low sandy coasts with dunes and *Posidonia* accumulations. The integrated local framework allows reuse practices to be extended by using plant biomass derived from the seagrass leaves. The paradigm is based on 'reuse-depollute-prevent coastal erosion-remodel the dunes' through the circular integration of natural waste along the shoreline.

Lessons learned

Ugento's model demonstrates the possibility of managing and preventing coastal erosion along a low sandy coast characterised by the presence of dunes and *P. oceanica*. It combines methodologies from manual collection of the waste on the dunes to monitoring the impact of erosion by satellite and planning for long-term coastal management. Social awareness is a key factor in preventing erosion by reusing biomass, as is the constant application of information from biomaterial science to the re-creation of the dunes.

A4.10 Hermes case (Albania, Bulgaria, Cyprus, Greece): a harmonised framework to mitigate coastal erosion

Website

http://www.interreg-balkanmed.eu/approved-project/18

Status

Complete (2017-2020).

Contact person

Georgios Sylaios (Democritus University of Thrace).

Site description and societal challenges addressed

Coastal erosion and sea level rise are some of the fast-growing environmental concerns faced by coastal communities. In Greece almost 30 % of coasts are eroding or are vulnerable to erosion. In Cyprus this percentage reaches 38 %. In Bulgaria almost 71 % of Black Sea beaches are eroding, while in Albania, a country with a 420 km long shoreline, coastal erosion is a significant issue for the northern and central parts. Hermes aims to develop a unified and harmonised framework for coastal erosion mitigation and beach restoration covering the four partner countries (Albania, Bulgaria, Cyprus, Greece) through the implementation of a coherent ensemble of studies, the sharing of already developed technical tools and the design of joint policy instruments at the local scale.

Nature-based solutions evaluated/implemented

Hermes focuses on developing a unified methodological framework, including a series of forecasting models, software tools and indicators, as well as the deployment of online monitoring systems, which can support the identification of locations where local authorities need to design and implement erosion mitigation measures. In addition, environmentally friendly technical works for coastal restoration are extensively studied, implemented and evaluated (e.g. sand fences, beach nourishment and geotube installation).

Main results

Hermes focuses on methodological development, monitoring and use of shared data. The project also analyses coastal erosion trends and identifies coastal erosion 'hotspots' using historical satellite and Google Earth images; evaluates erosion and climate change vulnerability indicators and assesses the relative influence of human interventions (e.g. river damming, illegal sand mining, uncontrolled urbanisation, ports); and integrates environmental and socio-economic data into a coastal web-based geographical information system (GIS). The deployment and operation of four oceanographic stations at pilot sites in Albania, Bulgaria, Cyprus and Greece provides a constant stream of data and information to local stakeholders and the broader oceanographic community. The result is to trigger a process that engages all involved parties at the local scale to seek environmentally friendly technical solutions to complex, fundamental challenges that can combine cost-effectiveness and sustainable development.

Effectiveness of nature-based solutions

The effectiveness of NbS depends crucially on the quality of their design and implementation. The methodology and monitoring system developed in the Hermes project produces data and information that promotes the identification of suitable sites for NbS and their technical design. As part of Hermes, three NbS actions were implemented along the Paggaion municipality (northern Greece) shoreline:

- the study and installation of sand fences along the Ammolofi sand dunes, aiming to protect them from eolian and coastal erosion;
- the study of a geotube system, acting as an offshore submerged breakwater, to be positioned along the eroded western part of a small marina;
- the study of a small beach nourishment project to restore the beach to the level before the construction of the marina.

As several permits are required before implementing the last two points, these NbS will be carried out after the end of Hermes project.

Innovativeness

The innovative features of the project are the joint coastal framework, including a novel modelling toolkit coupling meteorological, hydrodynamic, wave and morphodynamic models. The Hermes methodological framework blended data provided from external Earth observing systems (e.g. the US National Oceanic and Atmospheric Administration, Copernicus Marine Environment Monitoring Service, the European Marine Observation and Data Network) and locally collected data (from oceanographic buoys and local studies) with short-term operational forecasts (meteorological, hydrodynamic, wave and morphodynamic) and long-term climate change scenarios (Figure A4.3). This knowledge led to the best design for appropriate measures to mitigate coastal erosion and climate change impacts, while applying and promoting NbS and related techniques.

Transferability of results

The methodological framework of Hermes could be expanded to any Mediterranean/Black Sea shoreline, for example to assess the historical level of coastal erosion, to evaluate the vulnerability of coastal areas to erosion and climate change, or to monitor and model the open sea to nearshore processes.

Lessons learned

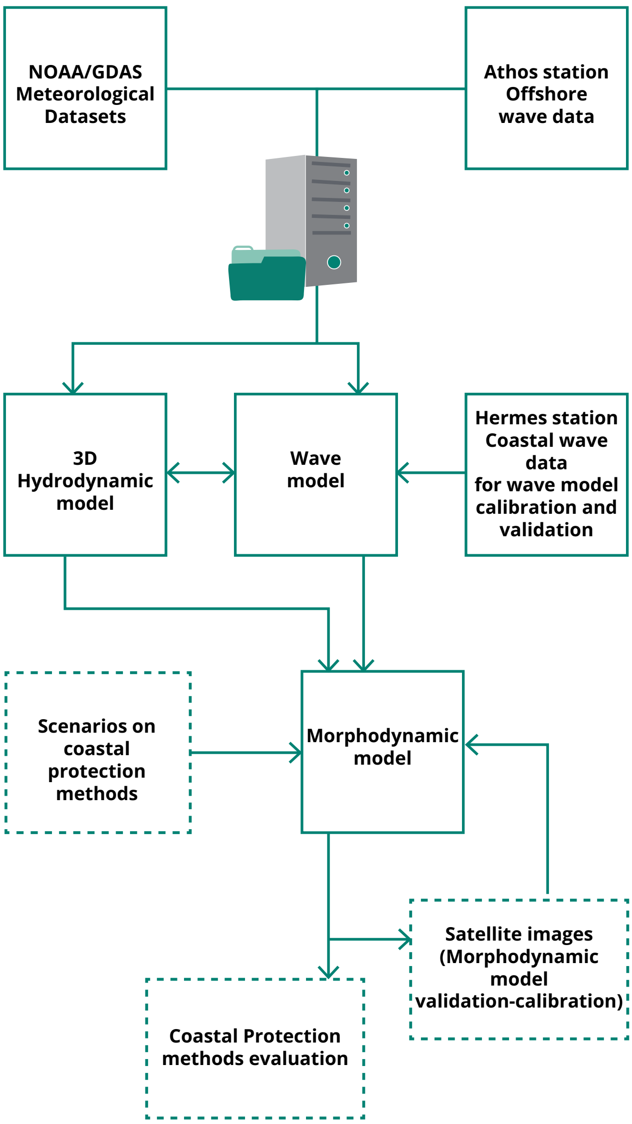
Good and reliable data and sound scientific knowledge are central to designing appropriate measures to mitigate coastal erosion and climate change impacts, while applying and promoting NbS and related techniques. Hermes is an ambitious project and is expected to:

- aid coastal stakeholders to harmonise and adapt to the most relevant EU policies on coastal zones;
- upgrade the current level of research and innovation in the field of coastal sustainable development, protection and adaptation;
- enhance responses to challenges driven by climate change; and

- sustainably use strategic coastal resources to achieve blue coastal growth.

