NATURE BASED SOLUTIONS IN UK CLIMATE ADAPTATION POLICY

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GLOSSARY

Adaptive management
A systematic, iterative approach for improving resource management by learning from management outcomes, and adjusting practices accordingly.

Agro-ecology
The application of ecological theory to farming systems. It has been adopted as an umbrella term that encompasses a range of sustainable farming practices which aim to protect and regenerate soils, reduce the use of agro-chemicals and sustain biodiversity on the farm.
See Box 3 (Section 3.4) for details.[1]

Agroforestry
The practice of growing trees on farms, including amongst crops, (silvo-arable), on pasture (silvo-pasture), alongside waterbodies (riparian) (see separate definitions), as shelterbelts along field boundaries, or in small patches of unproductive land such as field corners.

Biodiversity
The diversity of life, from the level of the gene to the level of the ecosystem. Includes genetic diversity, species diversity, habitat diversity and structural diversity. When we refer to biodiversity in this report we mean an appropriate level of diversity and species composition for a particular ecosystem, recognising that some ecologically important ecosystems naturally have fewer species than others.

Bioswale
A vegetated channel that can form part of a sustainable drainage system (SuDS), for example by conveying water to a detention basin, retention pond or raingarden.

Carbon sequestration and storage
Capture (sequestration) of carbon dioxide from the air through photosynthesis by terrestrial or aquatic plants, and subsequent storage in vegetation (above and below ground, i.e. roots), plant litter, dead wood, soils and sediments. Sequestration is expressed as tonnes of carbon (or carbon dioxide) removed from the air per hectare per year, and storage is expressed as total tonnes of carbon stored in soils and vegetation per hectare.

CCC
Climate Change Committee: an independent, statutory body established under the Climate Change Act 2008 to advise the UK and devolved governments on emissions targets and to report to Parliament on progress made in reducing greenhouse gas emissions and preparing for and adapting to the impacts of Climate change.

CCRA
Climate Change Risk Assessment. A CCRA for the UK must be produced every five years as mandated by the UK Climate Change Act 2008. This is informed by an independent risk assessment and advice from the Climate Change Committee (CCC). The CCC's advice for CCRA3 has just been released (June 2021).

Constructed wetlands
Artificially created wetlands planted with wetland plants such as reeds or rushes, which can be used to treat polluted effluent, e.g. from a sewage works, sewer or minewater discharge, or runoff from roads and car parks. These can either be semi-natural wetlands created by excavating a basin,[2] or engineered wetlands where the effluent is piped through a bed of sand or gravel.

Ecosystem services
The benefits people obtain from ecosystems, including provisioning services (supply of food, wood, freshwater and other goods), regulating services (carbon storage and sequestration, flood and erosion protection, air and water quality regulation, noise reduction, local cooling and shading, pest control, pollination) and cultural services (opportunities for recreation, education and interaction with nature, aesthetic value, and a sense of place).

ELMS
Environmental Land Management Scheme – the new system of financial support for farmers that will replace CAP (the Common Agricultural Policy) payments in England, being phased in from 2021 to 2027. It will include three tiers: the Sustainable Farming Incentive (SFI), which will replace the Basic Payments Scheme; Local Nature Recovery; and Landscape Recovery for large scale farmer collaborations.

FCERM
Flood and coastal erosion risk management. This includes both nature-based methods (NFM, SuDS or managed realignment) and conventional methods such as engineered embankments.

GHG
Greenhouse gas: gases which trap heat in the atmosphere and cause global heating and climate change. The main GHG is carbon dioxide (CO2), but others connected to land use include methane (CH4) and nitrous oxide (N2O), which both have a more powerful short term warming effect than CO2 per tonne emitted but do not last so long in the atmosphere. Methane comes from the digestive process of ruminant livestock (sheep and cattle) and can also be produced by decaying vegetation in wetlands, while N2O is mainly emitted from fertilisers and slurry applied to farmland.

Green (and blue) infrastructure
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. This network of green (land) and blue (water) spaces can improve environmental conditions and therefore citizens' health and quality of life. It also supports a green economy, creates job opportunities and enhances biodiversity.[3] This includes all types of green and blue (water) spaces such as parks, gardens, playing fields, playgrounds, allotments, cemeteries, churchyards, street trees, green roofs and walls, SuDS (see separate definition), waterbodies, roadside verges, footpaths and cycleways.

LA
Local authority, i.e. district council, county council, metropolitan area or unitary authority

Managed realignment
Re-aligning the shoreline, usually by breaching or removing an existing sea wall and creating a new wall further inland so that the area in between the old and new walls can revert to a saltmarsh, helping to protect communities further inland from coastal flooding and erosion.

NAP
National Adaptation Plan. These must be produced by the governments of England, Northern Ireland, Scotland and Wales in response to the Climate Change Risk Assessments produced every five years, as mandated by the 2008 UK Climate Change Act. The most recent set of NAPs were the second ones (NAP2). The third NAPs for each nation (NAP3) will respond to the CCRA3, and will be produced starting in 2023. The 'UK NAP' refers mainly to actions to be taken in England but also considers action on some UK-wide matters.

Natural capital
The elements of nature that directly or indirectly produce value to people, including ecosystems, species, freshwater, land, minerals, the air and oceans, as well as natural processes and functions. Natural capital is a broad term that includes many different components of the living and non-living natural environment, as well as the processes and functions that link these components and sustain life.[4] Natural capital produces a flow of ecosystem services.

NFM
Natural flood management. This encompasses a range of nature-based methods for reducing flood risk by intercepting rainfall, slowing the flow of water and storing it in the landscape. See Box 2 (Section 3.2) for details.

NbS
Nature-based solutions involve people working with nature to address societal challenges, providing benefits for both human well-being and biodiversity.[5,6] NbS can involve protection and restoration of a wide range of ecosystems, including forests, grasslands, wetlands, freshwater and coastal habitats, as well as creation of novel ecosystems such as green roofs, and sustainable management of agricultural land.

Restoration
Restoring an ecosystem by recreating it in a place where it would once have existed naturally, such as by planting native trees or recreating coastal saltmarshes, or improving the condition of degraded ecosystems such as by re-wetting peat bogs.

Riparian woodland
Planting trees on the banks of watercourses to help intercept runoff (e.g. from arable fields or roads), trap sediment and thus prevent pollution entering the water, and/or to protect aquatic species by shading and cooling the water.

Silvo-arable
Growing trees amongst crops, typically in rows with arable or horticulture crops in between ('alley cropping'). Fruit or nut trees can be used, to provide an additional income source. The trees provide shade and shelter for the crop, help to build soil fertility, protect from flooding and erosion, and provide habitat for pollinators, pest predators and wildlife.

Silvo-pasture
Growing trees on pasture, typically widely spaced, or in small groups, to provide shade, shelter and forage for livestock as well as many other benefits (see silvo-arable).

SMP
Shoreline management plan – long term plans agreed by local authorities and other stakeholders in coastal areas for the management of coastal flood and erosion risk.

SuDS
Sustainable drainage systems comprise a variety of features such as green roofs and walls, bioswales (vegetated ditches), retention basins (vegetated basins that are usually dry but fill up when there is heavy rain), detention ponds, and raingardens (small wetland areas). These are deployed to intercept rainwater at source, reduce runoff and promote infiltration into the soil, thus reducing surface water flooding, recharging groundwater and improving water quality while also providing benefits for wildlife and amenity value.

UKOT
UK overseas territories. Includes Anguilla, Bermuda, British Virgin Islands, Cayman Islands, Montserrat and Turks &Caicos Islands in the Caribbean; Ascension Island, Falkland Islands, St Helena, Tristan da Cunha, South Georgia and the South Sandwich Islands in the South Atlantic; Pitcairn Islands in the Pacific; Gibraltar and Akrotiri and Dhekelia (military bases in Cyprus) in Europe; British Antarctic Territory and British Indian Ocean Territory (Chagos Islands). Some of these territories are disputed.

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Wallasea Island managed realignment project.
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Saltmarshes can protect from coastal flooding.
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Back Cover image:
Flower-rich field margins can help reduce runoff and soil erosion in heavy rain while providing habitat for pollinators and natural pest predators.
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SUMMARY

Nature-based solutions (NbS) can play an important role in helping the UK to adapt to the impacts of climate change, including sea-level rise, floods, droughts and heatwaves. NbS involve stakeholders working together to protect, restore, connect and enhance the natural assets that underpin the resilience of our economies, health and well-being, providing benefits for both people and nature. Globally, there are many initiatives to protect forests and plant more trees with the aim of capturing and storing carbon, but there is much less recognition and support for the role of NbS in climate change adaptation. In this report, we summarise evidence on the many ways in which NbS can address climate impacts in the UK, and explore the barriers and enabling factors that influence their wider uptake. We show how NbS can help to address 33 of the 34 risks identified in the third Climate Change Risk Assessment (CCRA3), how they can help us adapt to a 2°C warmer world, and how they can be better integrated into UK and Devolved Administration policy, including in the next round of National Adaptation Plans.

We found evidence that a wide range of NbS are being deployed in the UK, protecting and enhancing the services that nature provides. As sea levels rise, saltmarshes, dunes and seagrass meadows are helping to protect against coastal flooding and erosion. Woodlands, hedgerows, heathlands and semi-natural grasslands intercept rainwater, prevent soil erosion and reduce flood risk to communities and infrastructure downstream, while restoring rivers, floodplains and wetlands to their natural functions is slowing the flow of floodwater and encouraging infiltration to recharge depleted aquifers. Ecological farming methods are restoring degraded soils, protecting food security and rural livelihoods from the impacts of unpredictable rainfall patterns, and agroforestry (trees on pasture or among crops) helps to protect and replenish soils while providing shade and shelter for crops and livestock. In urban areas, trees, parks, green roofs and walls, and sustainable drainage systems help to cool cities during heatwaves, as well as reducing stormwater runoff and urban flooding. And in the UK Overseas Territories, mangroves and coral reefs can protect coastal communities from tropical storms, while restoring cloud forests safeguards vital water supplies.

A key strength of NbS is that they deliver multiple benefits for people and nature. They tackle both the causes and effects of climate change, not only simultaneously protecting against several different climate impacts such as floods and heatwaves but also storing and sequestering carbon in soils and vegetation, and sometimes enabling reductions in greenhouse gas emissions from other sources such as fertilisers and fossil fuels. They can provide attractive, nature-rich places for recreation, education and interaction with nature, supporting human health and well-being, and can provide new business opportunities such as through eco-tourism. And, by definition, all NbS also support or enhance the health and diversity of ecosystems, in contrast to engineered solutions that often have negative impacts on both climate and biodiversity. They can thus tackle both the climate and biodiversity crises while also supporting health and local economies.

The map on the next page shows examples of some NbS in the UK, identifies case studies that are presented later in the report, and lists some of the wildlife species that can benefit.

NbS are often cheaper to implement and maintain than alternative climate adaptation options such as hard flood defences, and when all their multiple benefits are taken into account they usually have higher benefit: cost ratios. They can be used as standalone solutions or, in some cases, as part of a hybrid system that includes engineered or technological options, which may be necessary to provide full protection against extreme events such as large floods. However, there can also be some trade-offs between societal objectives, and around the distribution of costs and benefits. For example, planting new woodland on agricultural land to reduce flooding downstream will reduce food production, and could displace impacts elsewhere. To maximise benefits and address any trade-offs, NbS need to be well-designed and managed at the landscape scale by stakeholder partnerships that include local communities, to ensure that the right interventions are used in the right place, following good practice guidelines.

Although support for NbS is growing, a number of barriers currently limit the wider uptake of high quality NbS. These are related to a lack of information on NbS costs and effectiveness, lack of accessible finance, governance challenges, and inappropriate regulation, legislation and procurement processes that fail to recognise the multiple benefits that NbS can deliver. It's vital that governments across the UK transform their approach to NbS and apply the recommendations set out in this report: for the benefit of nature, climate and future generations.

NATURE-BASED SOLUTIONS FOR ADAPTING TO CLIMATE CHANGE IN THE UK: SOME EXAMPLES

NATURAL FLOOD MANAGEMENT AND RIVER RESTORATION

Where	Rural areas
Case studies	Eddleston Water - Scotland, River Otter - Devon
Facts	At Eddleston Water, planting trees and cross-slope hedgerows in the upper catchment, building log dams across side-streams, re-meandering the river and removing embankments to reconnect it to the floodplain reduced flood risk downstream by 30%.
Species	Salmon, trout, beavers, water voles, frogs, toads, newts.

PEATLAND RESTORATION

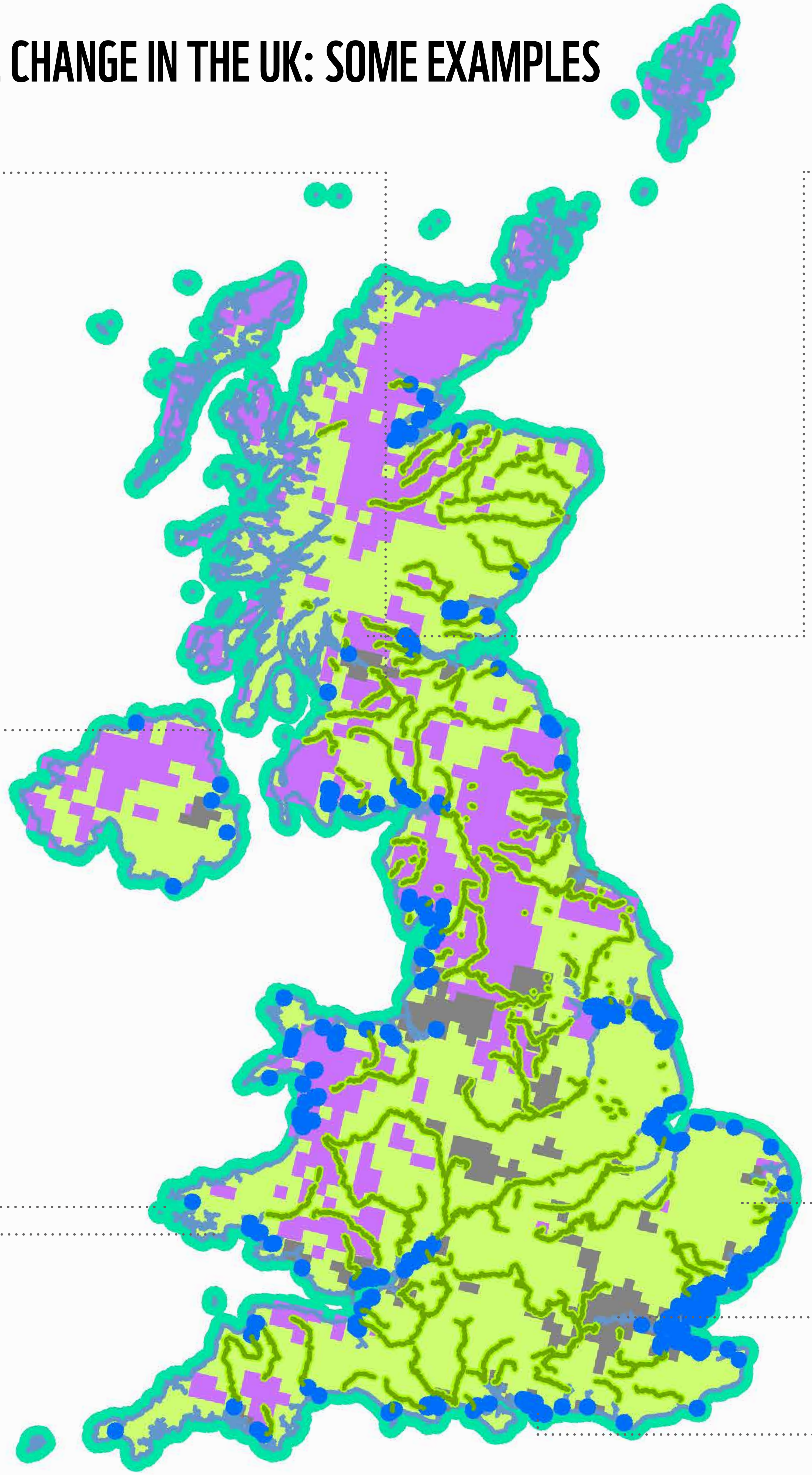
Where	Peat bogs,
Case studies	Garron Plateau - NI, Dove Stone - Peak District
Facts	Peatland and moorland supplies 70% of the UK's drinking water. Blocking drainage channels to re-wet degraded peatland can protect water supplies, improve water quality, reduce flood risk, reduce fire risk and protect carbon stores.
Species	Golden plover, curlew, hen harriers, merlins, dunlins.

SEAGRASS AND KELP RESTORATION

Where	Coastal areas
Case studies	Project Seagrass, Dale, West Wales
Facts	Over 80,000 properties in the UK could be lost to coastal erosion by the end of the century. Seagrass meadows and kelp forests stabilise marine sediments and reduce the erosive power of waves. Project Seagrass has restored two hectares of seagrass at Dale in West Wales, using almost 1 million seeds.
Species	Seahorses (seagrass), otters (kelp)

SUSTAINABLE DRAINAGE (SUDS)

Where	Urban areas
Case studies	Llanelli and Grangetown, South Wales
Facts	Half of the sewer network in England is already at maximum capacity and becomes overloaded in heavy rain, causing floods and water pollution. Well-designed sustainable drainage systems use a series of pools, basins, wetlands, raingardens and channels to collect and treat runoff from urban areas, so it can go straight into a watercourse instead of the sewer.
Species	Frogs, toads, newts



URBAN TREES AND GREEN SPACE

Where	Urban areas
Case studies	Greater Easterhouse, Glasgow
Facts	Trees and green space help to keep towns and cities cool, and soak up rainwater, preventing flooding. Surface temperatures can be up to 20ºC lower and air temperatures up to 8ºC lower under trees in a park. Scotland's 'Natural Health Service' is creating a network of green and blue spaces, especially in deprived areas, to reduce flooding and help people improve their physical and mental health.
Species	Garden birds, bees, butterflies.

AGROFORESTRY

Where	Farmland
Case studies	Wakelyn's, Suffolk
Facts	Growing trees on pasture or among crops can reduce flooding and soil erosion, provide shade and shelter for crops and livestock, and provide an additional income source for farmers.
Species	Farmland birds

GREEN ROOFS AND WALLS

Where	Urban areas
Case studies	London
Facts	There could be up to 7000 heat-related deaths per year in the UK by 2050. Green roofs and walls help to keep buildings cool in summer and warm in winter. They also soak up rainwater and can reduce runoff by 50% to 90%, reducing surface flooding.
Species	Birds, bees, butterflies, beetles.

SALTMARSH RESTORATION (MANAGED REALIGNMENT)

Where:	Coastal areas
Case studies	Medmerry, West Sussex
Facts	126,000 people in the UK are at significant risk of coastal flooding. Managed realignment of coastal defences and restoration of saltmarshes can be a more sustainable and affordable way of protecting coastal communities in the long term.
Species	Wading birds (avocets, redshanks, oyster catchers, black-winged stilts, etc)

RECOMMENDATIONS

Now is the time for visionary leadership, building on the momentum generated by the UK hosting of COP 26, the stark messages of the CCRA3 Evidence Report, the ground-breaking Dasgupta review of the economics of biodiversity, and the start of the UN Decade of Restoration. It is time to make new commitments, not through simplistic targets such as the number of trees planted, which can do more harm than good, but with an intelligent strategy to scale up delivery of high quality, carefully planned and locally specific NbS that deliver real and long-lasting benefits for people, climate and nature. We provide recommendations that can help to transform the role of NbS in UK policy, to simultaneously contribute to climate resilience, net zero goals and nature recovery while also strengthening our economy, creating green jobs, improving health and well-being and reducing social inequality. Detailed recommendations for each type of NbS are provided in Table 10, at the end of this report.


In UK overseas territories, coral reefs protect coastal communities from storm surges

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1.

Integrate a wider range of NbS into the next round of National Adaptation Plans.

While each devolved nation will have different priorities, we believe there are opportunities for a wider range of NbS to play a greater role in the third round of all four NAPs, building on recent policy initiatives and examples of good practice across the UK. Key opportunities that were rarely mentioned in the last NAPs include:

- **Seagrass meadows, kelp beds and coldwater reefs** for reducing coastal flood and erosion risk.
- **Coral reefs and mangroves** for storm protection and fish production in the UK Overseas Territories, and **cloud forests** for water security.
- **Natural regeneration of woodland,** which can be cheaper than tree-planting, avoids the need for plastic tree guards, and results in a more biologically diverse structure and composition which can be more resilient and provide greater benefits (e.g. for flood protection) in the long term.
- **Rewilding,** which can create a diverse mosaic of natural grassland, woodland and scrub that supports livestock and pollinators while also reducing flood and erosion risk, regenerating soil and promoting eco-tourism.
- **Green roofs and walls,** which can play a vital role in flood reduction and urban cooling if supported through planning policy, such as via the Urban Greening Factor in London and Green Space Factor in Swansea.
- **SuDS** are mandatory for new developments in Wales, with quality standards to ensure that they deliver multiple benefits for flood reduction, water quality, biodiversity and amenity. There are opportunities to apply stronger quality standards in the other countries, and to strengthen legislation in England in line with CCC recommendations so that high quality SuDS are effectively mandatory in new developments.
- **Vegetation for slope stabilisation** is being investigated in Wales and there is scope to also consider this in the other countries, in line with the CCC's advice to government for CCRA3.
- **Agroforestry** receives some support in Scotland, Wales and Northern Ireland but falls into a policy and funding gap in England. Key barriers are lack of long term funding and lack of information and advice for farmers.
- **Nature-based agriculture** to protect and regenerate soils and provide climate resilience received surprisingly little attention in the NAP2s but can be built into post-Brexit agri-environment schemes, in line with initial proposals in England (ELMS) and Wales (SLM).
- In addition, several NbS were mentioned in the NAPs but still require more policy support and funding to scale up deployment on the ground. These include **managed realignment,** which is falling short of targets set in the Shoreline Management Plans, **natural flood management,** which still faces high funding barriers, and **peatland restoration,** where restoration rates need to increase and proposed bans on burning and extraction need to be strengthened and brought forward.

2.

Mainstream NbS by developing coherent policies across all sectors.

Government departments at national, regional and local levels need to talk more to each other about NbS, to break down silos, overcome barriers, identify common goals and harmonise policy support.

- **Set up cross-departmental working groups in all four national governments** to promote the delivery of high quality NbS by developing shared visions, targets and action plans.
- **Integrate NbS delivery into local plans and policies through a participatory landscape approach,** to deliver a diverse portfolio of the right NbS in the right places while balancing multiple objectives.
- **Strengthen recognition of NbS as essential climate adaptation infrastructure in future revisions of the National Infrastructure Strategy,** by including more explicit support and funding for a broader range of NbS including urban green infrastructure and coastal habitat restoration.
- **Planning policy must provide stronger protection for existing semi-natural habitats.** Reforms to the planning system need to focus on protecting all natural assets, not just those with formal designations, even if an area is designated as a growth zone.
- **Ensure that regulations and legislation support and encourage scaling up of good quality NbS schemes** by negotiating affordable and streamlined licensing systems for seagrass restoration, beneficial use of dredging material, leaky dams and flood storage ponds in pre-approved locations, provided they comply with good practice guidelines.
- **Promote synergies between NbS for adaptation and mitigation.** Net Zero policies should support protection, restoration and connection of a wide range of habitats (beyond trees and peat), including native grassland, heathland, wetlands and coastal habitats, to provide climate adaptation services as well as carbon sequestration. Carbon storage and sequestration metrics are needed for these habitats.
- **Promote synergies between food security and other objectives** through supporting agro-ecology and agroforestry, which deliver adaptation services on farmland without compromising food production, and raising awareness of the need for dietary change and reduced food waste to free up land for NbS.
- **Integrate NbS for adaptation into national nature recovery plans and set strong environmental policies to support healthy, resilient and well-connected ecosystems.** Pressures on ecosystems need to be reduced, and NbS connected into ecological networks, so that current and future NbS will be resilient to future change.

3.

Fund high quality NbS for climate adaptation.

More finance for NbS is needed, including novel mechanisms that recognise their multiple market and non-market benefits. There are opportunities to channel private sector funding to a wider range of high quality NbS with benefits for climate adaptation, rather than just tree-planting for carbon sequestration.

- **Reform funding and procurement mechanisms so that they recognise the wider benefits of NbS.** It should be mandatory to consider NbS alongside conventional engineered options, and to take into account their wider benefits, when allocating funding such as for flood risk management projects. Where wider benefits cannot be meaningfully monetised, funding for high quality NbS could be ring-fenced.
- **Increase funding for research, demonstration, and long term monitoring.** This is needed to build the evidence base on NbS costs and effectiveness, and will help to unlock more funding from both the public and private sectors by providing consistent performance metrics that can justify investment.
- **Fund knowledge exchange networks, professional advisory services and information hubs.** This is particularly important for agroforestry and agro-ecology where lack of information for farmers is a major barrier.
- **Provide enough funding to enable delivery and regulatory bodies to oversee the scaling up of high quality NbS.** Many critical delivery bodies such as Natural England, the Environment Agency, NatureScot and SEPA are chronically under-funded.
- **Consider whether the UK Infrastructure Bank could help to support NbS,** such as by funding up-front costs until grants come through.
- **End perverse subsidies for activities that damage natural capital** (e.g. fossil fuel extraction).

- **Develop blended finance options** that use public funding to leverage private funding. **Ensure that different funding sources can work together** (such as agri-environment schemes, woodland creation grants, biodiversity gain, Net Zero funds and the Emissions Trading Scheme), and **develop mechanisms for stacking and bundling benefits** such as carbon sequestration, flood reduction, water quality, and biodiversity gain.

4.

Set standards for high quality and resilient NbS

and manage them adaptively to respond to change.

- **Apply the four NbS guidelines** (Box 1) and the more detailed IUCN Standard to ensure that NbS deliver real long term benefits for both people and nature, including through participatory design and delivery.
- **Set a minimum standard for green roofs** in national and local planning policies, equivalent to 'Biodiverse Green Roofs' with adequate depth of substrate to deliver cooling and drainage services, as defined in the 2021 GRO (Green Roof Organisation) code, to move away from the current preference for thin sedum mats with few benefits.
- **Adopt higher standards for sustainable drainage systems (SuDS)** to ensure that high quality open, vegetated systems with benefits for water quality, biodiversity and amenity are delivered rather than basic underground pipes and tanks. High standards already apply in Wales, although there are opportunities to provide more specific biodiversity criteria, and revised standards have been developed for England which should now be adopted.
- **Include an agroforestry standard in agri-environment schemes such as ELMS** to help farmers understand what constitutes good practice.
- **Design NbS to be compatible with a 2°C increase in average global temperatures** and related climate impacts, by selecting appropriate sites, using a diverse mix of suitable species, and planning to enhance ecosystem connectivity. Use adaptive management to respond to change and address the increasing variability in weather and climate.
- **Plan NbS to deliver measurable benefits for biodiversity** through enhancing the health, diversity and connectivity of ecosystems and their habitats and species, rather than through simplistic standalone targets such as the area or number of trees planted. Encourage use of diverse native species, and explore options for rewilding or natural regeneration if appropriate, to enhance benefits for biodiversity.
- **Set safeguards for NbS involving tree-planting.** There is a prevailing assumption that planting trees always has benefits for biodiversity and climate, which needs to be corrected through raising awareness that this depends on the tree species, woodland management, soil type and previous land cover, and setting specific objectives to improve biodiversity when planting trees.
- **Support practitioner and researcher knowledge-sharing networks to spread good practice** and provide solid evidence of efficacy and benefits of NbS, such as the proposed agroforestry network.

5.

Measure and monitor NbS delivery: targets, indicators and metrics.

National adaptation policies should set well-defined, ambitious and time-bound objectives for scaling up high quality NbS, and establish monitoring and evaluation processes to evaluate progress towards these objectives.

- **Define suitable indicators and metrics** for assessing the deployment, quality and outcomes of NbS for adaptation, along with co-benefits.
- **Improve the monitoring of biodiversity impacts,** which are rarely measured.
- **Strengthen technical, financial and institutional capacity** to ensure that NbS are well-designed, financed, implemented, monitored, evaluated, and mainstreamed.

Using a diverse mix of native flowers in field margins and urban green spaces maximises the benefits for biodiversity

CONTENTS

1. AIM OF THIS REPORT

Nature-based solutions (NbS) involve people working with nature to address societal challenges, providing benefits for both human well-being and biodiversity.[5,6] NbS can involve protection and restoration of a wide range of ecosystems, including forests, grasslands, wetlands, freshwater and coastal habitats, as well as creation of novel ecosystems such as green roofs, and sustainable management of agricultural land. Good practice guidelines have been developed to ensure that NbS are successful and sustainable (Box 1). These emphasise that NbS should be community-led, and should be explicitly designed to deliver benefits for biodiversity and ecosystem health as well as for people.

As countries across the world strengthen their efforts to tackle climate change, there is growing interest in the role that NbS can play in capturing and storing carbon, with a global focus on planting trees. Alongside this, NbS can also help to protect us from the impacts of climate change, such as floods, droughts and heatwaves, which are becoming increasingly severe. However, the role of NbS for adapting to these climate impacts has attracted less attention to date. For example, only 1.5% of all international climate finance supported NbS for climate adaptation in 2018.[7] This report therefore aims to increase recognition and support for the role of NbS in climate adaptation in the UK, including in the Overseas Territories.

Major climate risks in the UK are identified in Climate Change Risk Assessments published every five years, in accordance with the 2008 UK Climate Change Act. The third assessment (CCRA3) was published by the Climate Change Committee (CCC) in June 2021, and consists of over 1,500 pages of evidence including a Technical Report,[9] National Summaries for each UK country, Sector Briefings and supporting research, all of which are summarised by the CCC in its Advice Report to Government.[8] We refer to these documents collectively as CCRA3 or the CCRA3 Evidence Report. These assessments are followed by a government response, with the CCRA3 Government Report required in January 2022. They then feed into updates of the National Adaptation Plans produced by England, Northern Ireland, Scotland and Wales, due from 2023 onwards.

We aim to show how NbS can:

1. **address the climate risks identified in the CCRA3 Evidence Report, and play a strong role in the third set of National Adaptation Plans (NAP3) for the four countries of the UK;**

2. **at the same time, contribute to nature recovery and help to sustain the flow of ecosystem services on which people depend;**

3. **provide socio-economic and health benefits as part of an equitable Covid-19 green recovery;**

4. **be embedded across (and support) a wide range of UK and devolved policy areas, including agriculture, biodiversity, flood and coastal risk management, water resource management, public health, urban planning, transport, infrastructure, business, and international development.**

This report has been informed by a review of key literature, as well as in-depth discussions with policymakers, researchers and practitioners working with NbS in the UK. It builds on an earlier policy brief produced in November 2020 that provided general guidelines on how to incorporate NbS for climate adaptation within the UK's NDC and Adaptation Communication,[10] and accompanies a report on the potential for NbS to be used for climate change mitigation.[11] It draws on a wide range of evidence including a systematic global review of NbS for adaptation[12] and the recent report on NbS in the UK by the British Ecological Society.[13]

We start with an overview of how NbS can address multiple climate risks as well as delivering wider benefits (Section 2) and then show how they can help communities and businesses adapt to each of the main risks identified in the CCRA3 Evidence Report.

We show how this can simultaneously deliver benefits for biodiversity (Section 4), and explore further benefits for climate mitigation, livelihoods and health (Section 5). Finally we assess the factors that help or hinder the deployment of NbS for adaptation (Section 6), and draw out some key recommendations for how to better embed high quality NbS into policy and practice so that they can be scaled up across the UK (Section 7).

BOX 1: THE NBS GUIDELINES

The four NbS guidelines were developed in 2020 by a consortium of 20 UK-based organisations, to ensure investment in NbS is channelled to high quality biodiversity-based and community-led NbS and does not distract from or delay urgent action to decarbonise the economy.[14] They are intended to be complementary to the more detailed IUCN Global Standard for Nature-based Solutions.[15] For a detailed explanation of why these guidelines are needed, with full references, see the open-access peer-reviewed article "Getting the message right on nature-based solutions for climate change".[156]

1 **NbS are not a substitute for the rapid phase-out of fossil fuels and must not delay urgent action to decarbonize our economies.** NbS play a vitally important role in helping to mitigate climate change this century, but their contribution is relatively small compared to what must be achieved by the rapid phase-out of fossil fuel use. Furthermore, unless we drastically reduce greenhouse gas (GHG) emissions, global heating will adversely affect the carbon balance of many ecosystems, turning them from net sinks to net sources of GHGs.

2 **NbS involve the protection, restoration and/or management of a wide range of natural and semi-natural ecosystems on land and in the sea; the sustainable management of aquatic systems and working lands; or the creation of novel ecosystems in and around cities or across the wider landscape.** All ecosystem types hold opportunities for NbS to enhance the provision of ecosystem services to people for supporting multiple societal challenges. It is critical that we avoid turning ecosystems from carbon sinks into carbon sources. The world's remaining intact ecosystems and biomes are hotspots for both biodiversity and carbon storage, while also protecting people from climate change impacts. Yet many of these areas lack effective protection or are poorly managed. Degradation of ecosystems significantly reduces carbon storage and sequestration and increases vulnerability to climate-related hazards such as fire. It is also urgent to prevent inappropriate tree planting on naturally open ecosystems such as native grasslands, savannahs and peatlands, or replacement of native forests with plantations. NbS must be valued in terms of the multiple benefits to people and biodiversity, rather than overly simplistic metrics such as numbers of trees planted and short-term carbon gains. Management at the landscape scale, accounting for and utilizing interactions between ecosystems, as well as managing for climate risks to ecosystem services, can help secure and maximize long-term benefits.

3 **NbS are designed, implemented, managed and monitored by or in partnership with Indigenous peoples and local communities through a process that fully respects and champions local rights and knowledge, and generates local benefits.** NbS are explicitly designed and managed adaptively through just institutions to provide a range of benefits to local people, including supporting livelihoods and reducing vulnerability to climate change. They are designed to take the needs, values and knowledge of different sectors of society into account, and particularly of marginalized groups such as women. NbS are produced through partnerships between a diverse set of actors; local and Indigenous peoples should have control of the decision-making process, with financial, governance and/or in-kind support from researchers, and the private, public and charity sectors.