Hermes has successfully aided coastal stakeholders to harmonise and adapt to the most relevant EU policies on coastal zones, such as climate change, integrated maritime policy, maritime spatial planning, the integrated coastal zone management protocol, marine strategy, the Water Framework Directives and the Inspire Directive. Transnational territorial cooperation is an approach uniquely positioned to develop solutions that tap into an extremely diverse and solid body of knowledge and experience and bring the benefits of tested innovations to local communities that otherwise would probably not have access to them.

Figure A4.3 An indicative model chain to be developed and applied at all Hermes study sites



Source: Sylaios (2018).

A4.11 Terracing in mountains (France and Spain): preventing landslides with old techniques

Website

https://phusicos.eu

Status

Ongoing (2019-2022).

Contact person

Anders Solheim (Norwegian Technical Geotechnical Institute, NGI).

Site description and societal challenges addressed

Extreme precipitation has led to increased risks of flooding, rockfalls, landslides, debris flows and snow avalanches across various landscapes in more than 10 000 km^2 of hydrological basins in the Pyrenees. This has resulted in damage to agricultural land, infrastructure and urban areas. The objective of this case study is to propose, test, set up and monitor NbS to reduce these hazards. In some cases, revegetation/reforestation has demonstrated its usefulness for coping with hydroclimatic extreme events by reducing the hazard's intensity. However, this positive impact is very localised, and more importantly it does not include the broader implications of the socio-economic impact of land abandonment and reduction in the size of pastures. Demonstrations and monitoring of reforestation in relevant environments are needed to understand the implications of plant species, drainage systems and agro-pastoral practices.

Nature-based solutions evaluated/implemented

The consortium Working Community of the Pyrenees (CTP) is reaching out to local communities in these vulnerable natural areas to engage them in dialogue to co-design strategies, funding schemes, monitoring systems, services and policies related to various NbS. Proposed demonstrations will be realised in collaboration with and co-funded by two regional organisations, the French National Forest Office and the European Grouping of Territorial Cooperation (EGTC) Space Portalet. One of the goals is to propose land use changes and the use of local, natural materials as tools for stabilising slopes and preventing the release and run-out of rockfalls and snow avalanches, with the support of local communities. In particular, vegetation types that have decreased the risk of landslides, rockfalls or snow avalanches in the past will be proposed as new NbS.

Main results

The measures are not yet implemented. The old NbS carried out around 1915 consisted of terracing with dry walls and reforesting the Torrent de Arriatiecho, Biescas in Spain (Image A4.1). Torrents and debris flows were frequent before that but have not happened since the measures were implemented. Today, the measures are invisible from a distance and the slope is completely forested.

Effectiveness of nature-based solutions

The effectiveness of the measures will be monitored using a comprehensive framework of weighted indicators as input to multi-criteria analysis. The analyses cover all aspects of the NbS: not only their effectiveness in reducing risks but also their effect on the ecology and biodiversity of the area, the inhabitants' well-being and perception of NbS as a viable risk reducing measure, etc. Some of the measures, which include terracing and revegetation, are in fact 're-inventing' old techniques that have been partly forgotten.

Innovativeness

The NbS identified will be specified and described so that they can be implemented by local small and medium-sized enterprises. With successful implementation and thereafter further upscaling, this should boost the market for risk reduction in mountainous areas. This knowledge transfer will ensure (1) the appropriateness of the technical aspects, (2) the development of operational tools for risk assessment and monitoring of the related impacts of the NbS, and (3) collaboration between private and public stakeholders to operate the NbS.

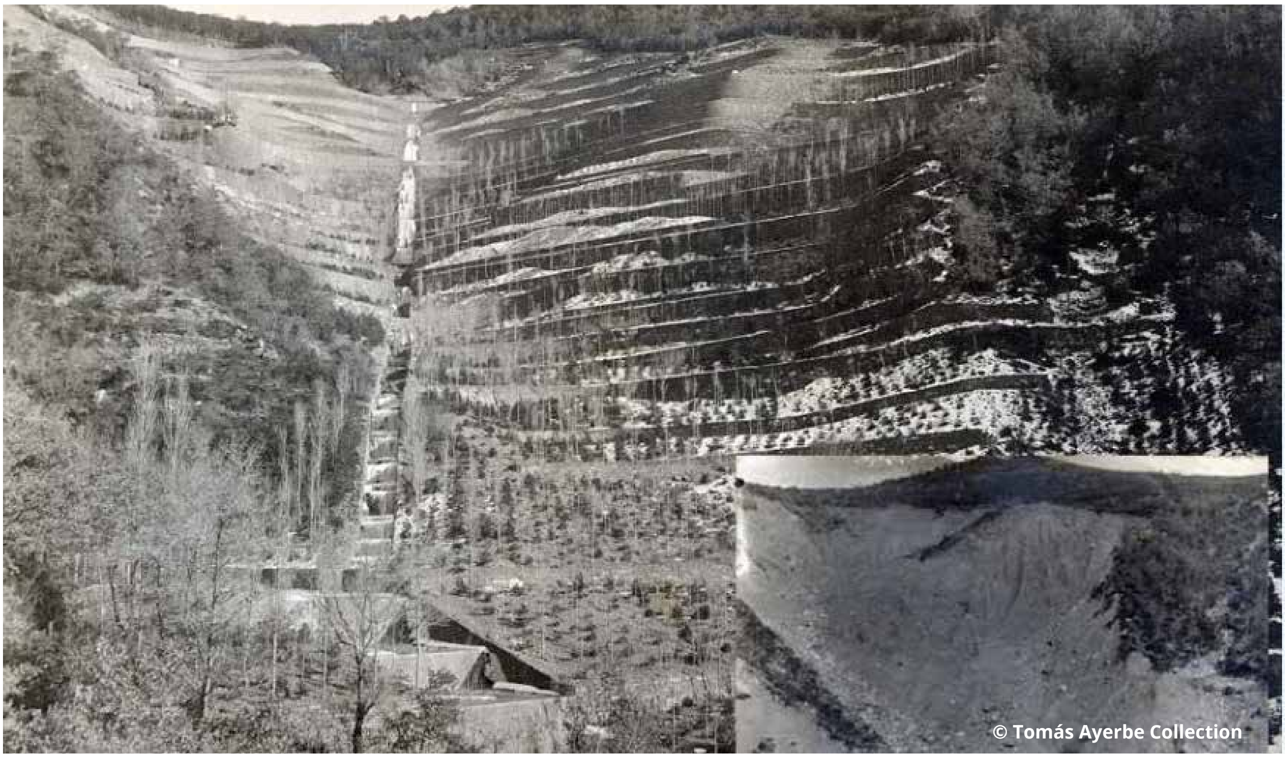
Transferability of results

Analysis of NbS will identify changes in the susceptibility to natural hazards affecting the whole Pyrenees range, conditioned by agro-pastoral and other NbS changes. Service and workflow development is transferable to other mountainous regions in Europe, such as the Alps and Massif Central.

Lessons learned

The implementation of the NbS is not yet complete. The lessons learned in the pre-implementation phase are as follows: (1) perform a thorough assessment of the benefits of NbS versus traditional 'grey' solutions; (2) create 'ownership' of the measures by involving stakeholders in a co-creation process; (3) address the need for detailed planning that includes all administrative levels and all stakeholder groups and (4) start the procurement process as early as possible and be prepared for delays.

Image A4.1 **State of the headwaters of the Arratiecho ravine around 1902-04, before work began to terrace the slopes with dry walls and reforestation (small photo). Appearance of the headwaters of the Arratiecho completely corrected and restored around 1915 (large photo).**



Note: The extreme erosion of a large part of the catchment area can be seen in this photo (small photo)

Annex 5
Knowledge platforms addressing nature-based solutions for climate change adaptation and disaster risk reduction at European and national levels

A5.1 Introduction

The term 'knowledge adaptation platform' refers to a comprehensive resource for decision-makers with the data, tools, guidance and information needed to adapt to a changing climate (Palutikof et al., 2019). Adaptation platforms have a range of functionalities, such as decision support tools to facilitate the decision-making process, components for capacity building, networking, dissemination and other features to assist adaptation planning and implementation. Commonly, knowledge adaptation platforms are online resources and are known as either 'web portals' or 'web-based knowledge portals'.

The knowledge platforms addressing the umbrella concept of nature-based solutions (NbS) for climate change adaptation (CCA) and disaster risk reduction (DRR) and the approaches it encompasses — ecosystem approach (EA) and ecosystem-based approach (EbAp), green infrastructure (GI) and blue-green infrastructure (BGI), ecosystem-based adaptation (EbA), ecosystem-based DRR (Eco-DRR), natural water retention measures (NWRMs), sustainable management (SM) and ecosystem-based management (EbM), as defined in Chapter 1 — have a valuable role to play as an interface for enhancing knowledge exchange between science, policy and practice, to promote the further development of NbS or some particular stages of the CCA or DRR policy cycles, and to scale up and step up the implementation of NbS.

Depending on the specific scope of each platform (political mandate, target audience, sector focus, funding model, etc.), they can have prominent or minor roles in the whole process, ranging from the provision of an overarching key component in the framing of CCA or DRR strategies (e.g. a decision support tool) to contributing specific input to the implementation of practical actions (e.g. with inspiring case studies).

Similarly, depending on the above-mentioned features and on the platform's main aims, these web portals contribute to different extents to sharing exemplary and/or innovative insights on how NbS can address a range of core societal challenges (as defined in Chapter 1, Table 1.1): improving society's resilience to extreme weather- and climate-related events (CSC1); food security, sustainable agriculture and forestry (CSC2); preserving habitat, reducing biodiversity loss and increasing green and blue spaces (CSC3); water management (CSC4); social justice, cohesion and equity and reducing the risks for groups of society highly vulnerable to climate change (CSC5); public health and well-being (related to climate change impacts) (CSC6); and making cities and human settlements inclusive, safe, resilient and sustainable (CSC7).

There is a variety of global platforms and partnerships supporting NbS uptake, and Box A5.1 offers some outstanding examples of them; this annex, however, focuses on the European level.

A5.1.1 Criteria for selecting the knowledge platforms

The landscape of CCA and DRR platforms in Europe is wide, various and rapidly evolving. These web-based knowledge portals have different underlying frameworks, purposes and objectives that are reflected in the range of contents they encompass and in the products and services they provide (EEA, 2018b). Opportunities for increasing the consistency and complementarity of the knowledge thus shared have already been identified (EEA, 2017a).

In this landscape we reviewed the most commonly known knowledge platforms in the research and practice community addressing themes related to NbS for CCA or DRR and contributing to solving the core societal challenges (as defined in Chapter 1).

To draw some meaningful considerations and comparisons, we selected those platforms meeting all or most of the following criteria:

- The platform has a European scope or a good European coverage and focuses on knowledge directly related to NbS and related approaches.
- The platform has a political mandate (directly refers to a legal instrument or provides a direct contribution to a policy regulation) related to CCA and/or DRR or aims to support policymaking and development and is maintained and operated by an official institution.
- The platform is operative and up to date. If developed by a research project or initiative, the platform is more than a project/initiative website and has the (potential) guarantee to continue beyond the project's end and to be continuously updated.

A5.2 Overview of relevant platforms

A5.2.1 European level

This section provides a short overview of 12 platforms — BISE, Climatescan, Climate-ADAPT, DRMKC, Natural Hazards — Nature Based Solutions platform, Nature-based Solutions Initiative, Naturvation Urban Nature Atlas, NWRM, OPPLA, Panorama, ThinkNature and weADAPT — that were selected according to the above criteria. The descriptions focus on what main NbS concepts/approaches and core societal challenges the platforms deal with, as well as highlighting whether the platforms specifically address CCA or DRR in some particular sectors. The information reported was inferred from screening the platforms themselves ([16]), and then validated by the platform managers ([17]).

Furthermore, a 'mapping' exercise offers a summary (through tables and graphs) of some of the main general features of the selected platforms and illustrates how their contents cover the NbS approaches and the core societal challenges that are relevant to the present report.

BISE

The Biodiversity Information System for Europe (BISE) is a web portal for data and information on biodiversity, strengthening the knowledge base in support to the implementation of the EU biodiversity strategy and the Convention on Biological Diversity (CBD) Aichi biodiversity targets (BISE, 2020).

BISE refers to GI and NbS as ways to protect natural capital and strengthen the functionality of ecosystems for delivering goods and services. The platform includes information on CCA and the ecosystem services related to climate and natural hazard regulation, and it has a specific section on GI with information on the EU policy framework, definitions and links to key publications and networks. Furthermore, the BISE country pages include an overview of national activities on GI undertaken by EU Member States.

BISE contributes to the core societal challenge on preserving habitat, reducing biodiversity loss and increasing green and blue spaces (CSC3), gathering references, information and resources related to the status of and threats to biodiversity and ecosystems in Europe, responses and solutions. In addition, the content in BISE is relevant to addressing societal challenges on resilience to climate change (CSC1, improving society's resilience to extreme weather- and climate-related events) and on sustainable management of terrestrial ecosystems (CSC2, food security, sustainable agriculture and forestry).

([16]) Last visit to the platforms was in June 2020.
([17]) Except for NWRM and OPPLA.