4 **NbS support or enhance biodiversity, that is, the diversity of life from the level of the gene to the level of the ecosystem.** Biodiversity underpins the societal benefits derived from NbS by supporting the delivery of many ecosystem services in the short term, reducing trade-offs among services (e.g. between carbon storage and water supply), and supporting the health and resilience of ecosystems in the face of environmental change, thus increasing their capacity to deliver benefits in the long term. To sustain ecosystem health, other location-specific ecological aspects must also be considered, such as ecosystem connectivity. Therefore, successful, sustainable NbS are explicitly designed and adaptively managed to provide measurable benefits for biodiversity and ecosystem health.

2. OVERVIEW OF HOW NBS CAN HELP THE UK ADAPT TO CLIMATE CHANGE RISKS

Key messages from the CCRA3 Evidence Report are alarming.[8] Even with ambitious global greenhouse gas (GHG) reductions, the UK is likely to experience a further 0.5°C increase in the annual average temperature by 2050. This is predicted to lead to more variable weather patterns including warmer and wetter winters, hotter and drier summers, and more extreme high and low temperatures, which in turn will lead to inland and coastal flooding and erosion, water scarcity, more frequent wildfires, increasing sea temperatures and ocean acidification. However, as global climate mitigation commitments are still well below the level needed to reach Net Zero by 2050, the actual temperature rise could be even higher. While it is essential to continue working towards a global Net Zero target, the UK must also plan to adapt to an average global temperature rise of at least 1.5 to 2°C and consider the possibility of up to 4°C warming during 2050-2100. We need to prepare to address these climate impacts as a matter of urgency.

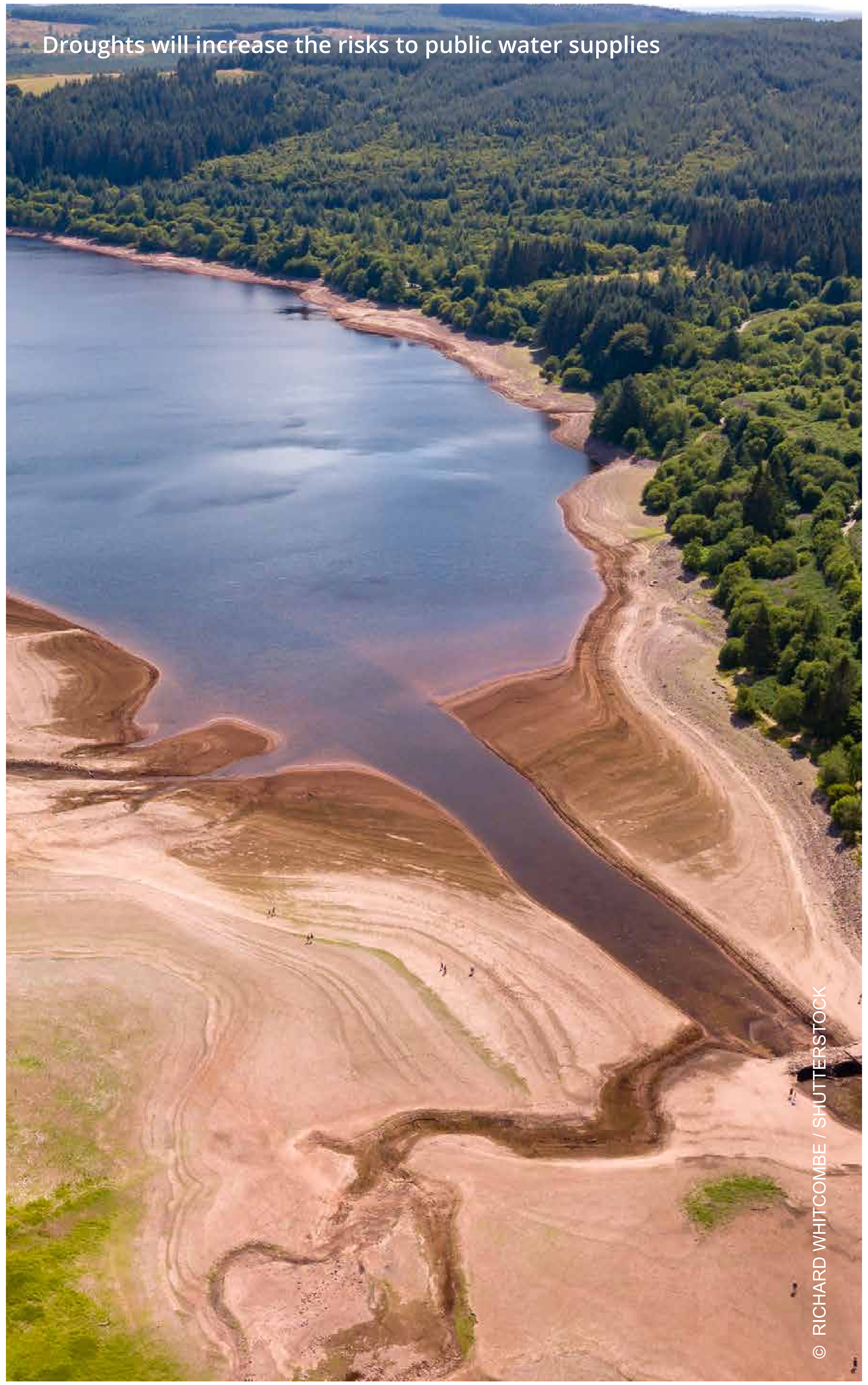
The 'adaptation gap' between the climate risks we face and the action we are taking is growing, and stronger action is urgently needed. Fifty-three separate risks have been identified in the CCRA3 Evidence Report, of which 34 require more action. These include risks to businesses, communities, public health and infrastructure from flooding, high temperatures and reduced water availability, as well as threats to the species and habitats that sustain essential ecosystem services such as carbon storage and agricultural productivity (Table 1). We show how NbS can help to mitigate 33 of these risks, either directly, such as when forests or coastal saltmarshes protect against floods and erosion (e.g. risks B1, B2, H3, H4), or indirectly, by enhancing the health, diversity and connectivity of ecosystems so that they are more resilient to change (e.g. risks N1, N2, N11-17). The final column of Table 1 indicates the section of this report that describes how NbS can address each risk.

EVEN WITH AMBITIOUS GLOBAL GREENHOUSE GAS (GHG) REDUCTIONS, THE UK IS LIKELY TO EXPERIENCE A FURTHER 0.5°C INCREASE IN THE ANNUAL AVERAGE TEMPERATURE BY 2050.

Table 1.
Climate risks identified in CCRA3 that require additional adaptation action

CCRA3 chapter/ code		Climate risks that require additional action	Section
Natural environment	N1	Risks to terrestrial species and habitats	4
	N2	Risks to terrestrial species and habitats from pests, pathogens and INNS	4
	N4	Risk to soils from changing conditions, including seasonal aridity and wetness	3.4
	N5	Risks to natural carbon stores and sequestration from changing conditions	5.1
	N6	Risks to and opportunities for agricultural and forestry productivity	3.4
	N7	Risks to agriculture from pests, pathogens and INNS	3.4
	N8	Risks to forestry from pests, pathogens and INNS	4.2
	N11	Risks to freshwater species and habitats	4.4
	N12	Risks to freshwater species and habitats from pests, pathogens and INNS	4.4
	N14	Risks to marine species, habitats and fisheries	4.1
	N16	Risks to marine species and habitats from pests, pathogens and INNS	4.1
	N17	Risks and opportunities to coastal species and habitats	4.1
Business	B1	Risks to business sites from flooding	3.1,3.2
	B2	Risks to business locations and infrastructure from coastal change	3.1
	B6	Risks to business from disruption to supply chains and distribution networks	3
Health, communities & built environent	H1	Risks to health and wellbeing from high temperatures	3.5
	H3	Risks to people, communities and buildings from flooding	3.1,3.2
	H4	Risks to people, communities and buildings from sea level rise	3.1
	H6	Risks and opportunities from summer and winter household energy demand	3.5
	H8	Risks to health from vector-borne diseases	*
	H11	Risks to cultural heritage	3.1,3.2
	H12	Risks to health and social care delivery	3.5
	H13	Risks to education and prison services	3.5
Infrastructure	I1	Risks to infrastructure networks from cascading failures	3 (All)
	I2	Risks to infrastructure services from river and surface water flooding	3.2
	I5	Risks to transport networks from slope and embankment failure	3.2
	I8	Risks to public water supplies from reduced water availability	3.3
	I12	Risks to transport from high and low temperatures, high winds, lightning	3.2,3.5
International dimension	ID1	Risks to UK food availability, safety, and quality from climate change overseas	3.6
	ID4	Risks to the UK from international violent conflict resulting from climate change	3.6
	ID5	Risks to international law and governance from climate change overseas that will impact the UK	3.6
	ID7	Risks from climate change on international trade routes	3.6
	ID9	Risk to UK public health from climate change overseas	3.6
	ID10	Risk multiplication from the interactions and cascades of named risks across systems and geographies	3.6

**Risks to health from vector borne diseases (H8) is the only risk for which there is no obvious potential for NbS to contribute.*


Droughts will increase the risks to public water supplies

The CCRA3 evidence report also identifies eight priority risk areas that require the most urgent action within the next two years, even before the third round of adaptation plans are formulated. NbS can play a key role in addressing the first four of these, and can also help address the other four (Table 2).

Nature-based solutions not only help people adapt to climate change but also support wildlife

Table 2:
Potential nature-based solutions to address the eight top priority climate risk areas identified in the CCRA3 Evidence Report

	Priority climate risk (from CCRA3)	How NbS can contribute
1	Risks to the viability and diversity of habitats and species	By definition, NbS are designed to support or enhance biodiversity, which underpins resilience to environmental change and thus secures the flow of benefits to people in the long term (Box 1, Section 4, Section 6.5).
2	Risks to soil health from flooding	Agro-ecological and regenerative farming methods can improve soil health, soil structure and organic matter content (Box 3, Section 3.4). This increases infiltration, storage and drainage of water in the soil, thus reducing the impacts of droughts and avoiding waterlogging. Cover crops, buffer strips, hedgerows and agroforestry can also reduce soil erosion caused by heavy rain, floods, or (if soil is fine and dry) wind. Other natural flood management (NFM) approaches such as protection or restoration of woodlands, peatlands and saltmarshes or construction of leaky dams can help to reduce flooding of farmland (Box 2, Section 3.2).
3	Risks to carbon stored and sequestered	Maintaining and restoring diverse and healthy ecosystems can help to reduce these risks (Section 4). Peatland restoration in ecosystems through re-wetting is particularly important (Section 5.1.2).
4	Risks to crops, livestock and forestry from heat stress, drought, waterlogging, flooding, fire, pests, diseases and invasive non-native species	Agro-ecological methods can improve soil health and soil water storage capacity, providing resilience to drought, heat stress and diseases, and species-rich field margins and hedgerows support natural pest predators. Agroforestry can provide shade and shelter to crops and livestock. Greater crop diversity can confer resilience to change. (Box 3, Section 3.4)
5	Risk of collapse of supply chains for food, goods and vital services	Agro-ecological approaches can improve food and water security not just in the UK but globally, helping to protect vital supply chains (Section 3.6). Coastal NbS and NFM can help to reduce flood and erosion risks to transport infrastructure such as roads, railways, ports and harbours worldwide. The UK can support this through targeted aid, capacity building, advocacy and by leading through example.
6	Risks to people and the economy from power system failure	NbS can protect power stations and other infrastructure from flooding and erosion, both on the coast (Section 3.1), e.g. through managed shoreline realignment with saltmarsh restoration, and inland through other NFM approaches (Section 3.2), which can also help sustain water supplies for power station cooling (Section 3.3).
7	Risks to human health and productivity from overheating of buildings	Urban green and blue infrastructure (green roofs and walls, green spaces, trees and water bodies) can cool buildings and other spaces used by people, as well as reducing the energy needed for air conditioning (Section 3.5).
8	Risks to the UK from climate change impacts overseas	NbS can help all nations to adapt to climate risks, thus reducing geopolitical and supply chain risks faced by the UK (Section 3.6).

A key strength of NbS is that they can often address multiple climate impacts and risks (Figure 1). For example, urban green spaces can reduce flooding, provide cooling, and enable water to soak into the ground to recharge aquifers, thus boosting water security. In addition, NbS support biodiversity (Section 4) and can also provide a range of further benefits (Table 2, Figure 2).

They can help to reduce greenhouse gases, sustain and diversify livelihoods, and deliver 'cultural ecosystem services' that improve health and wellbeing, such as nature-rich places for recreation and education (Section 5). There can be trade-offs between these different goals, or between different groups of beneficiaries, but these can often be avoided or minimised through careful design.

Figure 1.
Climate risks addressed by different nature-based solutions, showing how some address multiple risks

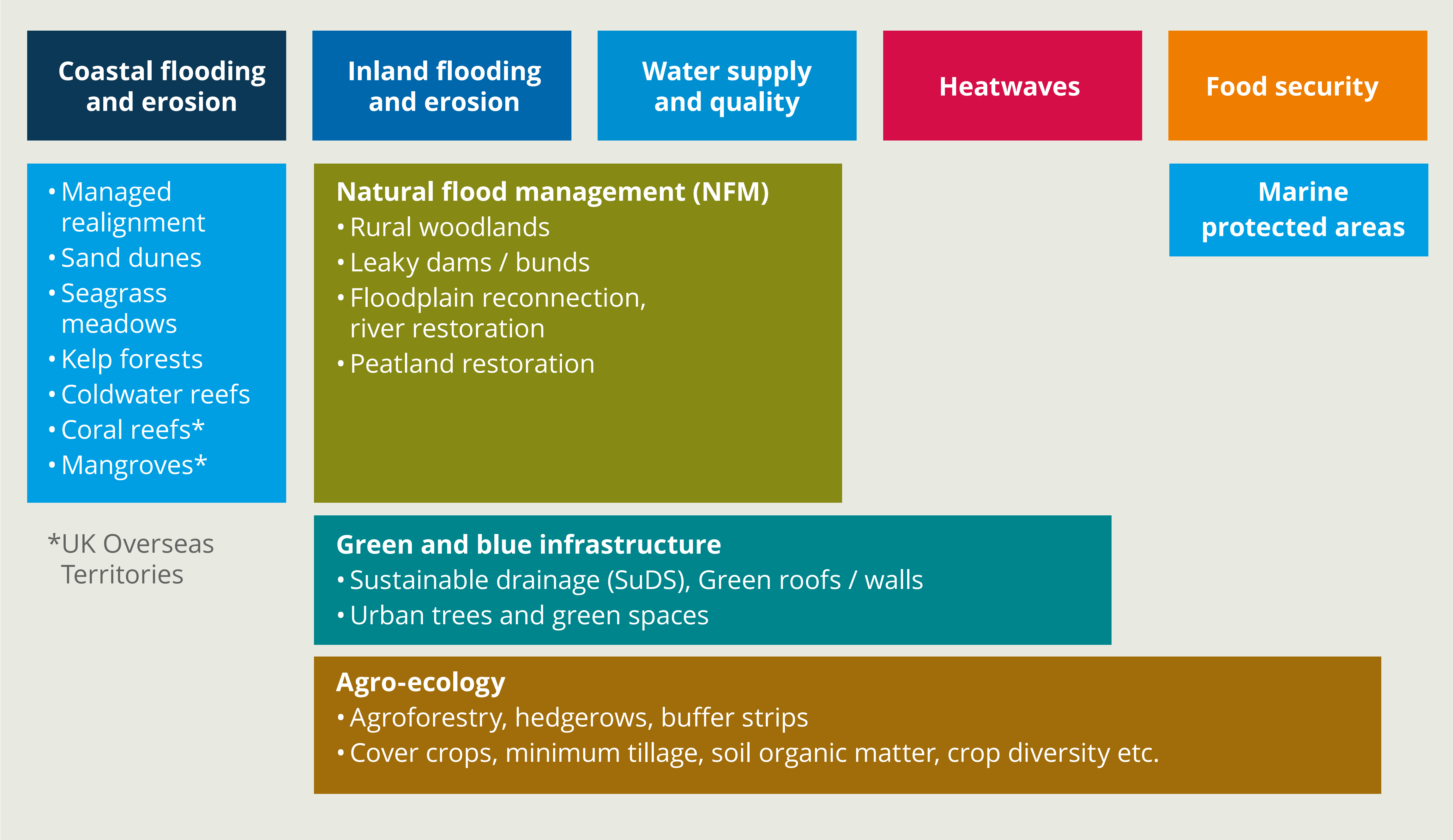


Figure 2.
Further benefits that can be delivered by NbS for climate adaptation (note: biodiversity benefits are integral to all NbS, by definition)

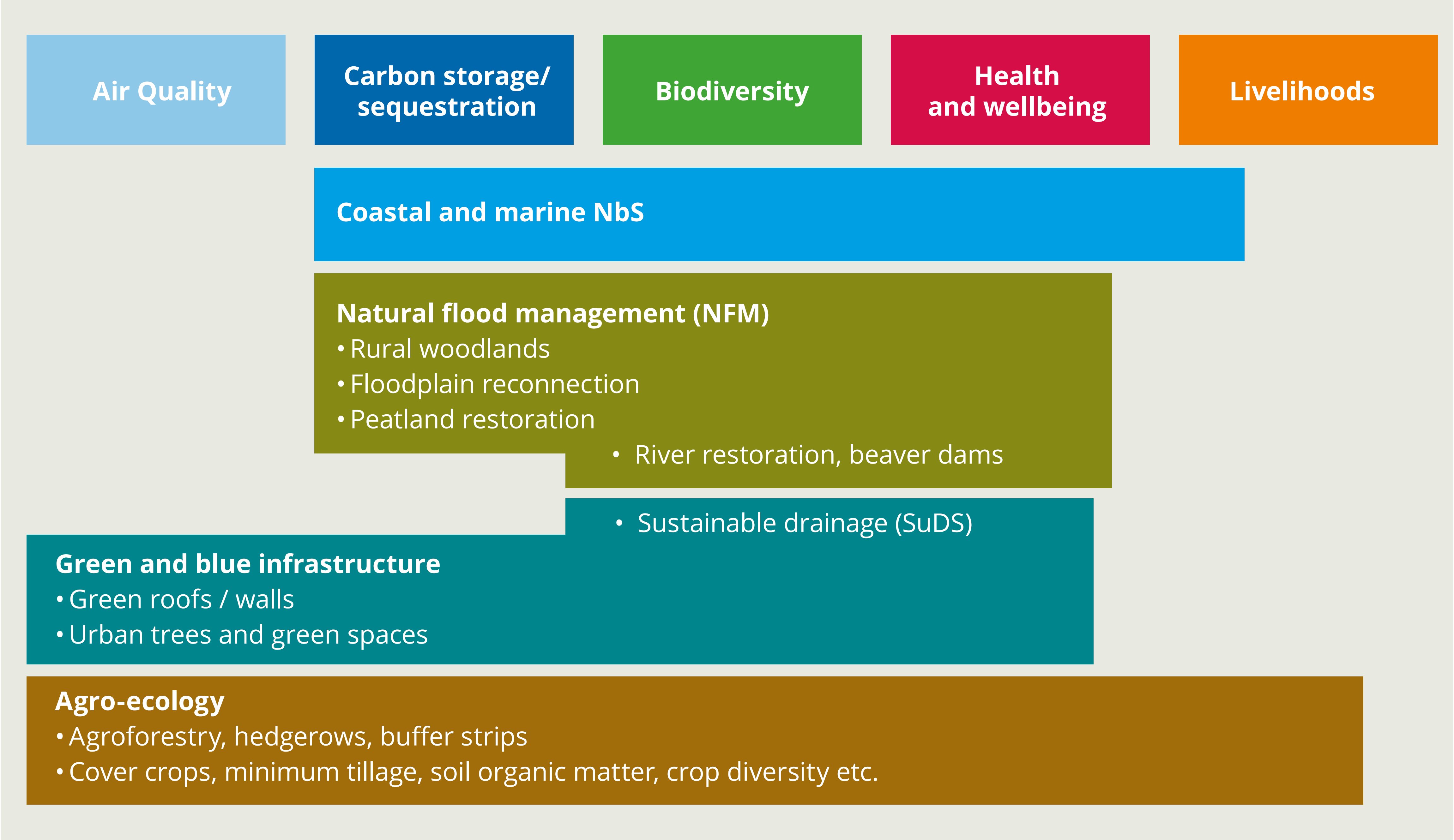


Table 3:
Climate adaptation (pale blue) and other benefits (pale green) provided by different types of NbS

Protection, restoration, creation or sustainable management of:	Coastal flooding and erosion	Inland flooding and erosion	Water security	Food security	Heatwaves	Air quality	GHG reduction	Biodiversity	Livelihoods	Cultural ecosystem services[f]
Natural or semi-natural woodlands		x	x		x	x	x	x		x
Shrubland and hedgerows		x			x	x	x	x		x
Agroforestry[a]		x			x	x	x	x	x	x
Wood pasture and parkland with scattered mature trees		x	x		x	x	x	x	x	x
Natural or semi-natural grasslands		x	x				x	x	x	x
Heathland		x	x				x	x		x
Peat bogs		x	x				x[e]	x		x
Wetlands		x	x			x	x[e]	x	x	x
Freshwater		x	x			x		x	x	x
Saltmarshes	x						x	x	x	x
Seagrass and kelp beds	x						x	x	x	x
Beaches, dunes and sea cliffs	x						x	x	x	x
Reefs[b]	x							x	x	x
Mangroves[b]	x				x		x	x	x	x
Sustainable agriculture / agro-ecology[c]		x	x		x	x	x	x	x	x
Urban green and blue infrastructure[d]		x	x		x	x	x	x	x	x

Notes.

The table is based on UK habitats of particular importance for climate adaptation, plus key overseas territory habitats (coral reefs and mangroves) and specific NbS options (agroforestry, sustainable agriculture, and urban green infrastructure).

a. Agroforestry includes silvo-pasture (trees on pasture) and silvo-arable (trees amongst crops).

b. Mangroves and coral reefs are applicable to overseas territories and for international policy, although cold water corals are also found in UK seas.

c. See Box 3.

d. Urban green and blue infrastructure includes parks, street trees, green walls and roofs, allotments, community orchards, created wetlands and sustainable drainage systems.[16]

e. Wetlands and peat can store vast amounts of carbon in soil and sediments, but can also emit carbon dioxide or methane if degraded, turning from a carbon sink to a source.

f. Cultural ecosystem services include opportunities for recreation, education, interaction with nature, sense of place and aesthetic value, all of which deliver health and wellbeing benefits.

NbS offer a number of advantages when compared to conventional engineered approaches such as sea walls, dams and flood embankments. A 2014 study by the Royal Society[17] found that although the costs and performance of engineered options are more predicatable, NbS are generally more affordable, especially when taking into account the wide range of co-benefits they provide. Maintaining existing vegetation, such as protecting an existing woodland, is one of the cheapest adaptation options, while creating new NbS costs more but can be more effective because it can be designed to suit the context. In contrast, engineered options provide few additional benefits, can be carbon-intensive (such as for concrete embankments and flood barriers, or air conditioning) and can also have negative impacts on biodiversity (such as when hard flood defences act as a barrier to the movement of fish and other species).

Importantly, NbS are better than engineered approaches at dealing with multiple hazards simultaneously. For example, forests offer protection against flooding, erosion, high winds and high temperatures. Also, the consequences of failure can be much lower for ecosystem-based options than for engineered infrastructure such as dams. NbS are also more adaptive to new conditions, as they can grow and evolve, and are less likely to create a false sense of security. They should, by definition, be implemented in partnership with local people, and this engagement is key to the sustainability of the approach,[17] as it helps build the capacity of communities to adapt to change.

However, it is also important to be aware of the limitations of NbS. Although some can be effective against even the most severe events, they typically perform best against smaller events and those that are slower onset or more extensive.[17] Therefore they may need to be used as part of hybrid approaches, in combination with engineered options, where they can often reduce the size and cost of the engineered component of the scheme. In addition, they can take a long time to become established and they can also take large land areas, which leads to land-use trade-offs. Also, NbS can themselves be vulnerable to climate change. This highlights the continuing need for rapid reductions in GHG emissions from fossil fuels and other sources, to reduce climate risks to manageable levels and avoid deterioration of the ecosystems that underpin NbS. It also highlights the need to maintain healthy and resilient ecosystems, and to reduce external pressures such as pollution as far as possible (Sections 4 and 6.5).

It is beyond the scope of the CCRA3 Evidence Report to recommend how the risks it identifies should be tackled – that is the role of the NAPs. However, NbS are identified as one of the main types of potential 'beneficial actions' for adaptation, including through 'increasing plant diversity, habitat creation, peatland restoration, soil conservation, increased blue carbon (coastal and marine vegetation), green sustainable urban drainage and urban greening.' In Section 3 we show how NbS can tackle the main climate risks identified in the CCRA3 Evidence Report: coastal and inland flooding and erosion, water security, food security, heatwaves, and international impacts that affect (or can be affected by) UK activities.

3. NBS FOR ADAPTING TO SPECIFIC CLIMATE RISKS

3.1 COASTAL FLOODING AND EROSION

Around 126,000 people in the UK are at significant risk of coastal flooding (over 1 in 75 years), and this causes average damages to homes of £82 million per year.[18] Although most (102,000) of these people are in England, those at risk in Northern Ireland, Scotland and Wales face more than four times the expected annual damage costs.[19] In addition, coastal erosion threatens 8,900 properties in England (which could increase to 82,000 by the end of the century), 2,720 in Northern Ireland, 212 in Scotland and 400 in Wales.[20] As sea levels rise and storms become more frequent, the risk to homes, roads, railways, power stations and landfill sites across the UK will increase.[21] Under a high population growth scenario with 4ºC global warming, the annual damage caused by coastal flooding in the UK is projected to increase from £0.4 bn to £1.0 bn by the 2080s. It will become increasingly difficult to protect these assets with hard defences such as sea walls, tidal embankments and breakwaters. In England, for example, if sea levels rise by 0.5 to 1 metre, as expected, over 20% (200 km) of coastal flood defences will become vulnerable to failure in storm conditions.[8] In all parts of the UK, socially vulnerable communities are the most affected.

In response, local councils in many regions are drawing up Shoreline Management Plans which identify where to 'hold the line' or even 'advance the line' seawards with hard defences. Where this is not possible or prohibitively expensive, councils may be forced to adopt a policy of 'no active intervention'.

This means that local residents or even whole communities may eventually need to move to new homes, which can be devastating for those affected.

NbS offer additional coastal protection options, which may result in fewer people losing their homes. This involves protecting and restoring coastal habitats such as sand dunes, beaches, saltmarshes, kelp beds and seagrass meadows, which dissipate wave energy and reduce the height of storm surges, reducing the impact on built defences. For example, one study estimated that an 80-metre wide strip of saltmarsh could reduce the required height of a sea wall from 12 to 3 metres. This would save £2600 to £4600 per metre of wall, which equates to £300,000-£600,000 (in 1995 money) per hectare (ha) of saltmarsh — 100 times the price of Grade 1 agricultural land — or £6,000 per ha in sea wall maintenance costs.[22] A more recent study estimates that a 200 metre wide strip of saltmarsh could completely attenuate waves, avoiding the need to build a sea wall at a cost of £2,116 per metre, equating to a value of £105,000 per ha of saltmarsh.[23]

Coastal habitats are under threat, however, and better protection is needed to safeguard the free services they provide. For example, about 60% of England's coastline has some form of artificial defence, and 46% of these defences are buffered from waves and storms by coastal habitats,[24] but one fifth of the area of these habitats was lost between 1945 and 2010, mainly due to coastal development and conversion to agriculture or golf courses.[24] In Scotland, three quarters (£13 bn worth) of the buildings and infrastructure within 50 m of the shoreline is protected by natural defences such as sand dunes, rather than artificial defences such as sea walls,[25] but dunes are often targeted for golf course development. Another problem is caused by hard coastal defences such as groynes and breakwaters which can disrupt the natural movement of sand needed to maintain beaches and dunes. This can be mitigated by stabilising dunes using brushwood fences or planting with native grasses.[26]

Managed realignment of the shoreline restores saltmarshes to protect coastal communities. This typically involves building a new sea wall further inland, then breaching the existing sea wall in a controlled manner, allowing a saltmarsh to develop in the area between the old and new sea walls which floods at high tide. Over a period of several years, new saltmarsh vegetation will grow and this will trap sediment from the sea, gradually building up the level of the marsh. Although this method results in the loss of coastal farmland and sometimes some properties, it will protect communities behind the new sea wall from flooding and erosion. There can be high capital costs, depending on the purchase cost of the land to be flooded, the cost of rebuilding the sea wall in a new location (if needed) and the amount of earth-moving required. For example, in some locations the land needs to be re-profiled to a suitable height and gradient to enable saltmarsh to thrive while still protecting inland assets.

However, managed realignment can be more cost-effective than maintaining or rebuilding higher sea walls in increasingly exposed locations, and it also avoids the risk of catastrophic flood damages if the existing wall is breached, while delivering co-benefits such as carbon storage and opportunities for recreation and eco-tourism (see Section 5). Nevertheless, the benefits provided by newly restored saltmarsh can take many years to reach the level provided by existing saltmarsh, especially if the land was previously used for intensive agriculture.[27,28,29]

Shoreline Management Plans in England and Wales promote a managed realignment policy for over 9% of the coastline by 2030, creating over 6,200 ha of new intertidal habitat, rising to 14% (11,500 ha) by 2060. Although 69 projects have been implemented (2% of the coastline) the rate needs to increase by a factor of five (from an average of 6 km per year for 2000 to 2016 to 30 km per year) to meet those targets.[21,104] There are no coastal NbS projects planned in Northern Ireland, and few in Scotland, partly because much of Scotland's coast is rocky, although settlements and farmland are typically concentrated along the softer areas of coast.

Even after successful realignment, 'coastal squeeze' may continue as the newly created saltmarshes are eventually submerged by rising sea levels and the relocated sea walls prevent them from migrating inland in response. Long term planning as well as ongoing 'adaptive management' will be needed to enable dynamic coastal habitats to move and adapt to changing conditions.

IN SCOTLAND, THREE QUARTERS (£13 BN WORTH) OF THE BUILDINGS AND INFRASTRUCTURE WITHIN 50M OF THE SHORELINE IS PROTECTED BY NATURAL DEFENCES SUCH AS SAND DUNES, RATHER THAN ARTIFICIAL DEFENCES SUCH AS SEA WALLS, BUT DUNES ARE OFTEN TARGETED FOR GOLF COURSE DEVELOPMENT.

CASE STUDY 1:
MEDMERRY MANAGED REALIGNMENT, WEST SUSSEX

Medmerry is one of the largest open coast managed realignments in Europe. The site was previously farmland, and was defended by a shingle bank which cost up to £300,000 per year to maintain, but which was still breached almost annually, putting 348 houses, a wastewater treatment plant, the only road to Selsey and 3,000 holiday caravans at risk of flooding. A major storm in March 2008 caused over £5 million of damage to local businesses and some areas had to be evacuated. The Environment Agency, Chichester District Council and Arun District Council opted for managed realignment, building a new shingle bank further inland. They engaged with a local stakeholder advisory group to work through initial opposition to the project.

The aim was to create 183 hectares of intertidal saltmarsh and mudflat habitat and 263 hectares of other priority habitats, as well as enhancing 3,402 hectares of SSSI (Site of Special Scientific Interest) from ‘unfavourable’ to ‘recovering’ condition. The scheme was implemented between 2011 and 2013, creating a nature reserve that is managed by the RSPB, together with 10 km of new footpaths and cyclepaths. The new habitats were quickly colonised by a variety of wading birds, with avocets and black-winged stilts breeding in 2014. [30]

The annual risk of flooding was reduced from 100% to 0.1%, estimated as saving £78 million (present value over 100 years). Other benefits were estimated to be worth £90 m over 100 years, mainly in terms of the ‘existence value’ of the biodiversity on the site (£87 m, based on a willingness-to-pay of £0.05 per ha per household within 50km per year, from a survey of a similar site in the same region), plus carbon (£3.3 m), recreation (£6.3 m) and fish production (£60,000), with a loss of -£2.9 m from lost arable crop production. Although these cost estimates are highly uncertain, the analysis indicates that the benefits far exceed the project cost of £28 m. Standard methods for appraising the viability of flood and coastal erosion risk management (FCERM) projects do not include a full evaluation of all ecosystem service co-benefits and therefore could underestimate the benefits of these schemes.[31,32] However, as the new habitat was used to ‘offset’ predicted future losses of internationally designated habitat elsewhere in the Solent due to coastal squeeze, enabling other flood and coastal erosion risk management schemes to be implemented, the total net impact should take these habitat losses into account.

ADDITIONAL EXAMPLES OF MANAGED REALIGNMENT

WALLASEA ISLAND, ESSEX

The RSPB's Wallasea Island Wild Coast Project in Essex has created 115 ha of intertidal saltmarsh habitat through managed realignment. This helps protect the adjacent land from coastal flooding and sea level rise.

HESKETH OUT MARSH, RIBBLE ESTUARY, LANCASHIRE

The RSPB, the Environment Agency and Natural England created a 180 ha wildlife-rich saltmarsh by natural flood management. The land was reclaimed from the estuary for agriculture in the 1980s by creating an outer wall, but stronger flood resilience was needed to help protect the local community. Funding for managed realignment allowed improvements to the inner sea wall (which would not otherwise have qualified for funding), cutting flood risk to 1050 ha of land from 1 in 50 years to 1 in 200 years, and the saltmarsh helps to protect the new sea wall from wave erosion.[33] Hesketh has attracted a wide variety of wading birds, including avocets, little egrets, redshank, teal and wigeon.[34]

STEART MARSHES, BRIDGEWATER, SOMERSET

Steart Marshes are a new wetland complex including freshwater, brackish and saline habitat created from former arable land by the Environment Agency and the Wildfowl and Wetland Trust. Water levels are controlled, and flood risk has been reduced by attenuating and storing floodwaters, while the marshes are estimated to sequester 92 $tC0_2$/ha/yr. Nationally important wintering populations of avocet, black-tailed godwit, lapwing, little egret and shelduck use the marshes, and visitor numbers have increased from approximately 11,000 in 2010 to over 49,000 in 2019. Food production continues, as local farmers raise saltmarsh lamb and beef, which is highly valued for its flavour. The total value of these benefits has been estimated at £491,155 to £913,752 per year.

Wallasea Island managed realignment project

© DAVID WOOTTON / DW PHOTOGRAPHY

Black-winged stilts at Steart Marshes

© PAUL MARSHALL / WWT

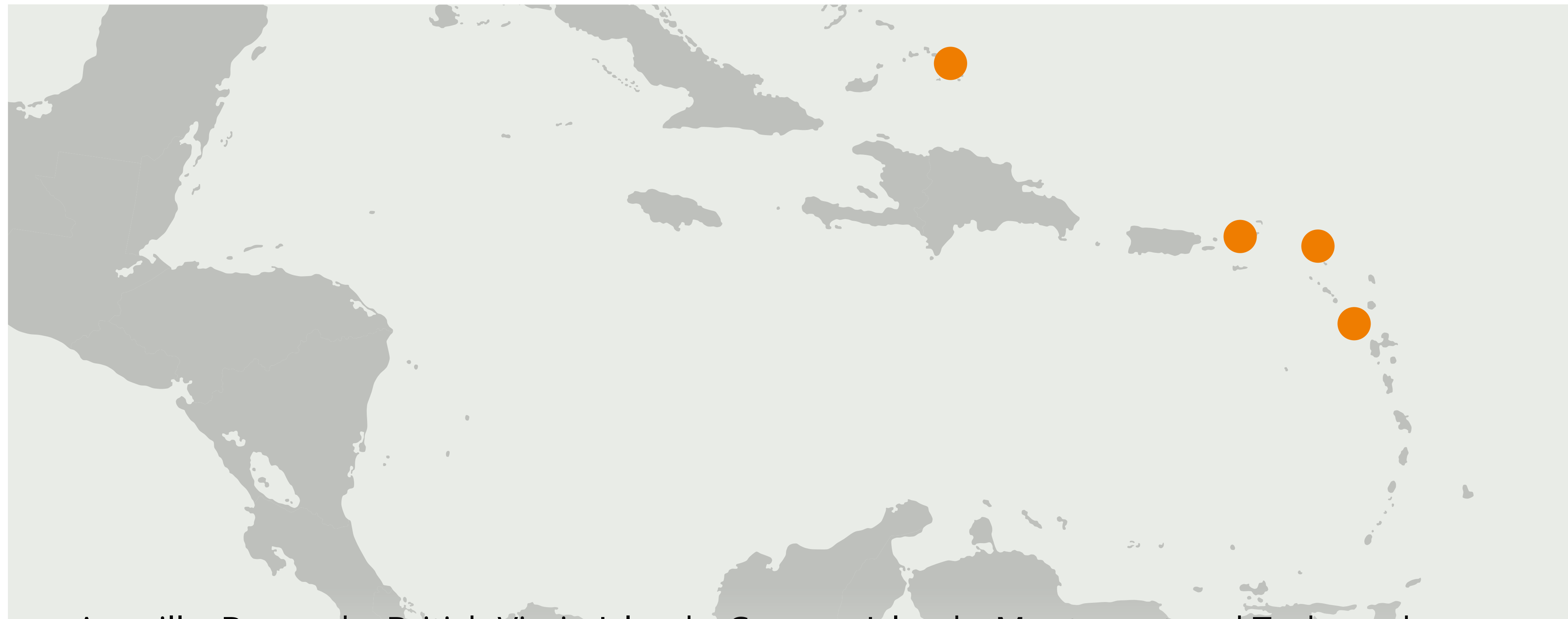
Seagrass meadows, kelp forests and cold-water reefs formed by corals, mussel beds and oysters can also attenuate waves, stabilise sediments and thus protect against coastal flooding and erosion. Coastal and marine habitats work in synergy with each other. For example, reefs and seagrass offshore can help to protect saltmarshes from erosion, while oysters help to clean seawater as they filter-feed, which is essential for seagrass to flourish, and saltmarshes and seagrass act as nurseries for the larvae of reef-building organisms such as shellfish. However, all these habitats are in decline. The area of seagrass meadows that once surrounded the UK has halved in the last 25 years[35] and 92% of seagrass habitat may have been lost in the UK in total, due to dredging, bottom trawling, coastal reclamation, pollution (including toxic minewater discharges) and overfishing of oysters.[36]

Marine Protected Areas have a vital role to play in safeguarding the remaining habitats, and there are also restoration efforts in progress such as a collaboration between Project Seagrass, Swansea University, WWF and Sky Ocean Rescue in west Wales.[37] In West Sussex, coastal protection from kelp forests was estimated to be worth £179 per ha, and restoring kelp forests to their full potential extent was estimated to have a coastal protection value of £1.2 million, and a total value of £3.2 million including the co-benefits for fish production, carbon sequestration, water quality regulation, recreation and tourism.[38]

In the UK overseas territories, coral reefs and mangroves can also provide coastal protection during extreme events such as hurricanes (Case study 2). A global review of 52 projects found that marine habitats such as reefs,

CASE STUDY 2:

MANGROVE AND SAND DUNE RESTORATION FOR HURRICANE PROTECTION IN THE CARIBBEAN UK OVERSEAS TERRITORIES



Anguilla, Bermuda, British Virgin Islands, Cayman Islands, Montserrat and Turks and Caicos are highly vulnerable to hurricanes. Hurricanes Irma and Maria cost $3.6bn and created many climate refugees. Coral reefs, mangroves, seagrass meadows and vegetated sand dunes provide vital coastal protection but have been cleared and degraded due to coastal development. Loss of these habitats also affects the tourism and fishing industries, which underpin local economies. The UK government recently provided new funding to help implement a *'Ridge to Reef'* approach to integrated watershed and coastal management. This aims to designate and protect primary intact ecosystems, restore degraded ecosystems such as riparian vegetation and wetlands, stabilise dunes and invest in sustainable agriculture.

Spatial planning can help to prioritise locations for restoration. On Anguilla, consultants at Environment Systems Ltd. produced flood risk and opportunity maps to prioritise six locations for mangrove restoration, based on sea depth, elevation and proximity to existing mangroves. Targeted restoration could protect large hotel resorts, as Anguilla is highly dependent on tourism. The islanders have established a nursery for mangroves and sand dune species, and youth groups help with planting.[41] Mangroves are also being restored in other overseas territories including the British Virgin Islands, with funding from the UK government's Darwin Plus initiative.[42]


Mangroves in the Caribbean

mangroves and saltmarshes were 2 to 5 times more cost-effective at lowering wave heights than engineered structures, for waves of less than 0.5m, and the cost-effectiveness increased in deeper water where installing engineered structures such as breakwaters was more expensive.[39] Globally, the cost of coastal floods would double and the cost of storms would triple in the absence of coral reefs.[40]

3.2 INLAND FLOODING AND EROSION

Almost 1.8 billion people in the UK are currently exposed to a significant risk of inland flooding (defined as being more than 1 in 30 years for surface water flooding and more than 1 in 75 years for fluvial flooding), with socially disadvantaged communities facing a higher risk on average.[18] Most of these people (1.5 million) are in England, but those in Scotland (142,000), Wales (138,000) and Northern Ireland (32,000) face higher expected annual damages and a higher ratio of uninsured losses to income ('relative economic pain').[18] Flooding also threatens vital energy, water, transport, health and education infrastructure, including 178 power stations, 575 substations, 650 clean water sites, 1,400 sewage treatment works, 3,500 km of rail lines and 10% of hospitals.[8] The annual cost of inland flooding is £1.7 billion, and this is projected to rise to £2.8 billion under a high population growth scenario with 4°C of global warming under current levels of adaptation.[18]

Large areas of prime agricultural land are also projected to be affected by more frequent flooding.[18] Heavy rain in conjunction with intensive cultivation leads to soil degradation and erosion, as can a combination of drought and strong winds in areas where soils are fine, dry and easily blown away, with around 2.9 Mt of soil being lost from erosion in England and Wales each year.[9] This has a knock-on effect on water quality, as soil polluted with agro-chemicals gets washed into watercourses.

There has been growing interest over the last few decades in the potential for 'natural flood management' (NFM) approaches to help tackle flooding and erosion. NFM can involve protecting, enhancing or creating a range of habitats, including woodland, shrubs, hedgerows, heathland, semi-natural grassland, peat bogs, wetlands and sustainable drainage systems (SuDS), as well as improving the way agricultural soils are managed. These measures help to reduce flooding and erosion in a number of different ways (Box 2).


Nature-friendly SuDS channel at Woodberry Down, Hackney, London

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BOX 2: HOW NATURAL FLOOD MANAGEMENT (NFM) CAN PROTECT FROM FLOODING AND SOIL EROSION

EVAPO-TRANSPIRATION

- Vegetation intercepts rainwater, which then evaporates before it can reach the ground
- Vegetation draws up rainwater from the ground through the root system, and releases it from leaf pores (transpiration)

INFILTRATION

- Plant roots help to make the soil more permeable so that rainwater soaks into the ground faster.
- A healthy soil structure, with plenty of organic matter and open pores (not compacted), will enable water to infiltrate into the ground more easily, and will increase the amount of water that can be stored in soils.

SLOWING THE FLOW

- Vegetation and leaf litter can physically slow the flow of water over the surface.
- 'Leaky dams' of tree trunks or branches can be built to slow the flow of water down a stream or gully. Beavers can also do this, creating ponds and wetland areas behind the dams.
- Rivers that have been straightened can be 're-meandered', and natural features such as gravel banks and large woody debris can be reintroduced to help slow the flow of floodwater.

STORING WATER

- Small bunds (earthbanks) can be built across slopes to help retain water in temporary ponds.
- Rivers that have been constrained within embankments can be reconnected to their floodplains so that floodwater can spill out of the river onto adjacent land, where it can gradually soak away.
- New ponds or wetland areas can be created on floodplains to help store water.

PROTECTING AND STABILISING SOIL

- Dense ground cover such as a thick layer of grass, herbaceous vegetation or leaf litter can intercept heavy rainfall and thus prevent erosion of the underlying soil.
- Plant roots help to bind together soil particles, reducing erosion and stabilising slopes against landslides.
- Dense ground cover can trap sediment, preventing it from being washed away by heavy rain.
- Reducing soil erosion using the methods above will help to stop watercourses from filling up with sediment, so that they retain their capacity to channel floodwater away.

SUSTAINABLE DRAINAGE SYSTEMS (SUDS)

- A suite of measures that apply the principles above can be deployed to reduce surface flooding and treat polluted runoff (Section 3.2.5). SuDS components include green roofs, green walls, trees and green spaces to slow and retain water, as well as permanent 'retention ponds', temporary 'detention ponds' and 'raingardens' with wetland plants, which can all be linked by vegetated channels known as 'bioswales'.[140]

Raingarden, Finland

NFM measures can have a significant impact on flood risk, especially when implemented widely across a catchment, but they are unlikely to be able to provide complete protection against the most severe flood events. After periods of prolonged rain, the ground and wetlands may become saturated so that infiltration no longer occurs, and the capacity of flood storage ponds may be exceeded. However, vegetation can still slow the flow to some extent through evapotranspiration and by providing a physical barrier. NbS can reduce the pressure on hard flood defences such as embankments, thus reducing maintenance costs and potentially reducing the size of the structures needed.

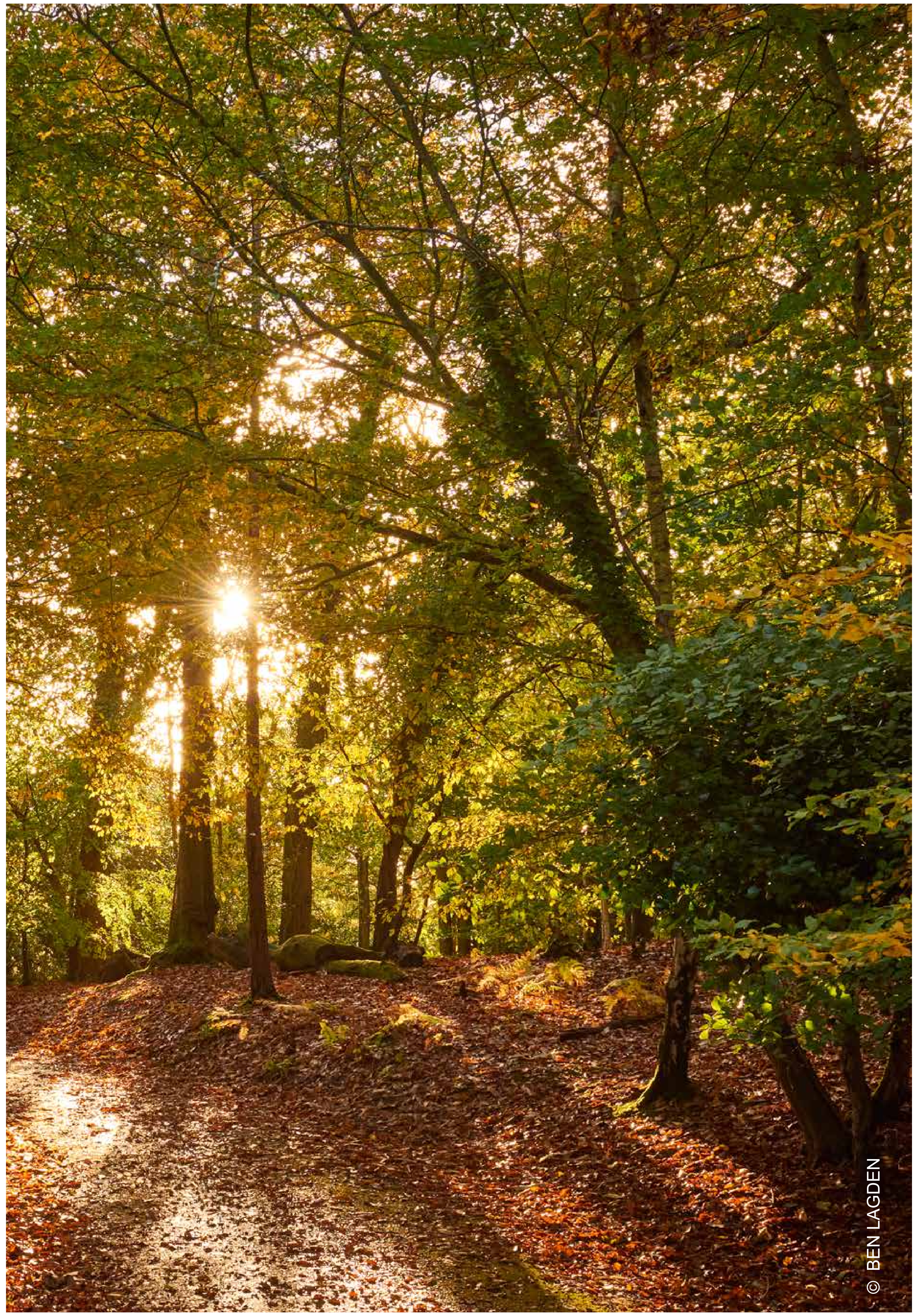
The Royal Society review of resilience to extreme weather found that ecosystem-based measures are more affordable than engineered measures and are mid-range in effectiveness, while SuDS, a hybrid option, can be more costly than other NFM measures but also more effective.[17] The British Ecological Society (BES) review of NbS provides a good overview of evidence on the effectiveness of NFM for flood reduction, in the chapters on freshwater systems[43] and peatlands.[44] Below we summarise some evidence on the effectiveness of the different components of NFM, but it is important to emphasise that these should be considered as part of a catchment-wide system.

3.2.1 WOODLAND, SHRUBLAND AND HEDGEROWS

Protecting and restoring woodlands, shrubland and hedgerows can reduce flood risk via the mechanisms described in Box 2: intercepting and soaking up rainwater, slowing surface flow and improving infiltration. The impacts depend on a number of factors, including the size and topography of the catchment, the area, age, species composition and location of the ecosystem, soil characteristics and rainfall patterns.

Evidence from the UK shows that woodland planting and other NFM measures are effective in small catchments (<20km^2) but there is less evidence for larger catchments (>100km^2).[45,46,47] Looking beyond the UK, however, there is good evidence from North America that forest cover of at least 30% in a catchment significantly reduces peak flows.[48] Most evidence concludes that woodland cover has less impact on more extreme flood events, but emerging evidence from a paired catchment study at Haweswater in Cumbria shows that semi-natural broadleaf woodlands can reduce peak discharge by up to 60% compared with pasture for both small and large storms. This is partly because the woodland soils are 3 to 7 times more permeable than the pasture.[49] Across all the flood risk catchments in Great Britain, Forest Research estimates that woodland provides a flood protection service equivalent to at least £718 million per year, compared to the cost of building flood storage reservoirs to offer equivalent protection if the woodland was replaced with managed grassland.[50]

Strategically planted woodland can have an impact at small scales. The well-known farmer-led initiative at Pontbren in Wales showed that planting narrow strips of woodland as shelter belts across farmland slopes could reduce local peak flood flows by up to 40%, and infiltration was 60 times higher within the shelterbelts than in the nearby grazed and compacted grassland, even just a few years after planting.[51] The depth of infiltration was affected by the shape of the tree roots, with ash trees providing deeper infiltration than birch.



The soils of semi-natural broadleaved woodlands have high rainwater infiltration rates, helping to protect from flooding.

The Environment Agency has developed a 'Working with natural processes' opportunity map[52] to target woodland planting for flood reduction in three key zones:

1. Riparian zones, within 50m of water courses, where trees can prevent or delay runoff from entering streams;

2. Floodplains, on the basis that trees can physically 'slow the flow' of water (note that this leads to a trade-off with restoration of floodplain meadows; see Section 4.2 and 4.4);

3. Soils with impeded drainage, where trees could help to improve infiltration.

As evergreen species retain their leaves all year round, they would be expected to deliver a greater flood protection service in winter than deciduous species. However, there is evidence that diverse natural forests of native broadleaved species could be more resilient to climate change (and thus deliver better protection in the long term) than non-native monoculture conifer plantations (which are unlikely to be NbS because of low biodiversity benefits).[53,136] Native evergreen species (Scots pine, yew, juniper and holly) as part of a diverse forest could help to offer good flood protection all year round.

There is potential for trees, shrubs and grasses to help stabilise embankments and cuttings alongside the UK road and rail network, of which approximately 8% is at risk of landslide disruption, especially during cycles of drought and heavy rain.[54] CCRA2 and UK NAP2 focused exclusively on further control of lineside vegetation to reduce storm damage, including from fallen trees and leaves on the line, and embankment stabilisation was presented purely as an engineering challenge.

In contrast, the CCRA3 Evidence Report recognises that removing trees is likely to increase landslide risk, and notes the potential to address slope stability through the use of the binding properties of plant roots.[9] There could be potential to investigate the use of shorter trees or shrubs, including native evergreen species that reduce the leaf loss issue (such as holly or juniper), to assist with cost-effective slope stabilisation. In fact, the Welsh government is investigating tree and shrub planting for earthwork stabilisation along the trunk road network as part of a 'Green Corridors' programme announced in 2018.[55]

3.2.2 UPLAND PEATLAND AND HEATHLAND

Upland peat moorland and heathland has been heavily degraded in the UK, due largely to drainage, overgrazing, air pollution and burning (e.g. to produce young heather shoots to feed grouse on shooting estates). These practices dry out the soil and kill the peat-forming sphagnum mosses, leading to large bare and eroded areas. Moorland degradation has been implicated in a series of large floods, including in Doncaster and the Calder Valley.[56]

There is growing awareness of the multiple benefits that healthy peatland provides, including flood risk reduction but also carbon storage and sequestration (see section 5.1), water supply (section 3.3), biodiversity (section 4) and recreation (section 5.2). Peatlands can be restored by blocking drainage gullies to re-wet the bog, and replanting sphagnum mosses or, alternatively, reseeding with a grass 'nurse crop' and heather mulch that stabilises the eroded surface and allows peatland vegetation to re-establish. On Kinder Scout in the Peak District, reseeding reduced peak storm discharge by 59% after four years, with dramatic reductions seen even in the first two years, as the re-vegetated moorland was able to 'slow the flow' of water.[57]

Restoration of heathland is also important for climate adaptation. Although heather on deep peat is considered to be degraded peat bog, heaths on shallower peaty soils are a valuable habitat in their own right. Restoring heathlands by blocking artificial drainage and reducing overgrazing can reduce flood and wildfire risk.[58]

National governments are funding peatland restoration across the UK. In Scotland, over 25,000 hectares have been restored since 2012 under the Peatland Action Plan, and a further £250 million will be invested over the next 10 years to restore 250,000 ha by 2030.[59] The National Peatland Action Programme in Wales is funding the restoration of 600-800 ha per year from 2020 to 2035.[60] In England, a £10m peatland grant scheme started in 2018, involving four local partnership projects and aiming to restore 6,580 hectares, around 1% of England's upland and lowland peat.[61]

The new England Peat Action Plan[62] commits the government to provide £50 million under the Nature and Climate Fund for restoration of 35,000 ha by 2025, after which further funding will be delivered under ELMS, the new Environmental Land Management Scheme. In Northern Ireland, although only 1% of peatlands have been restored over the last 30 years, including by NI Water (see Section 3.4), there are plans to provide more funding for restoration as part of the developing Northern Ireland Peatland Strategy.[63] Other organisations are also involved, including the EU funded Moors for the Future partnership, and the National Trust which owns 21,000 ha and is restoring over 3,000 ha.[61] The Committee on Climate Change (CCC) has called for certain landowners to be obliged to restore their peatland, including water companies and owners of peatland within sites of special scientific interest (SSSIs).

As well as actively restoring peatland it is also important to halt further damage. The Scottish Government has committed to introducing a ban on peatland burning, and will review the definition of peatland as being only those areas with over 50 cm depth of peat, and the England Peat Action Plan also commits to ban burning but only on Natura 2000 sites (i.e. those protected at European level). Similar ambitions are being considered by the governments in Northern Ireland and Wales, supported by the advice of the Climate Change Committee, and all four nations are seeking to end the use of peat for horticulture.[63]

3.2.3 GRASSLAND AND CROPLAND

Grassland protection and restoration tends to be overlooked as a climate adaptation NbS option, but semi-natural grasslands with good soil structure and dense vegetation can be effective in reducing overland flow and promoting rainwater infiltration into the soil. Floodplain meadows are a particularly attractive option: reconnecting floodplains to the river offers opportunities for floodwater storage and infiltration, as well as restoring a scarce habitat, as 97% of Britain's floodplains have been converted to intensive farmland or development. However, there are conflicts with the drive to plant trees, as floodplains and riparian zones have been targeted for tree-planting in the 'Working With Natural Processes' maps (see Section 3.2.1).[64]

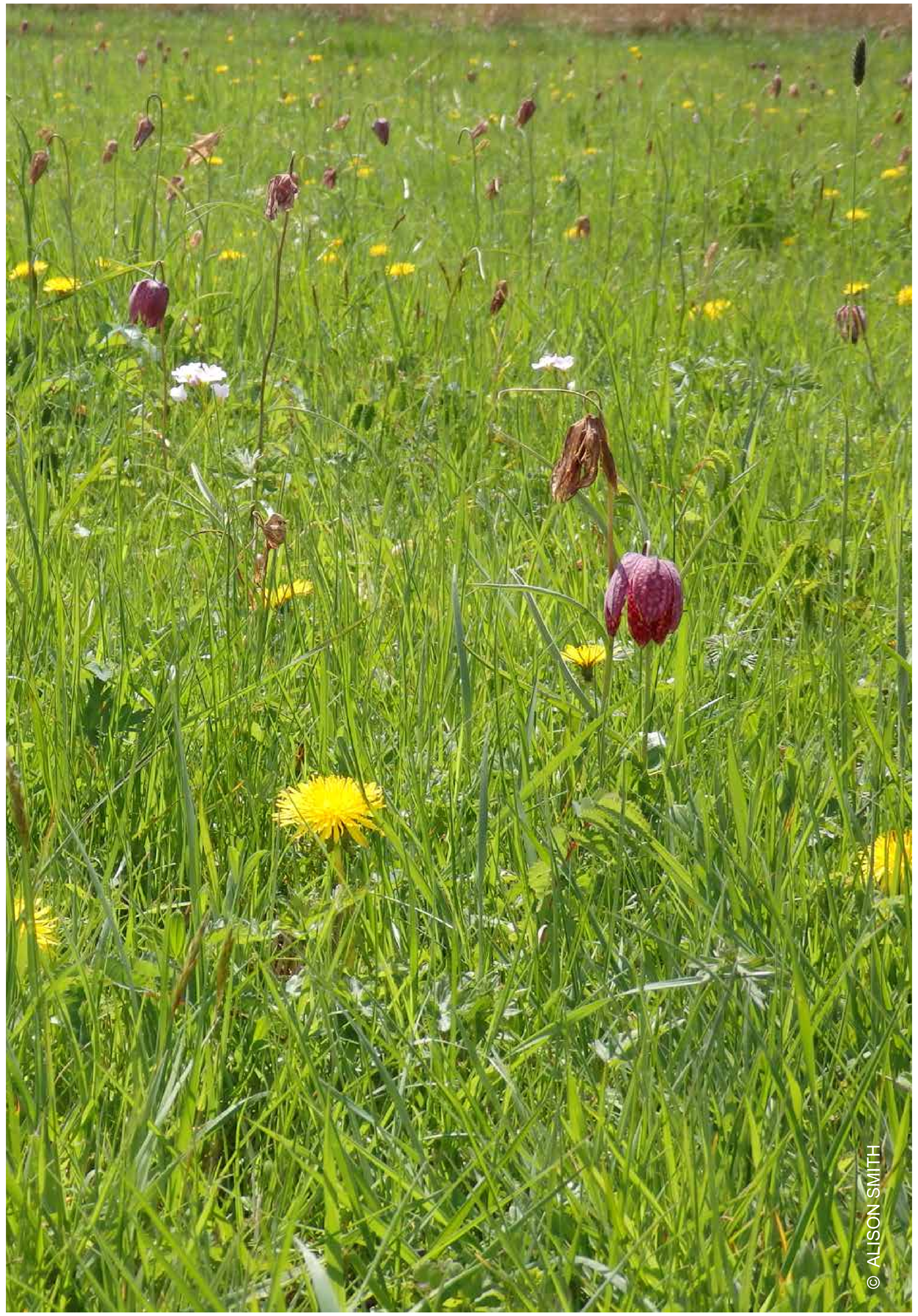
In contrast, intensively managed pasture ('improved grassland') can become compacted and overgrazed, leaving a short sward and reducing the infiltration of rainwater. Reducing livestock stocking density and letting the sward grow longer can improve the soil structure, helping to reduce flood risks.[65] This will reduce food production in the short term, but it will help to improve the long-term resilience of the farmland.

Arable land can also become compacted due to the use of heavy machinery. Cultivation on slopes can give rise to 'muddy floods' that can flow down roads and into houses, especially on erodible soil types and for certain crops such as maize and potatoes.[66] For highly vulnerable fields the best option is to convert to grassland, but there are a range of NbS options to help reduce flood risk. These include the use of buffer strips of long grasses and shrubs to intercept surface flow and trap sediment, as well as woodland strips or hedgerows across slopes, and silvo-arable (rows of trees amongst crops). Other agro-ecological farming methods can also help to reduce flood risk, including the use of cover crops so that the soil is never left bare; reduced tillage; and incorporation of additional organic matter into the soil to improve infiltration (Box 3).

3.2.4 FRESHWATER AND WETLANDS

Many rivers and streams in the UK have been artificially straightened and 'canalised', i.e. they now run between embankments. In heavy rain, runoff from the catchment shoots straight down the river and can cause flooding downstream. Flood peaks can be reduced by removing embankments so that floodwater can flow onto the floodplain, as well as re-introducing natural features such as meanders, gravel banks, woody debris and 'leaky dams'. More radically, beavers can accomplish the same effect by acting as 'ecosystem engineers,' creating a series of natural dams, pools and wetlands that delay the passage of floodwater (Case study 3).

Not all wetlands contribute to flood protection, as some are saturated for most of the year, especially in upland areas. However, wetland restoration projects in lowland areas offer the opportunity to build in flood control measures (Case Study 3).



Floodplain meadow, Oxfordshire.

There can be challenges in predicting the outcome of NFM interventions, and adverse impacts can arise if delaying the flood peaks in some tributaries means that they eventually arrive at the same time as flood peaks from other tributaries, thus increasing the height of the overall peak. However, the opposite is also true - NFM could be used to manipulate the timing of peak stream flows so that they are not synchronised, thus reducing the peak flow at the catchment outlet.[69]

River and wetland restoration, along with other NFM measures, are best implemented as part of a catchment-wide approach. The Stroud Frome catchment in south-west England provides a good example. A project officer worked with individual farmers and landowners to organise hundreds of small NFM interventions such as leaky dams, ponds and tree planting. Some 20% of the catchment is now drained through NFM interventions, and it is estimated that this has reduced the river height by 1.4 m. The introduction of large woody debris alone was estimated to provide £1.7 million in flood reduction benefits with a cost: benefit ratio of 6:1.[70] Similarly, restoration of Eddleston Water in Scotland was shown to reduce flood peaks as well as restoring the ecology of the river (Case Study 4).

CASE STUDY 3:
NATURAL FLOOD MANAGEMENT BY WETLANDS

BEAVERS ON THE RIVER OTTER, DEVON

Beavers were re-introduced to the River Otter in 2015 as part of a five-year trial. By 2019, the original two families had expanded to occupy 13 territories, creating 28 dams on tributaries in the catchment, and impounding almost 2km of rivers. On one of the side-streams, the dams reduced the flood risk to a downstream village. However, the dams also created some localised flooding of farmland elsewhere, which was managed by volunteers removing dams, reducing their height or installing flow bypass devices ('beaver deceivers') when necessary. The diverse and ever-changing mosaic of wildlife-rich ponds and wetlands has led to increased populations of water voles, amphibians, trout and lamprey, and the beavers have attracted eco-tourists and are welcomed by most local residents. However, it is important that a pro-active approach to managing conflicts and compensating for any losses continues, if the beaver re-introduction is to be sustainable. [67]

WICKEN FEN, CAMBRIDGESHIRE

Most of the Fenlands have been drained for arable farming. As the peat dries out, it oxidises and then subsides, so that most of the farmland is below sea level. Rivers now run between raised embankments three metres above the fields, posing a serious flood risk if embankments or pumps fail. At Wicken Fen, owned by the National Trust, arable land was restored to lowland fen and part of the site was converted to a flood storage area capable of dealing with a 1 in 20 year flood event. This is estimated to protect 53 houses and 50 ha of farmland from flooding, providing flood protection benefits of £35 /ha/y, as well as gains of £482/ha/y in nature-based recreation and £51 /ha/y in GHG reductions. [68]

GREYLAKE NATURE RESERVE, SOMERSET

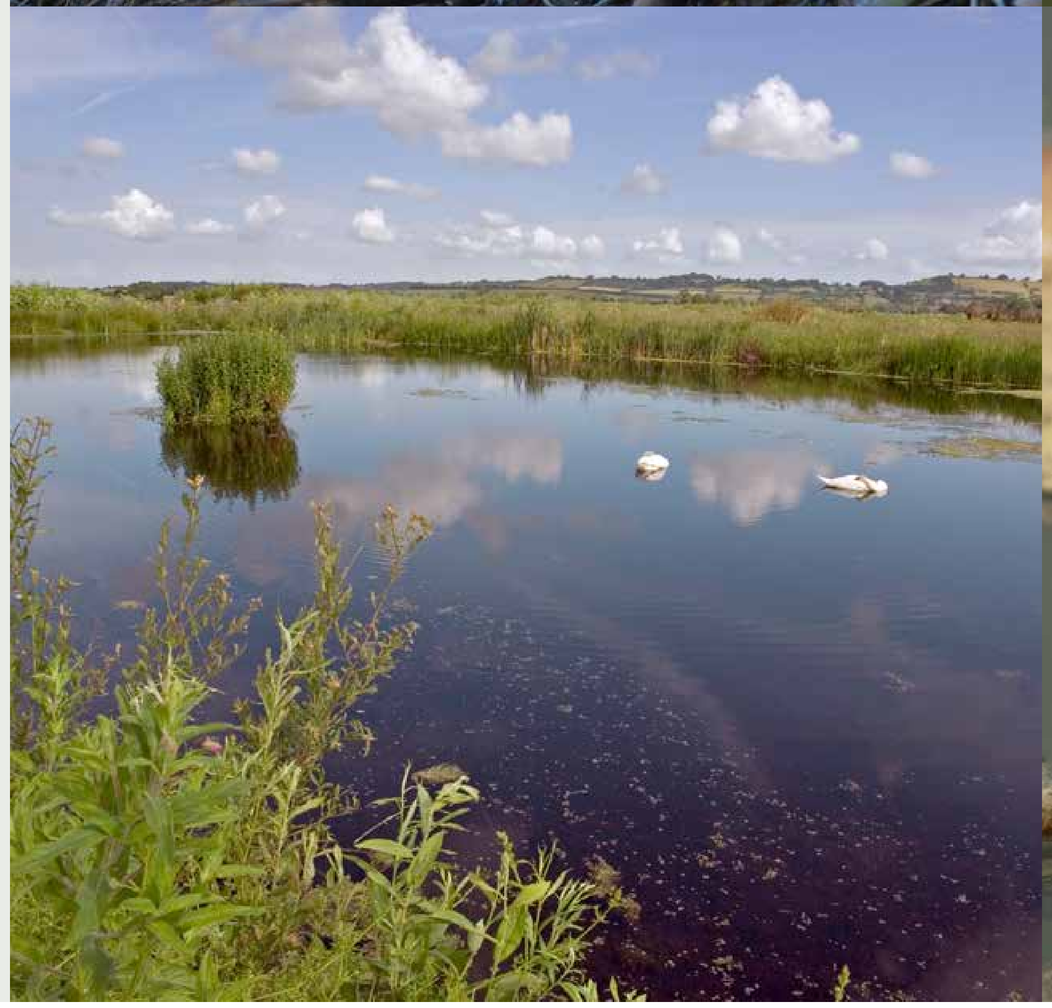
110 ha of deep-drained arable land was restored to wet grassland, reedbed and wet fen. Structures were installed to raise water levels by 80 cm, increasing the amount of carbon stored in peat and holding up to 1.1 million cubic metres of water at times of peak flood.