Box A5.1 EGlobal platforms and partnership relevant for supporting the uptake of nature-based solutions

Global Platform for Disaster Risk Reduction

The Global Platform for Disaster Risk Reduction (GPDRR) was first convened in 2007 and is a biennial multi-stakeholder forum established by the United Nations General Assembly to assess and review progress in the implementation of the global disaster risk reduction agenda, and to serve as a platform for governments and stakeholders to share good practice, identify gaps and make recommendations to further accelerate implementation.

The GPDRR is a critical component of the monitoring and implementation processes of the Sendai Framework for Disaster Risk Reduction (SFDRR 2015-2030). These efforts contribute towards the successful achievement of a risk-informed 2030 agenda for sustainable development. In 2017 at the fifth session of the GPDRR, the *Cancun high-level communiqué* stressed the close link between climate change and water-related hazards and disasters and highlighted integrated water resources management (IWRM) as an effective instrument for enhancing resilience and serving both disaster risk reduction (DRR) and climate change adaptation goals (GPDRR, 2017).

In 2019 at the sixth Session of the GPDRR (GP2019) the Parties adopted a Co-chairs' summary of the event (GPDRR, 2019). This summary includes recommendations for a mid-term review of the SFDRR, and for DRR to be fully integrated in the implementation of the Sustainable Development Goals (including developing disaster-resilient infrastructure through ecosystem-based approaches that leverage the complementarity across blue, green and grey infrastructure and adopting nature-based solutions, NbS).

Partnership for Environment and Disaster Risk Reduction

The Partnership for Environment and Disaster Risk Reduction (PEDRR), established in 2008, is a global thematic platform of the United Nations Office for Disaster Risk Reduction and aims to promote and scale up the implementation of NbS for DRR and to ensure that it is mainstreamed in development planning at global, national and local levels, in line with the SFDRR. This is conducted through the organisation of courses and workshops and the production of syntheses of the current and future challenges for NbS for DRR.

The Fourth International Science-Policy Workshop organised by PEDRR (12 - 14 February 2019) in Bonn (Germany) provided an update on the science-policy issues and gaps on ecosystem-based DRR and adaptation and highlighted how to improve mainstreaming and use of ecosystem-based approaches in the context of sustainable development. Finally, it also reviewed the activities performed by PEDRR since its inception and elaborated on PEDRR's vision for the next decade.

Friends of Ecosystem-based Adaptation

Friends of Ecosystem-based Adaptation (FEBA) is an international network that was created in 2015 and is hosted by the International Union for the Conservation of Nature (IUCN). The network includes experts from science, policy and practice and aims to share knowledge and practical experience on the effective design and implementation of ecosystem-based approaches to adaptation. For this purpose, FEBA has developed guidelines on the effective design and implementation of NbS and ecosystem-based approaches and provides policy advice to the United Nations Framework Convention on Climate Change, the Convention on Biological Diversity and other policy processes.

Climatescan

Climatescan is an interactive web-based map application for knowledge exchange on (over 5 000) 'blue-green' projects mostly on urban resilience, climate-proofing and CCA around the globe, with a good European coverage (Climatescan, 2020).

It involves over a thousand registered (public and private) participants around the world coordinated by the Hanze University of Applied Sciences (Netherlands). Most contributors upload their projects in Climatecafes (Climatecafe.nl): an international field education concept involving various fields of science and practice for capacity building in CCA. Climatescan has no policy mandate or direct link to a policy regulation; however, it does work with the Dutch national government to find solutions on CCA. The showcased practical local initiatives (called 'projects' in the portal) cover all the approaches of NbS for CCA and DRR. The projects are classified by (seven) sectoral focus topics (water, people, nature-biodiversity, heat, energy-climate mitigation, urban agriculture and air quality), covering over 20 categories.

Even if not explicitly mentioned on the portal, it can be deduced from the range of topical foci of the platform that its content is relevant to addressing all of the core societal challenges.

Climate-ADAPT

The European Climate Adaptation Platform (Climate-ADAPT) is mandated by the EU adaptation strategy to promote better informed decision-making in adapting to climate change. It provides the knowledge base and facilitates knowledge sharing on CCA in Europe at all administrative levels and for all the stages of the adaptation policy cycle (Climate-ADAPT, 2020b).

The platform includes sections on DRR and for ecosystem approaches and ecosystem-based approaches for CCA and DRR, presenting information on the EU policy framework, knowledge base, funding sources and links to relevant resources, as well as complete information on related contents in the Climate-ADAPT database (publications and reports; information portals; guidance documents; tools; research and knowledge projects; adaptation options; case studies; organisations). Overall, Climate-ADAPT covers (to different extents) several NbS approaches: ecosystem approach, ecosystem-based approach, GI/BGI, ecosystem-based adaptation, sustainable/ecosystem-based management and natural water retention measures. The platform considers 14 CCA-relevant sectors, including water management, forestry, agriculture, cities and coastal areas.

The Climate-ADAPT case studies deserve a special mention: they are a type of database item with a comprehensive structure, describing all the key implementation aspects of real adaptation measures. They are specifically developed for the platform with the support of the organisations responsible for the measure's implementation. The case studies in Climate-ADAPT include illustrative examples of how NbS are applied in Europe.

The content in Climate-ADAPT is particularly relevant to addressing the societal challenges on resilience to climate change (CSC1, improving society's resilience to extreme weather- and climate-related events), on climate change impacts on health and well-being (CSC6) and on reducing risk for groups of society highly vulnerable to climate change (CSC5), but they also can make a significant contribution to solving the rest of the core societal challenges.

DRMKC

The European Commission Disaster Risk Management Knowledge Centre (DRMKC) provides knowledge and evidence at all levels and at all stages of the disaster risk management cycle (prevention, reduction, preparedness, response and recovery), including those disasters associated with climate and so considering CCA (DRMKC, 2020). The DRMKC web platform facilitates information and knowledge sharing between policymakers, practitioners and scientists within and beyond the EU, enhancing the connection between science, operational activities and policy.

The platform gathers around 2 000 relevant research and operational projects in a database with search functions (the Project Explorer), and also maintains a set of web tools such as the Risk Data Hub (a GIS web of EU risk data and methodologies for disaster risk management) and the Gap Explorer (to analyse knowledge, methodologies and technologies available for different hazards). DRMKC promotes ecosystem-based-solutions for the elaboration of disaster risk management plans at national level that are developed on the basis of national risk assessments (ecosystem-based DRR).

The content in DRMKC is particularly relevant to addressing the societal challenges on resilience to extreme weather associated with climate change (CSC1), as it provides information on different hazards including heat waves, river floods, coastal flooding, flash floods, droughts and forest fires, all relevant for water management, forestry, agriculture, cities, coastal areas and other sectors.

Natural Hazards — Nature-based Solutions platform

The Natural Hazards — Nature-based Solutions platform provides hundreds of examples of projects from around the world, with several European cases (Natural Hazards — Nature-based Solutions platform, 2020). It was developed by the World Bank, the Global Facility for Disaster Reduction and Recovery, and Deltares. Its objective is to host and facilitate the exchange of practical guidelines, experience and lessons learned from a range of stakeholders, to provide guidance on the planning and technical implementation of NbS, and to promote these solutions in policymaking and investments in socio-economic development projects.