Further information can be found on the **RSPB website**

ST. AIDAN'S, AIRE VALLEY, LEEDS

The RSPB, the Environment Agency and Leeds City Council have converted a former opencast coal mine into a 400 ha inland wetland nature reserve, which reduces flood risk to the local community and provides a home for nature.

Further information can be found on the **RSPB website**



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CASE STUDY 4:
EDDLESTON WATER, SCOTLAND: RIVER RESTORATION AS PART OF NATURAL FLOOD MANAGEMENT

Eddleston Water in Scotland was a straightened river in a heavily grazed catchment, with 500 properties downstream at risk of flooding. Despite being a Special Area of Conservation, important for salmon, lamprey and otters, the river had 'bad' ecological status under the Water Framework Directive assessment.[71]

The Tweed Forum led a catchment management project to investigate the potential for natural flood management, with funding from the Scottish Government, the EU Interreg programme and the Scottish Environment Protection Agency. Acting as a 'trusted intermediary', they worked with local landowners to plant over 200 ha of native trees in the upper catchment, create cross-slope hedgerows and install 116 log barriers on high tributaries (above the level used by migratory fish), to create small wetlands. They also created 28 flood storage ponds, re-meandered three km of the main river and removed embankments, reconnecting the river with its floodplain. Gravel banks, riffles and pools formed in the restored river, leading to an increase in spawning salmon and other fish, and the river ecological status improved from 'bad' to 'moderate'.

The catchment was well monitored with a network of stream and rain gauges, and had 12 years of baseline data before the interventions. Analysis showed that flood peaks were reduced by 30% and delayed by over four hours, avoiding £950,000 of flood damages. Further benefits for carbon storage, water quality, recreation and aesthetic value were estimated to be worth £4.2 million net present value over 100 years. It was estimated that expanding the scheme through additional NFM measures would deliver a further £17.7 million of co-benefits on top of £2.85 million flood damages avoided.[43,72]


© TWEED FORUM

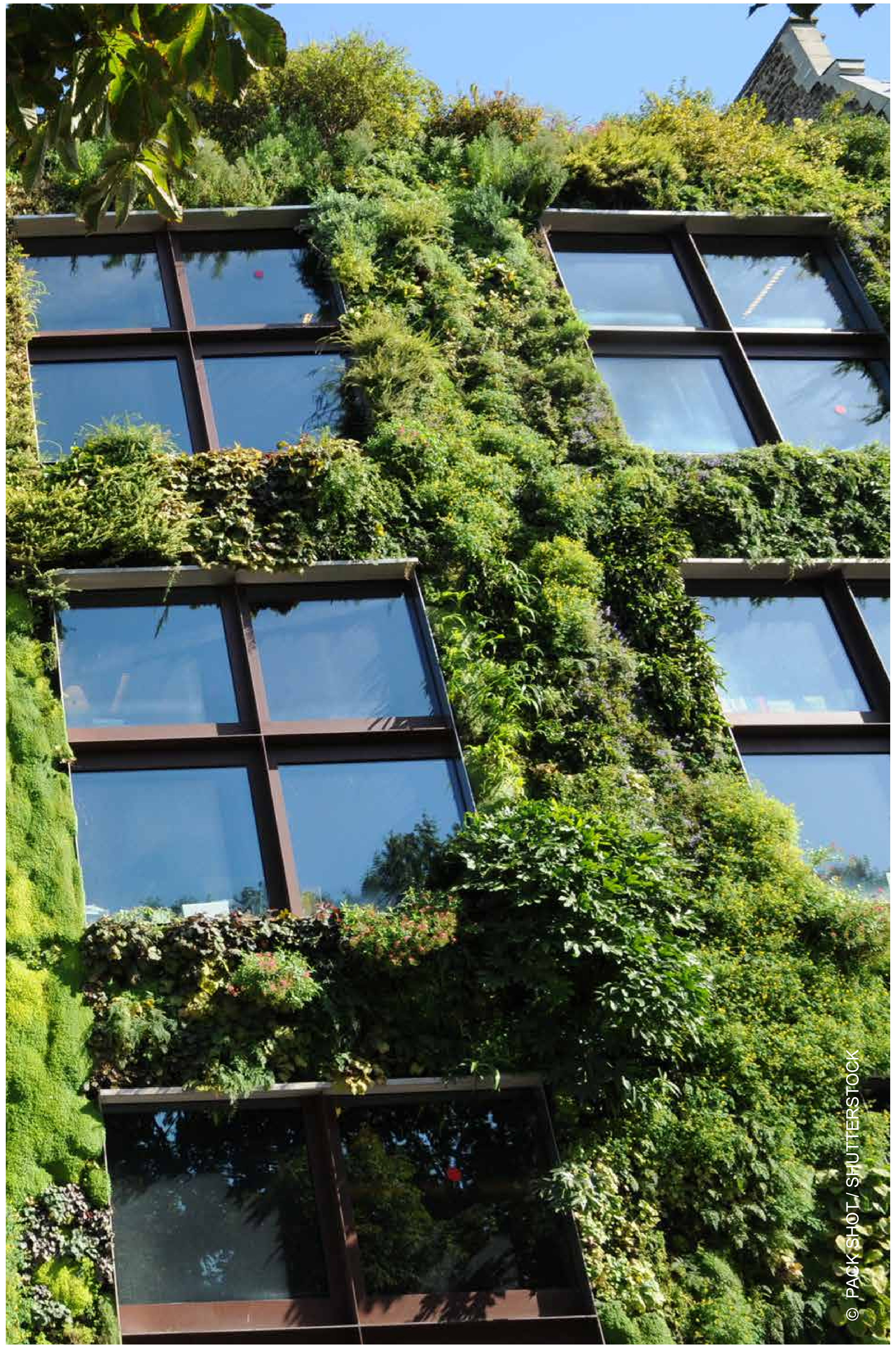
3.2.5 SUDS AND OTHER URBAN GREEN INFRASTRUCTURE

As extreme rainfall events become more frequent due to climate change, and the area of sealed surfaces increases, existing drainage systems will come under increased strain. In England, for example, half of the sewer network is already at maximum capacity. Investment in maintenance needs to increase by a factor of six in England and Wales to keep the sewer system functioning.[18] Installing and maintaining conventional drainage systems to cope with higher runoff volumes will become increasingly expensive.

SuDS (Box 2) offer a far more sustainable way to manage runoff, by tackling it before it enters the sewer network. Water can be intercepted by urban trees; it can soak into green roofs, green walls and urban green spaces; and it can be channelled into ponds, raingardens or wetlands via a system of bioswales. As well as preventing flooding, these systems can allow water to soak into the ground, thus recharging groundwater reserves, and they can also filter out pollutants (see Section 3.3), and provide biodiversity benefits and amenity value. SuDS have cheaper capital costs than traditional drainage systems and usually also cheaper operation and maintenance costs,[73] for example, saving over £500,000 (a 67% reduction) in creation and maintenance costs over 100 years in a large industrial and residential complex in Scotland.[74] The IGNITION project in Greater Manchester has compiled an extensive evidence base on the multiple benefits of the different components of SuDS (green roofs and walls, infiltration ponds and strips, trees and green spaces).[79]

Uptake of SuDS varies depending on policies in each of the UK countries. In England, planning policy states that SuDS should be integrated into all new developments, but weak standards mean that most of the schemes implemented are basic underground tanks and pipes (see Section 6.4).[75] In contrast, SuDS systems that deliver both flood protection and water quality benefits are mandatory in Scotland, and there are statutory standards and approval processes in Wales that encourage uptake of high quality systems with biodiversity and amenity benefits.[218] In Northern Ireland, planning policy states that SuDS are the preferred option for surface water management in new developments but there is a lack of evidence that they are being widely implemented in practice.[76] Retrofitting SuDS into existing developments is challenging, but there are emerging examples such as the RainScape initiative in Wales (Case Study 5)[77] and Slough 'sponge city'.[78]

Green roofs, which can be used as part of a SuDS system or as a standalone option, retain rainfall and delay runoff substantially compared to conventional roofs.[79] Studies in Germany showed that extensive green roofs with a substrate between 60 mm and 100 mm deep can intercept 50% of annual rainfall, and roof gardens, with soils typically 500 mm deep, can intercept up to 90%.[80] In the UK, 80 mm deep green roofs have been shown to retain 80% of the rainfall from events of 10 mm or less, but this capacity falls as the rain becomes heavier due to spatial limits on the water storage capacity.[81] 'Blue roofs' are a novel development, where rainfall is stored in a cellular mat beneath a green roof, or as a pond or wetland on the roof. The water stored can be released in a controlled manner, and/ or can be used to irrigate a green roof or green wall.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CASE STUDY 5:
RETROFITTING SUSTAINABLE DRAINAGE IN WALES

Welsh Water (Dŵr Cymru) has been investing in sustainable drainage projects around Wales to reduce the risk of surface flooding and water pollution due to overloading of combined sewer systems during heavy rain. They have worked with local communities to successfully retrofit SuDS into existing urban areas while still leaving space for parking and other needs.

In **Greener Grangetown,** a £2 million partnership with Cardiff Council, Natural Resources Wales and the Landfill Communities Fund, over 100 raingardens and 135 trees were added in 12 Victorian streets, leaving parking spaces in between.[82] The project used a diverse mix of native species of trees, shrubs and grass, creating attractive green space as well as a 'bicycle street' and a community orchard. Rather than pumping surface water eight miles to a treatment plant, the water is now cleaned by the raingardens and then discharged directly into the Taff river, reducing energy use and water treatment costs considerably. The benefits that could be quantified were estimated as being over £8 million up to 2045.[83]

In the **RainScape** programme, Dŵr Cymru invested £115 million between 2021 and 2020 in Llanelli and Gowerton, overcoming technical challenges such as the fact that some of the area was built on contaminated land and old mine workings, where infiltration was not possible. They created 12 SuDS basins and installed 45 planters, taking 41 houses off the flood risk register, and also created an outdoor education area with a pond, swale and playground at a primary school, co-designed with the children.[84]

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3.3 WATER SECURITY

16.7 million people in the UK already live in water-scarce regions, and climate change is expected to exert further pressure on UK water supplies.[8] Many parts of the UK will experience hotter, drier summers and more frequent and prolonged droughts, leading to water shortages. The pressure will be particularly severe in southern England where there is already over-abstraction of surface and groundwater, causing chalk streams to dry up, and population growth is expected to exacerbate this issue. Climate change is also expected to lead to water quality problems, as heavier rainfall events exacerbate soil erosion, runoff and associated pollution of surface water supplies, and can also lead to sewer overflows. Hot weather with low rainfall can also concentrate pollutants such as nitrates and phosphates in surface water, leading to growth of algal blooms. The cost of water treatment to deal with these issues is likely to increase.

NbS can be used both to enhance water supply and to improve water quality. Most of the NbS that provide flood protection (Section 3.2) also delay and store water, for example in ponds or wetlands, and/or increase infiltration into the soil. As rainwater infiltrates into the soil, it eventually either recharges underground aquifers that are used for borehole water supplies, or slowly flows horizontally beneath the surface to provide a steady recharge of surface water bodies. The water stored in ponds and wetlands can be used directly during the drier months, and can also infiltrate into the soil to recharge groundwater supplies.

Both storage and infiltration will also help to improve water quality, as soil and aquatic vegetation filters out pollution before water enters surface water or groundwater bodies. Riparian trees and buffer strips of tall or tussocky grasses, wildflowers and shrubs are particularly valuable for protecting water quality, as they can intercept runoff from arable fields and filter out sediment and pollution before it enters watercourses. Well designed SuDS that use a 'management train' of components such as ponds and wetlands are also highly effective in filtering out pollution, such as in the runoff from car parks and roads.[79]

For woodlands, the impact on water supply is more complex, because the process of evapotranspiration that acts to reduce flood risk can also reduce the amount of rainfall that reaches surface water or groundwater resources. This trade-off is strongest for fast-growing trees such as conifers, and it is less significant for broadleaf trees as they shed their leaves in winter when rainfall and groundwater recharge is most significant. It is also offset by the impact of tree roots, which enhance groundwater infiltration. Native broadleaf forests can improve water quality, by intercepting and absorbing polluted runoff, although conifer plantations have been associated with water pollution and acidification. In the UK overseas territories, cloud forests play a unique role in sustaining water supply by capturing mist from the air (Case Study 6).

Restoration of degraded peatland, wetland, grassland and heathland is also important for water supply. Around 70% of UK drinking water originates from upland catchments, including peatlands, which supply water estimated to be worth £208-888 million each year.[152] Peatland in good condition produces good quality water that requires little treatment, but degraded peat erodes easily and contaminates water supplies.[43] Blocking moorland drains can re-wet the peat and restore it to good condition, preventing erosion and increasing water retention. One experiment showing that blocking drains increased soil moisture by 34%,[86] and it can raise and stabilise the water table closer to the surface, making the system more resilient to drought.[87] Case study 7 shows two examples of peatland restoration to protect water supplies.

Wetlands are particularly valuable for improving water quality, as they can filter out pollution and trap sediment, and beaver-created wetlands can be particularly effective. A study in Scotland showed that a series of beaver dams and pools created 20 times more aquatic biomass and retained seven times more organic matter than an unmodified stream channel, and reduced phosphate and nitrate concentrations by over 40%.[90] Constructed wetlands created to treat effluent can also be highly effective, for example removing 82-96% of the iron from toxic minewater entering a Welsh river.[91]

Measures to improve agricultural soil condition, such as by adding organic matter, using cover crops and reducing tillage (Box 3), will help to retain water in the soil, providing resilience to drought. A review by the Royal Society found that some NbS for water conservation, including agroforestry and soil-water conservation measures, were more effective and more affordable than many grey infrastructure approaches such as irrigation, reservoirs and inter-basin water transfer.[17] However, in the second UK National Adaptation Plan the main focus was on streamlining the planning process for large reservoirs and water transfer infrastructure, and reducing water demand, with no mention of the potential role of NbS in supporting water security.[92]

Greylake Reserve.
Wetlands filter out pollution and allow water to soak into the ground, recharging groundwater supplies

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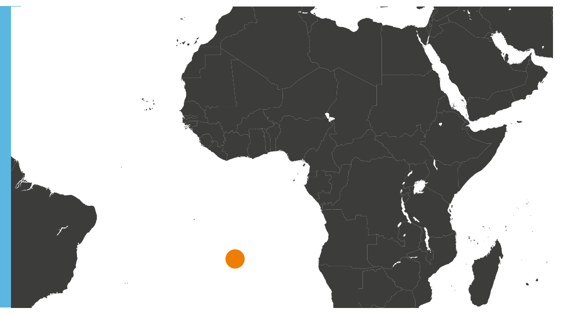
CASE STUDY 6:
UK OVERSEAS TERRITORIES, ST HELENA CLOUD FOREST



In St Helena, 60% of the water supply is captured from mist by the cloud forest. It drips into the peaty soils which are good at holding water, and eventually filters down to the rivers that supply local communities downstream. The cloud forest is the most important wildlife site anywhere on British soil, home to 250 unique species and a sixth of all unique British wildlife. But the forest that used to cover all land over 600m has been reduced to around 120 fragments due to human activities, putting many species at risk of extinction. The combination of climate change and loss of the cloud forest means that the island is suffering from increasingly severe droughts.

A detailed Peaks Management Plan was developed by a local partnership in 2019, which would increase water supply by up to a third through protecting, restoring, expanding and connecting the remaining fragmented cloud forest habitats, as well as boosting eco-tourism.[41] Following changes to ODA funding eligibility criteria and the loss of EU funds, St Helena found that there was no UK government avenue for funding the estimated costs of £2.4M for the three year programme; a problem also experienced by some other UK Overseas Territories.[131] However, it is hoped that new funding avenues are now emerging.[85]

Cloud forest restoration, St Helena.

CASE STUDY 7:
PEATLAND RESTORATION TO PROTECT WATER SUPPLIES

GARRON PLATEAU, COUNTY ANTRIM, NORTHERN IRELAND

The Garron Plateau, an internationally important Ramsar wetland site, contains the largest area of peat bog in Northern Ireland. It feeds the Dungonnell Reservoir, which supplies water for 12,000 people. However, by 2010, 95% of the bog had become degraded, with erosion of peat turning the water dark brown. NI Water worked with RSPB and the NI Environment Agency to help restore the bog, by negotiating agreements with farmers to reduce grazing density, and constructing thousands of small timber, peat and stone dams to block drains and ditches across the catchment. By 2016, 28% of the site had returned to favourable condition and 27% was still unfavourable but recovering.[88] This reduced the discolouration, turbidity (cloudiness) and organic carbon in the water, saving water treatment costs and reducing the carbon footprint of the water treatment works.[89]

Restoration works are continuing, and it is predicted that the total benefits that can be valued will outweigh the project costs by £37 million by 2045, with a cost: benefit ratio of 1: 3.9, mainly due to carbon sequestration. In addition, a 27% improvement in flood mitigation is predicted (a 6.3% improvement across the catchment), and the re-wetted bog will now be more resilient to climate change, as well as supporting moorland birds such as hen harriers, curlews and merlins and rare plants such as marsh saxifrage and bog orchid.[88]

DOVE STONE, GREATER MANCHESTER

Dove Stone is 4000 hectares of internationally important blanket bog in the north of the Peak District National Park, which has been degraded by over-grazing and burning, leaving large areas of bare peat and deep gullies. The RSPB is working with United Utilities, the site owner, together with other partners and local volunteers, to block the drains and gullies with heather and stone dams, replant sphagnum moss and create additional habitats including patches of trees, bilberry, heather, woodland flowers and ponds. This is intended as a nature-based solution to address poor water quality and provide resilience to drought and fire, while also sequestering carbon, providing health benefits, engaging the public and reversing biodiversity loss. Numbers of breeding waders such as curlews, golden plovers, red grouse and dunlins are already increasing in the restored areas.

Peatland restoration work, Dove Stone.

3.4 FOOD SECURITY AND AGRICULTURAL RESILIENCE

Agricultural production faces high risks due to climate change, including heat stress, drought, flooding, pests and diseases, both in the UK and overseas. This poses risks to food security that will affect everyone, but especially the most vulnerable, with global food system shocks likely to result in price rises that exacerbate food poverty and social inequality. For example, yields of onions, carrots and potatoes in the UK fell by 20-40% in the hot dry summer of 2018, and the price of vegetables imported into the UK rose by 45-132% in 2017 due to severe weather across Europe.[8]

The UK's second climate change risk assessment (CCRA2) Evidence Report highlighted these risks,[93,94] but in the second UK NAP, which covers policy in England and UK-wide 'reserved matters', the UK government disagreed that food security was a high risk, on the grounds that the UK has a diverse supply chain, importing food from over 180 countries. In contrast, the second NAPs for Scotland[223] and Wales[222] recognised the potential for climate disruption to food supply, and in Northern Ireland the NAP identified food security as one of the seven priority areas for action.[225]

The CCRA3 Evidence Report highlights that risks to food production are now even greater, and that global climate instability could well lead to multiple countries experiencing poor harvests in the same year, so that supply chain diversity may not be adequate insurance. Three of the eight priority risk areas identified by the CCRA3 Evidence Report relate to food security: risks to soils from flooding and droughts; risks to crops, livestock and forestry from heat stress, drought, waterlogging, flooding, fire, pests, diseases and invasive non-native species; and risks to global supply chains for food and other goods and services (Table 2). More adaptation action is urgently required, with a focus on maintaining healthy soils, water and biodiversity.

Agro-ecological approaches offer nature-based options for adapting to these climate impacts by building up the health and resilience of the natural capital assets that underpin agricultural production (Box 3). Measures that conserve soil and water, including the use of cover crops, retention and incorporation of crop residue, addition of organic matter, reduced tillage, riparian buffer strips and contour hedgerows can all help to reduce soil erosion, increase rainwater infiltration and increase soil water storage, thus reducing the agricultural impacts of both droughts and heavy rainfall. Many of these options are low-regret, i.e. beneficial and cost-effective even in the current climate, with a high NPV (Net Present Value).[95]

In addition, species-rich field margins, hedgerows and farmland trees (as well as patches of semi-natural habitat outside fields) can provide habitat for pollinators such as bees, hoverflies, butterflies and moths, and natural pest predators such as beetles, spiders, wasps, birds and bats, helping to combat the threat of new or increased pest populations in a warmer climate. Increasing crop diversity can also help to improve pest control, nutrient cycling, soil fertility, and water regulation, without compromising crop yields,[96] and can also confer resilience because if one crop fails due to unusual weather conditions, a different crop may thrive.


Flower-rich field margins provide habitat for pollinators and pest predators

BOX 3: NATURE-BASED AGRICULTURAL PRACTICES: AGRO-ECOLOGY AND AGROFORESTRY

Agro-ecology is the application of a suite of methods that aim to make farming sustainable and resilient in the long term, by building up soil health and supporting biodiversity while avoiding use of agro-chemicals as far as possible. These practices are classed as NbS because they have benefits for biodiversity compared to conventional agriculture. Key methods include:

COVER CROPS

Keeping the soil covered with crops, green manure (see below) or crop residue at all times, rather than leaving it bare during fallow periods, to avoid soil erosion and keep adding organic matter from plant roots.

GREEN MANURES

Using leguminous plants which absorb nitrogen from the air, such as clover and sanfoine, as cover crops, and ploughing them into the soil to add nitrogen and soil carbon without using synthetic fertiliser.

MINIMUM TILLAGE

Reducing the frequency and/or depth of tillage (ploughing) avoids loss of soil carbon, and damage to beneficial soil organisms such as earthworms. Crops can then be planted directly into the residue of the previous crop. This sometimes involves use of herbicides, as weeds are not removed through ploughing, but other methods of weed control are also possible.

ADDING ORGANIC MATTER TO SOIL

Adding compost, animal manure or green manure to soils builds up organic matter and improves soil health and soil structure, increasing infiltration and water-holding ability, and reducing the need for synthetic nitrogen fertilisers.

CROP DIVERSITY

Increasing the diversity of crops can help to avoid problems with pests and diseases, and improves resilience to environmental change.

BUFFER STRIPS

Strips of tall or tussocky grasses and herbaceous plants, shrubs and/or trees along the banks of watercourses or field margins can intercept and trap sediment and runoff, helping to reduce loss of soil and protect watercourses from pollution.

HEDGEROWS AND FIELD MARGINS

Especially when contouring across the slope, hedgerows can help prevent soil erosion, runoff and water pollution, while both hedgerows and species-rich field margins provide habitat for beneficial pest predators and pollinators. Hedgerow trimmings can be composted for use as a soil improver.

AGROFORESTRY

Growing trees amongst crops (silvo-arable) or pasture (silvo-pasture) can help protect against soil erosion and flooding, and shade or shelter crops and livestock from sun, wind and heavy rain. It can also diversify incomes, e.g. if fruit or nut trees are used.

CASE STUDY 8:
ORGANIC SILVO-ARABLE AGROFORESTRY IN EASTERN ENGLAND

WAKELYN'S FARM, SUFFOLK

Surrounded by a bleak landscape of monoculture crops, Wakelyn's is a haven of diversity. It was bought by plant scientist Prof. Martin Wolfe in 1992, with the aim of increasing the functional diversity of the whole farming system – including genetic diversity, species diversity and the structural diversity of habitats - to boost resilience to pests, diseases and other stresses. Fruit, nut, willow coppice and timber trees are grown in 56 north-south rows spaced 10-15 m apart, to minimise shading to the cereals, pulses and vegetable crops between the rows. The farm emphasises resilience through using local and on-site resources rather than relying on external inputs. Soil fertility is built up using leguminous cover crops such as clover, and the farm produces its own energy from solar panels and a woodchip boiler. It has also diversified its income sources through hosting a wide range of activities, including research, demonstration, education, a farm shop, bakery, café, holiday accommodation, and arts and crafts micro-businesses using the willow and hazel coppice. The mix of habitats on site support a wide range of wildlife, with 43 bird species including woodland birds such as bullfinches, blackcaps and greater spotted woodpeckers. [98]

WHITEHALL FARM, CAMBRIDGESHIRE

When Stephen and Lyn Briggs took over the tenancy of Whitehall Farm, they were staggered to see how much of the fine soil blew away from the intensively cultivated arable fields on dry, windy 'Fen blow' days. [99] To protect from wind erosion, stabilise the soil and improve humidity, they planted rows of apple trees 27 metres apart, leaving enough space for farm machinery to cultivate cereals in the alleys between the trees. Investing in this 125 ha silvo-arable system, the largest in the UK, was only possible because they were able to negotiate a long term 15 year tenancy agreement with the landlord, Cambridgeshire County Council, rather than the usual 3-4 year tenancy.

Agro-ecology principles were adopted throughout the farm, which was certified organic in 2007. [100] Fifteen modern and heritage varieties of apples are grown, along with a range of cereals and vegetables, and 15% of the area is left as habitat for pollinators and beneficial pest predators as part of an Integrated Pest Management system. Wildflower strips beneath the trees attract pollinators, and grassy, flower-rich buffers around every field protect soil from being washed into watercourses. Ditches are deliberately left 'scruffy' to provide habitat for wildlife, and seed mix strips are sown to support farmland birds. [101] Biodiversity has increased, with surveys showing higher numbers of reed buntings, little owls and barn owls.

To add value, a farm shop and café was set up which sells some of farm's products including apples, juice, flour and baked goods, as well as other locally produced goods. This diversifies their income, providing resilience if the cereal crop is affected by adverse weather, and also supports the local economy. The farm is also used as a demonstration and education site, to encourage others to adopt agroforestry.

Wakelyn's Farm agroforestry.

Silvo-arable with apple trees at Whitehall Farm.

Agroforestry provides a particularly wide range of adaptation benefits. Trees can improve soil infiltration rates and water holding capacity, protecting soils from both waterlogging and dessication, and fertility is enhanced as leaf litter and fine roots are incorporated into the soil. Sale of fruit, nuts or timber can provide diversified and increased income sources for farmers, and the trees can encourage pollinators and pest predators, especially if wildflowers are planted beneath them (Case study 8).

Trees and hedgerows provide shade and shelter for crops and livestock. Shelterbelts at field edges protect crops and livestock from strong winds and hot sun, and prevent crops and pasture from drying out in droughts, by increasing humidity and reducing the evapotranspiration rate. They also reduce physical damage of crops by wind and rain, potentially reducing the ingress of plant diseases. A shelterbelt of less than 40% porosity can reduce wind speeds by up to 90% and protect an area of 10 times the height of the shelter, while tall shelterbelts of between 40-60% porosity will protect an area up to 30 times their height.[97] Although the trees can shade crops and compete for water and nutrients, reducing crop yields up to a distance of 1-2 times the height of the trees, there is still an overall increase in yield. For example, wheat yields increased by 3.5% in a Canadian study of shelterbelts, and more in drier years.[97] Tree heights of up to 15m are recommended for shelterbelts, using native deciduous trees as they are well adapted to local conditions and have a leafless period which reduces the adverse effects of shading.

Trees on pasture also reduce livestock stress and promote more natural behaviour, and in some systems livestock may be able to browse the leaves and bark (once trees are established), which provide nutritional benefits. The shelter provided by trees can warm the soil in early spring and late autumn, prolonging the grass growing and outdoor grazing season and thus reducing the need for supplementary feed and cutting livestock housing costs. All these benefits can increase livestock productivity, including weight gain, the laying rate of hens, the milk yield of cows and the survival rate of infants.[102]

All these agro-ecological methods are classed as land-sharing; they produce food in a way that shares the land with wildlife. However, the net-zero policies modelled in the CCC's land use scenarios rely on 'land-sparing' methods, by increasing agricultural productivity in order to free up land for climate mitigation measures such as tree-planting and biofuel production.[103] This could cause unintended adverse consequences or 'maladaptation', because if yields are enhanced through increased use of agro-chemicals and irrigation there is a risk of further damage to the soils, water and biodiversity that sustain long term ecosystem health.[104]

Food security also encompasses the food we get from marine and freshwater ecosystems, which included important commercial fish species such as Atlantic cod and salmon, as well as lobsters, shellfish and even edible seaweed. Productivity is threatened by a range of climate impacts including higher water temperatures, lower rainfall (which can result in low river and lake levels, as well as higher concentrations of pollutants in water), and extreme rainfall events which wash large quantities of polluted runoff into watercourses and coastal waters. NbS can play a vital role in addressing these impacts. Key options include establishment of marine protected areas and sustainable fishing quotas, and protection and restoration of the seagrass, kelp, saltmarshes and reefs that are vital nursery habitats for fish and shellfish larvae, including by ending damaging practices such as bottom trawling and dredging. Coastal wetlands and saltmarshes also play a role by helping to remove excess nitrate and phosphate pollution before it reaches coastal waters, which protects the plankton populations at the base of the marine food chain.[105] Land-based NbS that improve water quality and quantity (Section 3.3) can also contribute to the health of aquatic habitats.

The UK Overseas Territories (UKOTs) are particularly important for seafood production. They are surrounded by vast marine areas containing important fisheries, and their coastal reefs and mangroves also act as vital habitats and nurseries for marine life. However these ecosystems are under threat from climate change[106] and must be maintained in a healthy condition to enhance their resilience to climate impacts. A number of projects funded by the UK government's Darwin Plus initiative are building the capacity for community-based management of fisheries in the UKOTs,[107] and are restoring mangroves damaged by hurricanes.[42] The government is also establishing a 400 million km2 'Blue Belt' of marine protected areas across the UK Overseas Territories, and is setting up a new £500 million Blue Planet Fund to help countries eligible for Official Development Assistance (ODA) to reduce poverty through the protection and sustainable management of their marine resources.[108]

3.5 HIGH TEMPERATURES AND HEATWAVES

High temperatures are a growing threat in the UK, especially to the elderly and people with heart and respiratory conditions. The 2020 heatwave caused over 2,500 heat-related deaths in England, and there could be up to 7,000 heat related deaths per year across the UK by 2050, as well as productivity losses for workers.[18] The CCRA3 Evidence Report identifies risks to human health and productivity from overheating of buildings as one of the eight priority risk areas where action is most urgently needed, and also notes that policies to address this risk are "still largely absent", despite it being highlighted in all three climate change risk assessments to date. People in hospitals and care homes are particularly vulnerable, with up to 90% of hospital wards being at risk of overheating.[8] Long periods of hot and sunny weather are also associated with air pollution, as higher concentrations of ground-level ozone form in polluted areas.[9]

Urban green and blue infrastructure can play a key role in cooling built up areas and reducing the urban heat island effect. Urban trees and woodland can shade buildings directly, as well as cooling the air through evapotranspiration and reflecting solar radiation, and green wooded spaces such as parks and gardens provide cool and shady places for recreation, with large, broadleaved trees being particularly effective.[109] For example, studies in the UK have shown that surface temperatures can be up to 20°C lower and air temperatures up to 8°C lower under trees in a park.[110]

In the wider countryside, riparian woodlands shade and cool water bodies which helps to protect freshwater species, while dense vegetation cover keeps soils cool, preventing soil degradation and protecting the worms and other organisms that are essential for soil health. Trees, hedgerows and green walls also help to filter out air pollution (although some tree species produce allergenic pollen, or biogenic volatile organic compounds that react with air pollution to form ozone on hot and sunny days).

Green walls and roofs can be particularly effective, as they insulate buildings from both heat and cold, saving energy costs and emissions from heating or air conditioning, provided they are well designed with adequate substrate depth (Box 4). Green roofs have been found to cool the buildings beneath them by as much as 12°C in Italy and 27°C in Texas compared to conventional roofs, while green walls can be up to 32°C cooler than conventional walls and can save up to 59% of energy in the building.[111] While they cannot be used on houses with steeply sloping roofs, they could be suitable for many hospitals, care homes, offices and flats that have flat or gently sloping roofs. Urban greening was estimated to deliver benefits worth nearly £300 million per year for 11 UK city regions, through avoided worker productivity losses and reduced cooling costs, and green roofs installed in the West Midlands were estimated to offset 25% of heat-related mortality.[8]

Heatwaves can coincide with droughts that could restrict the availability of water for maintaining green infrastructure. Several options exist for addressing this trade-off. Trees can be integrated with sustainable drainage systems that channel and store water in large tree pits around the tree roots, and also facilitate groundwater recharge.[109] More naturalistic planting that avoids water-hungry ornamental annual plants can help; mature trees have deep roots and can tolerate long periods without rain, while biodiverse green roofs using native dry meadow wildflower mixes can survive six weeks without rain.[112] Alternatively, rainwater or recycled 'grey' water from washing can be collected and used for watering plants. One innovative example is a 'vertical rain garden' in London that collects enough water from the roof to water a green wall for up to six weeks, storing it in slimline tanks behind the wall and using a gravity-fed seepage method that avoids the need for pumps (Figure 3).[113]

Urban parks with large, mature trees provide shade and cooling on hot days.

Figure 3.
Vertical rain garden installed on social housing in London.

CCRA2 noted the potential for green infrastructure to contribute to cooling and shading, along with the lack of specific supporting policies.[114] The second NAPs responded to this prompt in different ways, though in Northern Ireland green infrastructure was recognised only for flood prevention. In Scotland, cold-related deaths far exceed heat-related deaths, so the main focus was on improving green infrastructure so that people could take advantage of warmer weather to get more outdoor exercise (the 'Natural Health Service'), supported by a Green Infrastructure Fund.[224] In Wales, there was a focus on delivering more green infrastructure through the planning system. In England, the focus was on parks and urban trees, committing government to deliver more, better quality and well maintained local Green Infrastructure that provides multiple benefits for local communities, especially disadvantaged populations.