The NbS projects presented focus on interventions addressing disaster risk management and water resources management challenges to mitigate or adapt to climate change effects or natural hazards (covering CCA and DRR). Here the NbS are intended to cover the full range of approaches using ecosystems to increase resilience, making use of natural processes, and ecosystem services for functional purposes. The types of NbS are categorised into coastal wetlands, coral reefs and living shorelines, dunes and beaches, forests and vegetation, inland wetlands, mangroves, rivers and floodplains, and urban green spaces. The projects presented are completely 'green' (i.e. consisting of only ecosystem elements) or 'hybrid' (i.e. a combination of ecosystem elements and hard engineering approaches).

From the hazard types and benefits of the interventions presented, it can be deduced that the content of the platform is relevant to address all of the core societal challenges considered in this report.

Nature-based Solutions Initiative

The Nature-based Solutions Initiative is an interdisciplinary programme of research, policy advice and education based at the University of Oxford (United Kingdom) focusing on the science, policy and practice of NbS to address global challenges and increase their sustainable implementation (Nature-based Solutions Initiative, 2020).

Its website and associated two global platforms ('Nature-based Solutions Evidence Platform' and 'Nature-based Solutions Policy Platform') bring together evidence from scientific peer-reviewed literature on the effectiveness of investing in nature to deal with a range of climate impacts, including disasters, in support of CCA and DRR.

The interactive evidence map is well populated for Europe, with contents covering the economic, social and environmental dimensions of the most commonly implemented or planned NbS adaptation actions (ecosystem-based adaptation), such as the protection, restoration and/or afforestation of terrestrial forests or woodlands, coastal and marine habitats, and river catchments (including wetland), and it includes case studies.

The content of the platform is relevant to addressing major societal challenges, such as food security, climate change, water security, human health, disaster risk, and social and economic development. Therefore, it can be linked to all of the core societal challenges considered in the present report.

Naturvation Urban Nature Atlas

The Urban Nature Atlas developed by the Horizon 2020 (2017-2020) Nature-based Urban Innovation (Naturvation) project contains a thousand illustrative examples of NbS from about 100 European cities (Naturvation, 2020). The project aimed to assess what NbS can achieve in cities, to show how they respond to urban sustainability challenges by working with communities and stakeholders, and to use this knowledge to inform policy and practice.

The cities featured in the Urban Nature Atlas were selected to ensure appropriate representation of diverse urban conditions and environmental settings and considering their geographical distribution. The solutions, presented through an interactive map, are (either physical or discursive) interventions with 'function-enhancing' features, responding to a range of urban sustainability challenges. Approximately 200 NbS cases aim to address the challenges of CCA in various urban settings: external building greens, grey infrastructure with green features, parks, allotments and community gardens, blue areas, green indoor areas, green areas for water management (GI/BGI) and derelict areas. The Urban Nature Atlas clearly focuses on the urban sector, but it also covers other sectors considered in the report.

All of the above solutions are assessed in relation to the key urban sustainability challenges they address and are explicitly labelled according to the Sustainable Development Goals (SDGs) they are relevant to. Therefore, they can be linked to many core societal challenges, i.e. CSC1 on improving society's resilience to extreme weather- and climate-related events; CSC3 on preserving habitat, reducing biodiversity loss and increasing green and blue spaces; CSC4 on water management; and CSC5 on social justice, cohesion and equity and reducing risk for groups of society highly vulnerable to climate change.

NWRM

The Natural Water Retention Measures (NWRM) platform gathers information at EU level on NbS and GI applied to the water sector (NWRM, 2020). NWRM are widely recognised as nature-based green solutions that contribute to the objectives of the EU green infrastructure strategy and the Water Framework and Flood Directives. The main focus of NWRM actions is to enhance, as well as preserve, the water retention capacity of aquifers, soil and ecosystems with a view to improving their status, with multiple benefits including climate resilience and DRR. The platform contains a catalogue of 53 measures addressing four sectors (agriculture, nature, urban, forestry) and a large number of case studies across Europe, illustrating implementation of these NWRMs and links to impacts, benefits and policy objectives.

Regarding the core societal challenges, the content of the NWRM platform is particularly relevant to address CSC1 (improving society's resilience to extreme weather- and climate-related events) and CSC4 (water management).

OPPLA

The OPPLA platform is the EU repository for NbS (OPPLA, 2020b). It is an information hub capturing and selecting emerging knowledge on NbS and facilitating its sharing to support environmental management. It hosts the results of all EU research and innovation projects on NbS and provides a 'knowledge marketplace, collecting the latest thinking on natural capital, ecosystem services and NbS. The content of the platform is relevant for both CCA and DRR. It includes a wide range of case studies, networking and collaboration tools, and also commercial services. OPPLA's set of case studies aims to facilitate sharing and browsing examples of NbS from around Europe and beyond. The platform includes around 300 case studies covering sectors such as water management, forestry, agriculture, cities and coastal areas.

The target audience of the platform includes science, policy and practice, the public, private and voluntary sectors, large and small organisations, and individuals. Over 60 universities, research institutes, agencies and enterprises contribute to OPPLA as part of a joint activity between the OPERAs and OpenNESS projects, funded by the European Commission's seventh framework programme. The content in OPPLA is relevant to addressing all of the core societal challenges.

Panorama

Panorama — Solutions for a Healthy Planet — is a partnership initiative involving multiple interlinked thematic communities (Panorama, 2020), managed by the IUCN (International Union for Conservation of Nature) and GIZ (Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH). The Panorama web portal documents and promotes (over 600) successfully applied and replicable solutions to conserve or improve the health of biodiversity and ecosystems that have demonstrated positive impacts on nature conservation and/or sustainable development, across a range of regions and sectors around the world, with more than 50 cases located in Europe. These solutions (case studies) may be entire projects or only some aspects/phases/activities of a project. Even without a direct policy mandate, the content of the platform is very relevant (and tagged) for the Aichi targets of the strategic plan for biodiversity 2011-2020 and to several SGDs of the 2030 agenda for sustainable development.

The platform has a section specifically devoted to mainstreaming ecosystem-based adaptation, featuring (more than 130) solutions worldwide, including a dozen examples in Europe. Ecosystem-based adaptation cases are here understood as a subset of NbS, specifically focusing on CCA. The ecosystem types encompassed concern the following sectors: agriculture, desert, forests, marine and coastal, freshwater, grasslands, and the urban and built environment.

They explicitly address climate, ecological, economic and social challenges, covering the whole spectrum of the core societal challenges tackled in this report.