The NAP cited the 25 Year Environment Plan goal to plant a million urban trees, the aim to embed an Environmental Net Gain principle into planning, and plans to develop Green Infrastructure Standards. However, none of the NAPs noted the potential for green roofs or walls to contribute to urban cooling. The CCRA3 Evidence Report identifies a continuing need to increase green infrastructure, set greenspace targets and monitor uptake of green infrastructure as one of the beneficial actions for addressing overheating in buildings.

High temperatures also cause damage to infrastructure: they can cause railway tracks to buckle, electricity cables to sag, road tarmac to soften and rut, and signalling equipment to overheat and fail. There is potential for trees to shade railways and roads, also helping to make working conditions better for maintenance and construction workers, but there is a trade off with controlling vegetation to reduce storm damage such as through fallen trees, and ongoing issues of leaves on the line (see Section 3.2.1).

3.6 INTERNATIONAL IMPACTS

The UK is embedded in a globalized economy, which exposes it to transnational climate impacts through trade, travel, financial flows, and migration from climate-vulnerable countries.[115] Climate change can also create geopolitical instability, including the potential for international conflict, which can disrupt supply chains, affect UK economic interests abroad, and increase the demand for emergency humanitarian relief.

British people travelling, working or living overseas are directly exposed to international climate risks. For example, many popular destinations, such as southern Europe, the Middle East, and south-east Asia will be subjected to more frequent and more extreme heatwaves, particularly in urban areas, which can exacerbate existing poor air quality. With sea-level rise and increased severity of hurricanes, cyclones and other storms, popular coastal destinations will also be at higher risk of flooding, wind damage and coastal erosion.

These international climate risks are exacerbated by environmental degradation, as economies and societies are embedded in and dependent on nature.[116] More than half of global GDP depends directly on biodiversity and the ecosystem services that nature provides, but a fifth of countries worldwide are at risk from ecosystem collapse as biodiversity declines.[117] Cascading climate risks interact with biodiversity loss across interconnected geographical systems, causing impacts such as reduced commodity yields and supply chain shocks that disrupt global economic activity, with widespread systemic financial implications.[118] Over 20% of vegetated land worldwide is declining in productivity, mainly due to unsustainable land and water use practices, and 1.3 billion people are trapped on degraded land with few alternative livelihood options.[119] The loss and degradation of ecosystems, notably in tropical regions, also increases human exposure to pathogens. Over half of emerging human infectious diseases are linked to land conversion for agriculture.[120]

NbS are an essential strategy for addressing these complex, integrated challenges. They can build resilience at the global level, by restoring the ecosystems that underpin human health, prosperity and geopolitical stability, as well as contributing to sustainable economic development, climate change adaptation and climate mitigation. A global systematic review found evidence that NbS are effective for addressing 33 different climate impacts across the world,[12] and a recent evidence review across 70 countries in the Global South demonstrates that investments in nature (such as ecosystem protection and restoration) can be a win-win for biodiversity and economic development.[121]

Building resilience overseas through supporting the deployment of high quality NbS can therefore help to reduce the UK's exposure to international climate impacts. NbS that address food and water security, as described in sections 3.3 and 3.4, are particularly important because declining agricultural productivity and food shortages are key drivers of geopolitical instability, conflict and climate migration.[119] For example, the growing influx of migrants from Central America into the US has been linked to climate impacts on smallholder livelihoods.[122]

NbS options include agro-ecological methods for soil-water conservation (Box 3), increased crop diversity, which can enhance soil fertility and nutrient cycling while providing resilience to pests and diseases,[96] and agroforestry, which can boost soil health, provide shade and shelter for crops and livestock and provide alternative livelihood options if crops fail.[123] These techniques can improve yields and profitability more sustainably than conventional intensive agriculture, enhancing livelihoods and food security, and, like all NbS, engaging and empowering local communities to transform how they manage the land.[124]

Restoration and protection of coastal ecosystems, such as reefs, seagrass, kelp, saltmarshes and mangroves, is also critical for protection against storms, floods, erosion and salinisation, both in the UK Overseas Territories and elsewhere in the Global South. Mangroves and saltmarshes provide storm protection benefits for 40% of the world's population exposed to floods,[125] and mangroves provide flood protection benefits exceeding $US65 billion (£46 billion) per year, and protect 15 million people annually from flooding.[126]

In summary, there is evidence that NbS can contribute to reducing at least seven of the eight climate change risks specified in the international chapter of the CCRA3 Evidence Report, and can contribute to exploiting one of the two climate change opportunities (Table 4).

UK government already supports some NbS for climate adaptation overseas. For example, 18% (over £1 billion) of the £5.6 billion of bilateral International Climate Finance (ICF) between 2016 and 2021 was committed to ‘programmes that support NbS’. ICF is being increased to £11.6 billion from 2020 to 2025,[127] with £3 billion being targeted at nature recovery, including the £500 million Blue Planet marine conservation fund, as well as mangrove restoration and forest projects.[128] However, the CCC points out that this is being undermined by the abandonment of the UK government commitment to invest 0.7% of GDP in Official Development Assistance, and the tendency to divert funds to UK organisations rather than country partners.[129] It is crucial to restore this funding to achieve the Sustainable Development Goals and thus reduce international climate risks.[130]


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Table 4.
International climate risks and opportunities identified in the CCRA3 Evidence Report, and how NbS can contribute.

Risks	NbS Contribution
Risks to UK food availability, safety, and quality from climate change overseas	Supporting NbS for agricultural resilience overseas can reduce risks to UK food imports, particularly through agro-ecological methods to reverse soil degradation, increase crop diversity and support agroforestry.
Opportunities for UK food availability and exports from climate impacts overseas	Supporting NbS for agricultural resilience in the UK (section 3.4) could maximise any potential benefits for UK exports.
Risks to the UK from climate-related international human mobility	Supporting NbS can help to reduce climate-related human migration, conflict and governance risks, by delivering resilient landscapes that protect people from climate impacts, support food and water security and secure sustainable livelihoods.
Risks to the UK from international violent conflict resulting from climate change	
Risks to international law and governance from climate change overseas that will impact the UK	
Opportunities from climate change (including arctic ice melt) on international trade routes	We have not identified a role for NbS in contributing to this opportunity, but care must be taken not to cause additional damage to critical ecosystems through opening new trade routes, such as through oil leaks from shipping that could damage fragile Arctic ecosystems and fisheries.
Risks from climate change on international trade routes	NbS can help to reduce the risks of international trade routes being affected by flooding, landslides and coastal hazards.
Risk to the UK finance sector from climate change overseas	Many of the companies listed on the London stock exchange are implicated in international agricultural commodity supply chains that could be vulnerable to global climate-related shocks. Investing in the resilience of global agricultural production through NbS could reduce the risk to these investments.
Risk to UK public health from climate change overseas	NbS can address direct health risks to UK citizens travelling or living abroad, such as by protecting from storms and floods, or through the use of urban green infrastructure to provide cooling, flood protection, air quality improvements and recreation opportunities. Protection and restoration of ecosystems, especially in tropical regions, can also help to reduce the spread of zoonotic diseases that could enter the UK.
Risk multiplication from the interactions and cascades of named risks across systems and geographies	The direct impacts of climate change on the global economy intersect with impacts from the depletion of nature, which result in losses and disruption to global economic activity. NbS are essential to address these complex integrated challenges as they combine investing in protection of nature while addressing multiple climate and development challenges.

4 BIODIVERSITY BENEFITS OF NBS

NbS, by definition, sustain or enhance biodiversity and ecosystem health, because these properties underpin the long term sustainability of the benefits delivered by nature.[156] Healthy, diverse and well-connected ecosystems are more resilient to climate change impacts including droughts, floods, wildfires, pests and diseases, and therefore can continue to deliver multiple benefits into the future.[104]

The benefits of NbS for biodiversity depend on many factors, such as the land use prior to NbS implementation, the implementation method (e.g. planting or natural regeneration), the mix of species used, the design of specific features and habitats, and the management regime (thinning, grazing, mowing, fertilising, watering, control of invasive species, etc). Careful design is needed to maximise the benefits for biodiversity and avoid adverse impacts. Every NbS scheme should therefore explicitly plan to deliver biodiversity benefits, and should set specific biodiversity objectives and monitor the outcomes (Box 1).

Suitable biodiversity indicators for monitoring progress towards objectives will depend on the size of the project, but could include the areas of restored or protected habitats, the presence and abundance of target species, the number (richness) of species present from different taxa (birds, mammals, reptiles, amphibians, invertebrates, plants, fungi), and other measures of the health of soils, vegetation, freshwater and marine habitats. Species richness alone is not a suitable indicator: targets should aim for ‘appropriate’ levels of biodiversity for each ecosystem, recognising that some ecologically valuable ecosystems naturally have fewer species than others. In theory it is also possible to estimate a monetary value for biodiversity benefits, using ‘willingness to pay’ methods, but this may fail to capture the true value of biodiversity because it is a public good which delivers intangible benefits.

Although every site is different and should be assessed individually, preferably with advice from an ecologist, it is generally beneficial to aim for a diverse mix of native plant species, ideally of local provenance, together with a structurally diverse mix of habitats and micro-habitats to meet the needs of many different species. Specific aspects may be designed to meet the needs of target priority species and habitats, such as by including food plants for the caterpillars of particular butterflies, hibernacula for reptiles and amphibians, or bat roosts. Where appropriate, natural regeneration can lead to a structurally diverse and locally appropriate habitat mosaic that is more ecologically valuable than an actively planted habitat. However, NbS should be also designed for resilience to 2ºC climate change in the long term, which means that there may be a need to include (or target) different species to those originally present in the area. Planning at landscape scale, and integrating NbS into Local Nature Recovery Strategies and Nature Recovery Networks will help to connect NbS into an ecological network with the right habitat in the right place.[105]

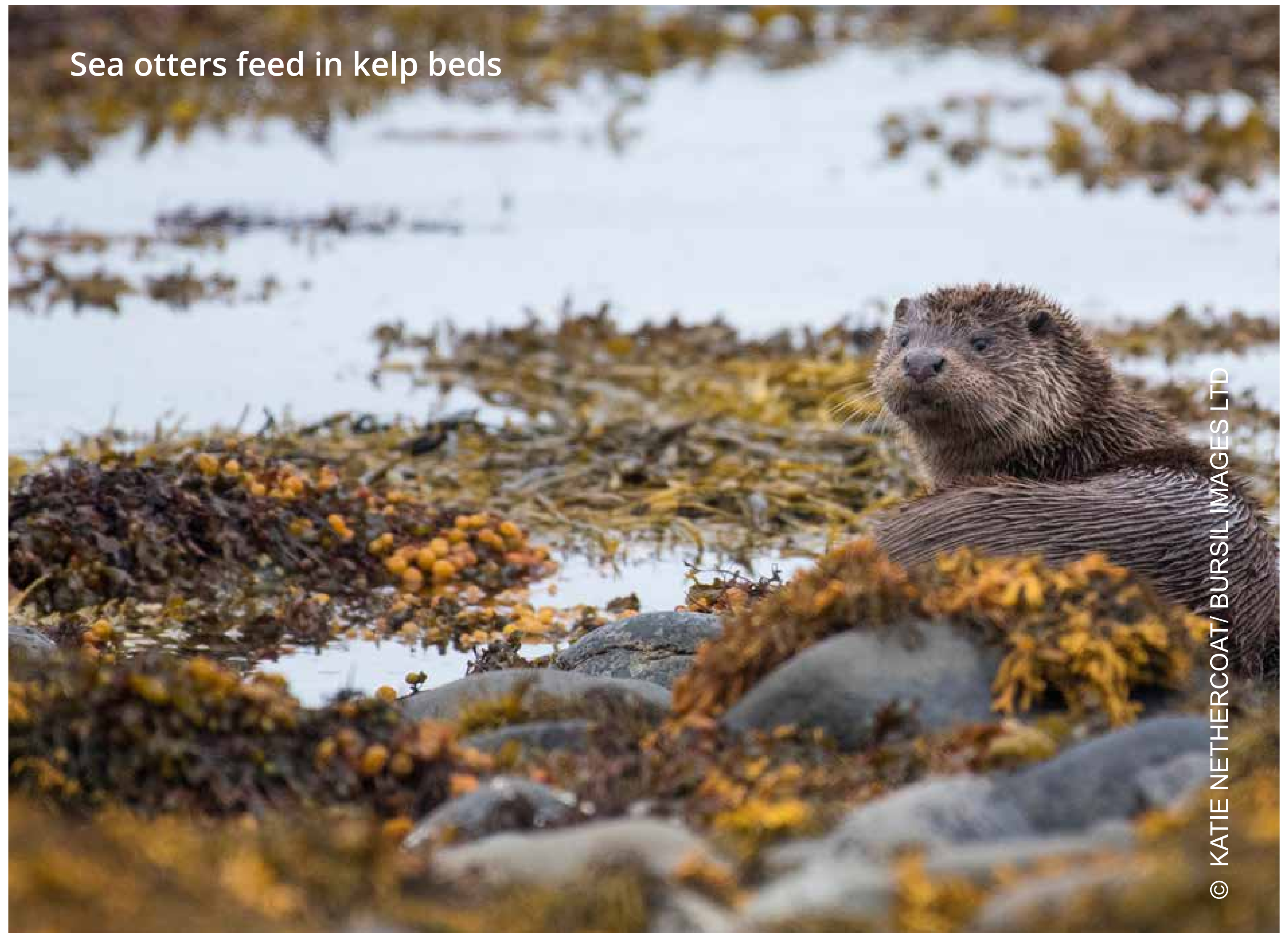
Scaling up the deployment of high quality NbS offers a major opportunity to help reverse biodiversity decline in the UK, both by protecting and restoring some of our most iconic natural habitats, and through more sustainable management of farmland, fisheries and forestry activities. This is particularly important in the UK Overseas Territories, which have 3,300 endemic species (compared to 90 in the rest of the UK), of which 75% are threatened.[131]

In this section we summarise some of the key opportunities.

4.1 COASTAL AND MARINE NBS

Protecting and restoring our degraded coastal and marine habitats will help the recovery of iconic species such as seahorses in seagrass meadows, otters in kelp forests and wading birds such as redshank and avocets on saltmarshes, as well as providing essential nursery habitats for fish and other marine organisms. The mangroves, coral reefs and beaches of the UK overseas territories are some of the world’s most threatened and ecologically significant habitats, supporting a wide range of marine life including turtles, fish and seabirds. The 5,000 km2 of coral reefs in the UKOTs are particularly important; only 11 nations have more than this.[132]

While it takes time for newly restored habitats to reach the same level of biodiversity as established habitats, some benefits can be seen in just the first few years, especially if new habitats are created next to existing ones that can act as a source of seeds and


Sea otters feed in kelp beds

invertebrate larvae. For example, the new saltmarsh that formed when an existing seawall was breached at Cwm Ivy in Wales was recolonised with saltmarsh vegetation and attracted a variety of wildlife in less than three years.[133] And at Medmerry (Case Study 1), black-winged stilts arrived and bred in the first year after managed realignment, only the third breeding record in the UK.[134] Coastal habitat restoration also helps to address the problem of 'coastal squeeze', which threatens three quarters of intertidal habitats, where they are at risk of permanent inundation from sea level rise yet they cannot migrate inland due to the presence of manmade infrastructure.[24]

4.2 WOODLANDS, SHRUBLAND, HEDGEROWS AND AGROFORESTRY NBS

Protecting existing woodlands, trees and hedgerows will have greater biodiversity and climate adaptation benefits than planting new ones, as it takes time to develop the full ecological functions and species richness of a natural woodland. Larger trees and older, more structurally diverse woodlands not only have a greater value for flood and erosion protection,[48] but also a particularly high biodiversity value, providing the cracks, crevices and hollows that are needed for shelter, nesting and hibernation sites by invertebrates, bats, birds, and small mammals such as dormice. For example, Peacock, Red Admiral, Small Tortoiseshell, Comma and Brimstone butterflies all need cracks and crevices to hibernate in over the winter, while woodpeckers get their food from insects in old dead trees, and tawny owls nest in tree hollows (Figure 4).

With NbS that involve increasing tree and woodland cover, it is vital to target the right trees in the right place. The biodiversity impacts depend on the species used, the planting and management methods, the previous use of the land and the impact on connectivity. Biodiversity benefits can be maximised by using a mix of native species or allowing natural regeneration, and blending woodland into a mosaic of other habitats such as shrubland, grassland, heath and wetland, ideally as part of a connected network that links existing habitats.

In general, trees should not be planted on scarce, ecologically valuable open habitats such as semi-natural grassland, heathland, peatland, wetland or potential floodplain meadow restoration sites, unless there are clear biodiversity benefits. For example, small patches of wet woodland could be appropriate on floodplains, and scattered native trees might be beneficial on overgrazed hillsides. High-grade productive farmland should also generally be avoided, as loss of farmland could simply displace food production impacts overseas where environmental impacts could be far worse, although there could be opportunities for planting on relatively unproductive areas such as field corners. Improved grasslands that are compacted or overgrazed, or low grade arable land, could be suitable for woodland creation.

Non-native conifer plantations are necessary for wood production, especially as 80% of the UK's wood products are currently imported, but they are not NbS as they generally have very low biodiversity value, and are likely to lead to a loss of biodiversity if planted on semi-natural habitats such as rough grassland or peatland.[53] The CCC net zero scenarios assume a 60:40 broadleaf: conifer mix,[135] and there is a risk that this could lead to inappropriate large-scale planting of non-native plantations on open habitats, undermining UK targets for nature recovery. The adverse impacts of plantations can be reduced by using a diverse species mix, which also helps to increase resilience to climate change,[136] and promoting a complex canopy structure, such as by mixing fast and slow growing species and spacing trees further apart to allow some natural vegetation to establish.[53] The UK Forestry Standard (UKFS) contains some criteria targeted at biodiversity, including that plantations should contain 5% native species and 10% open areas, and these criteria could be improved as part of an ongoing review.

In contrast, the CCC targets to implement agroforestry on 10% of farmland and increase the length of hedgerows by 40% are likely to have significant biodiversity benefits. Hedgerows are used by over 600 plant species, 1,500 insects, 65 birds and 20 mammals, and they are vital for the survival of declining farmland birds such as yellowhammers.[135] Both new native woodlands and hedgerows can be used to connect existing woodland patches, providing corridors for woodland species such as bats, birds and butterflies, to help them travel across landscapes in response to changing environmental conditions.

The CCC also specifies a target for 80% of broadleaved woodlands to be brought into active management compliant with the UKFS by 2030. Although thinning of plantations can have some biodiversity benefits by allowing more light into the forest so that natural vegetation can grow, other management activities such as clearing of understorey vegetation, or removal of mature trees and dead wood can have negative impacts on biodiversity.

Tree planting, agroforestry and forest management can also involve trade-offs with 'pest control' activities that target wildlife including hares, rabbits, voles, squirrels, deer and birds, either through shooting, trapping, contraception, exclusion via fences, electric fences and tree guards, or clearance of ground cover.[137] While some culling of large mammals such as deer is necessary given the absence of apex predators in the UK, hares are a priority species that is in decline, and smaller mammals are prey species for native wildlife such as foxes and raptors. Also, a certain degree of tree damage helps to promote a more diverse woodland structure, including open glades, as well as irregularities in tree shapes that provide useful cracks and hollows for wildlife (Figure 4).

Figure 4.
Protecting large, old trees supports birds and butterflies that occupy hollows, cracks and crevices, such as the tawny owl, great spotted woodpecker and the red admiral. Mature hedgerows with native shrubs such as the Guelder Rose shown here provide shelter, nesting sites and food for a wide range of wildlife including yellowhammers.

4.3 GRASSLAND AND CROPLAND NBS

Nature-based agriculture is crucial for biodiversity in the UK, because 70% of our land area is used for farming. Increased crop diversity and other agro-ecological methods, such as the use of species-rich field margins and reduced use of agro-chemicals, can have major benefits for biodiversity compared to intensive agriculture, as well as boosting habitat for pollinators and natural pest predators.[138] By reducing runoff of polluted and nutrient-heavy water from fields into rivers and streams, these methods also play a major role in protecting freshwater and marine habitats and species. For example, water pollution is a major cause of the loss of seagrass beds in UK estuaries.

Protecting and restoring species-rich semi-natural grassland, which is scarce in the UK, not only improves flood and erosion protection (compared to improved grassland), but also supports a wide range of invertebrates, small mammals, reptiles and birds. Meadow flowers provide an important source of nectar for bees, butterflies and moths, and food plants for caterpillars. Floodplain meadows also support wading birds, amphibians and reptiles. A major benefit of grasslands as NbS is that they can still be used for food production, as they need to be managed by grazing and/or mowing to prevent reversion to scrub and woodland.

However, semi-natural grasslands are often targeted for tree-planting. For example, the CCC envisages large scale planting on 'rough grassland' as part of Net Zero policy, and the Environment Agency's Working with Natural Processes (WWNP) maps target floodplains and riparian zones for tree planting to slow the flow of floodwater. Although the UK Forestry Standard does not allow tree planting on Priority Habitat grassland (calcareous grassland, lowland meadows, upland hay meadows, upland acid grassland and dry acid grassland), it can still take place on rough grasslands that are relatively species poor but have the potential to be restored. Ambitious tree-planting targets can therefore crowd out the options for restoring open habitats including grassland, wetland and heath. These trade-offs need to be managed by planning at landscape scale, including through setting clear objectives for biodiversity as well as climate adaptation services.

4.4 PEATLAND AND HEATHLAND NBS

Peatland includes some of our most iconic and treasured upland landscapes, home to birds such as curlews, golden plovers and hen harriers, and plants such as the carnivorous sundew.

Heathland is also a scarce and valuable habitat, which provides rich nectar sources for pollinators and supports a wide range of birds, butterflies, moths and other invertebrates, as well as reptiles such as adders and lizards. However, although restoring degraded heathland will deliver benefits for flood and erosion protection and water quality, it then needs to be managed to remove trees and shrubs, which can reduce flood and erosion protection to some extent compared to allowing succession to woodland.[58]

4.5 FRESHWATER AND WETLANDS

According to the NFM Dashboard, 188 km of rivers have been restored and over 7,000 ha of habitat created as part of NFM projects in England, while creating the capacity to store almost 1.7 million m3 of floodwater.[181] Protecting and restoring freshwater and wetland habitats has significant benefits for biodiversity. River restoration activities that 'slow the flow' of floodwater, such as re-meandering, introducing gravel banks and riffles, and adding woody debris will provide diverse habitats for fish and other aquatic organisms. For example, many species of fish spawn on gravel bars in rivers, including salmon and trout. Beaver-created wetlands are particularly valuable, increasing species richness and habitat heterogeneity. Integrating ponds and small wetlands into farmland to reduce flood risk can make a disproportionate contribution to biodiversity in the UK.[43]

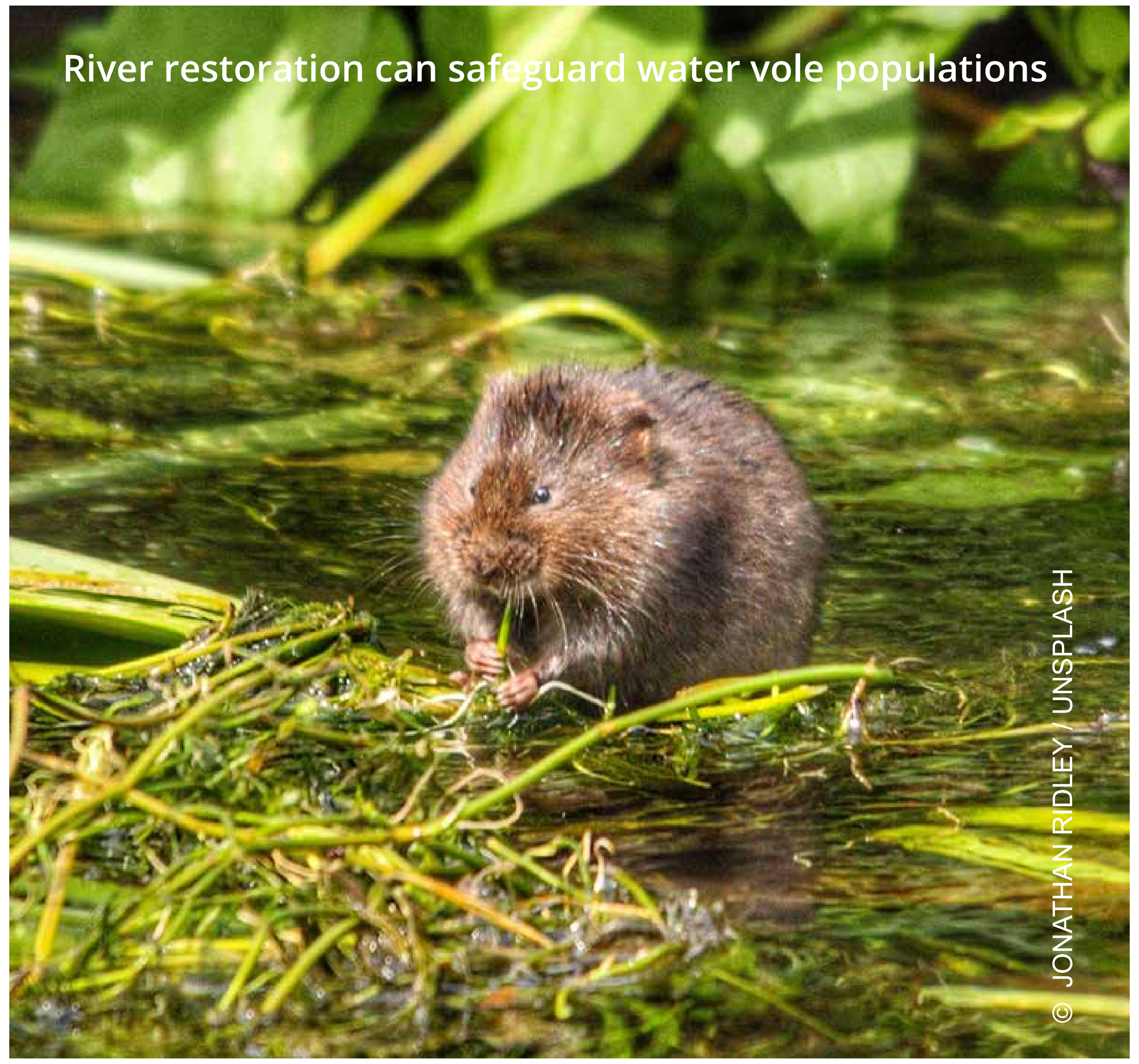
Freshwater habitats are at risk from low flows caused by drought and over-abstraction, and from high temperatures. NbS that aid groundwater recharge (Section 3.3) can help to mitigate low flows, and native riparian woodland can help to shade and cool streams, as well as intercepting polluted runoff and thus protecting water quality. However, excessive riparian planting on floodplains should be avoided as they are also ideally suited for restoration to floodplain meadows (Section 4.3).


Curlews benefit from restoration of wetlands, peatlands and moorlands


Toads and other amphibians can thrive in SuDS ponds


Protecting and restoring wetlands supports water birds like Herons


Restoring floodplain meadows and wetlands supports reptiles such as this grass snake


River restoration can safeguard water vole populations


Brown hares benefit from nature-based farming

4.6 URBAN GREEN INFRASTRUCTURE

As well as keeping cities cool and soaking up floodwater, green infrastructure is important to enable wildlife to survive in our increasingly developed landscapes. All types of green and blue infrastructure can support biodiversity, especially if larger areas such as parks are connected into a continuous network that permeates urban areas, using linear features such as rivers, hedgerows, footpaths, lines of street trees and roadside verges. However, the benefits delivered depend on careful design and management. This could include a shift from the traditional focus on intensively mown and managed green spaces to a growing preference for more naturalistic planting.

SuDS can be particularly effective for integrating a mix of habitats into the urban landscape. Well-designed schemes can include grass, wildflowers, trees, shrubs, ponds and wetland areas that can provide habitats and foraging opportunities for birds, bats, invertebrates, amphibians, fish and mammals. For example, a study of nine ponds in Scotland found that SuDS ponds supported 60-80% of the species richness of natural ponds.[139] Benefits are greatest if the systems are designed to include large, permanent water features with natural wetland vegetation.[79] SuDS can also act as wildlife corridors, providing a safe and sheltered route for both aquatic and terrestrial species across urban landscapes. Guidance from CIRIA[140] promotes the use of a diverse mix of locally appropriate native species to maximise biodiversity benefits, and WWT and RSPB have also produced a comprehensive guide on how to maximise the biodiversity benefits of SuDS.[141]

Green roofs and walls can also play an important role, especially in supporting invertebrates and birds, provided that good practice standards are followed (Box 4, Figure 4).

5 FURTHER BENEFITS OF NBS

A key strength of NbS is that if properly implemented they can deliver multiple benefits. In addition to addressing multiple climate risks (Section 3) while sustaining or enhancing biodiversity (Section 4), most will also increase the amount of carbon stored in soils and vegetation, and they also often provide benefits for livelihoods, and provide attractive nature-rich places for recreation and education (Table 2, Figure 2). Participatory planning and careful design can maximise synergies and manage trade-offs between these objectives, taking account of the needs of different groups of beneficiaries. In this section we explore these synergies and trade-offs in more detail, first for climate change mitigation, then for socio-economic goals including livelihoods, health and wellbeing.

5.1 CLIMATE CHANGE MITIGATION

NbS for climate adaptation can also contribute to climate change mitigation, in several ways.

1. Through protecting or increasing the carbon stored in soils, vegetation or sediments, compared to business as usual. The amount of carbon stored and sequestered depends on a number of factors including the ecosystem type and age, soil type, soil depth and condition, species, climate, location and management (e.g. harvesting, thinning, ploughing, mowing, planting method and use of fertilisers).

2. Through reducing energy consumption and the associated greenhouse gas emissions. For example, urban trees and green roofs and walls can shade, shelter and insulate buildings, reducing the energy demand for heating and cooling; constructed wetlands, SuDS or catchment management can reduce the energy needed for water treatment; and minimum tillage regimes can cut the use of fossil fuels by farm machinery.

3. Through avoiding the emissions 'embodied' in carbon-intensive materials such as concrete that would be used for engineered alternatives such as hard flood defences.

4. Agro-ecological methods that use organic sources of nitrogen such as from leguminous cover crops can reduce the emissions of methane and nitrous oxide from use of synthetic fertilisers.

However, the carbon stored and sequestered through NbS is vulnerable to ecosystem degradation due to climate change, such as from pests and diseases, fires, floods, drought stress, soil degradation, peatland degradation, sea level rise, salinization, and loss of saltmarshes through coastal squeeze. Therefore, the benefits of NbS will not be secured unless we limit climate change by drastically reducing GHG emissions from fossil fuels and other sources, and also improve the health and connectivity of natural habitats to increase their resilience to future change.[147]

The potential for NbS to contribute to climate change mitigation in the UK has been explored in a parallel publication by RSPB, WWF and the University of Aberdeen, which emphasised the need to protect the carbon stored in existing woodlands, peatlands, permanent grasslands and coastal habitats, as well as enhancing carbon sinks through improved management, restoration and creation of a broad range of native habitats.[11] The recent BES report on NbS also reports on the climate mitigation potential of NbS in the UK.[148] In this section, we summarise some of the key synergies and trade-offs with NbS for adaptation, focusing on woodlands, peatland and farmland.

BOX 4: BIODIVERSITY BENEFITS OF GREEN ROOFS

Green roofs and walls can be valuable for urban biodiversity, but the design is all-important. There are two broad categories.

INTENSIVE GREEN ROOFS

are designed as roof gardens for use by people, with thick substrates (20 - 100 cm) to support a variety of garden plants, lawns, shrubs and even small trees. They require intensive management and watering, as with any garden, but can support a range of garden wildlife depending on the design and species used.

EXTENSIVE GREEN ROOFS

are designed to be lightweight, with a thinner substrate, and to require little management. These have great potential value for biodiversity, especially for supporting pollinators and other invertebrates.[142] The recommended standard is known as a **'Biodiverse green roof'**, and is created by seeding and/or planting a substrate 8 -15 cm thick with a diverse mix of wildflowers and sedums, typically including dry meadow species such as vetch, yarrow and bird's-foot trefoil. Extra biodiversity interest can be added by using a mix of substrates such as chalk, gravel or natural soil, varying the substrate depth to create micro-habitats, and including sandbanks, shingle, rocks, dead wood, and even ponds or mini wetlands. Solar panels can also be incorporated ('bio-solar' roofs), and the green roof will improve performance of the panels as they operate better at cooler temperatures. These roofs do not require watering; even if they die back during a drought they can quickly recover. However, architects often specify lower quality extensive roofs using pre-grown blankets of sedum or wildflower turf. These can be quickly rolled onto the roof to create 'instant green', but have lower value for biodiversity and climate adaptation because they have thinner substrates (6–10 cm), require watering, and often fail. An earlier concept known as 'brown roofs' is no longer recommended; this attempted to mimic biodiverse brownfield sites that are being lost to development, by allowing plants to self-establish on a roof composed of loose soil or aggregate. However, colonisation was slow and dominated by a few wind-borne species, including some problem species like Buddleia and fleabane, and sometimes unsuitable or contaminated materials were used for the substrate, such as crushed concrete, which does not absorb water.[143]

A study of five green roofs in London found 74 species of spider and dozens of beetle species, of which 10% were nationally rare, as well as abundant snails, aphids and ladybirds.[144] This diversity of species – which even included two rare wetland spiders – was helped by the diverse features of the roofs, including shade created by solar panels and wetter areas where rainwater accumulated. Biodiverse green roofs can also provide foraging habitats for birds. In London, for example, roofs were designed with the aim of supporting black redstarts,[145] and flocks of up to 60 linnets have recently been observed feeding over green roofs.[143] Ground nesting birds including skylarks, oystercatchers, ringed and little ringed plovers, common terns and lapwings have also been known to nest on green roofs, although more research is needed to ensure that they can provide sufficient invertebrate prey to ensure breeding success.[146]

Figure 5.
Biodiverse green roofs with habitat features (1) and biosolar roof (2), compared to a poor quality sedum mat (3).