ThinkNature

The ThinkNature platform is a knowledge hub dedicated to NbS that provides access through dynamic map viewers to relevant project web sites, platforms, case studies and other resources on state-of-the-art practice (ThinkNature, 2020). The platform is an output of the Horizon 2020 (2016-2019) project ThinkNature — Development of a multi-stakeholder dialogue platform and think tank — supporting the understanding and promotion of NbS at local, regional, EU and international levels. The NbS featured encompass 'actions inspired by, supported by, or copied from nature that deploy various natural features and processes, are resource efficient and adapted to systems in diverse spatial areas, facing social, environmental, and economic challenges'. The five main goals include both CCA and DRR, and the topics cover ecosystem-based adaptation, ecosystem-based DRR, GI/BGI and sustainable/ecosystem-based management and all the sectors considered in this report.

The types of NbS are also classified according to the global challenges and the SDGs they relate to, including climate change, sustainable energy, food security, and economic and social development. Therefore, it can be deemed that the content of the platform is relevant to all of the core societal challenges considered in this report.

weADAPT

WeADAPT is a global collaborative platform facilitating learning and exchange on CCA among practitioners, researchers and policymakers (weADAPT, 2020).

The content of weADAPT focuses on CCA but is also relevant to DRR due to the intrinsic link between these fields. It has a specific section on disasters and climate change and on ecosystem-based adaptation, including concept description, links to further resources (publications and projects) and links to other initiatives. The section on ecosystem-based adaptation is currently being updated. It is being redesigned to focus on NbS in general and will feature sub-topic areas, including those on landscape and ecosystem restoration, ecosystem-based adaptation, ecosystem-based DRR and nature-based agricultural systems. Overall, the platform also has a database with more than 2 400 items relevant to a wide range of sectors, including water management, forestry, agriculture, cities and coastal areas. These, and the profiles of users registered on the sites, are searchable by filters (including hazard, context and sector). The database also includes adaptation case studies in Europe and worldwide that can also be searched by means of a visualisation feature called the Adaptation layer (map viewer).

The content in weADAPT provides information that contributes to the core societal challenges, in particular those with direct links to climate change impacts (CSC1 on improving society's resilience to extreme weather- and climate-related events, CSC6 on climate change impacts in health and well-being and CSC5 on reducing risk for groups of society highly vulnerable to climate change).

Platform mapping

The following three tables provide a summary overview (mapping) of some of the main features of the selected European platforms, with the aim of facilitating exploring and analysing the information.

Table A5.1 shows their general elements, namely policy relevance/mandate, target audience/intended users, content geographical coverage and governance level and some interesting functionalities and features.

Table A5.2 illustrates their coverage of the NbS topics relevant to this report, taking into account the definitions in Chapter 1 of this report and on Climate-ADAPT [18].

Table A5.3 illustrates their contribution to providing relevant knowledge and potential support for solving the core societal challenges, as defined in Chapter 1, Table 1.1.

Table A5.2 and Table A5.3 are complemented by graphs depicting the occurrence of the topics covered and the core societal challenges addressed, thus assisting the investigation, comparison and identification of common elements in the mapping results.

Table A5.1 Overview of European platforms — general elements

Platform		BISE	Climatescan	Climate-ADAPT	DRMKC	Natural Hazards — Nature-based Solutions platform	Nature-based Solutions Initiative	Naturvation Urban Nature Atlas	NWRM	OPPLA	Panorama	ThinkNature	weADAPT
Policy relevance / mandate													
The platform has a policy mandate or is directly linked to a policy regulation		✓		✓	✓		✓		✓				
Target audience/profile													
Governmental decision-makers (any level)		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Scientists		✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓
Practitioners (implementation)		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Private/business sector			✓		✓	✓	✓			✓	✓		
General public		✓	✓		✓		✓			✓			
Content, geographical coverage and governance level													
Geographical coverage/ governance level	Local		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Regional		✓		✓	✓			✓		✓	✓	✓
	National	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓
	Transnational		✓	✓	✓	✓					✓	✓	✓
	European	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓
	Global		✓		✓	✓	✓				✓	✓	✓
Functionalities and other features													
Capacity building/training (online help, webinars, fora)			✓	✓			✓	✓		✓	✓	✓	✓
Case studies [a]			✓	✓		✓	✓	✓	✓	✓	✓	✓	✓
Communication (newsletter, news, events)		✓	✓	✓	✓		✓	✓		✓	✓	✓	✓

[18] https://climate-adapt.eea.europa.eu/eu-adaptation-policy/sector-policies/ecosystem/document-definitions-ebi-3.pdf

Platform	BISE	Climatescan	Climate-ADAPT	DRMKC	Natural Hazards — Nature-based Solutions platform	Nature-based Solutions Initiative	Naturvation Urban Nature Atlas	NWRM	OPPLA	Panorama	ThinkNature	weADAPT
Functionalities and other features												
Interactive tools (map viewers, decision support tools, guidance, info submissions)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Climate services ([b])		✓	✓									✓
Searchable database		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Connections with other platforms ([c])		✓	✓	✓							✓	✓

Note: Tick-boxes were selected in consultation with platform managers, except the entries for NWRM and OPPLA. ([a]) Examples of actions implemented in practice that may inspire others. ([b]) The platform has a specific climate services component beyond links that offers users climate information and products. ([c]) The platform has connections with other platforms beyond simple links, e.g. cross-harvesting elements or databases.

Source: EEA.

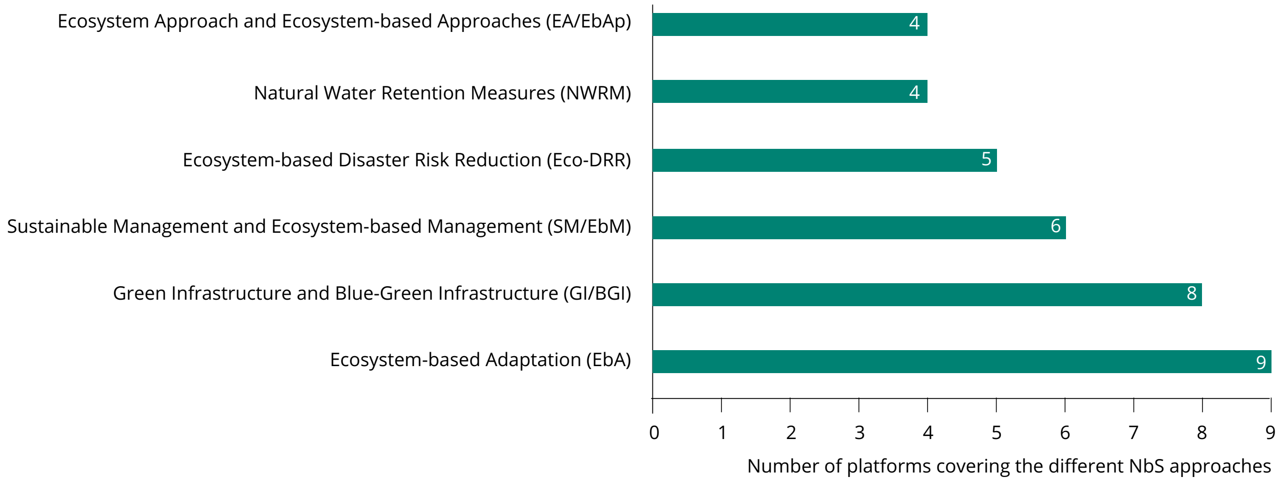
Table A5.2 Overview of European platforms — content coverage of topics relevant for nature-based solutions