5.1.1 WOODLANDS, SHRUBLAND, HEDGEROWS AND AGROFORESTRY

There are strong synergies between climate adaptation and mitigation for many tree-based NbS, including protection of existing woodlands, hedgerows and trees, creating new hedgerows, and agroforesty. All these options store and sequester carbon as well as potentially delivering adaptation benefits including flood and erosion protection, urban cooling and (for agroforestry) food security. However, delivering the UK Net Zero target of planting 30,000 hectares of new woodlands each year, to increase forest cover from 13% to 17% by 2050, will require careful design in order to avoid trade-offs.[135] For example, if trees are planted on high grade farmland, this could simply displace food production to less productive areas overseas, potentially causing deforestation that outweighs any gains in carbon stored in the UK. Agroforestry and hedgerow planting on existing farmland offer options for increasing carbon storage and sequestration with less impact on agricultural production, while reducing the risk of soil carbon loss.

Care is needed to ensure that tree planting delivers the intended climate mitigation benefits, as soil carbon can be oxidised and lost to the atmosphere during site preparation and planting. Natural regeneration of woodland can avoid this soil disturbance; it is particularly suitable if there is a nearby woodland to act as a source of seeds, or if the site still contains seeds from when the land was wooded, although seeds can be brought in from other locations if necessary. Although carbon sequestration could be lower compared to a planted woodland in the first few years, naturally regenerated woodland can have a more diverse forest structure and composition which is more resilient to climate change in the long term.

It is also important to avoid planting trees on peat (organic) or peaty (organo-mineral) soils, because large amounts of carbon will be lost from the soil as the trees dry out and degrade the peat, which could far outweigh the carbon absorbed by the trees as they grow.[149,150] Similarly, planting trees on heathlands does not lead to significant net gains in carbon, due to emissions from soil disturbance, particularly on wetter soils.[58]

The UK Forestry Standard (UKFS) currently only prevents planting on 'deep peat'. Definitions of deep peat vary, with the UKFS definition currently being over 50 cm, although others use a definition of 40 cm in England. These definitions are under review and may change. However, even 'shallow' peat soils where planting is permitted can store vast amounts of carbon. Modelling suggests planting on peat should be avoided all together and that low-grade agricultural land should be targeted instead.[151] The new Peat Action Plan for England proposes that 'any replanting in areas of peaty soils is guided by clearly defined information on the location and condition of peat including its hydrological integrity, its potential for successful restoration, and the dynamics of long term carbon storage'. The intention is to move 'beyond simple metrics such as peat depth' to consider 'realistic prospects for restoration of peat'. The plan states that 'We will publish new UK Forestry Standard Practice Guidance that will help determine when afforested peat should be restored to bog, and to minimise damage to peaty soils from tree planting.'

The CCRA3 Evidence Report recognises these potential trade-offs, and points out a further issue: in order to avoid good quality agricultural land, trees are more likely to be planted on organo-mineral or organic soils, which could result in loss of soil organic carbon through erosion and compaction.[104] They also cite a study from Wales showing that organo-mineral soils are also often on steeper slopes, making them more vulnerable to erosion, as well as being close to deep peat soils which could be adversely affected by the hydrological impact of the planting disturbance. As well as reducing or eliminating the intended carbon benefits, planting trees on these peaty soils therefore risks exacerbating flooding, erosion and water quality issues. The BES review also sounds a note of caution about tree-planting targets, pointing out that there will be a time lag before carbon sequestration rates become significant, and warning that experimental evidence shows limited or variable changes in carbon stocks and sequestration, in contrast to the benefits predicted by modelling.[53] Also, where the new woodlands are intended to be productive plantations, harvesting and thinning the trees will reduce carbon storage and sequestration, and the net impacts depend on the end use of the harvested wood products. If used for fuel, the net impact depends on the carbon intensity of the displaced energy source, while if used for timber the impact depends on the lifetime of the product, and displaced emissions from the alternative material (e.g. there will be emission savings if wood replaces steel or concrete). For short-lived products such as paper or cheap furniture, most of the carbon sequestered in the wood will be returned to the atmosphere shortly after harvest when the product is disposed of, either to landfill or to an incineration plant. The impacts also depend on the rotation length of the trees before they are harvested, and on the albedo effect – conifers are darker and therefore absorb more solar radiation than broadleaved trees, warming the atmosphere. Accounting for these impacts is complex and data is lacking, meaning that the carbon impacts of tree planting are variable and uncertain.

5.1.2 PEATLAND AND FENS

Protecting and restoring peatlands and fens for flood control and water supply has major synergies with climate change mitigation, as they preserve vast amounts of carbon in their waterlogged soil. Healthy peat bogs are thought to be approximately climateneutral, as the carbon sequestered is offset by methane emissions, but healthy fens act as a carbon sink because they sequester more carbon than bogs.[152] However, 80% of the UK's upland peatlands have been degraded through overgrazing, drainage for agriculture, burning (to create young heather shoots for grouse on shooting estates), or afforestation with conifer plantations, while fens that have been drained for agriculture are subsiding at 1-3cm per year. Degraded bogs and fens are now a major source of carbon emissions, and this is expected to increase as summers become hotter and drier.[153] Restoring all UK peatlands to near natural condition would cost £8.4-21.3 billion but the climate benefits are estimated to be worth £109 billion.[152]

Restoring peatland has become one of the highest priority options in the UK's Net Zero strategy. The CCC recommends that the UK should restore all upland peat by 2045, rewet 38% of lowland peat used for crops and 8% of lowland peat used for grass by 2035, ban burning on all sites and ban all use of peat for horticulture by 2023 in order to meet our climate targets.[154] Also, they advise that 16,000 ha of plantations (those in the lowest productivity class) should be removed from peatland to halt further degradation, and water companies should have an obligation to restore peatlands that they own. However, total commitments across the UK fall short of these targets, with planned restoration rates being half of what is needed.[154] For example, the England Peat Action Plan only bans burning on 40% of upland peatland, and is only consulting on banning amateur use of peat in horticulture.[62]

5.1.3 GRASSLAND AND CROPLAND

There are strong synergies between climate adaptation and mitigation on grassland and cropland. In particular, agro-ecological methods are designed to increase soil carbon and reduce the use of synthetic fertilisers. If accompanied by a reduction in consumption of animal products, this could meet dietary requirements while reducing agricultural GHG emissions by 45% compared to 2010 levels.[155]

Restoration of floodplain meadows can also provide carbon benefits, as they trap carbon-rich sediment every time they flood.[65] There is evidence that species-rich grassland have higher carbon sequestration rates as well as being more resilient to climate change.[65]

However, there are also possible trade-offs with the Net Zero agenda. For example, the CCRA3 Evidence Report points out that growing maize as biofuel input to anaerobic digesters can cause soil erosion and loss of soil nutrients if planted in inappropriate locations such as steep slopes, which would undermine climate resilience in the agriculture sector.[104] These trade-offs can be managed through intelligent policy design and landscape planning.

5.2 SOCIO-ECONOMIC GOALS

The design and implementation of NbS projects and supporting policies should fully involve all relevant stakeholders,[156] and this can help to maximise their socio-economic benefits. Well-designed NbS can create and sustain livelihoods, boost local economies, and improve health and well-being, and these benefits can often be targeted towards those most in need. NbS can support livelihoods and economies in several ways:

- **Temporary jobs for establishing NbS.** NbS are typically relatively labour-intensive, providing more jobs per £1 invested than other infrastructure such as fossil fuel power generation.[157,158] For habitat restoration, jobs created per 100 ha range from 22-114 for woodland, 1-4 for peatland and 30-56 for coastal habitats. This means that planting an extra 20,000 ha of woodland per year could create 5,000 jobs, restoring 55% of peatland could create 500-2,000 jobs between 2021 and 2050, and restoring 13,550 ha of coastal habitat in priority locations identified by the RSPB over 10 years could create a further 400-750 jobs. Further jobs can be created by supporting the green roof and sustainable drainage industries.[153] As NbS often have large up-front costs, from buying the equipment, materials and services needed to create or restore ecosystems, they also have high multiplier effects and generate high gross value added (GVA) for the economy.[105]

- **Permanent jobs for managing NbS or in new businesses.** NbS can create additional jobs for managing or monitoring habitats, and new business opportunities such as for eco-tourism, visitor centres and cafes. For example, ongoing maintenance is expected to generate £314,000 in GVA per 100ha over 100 years for woodland, and £321,000 for peatland.[105] There could also be jobs in positioning the UK as a world leader in natural capital assessment and green finance.[92] The potential for growth in nature-based jobs has been identified as a particularly strong opportunity in Scotland.[159]

- **Protecting existing livelihoods.** NbS can protect and restore the natural capital stocks that underpin livelihoods in fishing, forestry and agriculture, making them more resilient to environmental change. For example, marine protected areas play an important role in sustaining fish stocks. Saltmarshes, seagrass and kelp beds are nurseries for valuable commercial fish and shellfish species, including scallops, crabs, shrimp, lobsters and sea bass, thus supporting coastal livelihoods.[35] Scotland's best protected marine reserve (protected by the community) was found to be acting as a source of larvae to the surrounding seas, with the density of juvenile scallops and the age and size of adult scallops being significantly greater within the reserve than outside it.[160] In agriculture, trees in silvo-arable systems can provide additional income from sale of fruit or nuts, and trees and hedges provide shade and shelter to crops and livestock in extreme weather.[102]

- **Improved health and wellbeing, and productivity increases.** NbS can protect against air pollution and noise, and provide pleasant green spaces for recreation, education and interaction with nature that improve physical and mental health and well-being. This can equip people to deal better with the stresses caused by climate change, and can also increase labour productivity, reduce healthcare costs and reduce time off work for sickness. For example, air pollution causes 40,000 premature deaths and 6 million sick days a year.[161,53] Even though trees can only remove a relatively small proportion of this pollution, urban woodlands are estimated to provide health benefits worth at least £41M /y to the 83% of people who live in UK urban areas.[105] Peatland and wetland restoration also has significant benefits for recreation, as this includes large areas of our National Parks, which are popular with walkers. NbS that improve water quality provide health and recreation benefits for swimmers and other people doing watersports or using waterside areas, especially in coastal waters, which attract 423 million day trips per year.[23]

- **Reducing social inequality.** NbS can play a role in 'levelling up' and making a green recovery from the COVID pandemic. Only 35% of households with annual incomes below £10,000 are within a 10-minute walk of a publicly accessible natural green space, compared with 59% of those earning over £60,000, and deprived communities also tend to have worse problems with air quality, water pollution, flooding, heat and noise – all of which can be addressed with well-designed green-blue infrastructure. The NHS could save over £2 billion in treatment costs if everyone in England had equal access to good quality green space.[162] The Green Alliance estimated that improving woodland, peatland and urban parks, could create 16,050 secure and well paid entry level and graduate jobs in areas where they are most needed, including in northern England and the Pennines, as well as improving wellbeing for half a million people who live in neighbourhoods that currently have no trees or green spaces.[157] Attractive green and blue infrastructure can also help to regenerate deprived urban areas. However, it is important to design these schemes carefully and in consultation with local communities, so that this does not result in 'gentrification' that prices out local people.

- **Avoiding damage.** By protecting against floods, erosion, droughts and heatwaves, NbS can avoid costly damage to houses, infrastructure, crops, farmland, water supplies and other key built and natural assets, as well as damage to health and loss of life.

- **Saving money compared to other options.** NbS can be cheaper overall than conventional options. For example, installing a green roof for water retention can be cheaper than installing an underground tank and can save money on water treatment charges, and retrofitting a green roof to an older building can be cheaper than installing roof insulation and having to regularly re-waterproof the roof.[163]

Overall, there is evidence that investing in NbS can deliver high cost-benefit ratios. For example, the value of marine reserves in the UK was estimated at between £10.2-£25.5 million at a benefit: cost ratio of 5.5-12.7:1. For every £1 invested, there is an estimated return of £4.62 for peatland restoration, £2.79 for woodland and £1.31 for saltmarsh, and that is a conservative estimate as it is based only on carbon sequestration, recreation and (for woodland) air quality benefits.[105] Restoration of saltmarsh is estimated to generate £880,000-£4,800,000 in gross value added (GVA) per 100 ha of restored habitat,[105] and the water quality benefits of coastal wetlands (including salt marshes and intertidal mudflats) were estimated as £2,676 per hectare (in 2010 prices).[165]

However, there can be trade-offs between livelihoods and NbS, where restoration or protection of ecosystems reduces the land available for productive agriculture or forestry. One of the most important examples is for the lowland peat of the East Anglian Fens, which has been drained to create 50% of the UK's most productive Grade 1 cropland. It covers less than 4% of England's farmed area but produces 33% of our vegetables, and the food chain is worth £3 billion to the UK economy.[166] Restoration to fenland is cost-effective, for both climate change adaptation and mitigation, but it will significantly reduce food production as well as threatening jobs and the local economy. Research is ongoing into the option of raising the water table in winter to reduce emissions, or switching to paludiculture (wetland farming, e.g. of reeds, sphagnum moss or blueberries).[62]

Some NbS options are effective in avoiding these trade-offs. For example, agroforestry and crop diversification can boost climate resilience and biodiversity without compromising yield.[96] However, if we are to make space for NbS without increasing imports of food and timber, we need to free up land through reducing food waste and shifting to lower meat diets.[167] Improved agricultural productivity can also free up land, but this would not be classed as NbS if it resulted in adverse environmental impacts such as increased air and water pollution or GHG emissions (e.g. from greater use of agro-chemicals), over-abstraction of water for irrigation, or loss of hedgerows and other species-rich farmland habitats.

6 ENABLERS AND BARRIERS

We carried out a series of interviews with NbS practitioners and policy experts, followed by a stakeholder workshop, to gather information on the barriers to NbS implementation and the key factors that can enable wider uptake of good quality NbS. We also drew on relevant literature, including a review of barriers to NFM.[168] From this, we identified a wide range of enablers and barriers which affect the design, implementation, monitoring and evaluation of NbS. These are broadly related to information, finance, governance, and pressures on ecosystems, although these factors overlap and interact. We cover these below, splitting governance into two sections: landscape and seascape governance (co-ordination of NbS actions), and policy, regulation and legislation (the supporting framework that affects implementation of NbS).

6.1 INFORMATION

Despite a growing evidence base,[12,169] there are still knowledge gaps around the technical design, implementation, costs and effectiveness of NbS, including their cost-effectiveness in comparison to alternative approaches (Table 5). Context-specific knowledge is crucial to identify implementation opportunities and guide the design of NbS, as knowledge from one social and ecological context may not always be transferable to a different situation.[170] However there is also a need for standardised metrics that are broadly applicable to many contexts, which can be used to understand and demonstrate effectiveness at scale. For example, the government is working with the green finance sector to develop water metrics, e.g. for peatland restoration, to unlock private sector funding, and the CCC plans to develop metrics to measure progress on managed realignment and the extent and quality of coastal habitats.[21]

NbS are embedded within interlinked ecological and social systems that are inherently unpredictable and dynamic, particularly in the face of climate change. For example, it is hard to predict the exact outcome of natural flood management approaches, given the ongoing changes in vegetation condition, weather patterns and land use across a catchment. Similarly, the quality of the water flowing out of a constructed wetland may be more variable than if the water was treated with chemicals. This can lead to NbS being perceived as more risky than conventional approaches, and regulators may be unwilling to accept this larger envelope of uncertainty (Box 5).

At present, most NbS evidence is from small scale pilot studies, as large scale trials over long time periods are often costly and technically challenging. This lack of evidence means that predicting the impact and cost-effectiveness of NbS at the landscape scale is complex and onerous for project stakeholders and planners. Also, even where scientific research to gather evidence is underway, this often requires many years of monitoring and analysis which may be out of step with the immediate needs of policymakers and practitioners.[171] This lack of evidence contributes to a general lack of awareness of the benefits of NbS amongst local communities and other stakeholders. Even where evidence does exist, many people are not aware of it.

More long term research, demonstration and monitoring of NbS in action is needed to fill these evidence gaps, potentially delivered via Centres of Excellence that can co-ordinate activities between researchers and practitioners. Online evidence hubs and knowledge exchange networks play a vital role in compiling and disseminating information to those who need it. Good examples include the Ecosystems Knowledge Network with their webinars and case studies,[172] the Working with Natural Processes online hub for NFM evidence,[173] the NFM Dashboard,[181] the Agricology network for nature-based farming[174] and the IGNITION[79] and Naturvation[175] evidence hubs for urban green-blue infrastructure.

There is also a need to build up the wide range of different skills and knowledge required for implementing NbS, by ensuring that practitioners, policymakers and other relevant organisations have access to good training materials and courses with recognised qualifications. For example, the FarmEd centre in Oxfordshire provides an online information hub, a demonstration site and a training centre for agro-ecology and regenerative farming methods.[176] Traineeships can also support the development of skills for NbS, such as those being developed by Defra and the DfE for peatland restoration in England.[62] In Scotland, an action plan is being developed to ensure that businesses and workers receive the right support and training so that they can take advantage of an expected growth in jobs associated with expansion of the nature-based sector.[159]

Extension and outreach services are vital to support practitioners trying to implement new nature-based techniques. For example, the Agroforestry ELMS Test found that an 'army of farm advisors' is needed to show farmers how to introduce agroforestry on their land,[177] together with peer-to-peer knowledge exchange and mentoring.[178,179] Visits to demonstration sites are also vital - stakeholders are much more likely to understand the potential of NbS if they can see the benefits first hand, particularly when implemented by a neighbouring landowner, friend or colleague.

BOX 5: INFORMATION BARRIERS AND ENABLERS TO NATURAL FLOOD MANAGEMENT

Flooding is an emotive as well as an economic issue, because it puts people in danger and causes severe damage and distress. Decision-makers need relative certainty that houses and property will be adequately protected from flooding, and communities at risk generally expect and demand hard flood defences. They may not be aware of the influence of catchment land use in controlling flood peaks, and may not trust, or even be aware of, natural solutions.[180] Lack of evidence on the performance of NFM measures, particularly for extreme events, is therefore a particular challenge. This can limit wider implementation of NFM, even though it is widely promoted in guidance and policy initiatives such as Scotland's Flood Risk Management Act 2009, the Welsh Government's Natural Resources policy and England's 25 Year Environment Plan.[18]

The available evidence is mainly for small catchments or from modelling studies, and it is difficult to gather convincing evidence from larger catchments because the impact of NFM measures can be masked by changes in land use across the catchment, as well as by natural variability.[43] Long term empirical studies are needed to address this. In the UK NAP2, the government allocated £15 million specifically for natural flood management projects in England, which is building the evidence base further, and new evidence should emerge from NERC-funded projects such as LANDWISE, Q-NFM and PROTECT-NFM, as well as NFM and catchment management schemes funded by the Welsh Government.[18]

A study of NFM barriers and enablers for Defra[168] recommended creation of an information hub for stakeholders. This could bring together existing evidence from the Environment Agency's Working with Natural Processes (WWNP) evidence base and other sources, including the NFM dashboard which shows the benefits delivered by NFM projects in England.[181] It could also host the NFM opportunity maps developed as part of the WWNP initiative for England and Wales, and similar maps developed for Scotland and Northern Ireland, which show suitable locations for NFM actions such as installing leaky dams and flood storage areas, or planting trees to 'slow the flow'. A Scottish NFM network has been established to share knowledge and best practice, and there are other communities of practice such as the Catchment Based Approach (CaBA) community. An industry-standard NFM design manual is also being developed.[182]

The NFM barriers study also recommended funding outreach services to provide targeted and personalised guidance for farmers on the NFM potential of their land. Advisors should be supported by government agencies, and need to have local knowledge and understanding of the farming sector, and good understanding of the funding mechanisms and science behind NFM.[168]

Finally, methods for evaluating the multiple benefits of NFM are needed, especially as the co-benefits may be very substantial, and may even exceed the flood protection benefits (see Case Studies 1 and 3). For example, the B£ST tool was used to evaluate the co-benefits of NFM in the Eddleston catchment, allowing them to be integrated into the Scottish flood appraisal process.[183]

Farm visit to FarmEd in Oxfordshire, which teaches sustainable farming and natural flood management

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Table 5.
Information barriers and enablers

	Barriers	Enablers
Evidence base	Lack of standardised metrics to assess effectiveness	- Funding for researchers and practitioners to work together to develop standardised metrics for different scales (site-specific or landscape)
Evidence base	Lack of evidence on what 'good' NbS look like in different contexts	- Long term, interdisciplinary research and monitoring of demonstration projects - Standardised monitoring and assessment framework for NbS climate adaptation outcomes that includes wider benefits for health, environment and the economy, even when those cannot be meaningfully monetised - Centres of excellence for NbS research and demonstration, e.g. a global centre, local or regional centres and/or topic-based centres, which could be integrated with regional or national delivery institutions
Evidence base	Lack of evidence on effectiveness of NbS for climate adaptation (especially at large spatial scales, or extreme events and over long time scales) and how NbS compare to engineered options	
Evidence base	Harder to predict some outcomes (e.g. flood protection, water quality, pooling) compared to engineered options	
Evidence base	Hard to measure and quantify some of the wider benefits of NbS, e.g. for health and wellbeing	
Access to knowledge	Lack of awareness of NbS opportunities and benefits	- Information and evidence hubs - Demonstration sites - Outreach and engagement
Access to knowledge	Lack of skills and knowledge to design and implement NbS implemented	- Opportunity maps to show where different types of NbS could be - Training centres; training courses and material (e.g. handbooks) - Peer-to-peer learning, site visits, knowledge exchange networks, and one-to-one advisors - Design manuals - Standards

6.2 FINANCE

There is a significant funding gap for NbS worldwide. The World Economic Forum estimates that we need to invest over USD 8 trillion in nature restoration by 2050 if we are to meet global climate, biodiversity and land degradation targets.[184] Current investments are only USD 133 billion per year, mainly (86%) from public funds, and this needs to triple by 2030 and quadruple by 2050.[184] Only 1.5% (USD 3.8–8.7 billion) of international climate finance was targeted towards NbS for adaptation in 2018, although the UK was one of the major bilateral donors (see Section 3.6).[7] Worse, almost USD 1 trillion per year of perverse subsidies flow to activities that damage nature, including fossil fuel production and unsustainable farming, fishing and forestry, undermining nature's capacity to provide climate adaptation benefits.[185]

This lack of finance is recognized as one of the main barriers to NbS implementation in the UK.[105] Upfront costs of NbS are often high, particularly for restoration of degraded ecosystems, and it can take a few years before significant benefits are delivered (e.g. as trees grow or peatland recovers), even though the overall benefits in the long term are expected to outweigh the initial investment.[170] Funding mechanisms need to reflect all the long term benefits of NbS, including avoided operational and maintenance costs such as from maintaining flood defences (Case study 1) or treating polluted water (Case studies 5 and 7).

Public funding is vitally important, but private finance is also needed in order scale up delivery of NbS.[105,186] However, as NbS often deliver more public benefits than private benefits, they may not provide a direct revenue stream that can attract private investors. The short-term nature of business and political decision-making can also be a formidable barrier to the longer term planning, implementation, and maintenance required for the sustained delivery of NbS benefits.

Finance barriers are related to lack of evidence on NbS outcomes (Section 6.1), which increases the perceived risk of investing in NbS. This causes a Catch-22 situation where lack of investment limits opportunities to gather more evidence through monitoring and evaluating real-life NbS projects. Funding must therefore address information and evidence barriers, through funding monitoring, demonstration, outreach and knowledge exchange as well as supporting project capital and operating costs.

A further challenge is that NbS costs and benefits are often distributed across different stakeholder groups, and the benefits often cannot be capitalized by a single entity, resulting in a problem of ownership.[170] For natural flood management, for example, many landowners across a catchment may need to make changes on their land, and many different businesses and residents downstream will share the benefits of flood protection, while some organisations might receive different benefits, such as water companies benefiting from lower water treatment costs.

Long term strategic funding sources are needed to address these barriers. Government investments can be used to catalyse private investments, effectively reducing perceived investment risks.[187] For example, Defra's £10 million Natural Environment Investment Readiness Fund is intended to kick-start the private sector market for natural capital investments in England.[188] It has also been suggested that specific sectors could be supported, e.g. through the creation of an Agro-ecology Development Bank.[189] The insurance industry can also play a role in financing NbS, to reduce their exposure to the risk of high payments for climate-related damage, and potential mechanisms are being investigated via initiatives such as the EU's NAIAD project.[190]

Innovative blended finance mechanisms are emerging to enable equity and risk to be shared within multilateral consortia involving companies, communities, governments, NGOs, and financial institutions, replacing the traditional debt-finance model.[170] In these partnerships, both lenders and investors are closely involved as project stakeholders, which can help build understanding, influence and trust in the programme. This can help reduce the perceived risk of investing in NbS, enabling larger-scale, longer-term investments. To facilitate these shared financing arrangements, financial mechanisms need to be developed for stacking or bundling of different benefits, such as flood protection, water quality improvements, carbon sequestration and biodiversity gain. The Landscape Enterprise Networks (LENS) approach is one example of a system for building 'collaborative value chains', which enable groups of businesses to co-procure landscape outcomes from land-based organisations.[191]

Performance reward payment schemes for the generation of 'public goods' could generate substantial revenue for NbS and also address the funding gap for NbS operational costs. Post-Brexit agri-environment schemes such as ELMS in England and Sustainable Land Management in Wales are expected to play a crucial role, provided that support for NbS for climate adaptation is expanded beyond the limited funding available under current schemes.

Draft plans for ELMS currently offer funding for some agro-ecological methods such as use of cover crops, reduced tillage, buffer strips and adding organic matter to soils,[192] and peatland restoration is also expected to be included in future.[62]

It is important to strike a fair balance between using regulations to ensure that minimum environmental standards are achieved, and paying a fair price for the delivery of additional public benefits, such as through ecosystem restoration. For example, in Wales, National Minimum Standards will be used to set a regulatory baseline for issues such as air and water pollution from farms, and the Sustainable Farming Scheme will then reward additional efforts.[193] Funding and resources are needed for professional advisors to help farmers develop evidence-based action plans, and also for regulatory bodies to enforce these baseline standards through both remote monitoring and on-the-ground inspections.[194]

Conservation Covenants, which already exist in Scotland[195] and are being introduced in the Environment Bill for England, could also support long term NbS investments. These are private legally binding agreements between a landowner and a body responsible for protecting or enhancing the natural features of the land for public good, which could be a charity, public sector or private sector organisation. Crucially, they apply not only to the current owner but also to subsequent owners of the land, guaranteeing long term benefits.[196]

There are also greater opportunities for integrating NbS into investments in other infrastructure. Procurement rules need to change to ensure that NbS are always considered as part of infrastructure planning and renovation projects, and designed in at an early stage. For example, installation of SuDS schemes for dealing with road runoff can be integrated into scheduled transport infrastructure projects (Box 7).

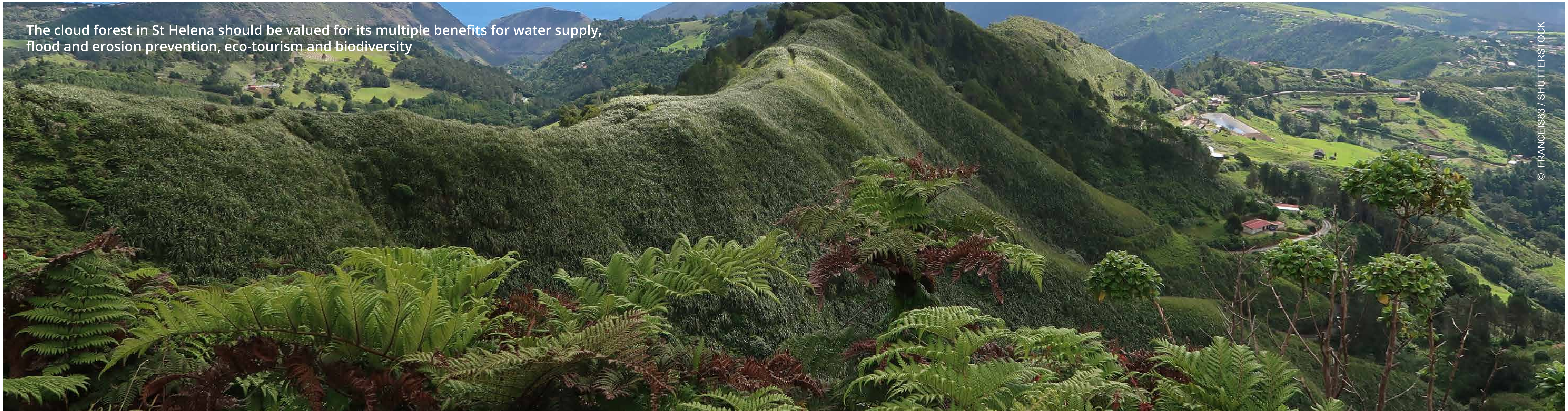
Certain NbS options are neglected under current funding systems in some or all parts of the UK, including natural regeneration, rewilding and agroforestry. Natural regeneration of woodland can reduce costs, maintain local adaptation to conditions and create a varied age structure (as well as avoiding the need for plastic tree guards). It is funded in Scotland (for native woodland), Northern Ireland (under the Environmental Farming Scheme),[197] and England (for areas within 75 m of a viable seed source), but not yet in Wales, though it has been recommended for inclusion under the new SLM scheme.[194,198] Rewilding can create a diverse mosaic of natural grassland, woodland and scrub that supports livestock and pollinators while also reducing flood and erosion risk, regenerating soil and promoting eco-tourism.

Although it cannot be 'designed' to deliver specific benefits, it is a promising approach for climate adaptation in areas where conventional agriculture is unproductive. However there are currently no funding mechanisms. In England, the new Biodiversity Metric which is expected to deliver funding for NbS is not well suited to reflecting the biodiversity benefits of rewilding, as it is not designed for complex habitat mosaics that include 'undesirable' plants such as ragwort, nettles, thistles, docks and bramble.

For agroforestry, Scotland, Wales and Northern Ireland provide funding for trees on grassland but the eligibility criteria are narrow and limit uptake,[199,200] while agroforestry in England falls into a policy and funding gap between farming and forestry.[135] The planting density for silvo-arable systems (75-200 trees per hectare) is too low for woodland creation grants, which require at least 400 trees per hectare, and funding for agroforestry under the Basic Payment Scheme (farming subsidies per unit of land area, set by the EU) depends on how individual Rural Payment Agency inspectors interpret the eligibility rules, which are rather unclear.[201] Another issue is that farmers on short term tenancies cannot benefit from their investment in planting trees, or are prevented from doing so by tenancy agreements. Longer term agreements could help to overcome this barrier (see Case Study 8).

Access to funding for NbS can also be limited by complex application processes with extensive paperwork, inappropriate evidence and modelling requirements, and delayed payments, which make it hard to recover upfront costs in a timely manner. For example, some NGOs do not have the resources to carry out complex modelling and mapping studies to predict the value of flood risk reduction or water quality improvements for a particular site.[105,168] Other approaches to quantify the potential benefits of projects, such as surveying people's willingness to pay for environmental improvements, are also time-consuming and expensive. Although the benefits of NbS can be harder to predict than engineered interventions, this should not be a barrier to scaling-up interventions which have been shown to deliver substantial social and environmental benefits when undertaken in the right place. Some of these barriers are now being addressed by new funding mechanisms which offer more flexibility and simpler application processes, such as online reverse auctions through EnTrade and similar platforms.[168]

Finally, there can be a narrow focus on cost-benefit analysis in the decision-making process, which neglects the multiple benefits of NbS. Better methods are needed for integrating multiple non-market benefits into decision-making, which will require new economic thinking (Box 6). All these barriers and enablers are summarised in Table 6.



The cloud forest in St Helena should be valued for its multiple benefits for water supply, flood and erosion prevention, eco-tourism and biodiversity

BOX 6: VALUING THE MULTIPLE BENEFITS OF NBS

NbS may appear to be less cost-effective than alternative options if there is a narrow focus on one outcome, such as flood risk reduction. However, when all the multiple benefits of NbS are taken into account, they often have favourable cost-benefit ratios, as well as creating jobs and generating additional value through multiplier effects.[105] There is a clear need to improve the measurement and communication of these multiple benefits to inform policy and investment decisions.

Reliance on cost-benefit analysis (CBA) presents a challenge to NbS finance, particularly as CBA is an essential part of government decision-making. While CBA is well-suited for engineered infrastructure, it is poorly suited for NbS. First, NbS have many stakeholders and provide diverse benefits, yet cost-benefit analyses do not differentiate between beneficiaries, and they exclude many societal benefits that cannot be monetised.[105] Monetising benefits also falsely implies that they can be traded off with each other, yet often this is not the case (i.e. they are non-commensurate). Second, uncertainty in the prediction or measurement of outcomes and the accuracy of the valuation methodology can reduce the usefulness of CBA. Third, the high discount rates applied by the UK Treasury value short-term benefits more highly than long-term outcomes. Given that NbS benefits continue to grow as ecosystems mature, this further disadvantages them in the appraisal process.

To overcome the shortfalls of CBA, there is a need for alternative valuation methods that demonstrate the wider benefits from NbS, especially for non-market values, and business case guidance should be updated to require full assessment of these multiple benefits.[183]

More fundamentally, this requires a shift in economic thinking away from the current narrow focus on economic growth and towards policy priorities rooted in social well-being and environmental health.[116] For example, relying on housing construction to drive growth following the 2008 financial collapse led to the government watering down proposed standards for multi-functional SuDS, as this was perceived to be a brake on economic recovery. The same pattern is emerging as part of recovery from the COVID-19 crisis, as only $368bn (18%) of $14.6tn COVID-induced spending by 50 major economies in 2020 was ‘green’, and only $56bn of this (2.5%) was on NbS.[202]

As the Dasgupta review into the Economics of Biodiversity emphasises, there is a clear need to move beyond GDP as our sole measure of economic success, to incorporate measures of progress towards social well-being and environmental health.[116] This way, the valuation of NbS can be framed around contribution to these policy priorities, as opposed to solely monetary costs and benefits.