	NbS approaches					
	EA/EbAp	GI/BGI	EbA	SM/EbM	NWRMs	Eco-DRR
BISE		✓				
Climatescan	✓	✓	✓	✓	✓	✓
Climate-ADAPT	✓	✓	✓	✓	✓	
DRMKC						✓
Natural Hazards — Nature-based Solutions platform	✓	✓	✓	✓	✓	✓
Nature-based Solutions Initiative			✓			
Naturvation Urban Nature Atlas		✓	✓			
NWRM		✓			✓	
OPPLA	✓	✓	✓	✓		
Panorama			✓	✓		
ThinkNature		✓	✓	✓		✓
weADAPT			✓			✓

Note: Tick-boxes were selected in consultation with platform managers, except the entries for NWRM and OPPLA.

Source: EEA.

Figure A5.1 Number of platforms covering the various approaches to nature-based solutions



Note: Based on the list of platforms selected for this study.

Source: EEA.

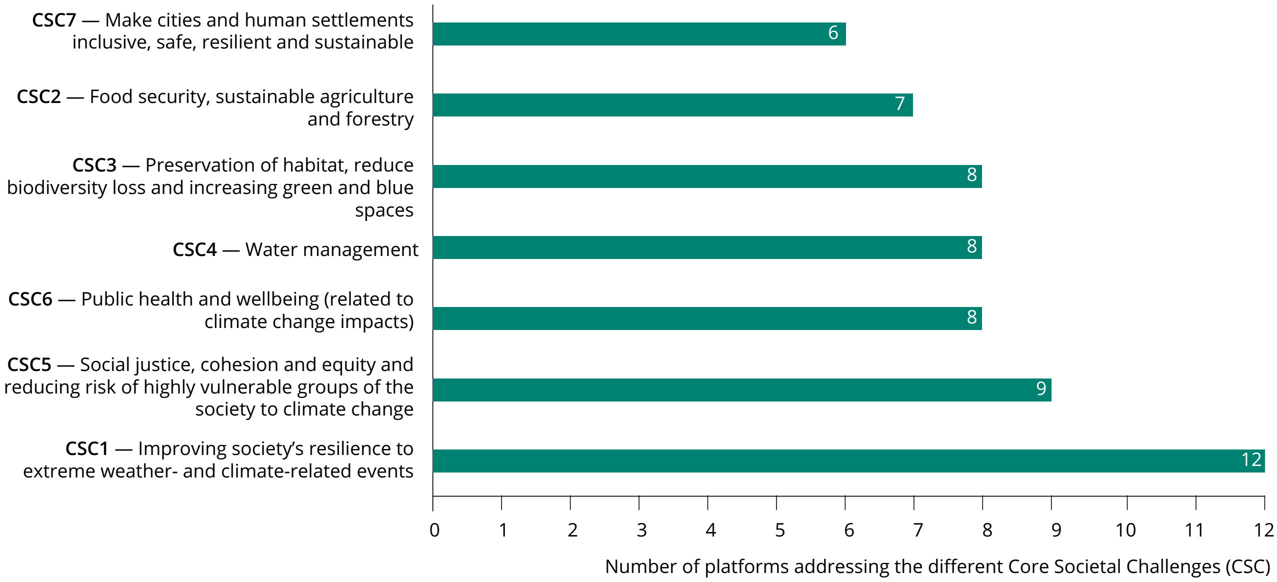
Table A5.3 Overview of European platforms — content relevant to the core societal challenges

	Core societal challenges						
	CSC1	CSC2	CSC3	CSC4	CSC5	CSC6	CSC7
	Improving society's resilience to extreme weather- and climate-related events	Food security, sustainable agriculture and forestry	Preserving habitat, reducing biodiversity loss and increasing green and blue spaces	Water management	Social justice, cohesion and equity and reducing risk for groups of society highly vulnerable to climate change	Public health and well-being (related to climate change impacts)	Make cities and human settlements inclusive, safe, resilient and sustainable
BISE	✓	✓	✓				
Climatescan	✓	✓	✓	✓	✓	✓	✓
Climate-ADAPT	✓				✓	✓	
DRMKC	✓						
Natural Hazards — Nature-based Solutions platform	✓	✓	✓	✓	✓	✓	✓
Nature-based Solutions Initiative	✓	✓	✓	✓	✓	✓	✓
Naturvation Urban Nature Atlas	✓		✓	✓	✓		
NWRM	✓			✓			
OPPLA	✓	✓	✓	✓	✓	✓	✓
Panorama	✓	✓	✓	✓	✓	✓	✓
ThinkNature	✓	✓	✓	✓	✓	✓	✓
weADAPT	✓				✓	✓	

Note: Tick-boxes were selected in consultation with platform managers, except the entries for NWRM and OPPLA.

Source: EEA.

Figure A5.2 Number of platforms addressing the various core societal challenges



Note: Based on the list of platforms selected for this study.

Source: EEA.

A5.2.2 National level

This section complements the previous one with a short account of the knowledge platforms addressing NbS for CCA and DRR at the national level in Europe.

In order to collect information on the existence of such platforms and of their characteristics with the same level of detail as at the European level (i.e. target audience, geographical coverage, content, structure and functionalities), a questionnaire was sent to the relevant EEA/Eionet national reference centres (in June 2020). However, only 13 (out of 32) responded, and the subsequent Eionet consultation (in August 2020) provided some additional information for only one more country. Therefore, a representative overview cannot be derived from such limited data. However, we can report that six European countries have a knowledge platform addressing NbS for CCA and DRR. Specifically, five countries (Austria, Montenegro, Norway, Poland and Spain) have a national platform on CCA or DRR that include some elements of NbS.

Furthermore, two countries have a national sectoral platform encompassing the NbS topics: Austria on water and biodiversity and Czechia on national hazards, focusing on droughts and floods. (The other eight countries ([19]) replied that they do not have a specific national knowledge platform covering NbS and related concepts.)

Therefore, it can be deduced that currently there are only a few examples of national knowledge platforms tackling NbS and related concepts for CCA and DRR across Europe that complement the well represented European landscape of NbS knowledge platforms. This conclusion points to room for improvement at the national level.

On the other hand, there are European platforms that gather relevant national information on NbS in a systematic way. For example, BISE gathers data from all EU Member States regarding their GI national policy framework, implementation, mainstreaming and financing of GI, the knowledge base and the challenges and opportunities for GI development.

([19]) Albania, Bosnia and Herzegovina, Bulgaria, Cyprus, France, Ireland, Italy and Slovenia.