Table 6.
Finance barriers and enablers

	Barriers	Enablers
Access to finance	High up-front costs, lag before benefits observed Lack of public sector funding, especially for large scale, long term projects Lack of funding to cover NbS operation costs	- Clear Treasury and devolved administration commitment to support high quality NbS and end perverse subsidies that damage nature - Public funds for operation as well as capital costs - Minimum standard baselines for ecosystem protection and sustainable land management, with public funding for public goods to reward those who go further - Channel green recovery funds to high quality NbS
Access to finance	Lack of private sector funding due to perceived investment risks	- Information hubs for costs and benefits - Government support and public funding to catalyse private funding (i.e. blended finance)
Access to finance	Short-term business and political decision-making	- Provide secure long term funding mechanisms, e.g. 5-20 years, such as via agri-environment schemes
Access to finance	Costs and benefits accrue to multiple stakeholders	- Equity and risk sharing agreements - Mechanisms for stacking and bundling different benefits (flood protection, water quality, etc)
Access to finance	Some types of NbS are not funded across the UK (woodland expansion through natural regeneration, rewilding, agroforestry)	- Wider funding mechanisms that support natural regeneration and rewilding (which can have lower costs than other approaches), agroforestry, etc
Access to finance	Onerous application system, inappropriate evidence and modelling requirements. Late payment	- Streamlined application systems and evidence requirements; funding for advisors to help applicants. Prompt payment
Access to finance	Donor channels do not explicitly promote NbS for adaptation (e.g. focus on tree planting for climate mitigation)	- Promotion of NbS for adaptation to donors Criteria to channel donor funding to high quality NbS for climate adaptation
Valuation and policy appraisal	Lack of accepted methodology for valuing NbS comprehensively Over-reliance on CBA	- Alternative valuation methodologies, beyond monetary valuation, to capture and communicate multiple NbS benefits, and how those contribute to policy priorities on social well-being and environmental health
Valuation and policy appraisal	High discount rates used for project funding appraisals	- Lower discount rates for NbS project appraisal, where appropriate
Valuation and policy appraisal	Narrow understandings of value, overarching focus on monetisable benefits and GDP economic growth.	- Policy appraisal processes that recognize and account for non-monetisable NbS benefits - Multi-dimensional indicators of social well-being and environmental health for policy and decision-making, moving beyond GDP as the sole indicator of success
Evidence and metrics	Lack of evidence on effectiveness	- Accessible information on NbS effectiveness & cost-effectiveness (Table 5)
Evidence and metrics	Lack of standard metrics to measure the benefits of NbS makes it difficult for funders to compare investment options	- Standardised metrics for assessing NbS outcomes

6.3 LANDSCAPE AND SEASCAPE GOVERNANCE

NbS can cut across landscapes, seascapes and jurisdictional boundaries and involve a wide range of stakeholders at different governance levels, including local communities, civil society organizations, businesses, landowners, farmers, local authorities (parish, district and county councils and unitary authorities), different national government departments, government delivery bodies and regulators. These actors often operate in silos and can have different priorities, interests, expectations, and values, leading to conflicts. For example, there can be conflicting demands for land for housing, food production, forestry, nature conservation and flood risk management, while in coastal and marine systems there can be a need to balance the needs and impacts of tourism, fishing, flood protection and nature conservation. There are also interactions between landscapes and seascapes, via the runoff of eroded soil and pollution into the sea. A participatory systems approach at landscape level is needed to maximise synergies and avoid conflicts between these demands, while co-ordinating different initiatives and policies such as agri-environment schemes, nature recovery strategies, flood and coastal risk management strategies, Net Zero, housing targets and Local Plans.

NbS are most effectively delivered by local partnerships, which can work across land ownership boundaries, negotiate solutions to conflicts, and use their collective power to unlock funding.[53] Early and regular stakeholder engagement is essential, and it can take a long time to build relationships and earn trust. Projects need to identify all the relevant stakeholders at the outset. Trusted intermediaries are key to generate local support, foster engagement and overcome barriers, and sometimes NGOs are more trusted than local or national government actors (e.g. the Tweed Forum, Case Study 4).[43] Solutions should be co-designed to ensure that they meet stakeholder needs, and to ensure buy-in (Case study 5). Some stakeholders may not support NbS or can even oppose them. This can be due to lack of awareness of their benefits, lack of perceived responsibility for action, the discounting of climate risks,[203] and real or perceived land-use trade-offs and opportunity costs. This can be a particular issue for natural flood management projects.[168] As well as closely engaging stakeholders in co-designing projects from the start, demonstration projects and other actions to raise awareness of the multiple benefits of NbS can help to build public support. However, it is also important to manage expectations, such as being clear that NFM alone may not provide full protection against very large storm events.

Landscape-level organisations such as Catchment Management groups, Coastal groups, Local Nature Partnerships and Farmer clusters should be supported with additional government funds and resources, to build their capacity for the challenges of cross-sectoral and cross-disciplinary working.[204] In England, the proposed Landscape Recovery element of ELMS could also provide a suitable forum for planning NbS. Clear and robust (but proportionate) mechanisms should be developed for defining ownership and sharing risks, costs, liabilities, benefits, funding and responsibilities. For example, landscape scale natural flood management projects could lead to disagreements about how much each participant is paid, who is responsible for maintaining NbS features such as leaky dams, and what happens if they fail. Formal legal agreements can be helpful in clarifying stakeholder rights, responsibilities and ownership of NbS features, and development of standardised legal frameworks could help to reduce unnecessary costs and uncertainty.[168]

As NbS cut across sectors and land-use types, they also require diverse skills in design, implementation and management. Strong, well-connected partnerships, with mechanisms to determine and build the required skillsets within the network, can help tap into the necessary human and financial capital to design and implement NbS.

Strategic spatial planning will be needed to manage trade-offs and avoid unintended adverse impacts. It is important to implement the right NbS in the right place. For example, woodlands could be established on steep slopes to reduce soil erosion and flooding, floodplains could be targeted for meadow restoration, and high quality arable land could be retained for food production using agroforestry, hedgerows, species-rich field margins and buffer strips to deliver climate adaptation benefits without reducing yields. In Scotland, five Regional Land Use Partnerships are being trialled to help define land use strategies for a green recovery and net zero, and these could also explore potential to use NbS for climate adaptation.[205]

6.4 POLICY, REGULATION, AND LEGISLATION

Policy, regulation and legislation has a vital role to play in driving the wider uptake of NbS for climate adaptation. Over-arching policies are important in setting the context, principles and overall ambition. For example, in Wales, the Well-being of Future Generations Act was directly cited as a driver for policies to support SuDS[206] and sustainable farming. In England, the 25 Year Environment Plan aims to increase the deployment of natural flood management, SuDS, green infrastructure, urban trees, sustainable farming and peatland restoration; and the Environment Strategy for Scotland also aims to improve the environment to enhance benefits for people.

Table 7.
Governance barriers and enablers

Barriers	Enablers
Multiple stakeholders with different priorities - stakeholders operate in silos - misalignment of stakeholder priorities, interests or values - lack of support or opposition to NbS from some stakeholders - land use trade-offs - opportunity costs of land for NbS - conflicts or lack of policy alignment with local plans	- Map all relevant stakeholders at the start - Early and regular stakeholder engagement - Co-design NbS to meet stakeholder needs and co-implement through local partnerships - Mechanisms to support coordinated action between multiple stakeholders, across sectors and governance levels - Integrate NbS into all sector plans and policies: agri-environment, nature recovery, flood risk management, net zero, local plans, etc. - Use trusted intermediaries (perhaps including NGOs) and local advisors to explore barriers and and generate local support. - Awareness raising and demonstration. - Systems approach to landscape planning, focus on right NbS in right place
Multiple beneficiaries lead to confusion over risks, liabilities, ownership and responsibilities (e.g. for maintenance & monitoring)	- Clear and robust (but proportionate) mechanisms for defining ownership and sharing risks, costs, liabilities, and responsibilities - Mechanisms for stacking payments for different benefits (flooding, water quality,...) - Build strong relationships based on trust
Landscape governance networks lack organisational capacity to tap into human capital, financial capital, or knowledge to design and implement NbS	- Capacity training and funding to support collaborative cross-sectoral / multi-disciplinary partnerships

High profile reports by the government's independent advisors are also influential. The Dasgupta review commissioned by HM Treasury stresses the need to transform governance systems to reverse the loss of the natural systems that sustain human well-being, and the final report of the Natural Capital Committee (NCC) states that *"all publicly funded infrastructure projects and programmes, infrastructure providers and public bodies should be required to invest in maintaining and enhancing natural capital."* [207] Beneath this high level policy guidance, the National Adaptation Plans of the four UK countries provide a more detailed policy framework that includes NbS to varying degrees (Table 10).

However, despite these overarching enabling policies, deployment of high quality NbS can be hindered by a range of institutional barriers associated with:

1. Disjointed or siloed decision-making
2. Weak or under-resourced strategies, targets and capacity to deliver NbS
3. Path dependency (rigid institutional norms, rules, and practices that favour conventional options over NbS)
4. Weak or inappropriate regulations, standards and planning policies

Disjointed and siloed decision-making at both national and local government levels can lead to missed opportunities for NbS. For example, in Northern Ireland, Daera is responsible for coastal habitats but the Department for Infrastructure is responsible for coastal protection,[225] with a focus on hard sea walls that may miss opportunities for NbS. Lack of policy coherence can also lead to activities in one sector causing damage to existing NbS, or implementation of poor quality interventions aimed at just one goal that fail to deliver multiple benefits.

For example, policies to promote housing and infrastructure development are driving the loss of woodlands and wetlands that provide climate adaptation services; while policies to promote large scale tree-planting for climate mitigation and flood protection could undermine nature recovery targets, if low-diversity non-native plantations are created on biodiverse open habitats. NbS offer the potential for synergies between many policy goals, but only if carefully designed and supported by an integrated approach that addresses climate change and nature recovery alongside other policy issues.

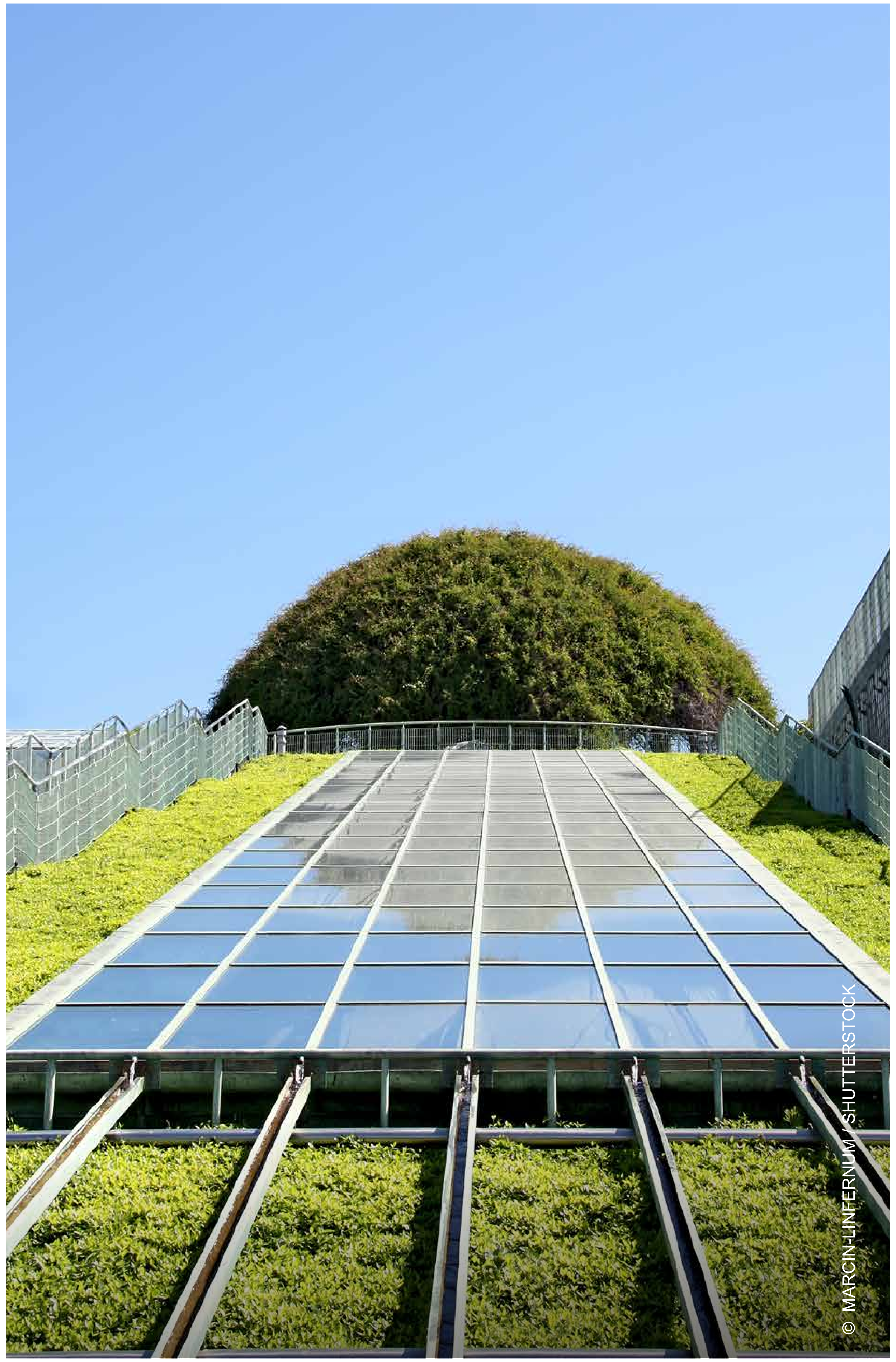
Policy coherence could be promoted through developing shared cross-departmental visions and targets for NbS, using a systems approach to consider interactions between policy objectives. For example, building on the impetus of the Dasgupta review, key government departments could set shared targets for mainstreaming the uptake of NbS for climate adaptation and nature recovery, overseen by a cross-departmental team. Similar cross-departmental policy co-ordination on NbS is needed at local government level, and this could be aligned with the work of Local Nature Partnerships involving both local authorities and other stakeholders.

Measurable, realistic targets for actions to support NbS for climate adaptation need to be accompanied with the necessary resources to deliver them, and grounded in legal frameworks such as the Environment and Agriculture bills. For example, Shoreline Management Plans in England and Wales lack a legal basis, making the delivery of managed realignment schemes very challenging, especially because they often span multiple local authorities and do not match the timescales of Local Plans.[21] It is also crucial to address capacity gaps for critical delivery bodies that have had their funding slashed in recent years, which cannot carry out their statutory duties to maintain our environmental assets, let alone leading the scaling up of quality NbS, without adequate resources.

For example, over the last ten years funding has been cut by 40-50% in real terms for government agencies such as Natural England,[208] the Environment Agency,[209] NatureScot and SEPA. [210]

'Path dependency' is another barrier – this means that decision-makers are led down a well-worn path towards established options, such as engineered infrastructure and conventional agriculture, rather than novel and innovative options involving NbS. To overcome this institutional inertia, we need to raise awareness of the benefits of NbS for climate adaptation amongst decision-makers and planners. It is encouraging to see that the Welsh government states that 'living infrastructure' is part of critical national infrastructure requirements for businesses, communities and public services in the same way as 'built' solutions", and in Scotland the definition of 'infrastructure' includes "natural assets and networks that supply ecosystem services."[211] Also, the 2020 UK National Infrastructure Strategy recognises the potential for NbS to contribute to both climate change adaptation and mitigation, and mentions some specific NbS options (flood and coastal defence, peat restoration, tree planting, and coastal habitat restoration to capture polluted runoff).[212] There is scope for much greater integration of a wider range of NbS in future UK infrastructure strategies, with specific funding allocated to increase their uptake, and this could be supported by the Natural Capital Principles being developed by the National Infrastructure Commission.[213]

Rigid institutional rules and practices can perpetuate the bias towards conventional solutions for climate adaptation. For example, as mentioned in Section 6.2, public procurement processes should be revised to mandate consideration of NbS options as an alternative or complementary approach to engineered infrastructure. This would be in line with the NCC recommendation that all infrastructure projects should take full account of natural capital by including it in the project appraisal process, as per the Treasury's Green Book guidelines.



NbS also need to be better integrated into Local Plans and other local authority policies and activities. For example, local planning policy is the main driver for the uptake of green roofs and walls. London has been the most successful region of the UK for delivery of green roofs, with 42% of the market, via the use of a tool called the Urban Greening Factor (UGF), which calculates the proportion of a new development that will be covered by green space.

The Mayor of London has set an expectation that new developments will achieve a UGF score of 0.4, which almost guarantees that green roofs will need to be installed. A similar approach is being adopted via a Green Space Factor in Swansea.[214]

However, in addition to policies driving the quantity or area of NbS, it is vital to use regulations and standards to ensure good quality. Well designed standards and regulations can incentivize creativity and innovation, delivering higher quality and more resilient NbS with wider benefits for people and nature. For example, the Trees in the Townscape principles can be applied to ensure high quality integration of trees into urban areas.[215] For green roofs, this means that the area-based UGF score needs to be accompanied with a minimum quality standard set in planning policy, equivalent to meeting the GRO code criteria for Biodiverse Green Roofs (Box 4, Section 4.6).[111] The uptake of SuDS illustrates this point; while high standards were adopted in Wales, weak planning policy in England has resulted in widespread installation of basic underground tanks and pipes which are costly to maintain and deliver no benefits beyond runoff reduction (Box 7).

CASE STUDY 9:
LICENSING BARRIERS TO MARINE AND COASTAL RESTORATION PROJECTS

SEAGRASS MEADOWS

There are high licensing fees and a heavy administrative burden for marine restoration projects such as restoration of seagrass beds (including collection of seed) or oyster reefs. These projects are often placed in the same licensing category as extractive activities by large businesses. For example, some projects have cost up to £10,000 in fees, putting them out of reach of the small environmental charities working in this area. Options to address this barrier include:

- A new marine licensing exemption for nature-positive restoration projects (similar to that for extractive activities such as shellfish harvesting).
- Cap or remove licensing fees for NbS projects
- Remove rental fees for ‘use’ of seabed
- Proactively identify and secure areas for restoration in spatial planning

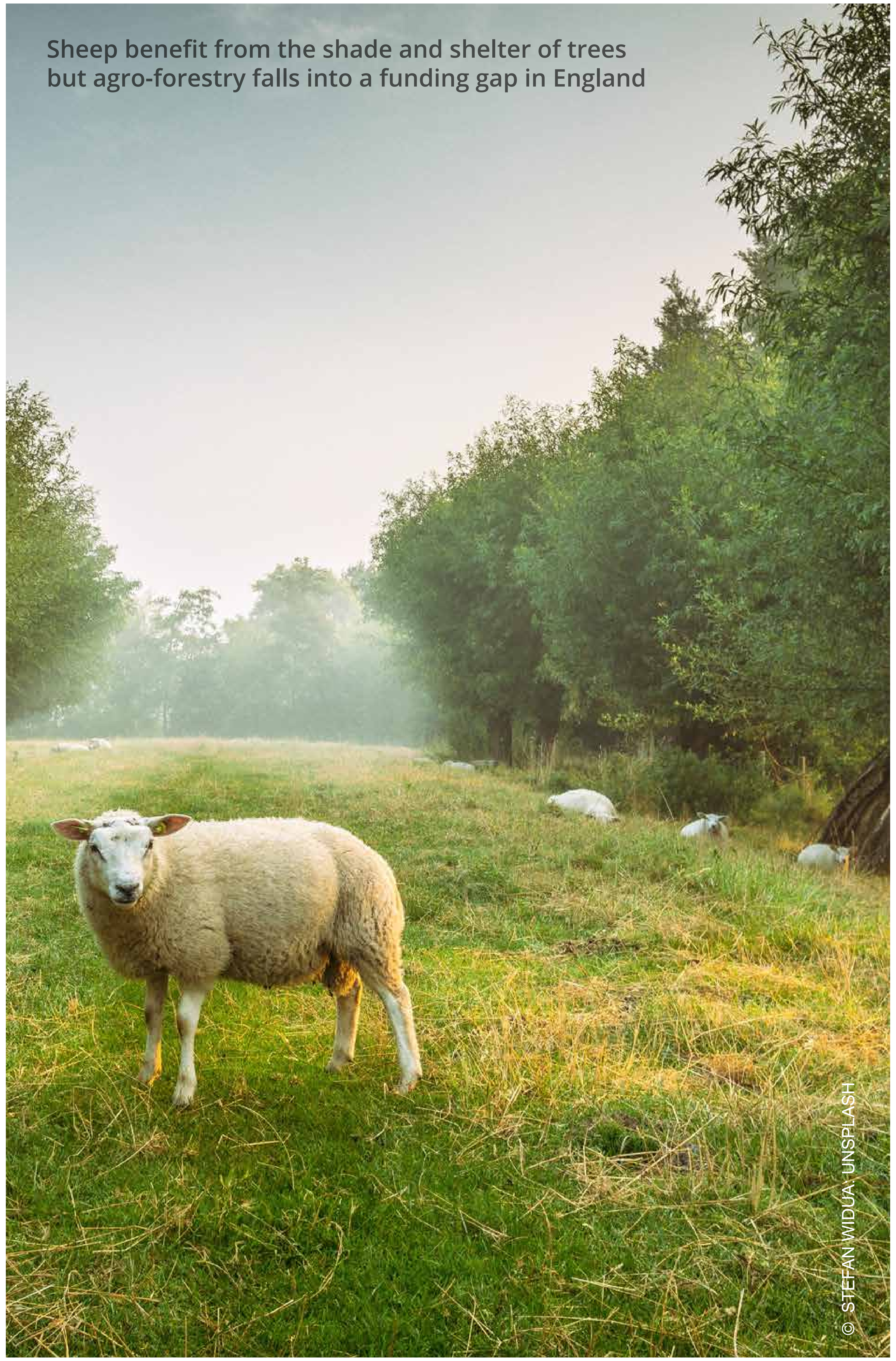
BENEFICIAL USE OF DREDGING MATERIAL

There are many beneficial uses for material dredged from the sea floor, such as for building up the level of islands used by nesting seabirds that are threatened by sea-level rise, and for sculpting new landforms in managed realignment projects. However, the licensing fees charged by the Marine Management Organisation (MMO) in England are inconsistent and often very costly, being more appropriate for use by large industrial players such as construction companies rather than charities carrying out beneficial restoration work. As a result, less than 1% of dredged material is used for conservation benefit - most is deposited at sea as waste. The RSPB Beneficial Use of Dredging working group has been working towards addressing this issue by negotiating pre-approved locations where dredging material can be extracted or re-used for habitat improvement, but this is not yet agreed by the MMO.

Wetland restoration to provide flood protection, clean water and carbon storage at Seven Lochs Wetland Park in Scotland

There are also cases where planning consent and licensing requirements are tailored only to conventional solutions and do not work for NbS. Planning processes can also be inconsistent, with local authorities taking different approaches. For example, some may ask applicants to pay a licensing fee for every NFM feature (such as a leaky dam) installed, while others might provide a single license for all features. Navigating the necessary consent and planning permissions and supplying the required information can therefore be complex, expensive and time consuming, which is a particular barrier for smaller players such as community groups, NGOs and many landowners. For example, costly and inconsistent licensing processes act as a barrier to marine and coastal restoration projects (see Case Study 9). These barriers could be addressed by streamlining and simplifying licensing and consent requirements and procurement schemes so that they do not discriminate against beneficial activities such as NbS. Application forms could also be less prescriptive, with more consideration of environmental and societal co-benefits, rather than focusing purely on one outcome (such as the level of flood protection provided).[168]

Conflicts can arise even with well-designed and generally beneficial legislation, due to the exceptional circumstances surrounding some types of NbS. For example, some managed realignment projects are prevented because they would disrupt coastal footpaths or heritage sites, even if those assets were already at risk of loss due to sea level rise. A flexible approach is required to deal with this type of unforeseen barrier, considering each case on its merits.



Sheep benefit from the shade and shelter of trees but agro-forestry falls into a funding gap in England

BOX 7: DELIVERING HIGH QUALITY SUSTAINABLE DRAINAGE SYSTEMS (SUDS)

During extreme rainfall events, which are projected to increase in future, many combined sewers (shared by wastewater and stormwater) are overloaded and discharge untreated sewage into watercourses. Sustainable drainage systems (SuDS) can reduce storm runoff at source, and thus reduce the risk of flooding as well as avoiding sewer overflows and protecting water quality. Well-designed open, vegetated SuDS schemes are cheaper to construct and maintain than conventional underground piped drainage systems, and deliver far greater benefits for biodiversity, human health and wellbeing, place-making and urban cooling.[216]

Following disastrous floods in England in 2007, the Pitt review recommended far greater use of SuDS to avoid overloading the sewer system during heavy rainfall. The review led to the 2010 Flood and Water Management Act, of which Schedule 3 contained provisions for increasing the use of high quality SuDS. This removed the automatic right to channel surface runoff from new developments into the sewer system, so that Local Authorities (LAs) could require developers to install SuDS instead. LAs would be responsible for approving SuDS, and would 'adopt' those that conformed to national standards, i.e. they would be responsible for maintaining them.

Schedule 3 was implemented by the Welsh Government in 2018, using statutory national standards that specified SuDS should be multi-functional, with benefits for water quality, public amenity and biodiversity as well as runoff reduction. LAs engage with developers at the pre-application stage to encourage good design that leaves adequate space for SuDS, and they then either adopt a SuDS scheme or agree a long-term maintenance strategy via a management company, freeing developers from long-term maintenance commitments which were previously a disincentive. SuDs are also obligatory for new developments in Scotland, overseen by Scottish Water,[217] and are the preferred approach in Northern Ireland, where NI Water can refuse a surface water connection to the sewer, although neither of these countries set standards that promote truly multifunctional SuDS.

However, Schedule 3 was never adopted in England, where the government decided that SuDS would be delivered through planning policy instead. This contained many loopholes that allowed developers to argue that SuDS was too expensive or took up too much land area, so they were often able to opt out of delivering SuDS. In addition, standards for SuDS focused only on runoff rate, so many schemes consist of underground pipes and storage tanks, rather than the networks of green roofs and walls, bioswales, ponds and raingardens that delivery genuine biodiversity and amenity benefits.[218]

Following pressure from SuDS practitioners and environmental groups, the National Planning Policy Framework was strengthened in July 2018 to require multifunctional SuDS to be delivered 'where possible' as part of any development. However, the government has not yet revised the accompanying National Planning Policy Guidance, which still contains loopholes that enable developers to opt out.[18] Although most major new developments in England now include SuDS, they are still predominantly low quality. Defra commissioned revision of the non-statutory technical standards to encourage multi-functional SuDS which align much better with government aims on nature recovery, climate adaptation, mitigation and place-making,[219] and it is hoped that these improved standards will soon be adopted by government. The next step is to tackle barriers to the adoption of SuDS by LAs, water companies, highways agencies and their engineers, who are sometimes reluctant to adopt these unfamiliar solutions. Measuring the multiple benefits of SuDS (e.g. via the B£ST tool) and showing how they provide opportunities to deliver other policies such as for water quality, nature recovery networks, health and well-being could help to overcome this reluctance. Developers, civil engineers, drainage engineers and landscape architects need to be trained and encouraged to take up these innovative solutions, perhaps through integrating SuDS into accepted quality badges such as BREEAM.

Delivering good quality SuDS will require co-ordination amongst many different players, so that flooding and water quality can be tackled together in an integrated way. However the new drainage and sewerage management plans (DSMPs) introduced in the Environment Bill do not fully integrate the activities of water and sewerage companies and local flood authorities.[216] One potential solution, proposed in 2015, might be to set up a Catchment System Operator to co-ordinate activities at catchment scale,[220] although collective governance can be a more legitimate and sustainable approach.

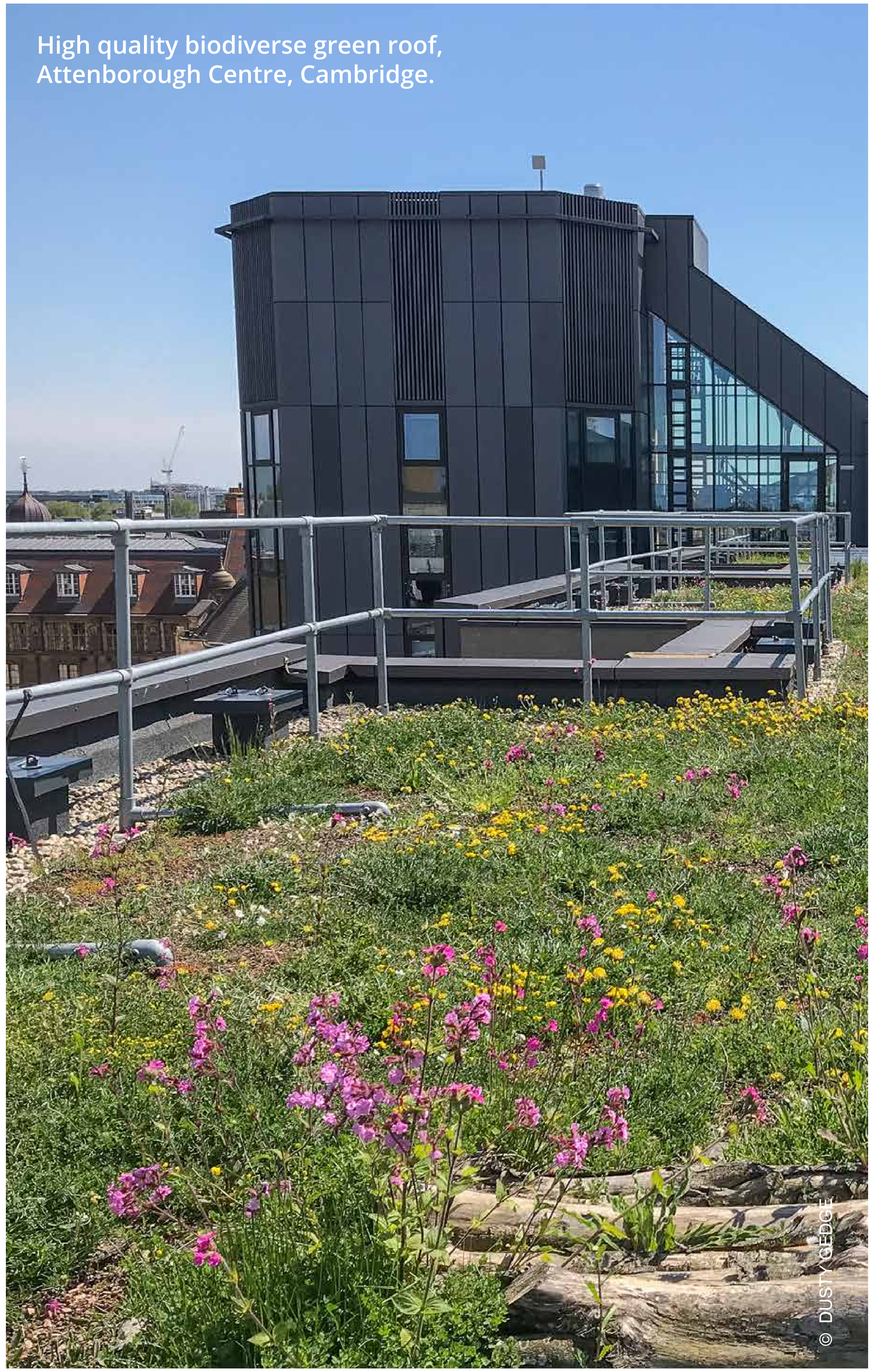
There are also opportunities for highways agencies to incorporate SuDS during infrastructure upgrades, such as when providing cycleways or charging points for electric vehicles, in order to treat runoff from roads before it reaches watercourses. This could be done by amending the Transport Act so that authorities requiring new gully connections to a drainage network would need to incorporate multifunctional SuDS to reduce runoff and improve water quality.[216]

Finally, the Government could direct Ofwat to ensure that water companies use integrated, catchment-scale, NbS in preference to carbon-intensive hard infrastructure, even where performance is less predictable, reflecting the high value that customers place on the environment.[216]

In line with this, the CCC has recommended that legislation on SuDS in England should be strengthened by enacting Schedule 3 of the Flood and Water Management Act, ending the automatic right of new developments to connect to the public sewer and making technical standards for multifunctional SuDS mandatory, as well as resolving SuDS adoption issues.[231]

Table 8.
Policy, regulation and legislation barriers and enablers

Barriers	Enablers
Siloed government departments and using agencies and disjointed decision-making processes	- Promote policy coherence through shared visions and targets, and using a systems approach - Establish cross-departmental policy initiatives and working groups, with independent oversight to monitor progress - Mainstream NbS for adaptation into other sectors (transport, planning, Treasury, etc) - Mandatory consideration of NbS options for infrastructure procurement - Explore and emphasise opportunities for NbS to exploit synergies and manage conflicts
Weak strategies with inadequate, unrealistic or under-resourced targets. Underfunded delivery bodies.	- Clear and strong government mandates for NbS in all four country parliaments - Give relevant strategies a legal basis, e.g. in the Environment and Agriculture Bills in England - Set measurable and realistic targets and provide resources to deliver them, perhaps via an independent well-funded cross-sectoral body to oversee funding of an NbS program - Ensure delivery bodies are adequately funded
Path dependency, i.e. inflexible institutional norms, rules, and practices - Resistance to novel and innovative NbS solutions - Planning processes tailored to and biased towards engineered solutions - Power-relations; e.g. influence of large industries on infrastructure choices	- Raise awareness of NbS including demonstration sites - Educate planners and engineers about benefits and implementation - Reform planning processes as appropriate - Reform procurement schemes to mandate consideration of NbS as an option alongside conventional solutions
Planning consent and licensing requirements are complex, expensive and inconsistent (e.g. for marine restoration)	- Streamline and simplify licensing and consent requirements for NbS where appropriate (while maintaining environmental protection standards)
Weak regulation and standards (e.g. for SuDS and green roofs in planning policy)	- Strengthen regulations and standards to promote protection and creation of high quality NbS.