Annex 6 Glossary

Climate change adaptation

Climate change adaptation is the process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate or avoid harm or to exploit beneficial opportunities. In some natural systems, human intervention may facilitate adjustment to expected climate and its effects (IPCC, 2014b).

- **Incremental adaptation** includes adaptation actions that predominantly aim to maintain the essence and integrity of a system or process at a given scale.
- **Transformative adaptation** includes adaption actions that may change the fundamental attributes of a system in response to climate and its effects and find different solutions.
- **Adaptation constraint** includes factors that make it more difficult to plan and implement adaptation actions or that restrict options. Adaptation deficit is the gap between the current state of a system and a state that minimises adverse impacts from existing climate conditions and variability.
- **Adaptation limit** is the point at which an actor's objectives (or system needs) cannot be protected from intolerable risks through adaptive actions. There are two kinds of adaptation limits: (1) hard adaptation limits in which no adaptive actions to avoid intolerable risks are possible; and (2) soft adaptation limits in which options to avoid intolerable risks through adaptive action are currently unavailable (IPCC, 2014a).

Disaster

Disaster is a serious disruption of the functioning of a community or a society, at any scale, due to hazardous events interacting with conditions of exposure, vulnerability and capacity and leading to one or more of the following: human, material, economic and environmental losses and impacts (UNDRR, 2017).

Disaster risk

Disaster risk is the potential loss of life, injury, or destroyed or damaged assets in a system, society or community in a specific period of time, determined probabilistically as a function of hazard, exposure, vulnerability and capacity (UNDRR, 2017).

Disaster risk assessment

Disaster risk assessment is defined as a qualitative or quantitative approach to determining the nature and extent of disaster risk by analysing potential hazards and evaluating existing conditions of exposure and vulnerability that together could harm people, property, services, livelihoods and the environment on which they depend (UNDRR, 2017).

Disaster risk management

Disaster risk management (DRM) is the organisation, planning and application of measures preparing for, responding to and recovering from disasters (UNDRR, 2017). DRM and disaster risk reduction (DRR) are interlinked: DRR is the policy objective of DRM, and the goals and objectives of the latter are defined in DRR strategies and plans.

Disaster risk reduction

DRR aims to prevent new and reducing existing disaster risk (exposure, hazard or vulnerability), and manage residual risk, all of which contribute to strengthening resilience and therefore to the achievement of sustainable development (IPCC, 2014a; UNDRR, 2017).

Exposure

Exposure includes the people, infrastructure, housing, production capacities and other tangible human assets located in hazard-prone areas (UNDRR, 2017).

Extreme weather- and climate-related event

An extreme weather event or an extreme climate event is defined as an event that is rare in time at a particular location. It would normally be as rare as or rarer than the 10th or 90th percentile of a probability density function estimated from observations (IPCC, 2014a). Such events often have the highest impacts on and cause the greatest damage to human well-being and to both natural and managed systems.

Hazard

Hazard is defined as a process, phenomenon or human activity that may cause loss of life, injury or other health impacts, property damage, social and economic disruption or environmental degradation. Natural hazards are predominantly associated with natural processes and phenomena. Hazards may be single, sequential or combined in their origin and effects. Each hazard is characterised by its location, intensity, frequency and probability (UNDRR, 2017). Multi-hazard refers to (1) the range of multiple major hazards that a country faces, and (2) specific contexts in which hazardous events may occur simultaneously, cascading or cumulatively over time, and taking into account the potential interrelated effects of these (UNDRR, 2017).

Hazardous event

Hazardous event is defined as the manifestation of a hazard in a particular place during a particular period of time. Not every hazardous event may cause a disaster, but severe hazardous events may cause a disaster, as a result of the combination of hazard occurrence and other risk factors (UNDRR, 2017).

Land use and land use change

Land use refers to the sum of arrangements, activities and inputs undertaken in a certain land cover type (a set of human actions). The term land use is also used in the sense of the social and economic purposes for which land is managed (e.g. grazing, timber extraction and conservation). Land use change refers to a change in the use or management of land by humans, which may lead to a change in land cover. Land cover and land use change may have an impact on the surface albedo, evapotranspiration, sources and sinks of greenhouse gases, or other properties of the climate system and may thus give rise to radiative forcing and/or other impacts on climate, locally or globally (IPCC, 2014a).

Mitigation (of climate change)

A human intervention to reduce the sources or enhance the sinks of greenhouse gases (IPCC, 2014a).

Resilience

Resilience is the capacity of social, economic and environmental systems to cope with a hazardous event or trend, responding or reorganising in ways that maintain their essential function, identity and structure, while also maintaining the capacity for adaptation, learning and transformation (IPCC, 2014a).

Risk

Risk is defined in this report as the potential for consequences in which something of value is at stake and the outcome is uncertain, recognising the diversity of values. Risk is often represented as the combination of the probability of a hazardous event and its negative consequences (probability of occurrence of events or trends multiplied by the impacts if these events or trends occur). In this report, the term risk is used primarily to refer to the risks of impacts due to natural hazards from selected extreme hydrological, meteorological, climatological and geophysical events (IPCC, 2014a; UNDRR, 2017).

Sensitivity

Sensitivity is the degree to which a system or species is affected, either adversely or beneficially, by climate variability or change (IPCC, 2014a). In contract, coping capacity is the ability of people, organisations and systems, using available skills and resources, to manage adverse conditions, risk or disasters. The capacity to cope requires continuing awareness, resources and good management, both in normal times and during times of crisis or adverse conditions. Coping capacities contribute to the reduction of disaster risks and strengthen resilience (UNDRR, 2017).

Slow onset event

A slow onset event includes sea level rise, increasing temperatures, ocean acidification, glacial retreat and related impacts, salinisation, land and forest degradation, loss of biodiversity and desertification (UNFCCC, 2012).

Vulnerability

Vulnerability is defined in this report as the propensity or predisposition of an individual, a community, assets or systems to be adversely affected by the impacts of hazards. It includes a variety of concepts and elements, such as sensitivity or susceptibility to harm and lack of capacity to cope and adapt. Vulnerability is a result of diverse historical, social, economic, political, cultural, institutional, natural resource, and environmental conditions and processes (UNDRR, 2017; IPCC, 2014a).

European Environment Agency

Nature-based solutions in Europe : Policy, knowledge and practice for climate change adaptation and disaster risk reduction

2021 — 159 pp. — 21 x 29.7 cm

ISBN 978-92-9480-362-7
doi: 10.2800/919315

TH-AL-21-001-EN-N
doi:10.2800/919315

Working with nature can help prevent the worst impacts of climate change, and biodiversity and ecosystem loss. Nature-based solutions offer ways to do this. Science and policy have begun to recognise their potential.

The knowledge base is expanding rapidly, with gaps identified and plans to fill them. However, challenges for implementation remain at the local level, as demonstrated by the case studies in this report.

European Environment Agency
Kongens Nytorv 6
1050 Copenhagen K
Denmark
Tel.: +45 33 36 71 00
Web: eea.europa.eu
Enquiries: eea.europa.eu/enquiries

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