High quality biodiverse green roof, Attenborough Centre, Cambridge.

6.5 PRESSURES ON ECOSYSTEMS

NbS can be vulnerable to environmental pressures including air and water pollution, habitat loss and fragmentation, invasive species, and climate change. These pressures can be reduced through strong and well-enforced regulation and investment to reduce pollution and GHG emissions, protect existing habitats and species against loss from development, reduce over-abstraction of freshwater, conserve soils and control harmful invasive non-native species. In England, proposed changes to the planning system that envisage 'growth zones' where there would be a presumption in favour of development could weaken protection for existing natural assets, with negative impacts on their climate adaptation services. This loss of natural assets could be exacerbated by further proposed changes that would weaken protected species legislation.

In addition, NbS need to be designed to support and enhance healthy, biodiverse and connected ecosystems that will be naturally more resilient to climate change, using species appropriate for the expected level of climate change, i.e. a 2°C increase in global temperatures (Section 4).

Connectivity is particularly important, to enable species to migrate in response to climate change. In England for example, the 25 Year Environment Plan committed the government to create or restore 500,000 hectares of wildlife-rich habitat outside protected sites as Nature Recovery Areas, which could contribute to a national Nature Recovery Network. There is also an aim to restore 75% of protected sites to favourable condition by 2042. Greater ambition, such as restoring more than 75% of sites, and doing this before 2042, would provide much greater benefits, if adequate resources were provided.

Table 9.
Pressures on ecosystems and enabling factors

Barriers	Enabling factors
Pressure on ecosystems can affect the performance of NbS, including from: - **pollution** - **climate change** - **habitat loss and fragmentation** - **over-exploitation of resources** - **damaging activities such as burning of peatlands,** or **dredging and bottom trawling** in the sea.	Reduce pressures: - cut fossil fuel emissions; enforce regulations on air and water quality, water abstraction, habitat and species protection, soil conservation, etc. - Protect and enhance existing habitats; protect species - Improve habitat connectivity via nature recovery networks - Focus on quality and biodiversity of NbS - Design NbS for a 2°C increase in global temperatures - Funding for ongoing adaptive management - Increase size of marine protected areas and enforce protection more effectively


Hedgerows provide vital corridors to connect habitat patches across landscapes

7 RECOMMENDATIONS

Now is the time for visionary leadership, building on the momentum generated by the UK hosting of CoP 26, the stark messages of the CCRA3 Evidence Report, the ground-breaking Dasgupta review of the economics of biodiversity, and the start of the UN Decade of Restoration. It is time to make new commitments, not through simplistic targets such as the number of trees planted, which can do more harm than good, but with an intelligent strategy to scale up delivery of high quality, carefully planned and locally specific NbS that deliver real and long-lasting benefits for people, climate and nature. In this section we provide recommendations for how we can transform the role of NbS in UK policy, to simultaneously achieve climate resilience, net zero, and nature recovery while also strengthening our economy, creating green jobs, improving health and well-being and reducing social inequality.

These recommendations address the information, finance and governance barriers and support the enabling factors discussed in the previous section. They are in line with the four guidelines developed by UK research, conservation and development organisations in 2020 to ensure that investment is channelled to high quality biodiversity-based and community-led NbS (Box 1), and are designed to support the development of the next round of National Adaptation Plans as well as wider national and local government policies.

7.1 INTEGRATE A WIDER RANGE OF NBS INTO THE NEXT ROUND OF NATIONAL ADAPTATION PLANS

The second round of NAPs recognised and supported NbS to varying degrees (Table 10). While each UK nation will have different priorities, as reflected in the four National Summaries of CCRA3, we believe there are opportunities for a wider range of NbS to play a greater role in the third round of all four NAPs, building on recent policy initiatives and examples of good practice across the UK. Some NbS were barely mentioned in the second NAPs, while others were mentioned only in the Natural Environment chapter and not in the other sector chapters (Infrastructure, Built environment, Business and industry and International dimension), perpetuating a siloed approach to adaptation policymaking. Even those NbS that were widely mentioned (such as peat restoration and natural flood management) may require additional policy support in some of the next NAPs, to scale up delivery of high quality projects. Key opportunities for broadening the role of NbS in the third NAPs are summarised below, and specific recommendations for maximising the benefits of all types of NbS are provided in Table 11.

1. **Managed realignment** was not mentioned at all in the NAP2 for Northern Ireland, and the CCRA3 National Summary suggests that it would be beneficial to consider the potential for managed realignment and to develop shoreline management plans (SMPs). SMPs were mentioned for England, but without any additional policy support to speed up delivery, which is well behind target (Section 3.1).

2. **Seagrass meadows, kelp beds and coldwater reefs** were only mentioned in the Scottish NAP2, and then only in terms of nature conservation. The CCRA3 National Summary states that there is potential to consider protection and restoration of these habitats as a potential NbS for reducing coastal flood and erosion risk, and to provide a programme of funding to support this.

3. **Coral reefs and mangroves** are vitally important for storm protection and fish production in the UK Overseas Territories, while cloud forests provide water security. The UK government could support further protection and restoration of these habitats as part of their commitment to provide technical and financial assistance for climate and biodiversity actions by the UKOTs, as they prepare their own climate mitigation and adaptation plans.[221]

4. **Natural flood management** was mentioned in all four NAP2s, although specific funding was only mentioned in England. Interestingly, none of the NAPs appeared to recognise the role of NFM and SuDS for enhancing groundwater recharge and thus addressing water security issues.

5. **Floodplain meadows and river restoration** are mentioned in all NAP2s, but there is no recognition of the potential for inappropriate tree-planting on floodplains to conflict with the goal of restoring floodplain meadows, which have the advantage of allowing food production to continue via low level grazing.

6. **Peatland restoration** is strongly supported in all NAP2s, with funding and policy support, although there is scope for this to be strengthened through more rapid phase-out of damaging activities (burning, and extraction for horticulture) and more support for restoration in Northern Ireland.

7. **Natural regeneration of woodland,** which can be cheaper then tree-planting and may result in a more resilient structure with greater adaptation benefits, is currently supported for native woodland in Scotland, for all woodland in Northern Ireland, and for land within 75 m of a seed source in England,[222] but not yet in Wales.

8. **Rewilding** can create a diverse mosaic of natural grassland, woodland and scrub that supports livestock and pollinators while also reducing flood and erosion risk, regenerating soil and promoting eco-tourism. Although it cannot be 'designed' to deliver specific benefits, it should be supported in the next NAPs as a promising approach for climate adaptation in areas where conventional agriculture is unproductive.

9. **Green roofs and walls** can play a vital role in flood reduction and urban cooling, but they are only mentioned in the NAP2s for Scotland and Wales. There are opportunities to enhance uptake through planning policy, such as via the Urban Greening Factor in London (Section 6.4).

10. **SuDS** are strongly supported in the Welsh NAP2, with quality standards to deliver wider benefits. There are opportunities to apply stronger quality standards in the other countries, and to resolve adoption issues in England (Section 6.4).

11. **Urban trees and other green infrastructure** are strongly supported in the NAP2s for Wales and Scotland, but not mentioned at all in the NAP2 for Northern Ireland. In England, despite an urban tree planting fund, urban green spaces are still disappearing as a result of conflicts with housing targets.

12. **Vegetation for slope stabilisation** is being investigated in Wales. There is scope to also consider this in the other countries, especially England where UK NAP2 focuses on increased clearance of vegetation as a hazard, in contrast to the CCRA3 Evidence Report recommendation that vegetation can be used to stabilise slopes.

13. **Agroforestry** was only mentioned in Scotland's NAP2, and while there is some support for agroforestry on grassland in Scotland, Wales and Northern Ireland it falls into a policy and funding gap in England (Section 6.2). Long term financial support for both silvo-pasture and silvo-arable agroforestry should be included in agri-environment and/or woodland creation schemes where this is not already the case.

14. **Nature-based agriculture / agro-ecology** receives surprisingly little attention in the NAP2s. There are major opportunities to build agro-ecological methods into post-Brexit agri-environment schemes, as with the draft Sustainable Farming Incentive in England which funds some measures such as cover crops and reduced tillage.


Urban trees and green spaces provide cooling, shading and flood protection, and must be better protected from development

Table 10.
Role of NbS as stated in the second National Adaptation Plans for England (in the UK NAP2, which covers England and UK-wide matters), Wales,[223] Scotland[224] and Northern Ireland.[225]
Note that support for NbS may be provided under other programmes even if not explicitly mentioned in the NAP, and further support has been provided since NAP2 in many cases.

Type of NbS	UK (England + UK-wide matters)	Northern Ireland	Scotland	Wales
Managed realignment and dune restoration	Shoreline management plans mentioned; no additional action	No mention, though the value of habitats for coastal protection is mentioned in general terms. Coastal flood risk is not a priority	Role of dunes and saltmarshes for coastal protection acknowledged; area restored is a potential indicator. Dynamic Coast project is investigating resilience of coastal habitats	£150 m for coastal risk management 2019-22 to support LAs to deliver SMPs but not clear how much would go to managed realignment. Natural Resources Policy aims to support coastal NbS
Seagrass, kelp, reefs	No mention	No mention	Extent of seagrass, kelp and cold-water coral are indicators for biodiversity, not as coastal NbS	No mention
Marine protected areas (MPAs)	Marine Plans, Marine Conservation Zones, Fisheries Bill, Blue Belt (Overseas)	Daera to produce management plans for MPAs	Proportion of MPAs with a management plan is a potential indicator	Complete the MPA network and work towards good status; more research needed
Natural Flood Management (NFM) (general)	£15 M out of £2.6 bn FCERM budget, to expand evidence base. No mention of the role of NFM or SuDS in facilitating groundwater recharge to address water security	Role of habitats for flood protection mentioned. References Sustainable Water strategy which encourages limited NFM (e.g. wetland creation)	Extent of NFM network is a potential indicator. EU funded Eddlestone Water case study. Beaver re-introduction supported via a management framework	Aim to increase NFM including through river basin management plans. Barrog catchment case study
Woodlands for flood and erosion management, water quality and cooling	5-10,000 ha/year target in England; Woodland grants. £5.7 million for Community Forests and the Northern Forest	Forest expansion scheme to increase woodland from 8% to 12% of NI. Targets mixed species & areas >5 ha for carbon, flood protection and biodiversity. No consideration of native vs non-native species. Riparian buffer strips supported in Environmental Farming Scheme. Riparian native tree planting areas to be identified to protect fish from higher temperatures	Aim to increase woodland cover to 21% by 2032, from current target of 10,000 ha/y to 15,000 ha/y by 2024-5 (now increased to 18,000 ha/y). For carbon, economy and NFM. Native woodland creation and natural regeneration in native woodland are indicators	2000 ha /y from 2020 to 2030. New National Forest will be designed to maximize adaptation benefits including flood and erosion protection and cooling. Riparian trees for water quality. Farmers will be encouraged to plant woodland. Woodlands for Wales under Glastir agri-environment program to be replaced by new Sustainable Farming scheme
Floodplain restoration	'Well-managed floodplains can store water', no mention of meadow restoration	References Sustainable Water strategy which encourages floodplain reconnection	EU funded Eddleston Water case study	Restoration of floodplain grasslands to slow the flow and improve water quality and supply, via river basin management plans
River restoration	Mentioned re habitat restoration and water security	Case study of Connswater Greenway (for flood protection) but no supporting actions.	EU funded Eddleston Water case study	Not explicitly mentioned but River Basin Management Plans are prominent. Possibly few modified rivers in Wales
Peat restoration	Commitment to end extraction. £10M for restoration 2018-21. Superseded by England peat action plan: partially ban burning and consult on banning amateur horticultural use. £50M for restoration 2021-25 (Nature for Climate Fund) with future support via ELMS	Yes, led by NI Water as part of catchment management for drinking water quality	Area of peat restored and in recovery are indicators. National Peatland plan provides grants to support increase in peatland restoration from 10,000 ha/y to 20,000 ha/y after 2018	Five year peat restoration program in preparation at time of NAP2, for carbon storage and water supply

Type of NbS	UK (England + UK-wide matters)	Northern Ireland	Scotland	Wales
Slope stabilisation	NbS not considered. Focus on vegetation clearance on road and rail embankments	NbS not considered	NbS not considered	Green Corridor initiative will investigate tree and shrub planting for contributing to slope stability on the trunk road and motorway network
Sustainable drainage systems (SuDS)	Promoted via non-statutory planning policy. Expects OfWat to encourage water companies to adopt SuDS. Cites 25 YEP commitment to improve planning guidance to improve quality of SuDS (current weak standards do not encourage wider benefits)	NI Water and DfI to increase number and % of SuDS in new developments. Good uptake but weak standards do not encourage wider benefits	Not explicitly mentioned. A 'blue-green cities' program is exploring opportunities for flood protection	Mandatory SuDS with strong standards to ensure wider benefits for water quality and biodiversity
Green roofs and walls	Not mentioned	Not mentioned	Part of pollinator strategy	Mentioned once as part of green infrastructure
Urban green space and trees	Mentioned for cooling and health. Goal to plant 1M urban trees	Not mentioned	Green infrastructure fund aims to increase GI by at least 140 ha especially in areas of deprivation. Extent of urban greenspace is an indicator, and GI funding is a potential indicator. Aims include flood protection, cooling, health and wellbeing ('Natural Health Service') and outdoor education	Cross-disciplinary working group established to deliver more green infrastructure. Increase urban trees for cooling, flood protection and health. GI should be biodiverse where appropriate
Agro-forestry	Not mentioned	Not mentioned	Forestry strategy includes role of woodlands in providing shade and shelter for livestock. Farming with Nature; a Soil Association knowledge exchange program, will look at agro-forestry.	Not mentioned, although it mentions 'integrating trees, woodland and shrubs with agriculture'
Agro-ecology	Will update guidance on tillage choice and incentivise good soil management through ELMS	Research into healthy soils ongoing. Only indicator for soil and agriculture risks is area of new woodland planted	Wildflower meadows part of pollinator strategy. Farming with Nature, a Soil Association knowledge exchange program, covers agro-ecological methods.	Aim to promote good agricultural practice to increase resilience of soils and water

7.2 MAINSTREAM NBS BY DEVELOPING COHERENT POLICIES ACROSS ALL SECTORS

Although awareness of NbS is growing across different national and local government departments, there are opportunities to improve policy coherence. Government departments at national, regional and local levels need to talk more to each other about NbS, to break down silos, overcome barriers, identify common goals and harmonise policy support. Specific recommendations to help achieve these aims are listed below.

1. **Set up cross-departmental working groups in all four national governments** to promote the delivery of high quality NbS by developing shared visions, targets and action plans. These groups should include departments and agencies responsible for environment, agriculture, forestry, water, climate change, marine management, business, planning, transport, health and education, with high level support from the Treasury, Cabinet Office and devolved equivalents. A systems approach should be applied to consider interactions between policy objectives, to ensure that NbS are integrated into all relevant departmental policies in a way that delivers on shared goals and avoids conflicts. Ideally there would be oversight of this process from independent advisors to help guard against sub-optimal decision-making due to power imbalances between departments.

2. **Integrate NbS delivery into local plans and policies through a participatory landscape approach,** to deliver a diverse portfolio of the right NbS in the right places while balancing multiple objectives. In England, for example, NbS should be integrated into Local Plans, Local Nature Recovery Strategies and Flood and Coastal Erosion Risk Management Strategy, working with Local Nature Partnerships, Local Enterprise Partnerships, Catchment Partnerships, Farmer Clusters, Coastal Groups and other relevant stakeholders. Involving all stakeholders in dialogue and negotiation can help to ensure that NbS are effective, legitimate and sustainably managed in the long term as part of a 'just transition' that respects local livelihoods and ensures an equitable distribution of benefits. Funding needs to be provided for Local Nature Partnerships and other landscape level organisations who can act as trusted intermediaries and convenors for this process.

3. **Strengthen recognition of NbS as essential climate adaptation infrastructure in future revisions of the UK National Infrastructure Strategy,** by including more explicit support and funding for a broader range of NbS including urban green infrastructure and coastal habitat restoration. In Wales, for example, NAP2 states clearly that "Our 'living infrastructure' forms part of the critical national infrastructure requirements for our businesses, communities and public services in the same way as our 'built' solutions", and in Scotland the definition of 'infrastructure' includes "natural assets and networks that supply ecosystem services." [227]

4. **Planning policy must provide stronger protection for existing semi-natural habitats.** Natural assets such as hedgerows, woodlands, semi-natural grasslands, heathland, wetland, peatland, sand dunes and urban trees, all of which offer vital protection from climate impacts, are all still being lost to development, especially through exemptions for 'nationally significant infrastructure'. This loss would be likely to increase under proposed reforms to the planning system in England that would result in a development free-for-all within designated 'growth zones', with no local planning oversight, especially if protected species regulations are also weakened in line with recent suggestions. Reforms to the planning system need to focus on protecting all natural assets, not just those with formal designations, even if an area is designated as a growth zone.

5. **Ensure that regulations and legislation support and encourage scaling up of good quality NbS schemes.** Specifically, by negotiating affordable and streamlined licensing systems for seagrass restoration, beneficial use of dredging, leaky dams and flood storage ponds that conform to good quality guidelines in pre-approved locations (see Section 6.4 and Case Study 9).

6. **Promote synergies between NbS for adaptation and Net Zero policies.** High quality NbS have benefits for both adaptation and mitigation, but simplistic area-based targets for tree planting could lead to a dominance of low diversity plantations of non-native species that may have low resilience to climate change, crowding out opportunities for more resilient NbS with wider benefits. Net zero strategies (including the next carbon budget and CCC scenarios) should support protection, restoration and connection of a wide range of habitats, including permanent species-rich grassland, heathland, inland wetlands and coastal habitats, to provide locally specific climate adaptation services as well as carbon sequestration. This will require funding for research on carbon storage and sequestration in these other habitats.

7. **Promote synergies between food security and other objectives.** Nature-based agricultural practices such as agro-ecology and agroforestry have the potential to deliver adaptation services on farmland without compromising food production. The public and policymakers need to be aware of the need for dietary change and reductions in food waste to free up land for NbS that deliver climate mitigation, adaptation and nature recovery.

8. **Integrate NbS into national nature recovery plans and set strong environmental policies to support healthy, resilient and well-connected ecosystems.** Pressures on ecosystems need to be reduced, so that current and future NbS will be resilient to future change. This requires greater efforts to reduce GHG emissions, air pollution, water pollution, over-abstraction of water supplies, and damaging activities such as peat burning, bottom trawling and dredging, as well as increasing the connectivity and condition of ecosystems. In England for example, the 25 Year Environment Plan (25 YEP) aims to create or restore 500,000 hectares of wildlife-rich habitat outside protected sites to form part of a Nature Recovery Network. There are opportunities to strengthen the 25 YEP in the next revision (expected in 2023), going beyond the current target (to restore 75% of protected sites to favourable condition by 2042), if adequate resources were provided.

7.3 FUND HIGH QUALITY NBS FOR CLIMATE ADAPTATION

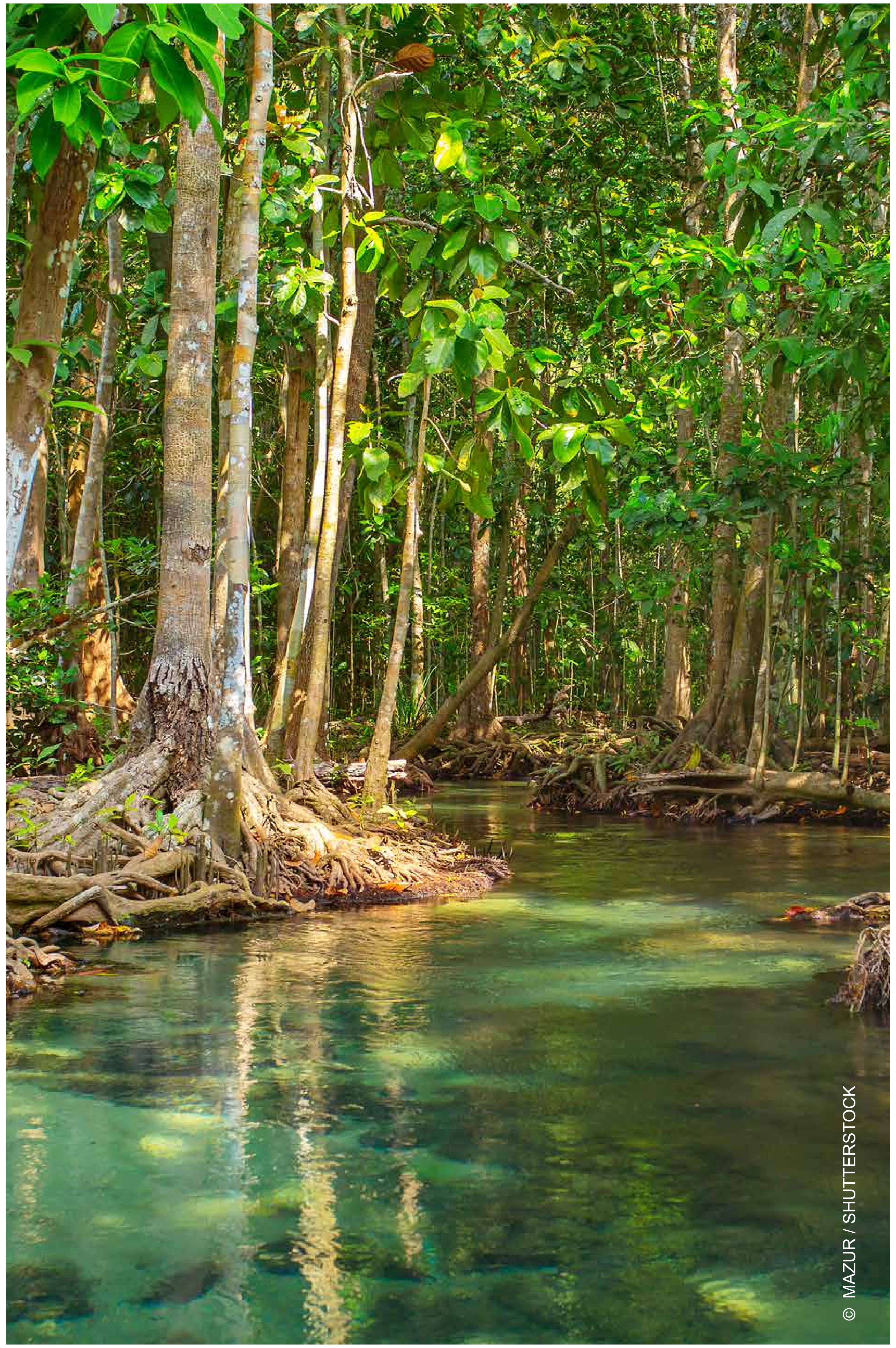
Although NbS generally have high cost-benefit ratios when all societal benefits are taken into account, funding mechanisms can be biased towards more conventional options. More finance for NbS is needed, including novel mechanisms that recognise their multiple market and non-market benefits. There is increasing interest in NbS for carbon sequestration from the private sector, much of which is flowing towards tree-planting, and there are opportunities to channel some of this funding to a wider range of high quality NbS for climate adaptation.

1. **Public funding for high quality NbS for climate adaptation should be increased,** in line with the recommendations of the Dasgupta report and the Natural Capital Committee that all publicly funded infrastructure projects and programmes, infrastructure providers and public bodies should be required to invest in maintaining and enhancing natural capital.

    a. **Reform funding and procurement mechanisms so that they recognise the wider benefits of NbS.** It should be mandatory to consider NbS alongside conventional engineered options and to take into account their wider benefits when allocating funding, such for flood risk management projects. Where wider benefits cannot be monetised, funding for high quality NbS could be ring-fenced.

    b. **Provide more funding for delivery bodies,** many of which are chronically underfunded and need more resources to oversee the delivery of high quality NbS, such as Natural England, the Environment Agency, NatureScot and SEPA.

    c. **Provide more funding for research, demonstration and long term monitoring** of key projects, especially at large scales, to expand the evidence base on the environmental, social and economic benefits of NbS for adaptation and to inform good design. This will help to unlock more funding from both the public and private sectors by providing consistent performance metrics that can justify investment.



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d. **Fund knowledge exchange networks, professional advisory services and information hubs.** This is particularly important for agroforestry and agro-ecology where lack of information for farmers is a major barrier.

e. **Consider whether the UK Infrastructure Bank could help to support NbS,** such as by funding up-front costs until grants come through, and consider potential for new funding bodies such as an Agro-ecology Development Bank.[189]

f. **Perverse subsidies for activities that damage natural capital should be ended** (including subsidies for fossil fuel extraction) in line with the Dasgupta review recommendations.

2. **Public funding needs to leverage private funding,** including through the development of new blended public / private finance mechanisms, and should be targeted towards achieving a step change in delivering higher quality NbS for adaptation.

3. **Ensure that different funding sources can work together** (such as agri-environment schemes, woodland creation grants, biodiversity gain, Net Zero funds and the Emissions Trading Scheme) and **develop mechanisms for stacking and bundling benefits** such as carbon sequestration, flood reduction, water quality, and biodiversity gain.

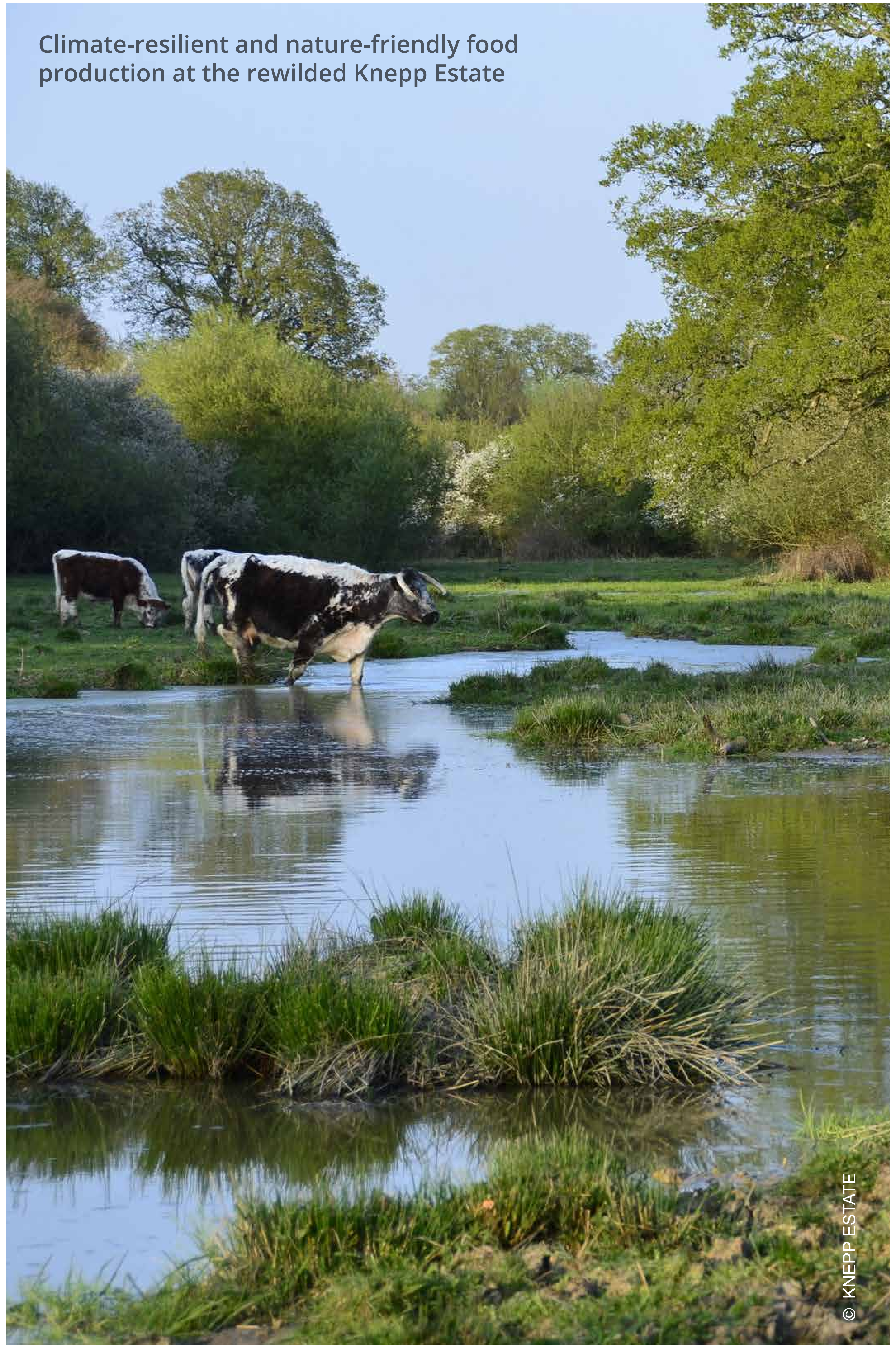
7.4 SET STANDARDS FOR HIGH QUALITY AND RESILIENT NBS

While it is encouraging to see the increase in attention and funding flowing towards NbS, it is important to apply standards to ensure that NbS are high quality, resilient, and multifunctional, and are managed adaptively to enable them to respond to change. Over-simplistic targets and weak standards could lead to poor quality interventions that under-perform or even cause damage.

1. **Apply the four NbS guidelines** (Box 1) and the more detailed **IUCN Standard,**[15] to ensure that NbS deliver real long term benefits for both people and nature, including through participatory design and delivery.

2. **Set clear objectives for NbS schemes, and monitor and evaluate the outcomes** against a baseline using suitable indicators (see next section).

3. **Plan NbS to deliver measurable benefits for biodiversity** through enhancing the health, diversity and connectivity of ecosystems and their habitats and species, rather than through simplistic standalone targets such as the area or number of trees planted. This is essential to ensure the long-term resilience of NbS to climate change and other risks, and in turn the sustainable delivery of benefits for people and the economy. Encourage use of diverse native species, and explore options for rewilding or natural regeneration if appropriate, to enhance benefits for biodiversity.


Climate-resilient and nature-friendly food production at the rewilded Knepp Estate

© KNEPP ESTATE

4. **Set safeguards for NbS involving tree-planting.** There is a prevailing assumption that planting trees always has benefits for biodiversity, which needs to be corrected through raising awareness that this depends on the tree species, woodland management and previous land cover. Avoid planting trees on native grassland, heathland, wetland or bog unless this is agreed as part of a nature recovery strategy with demonstrable benefits for biodiversity and carbon (e.g. for patches of low density native woodland on overgrazed uplands, or small areas of wet woodland on floodplains). Ensure that trees are not planted on peat (including shallow peat) or peaty soils. Non-native conifer plantations (and intensively managed native plantations) are needed to reduce the UK's high imports of wood, but they are not NbS because they generally have low biodiversity benefits or negative impacts. Forestry standards need to support more biodiverse and resilient production methods (see Section 4.2).

5. **Set a minimum standard for green roofs** in national and local planning policies, equivalent to 'Biodiverse Green Roofs' with adequate depth of substrate to deliver cooling and drainage services, as defined in the GRO code, to move away from the current preference for thin sedum mats with few benefits.

6. **Adopt higher standards for sustainable drainage systems (SuDS)** to ensure that high quality open, vegetated systems with benefits for water quality, biodiversity and amenity are delivered rather than basic underground pipes and tanks. High standards already apply in Wales, although there are opportunities to provide more specific biodiversity criteria, and revised standards have been developed for England which should now be adopted in line with CCC recommendations.[231]

7. **Promote the Trees in the Townscape principles** to ensure high quality integration of trees into urban areas.[228]

8. **Include an agroforestry standard in agri-environment schemes such as ELMS** to help farmers understand what constitutes good practice.

9. **Support practitioner and researcher knowledge-sharing networks to spread good practice** and provide solid evidence of efficacy and benefits of NbS, such as the proposed agroforestry network. [229]

10. **Design NbS to be compatible with a 2°C increase in average global temperatures** and the associated impacts such as changing weather patterns, water shortages or sea level rise, including by selecting appropriate sites, a diverse mix of suitable species, and planning to enhance ecosystem connectivity. Use adaptive management to respond to change and address the increasing variability in weather and climate.

7.5 MEASURE AND MONITOR NBS DELIVERY: TARGETS, INDICATORS AND METRICS

National adaptation policies should set well-defined, ambitious and time-bound objectives for scaling up high quality NbS, and establish monitoring and evaluation processes to evaluate progress towards these objectives. We need to know whether NbS are integrated into adaptation policy and processes in different sectors, to what extent they have been deployed, and what are the outcomes. We also need to build capacity for practitioners and researchers to effectively monitor NbS processes and outcomes over the long term, including through funding research to address evidence gaps.

1. Define suitable indicators and metrics for assessing the deployment, quality and outcomes of NbS for adaptation, along with co-benefits. Metrics could include number of people with reduced exposure to climate risks; value of assets with reduced exposure; length of protected or restored coastal habitats; proportion of working landscapes under sustainable management; increase in area of urban greenspace; and area of restored habitats that target specific opportunities (e.g. woodlands in appropriate locations and on suitable soil types to reduce flood risk). Funding for further research is needed to build the evidence base to inform these metrics.

2. Improve the monitoring of biodiversity impacts, which are rarely measured. Metrics could include area of habitats restored and protected (including a target for complete protection of priority habitats such as ancient woodlands, mangroves, reefs and saltmarshes); condition of habitats; habitat connectivity; abundance and diversity of species across multiple taxa (e.g. plant, fungi, bird, mammal, invertebrate and soil microbial diversity); use of appropriate native species; and number of large, mature street trees.

3. Strengthen technical, financial and institutional capacity to ensure that NbS are well-designed, financed, implemented, monitored, evaluated, and mainstreamed. This includes funding for monitoring and research, and generating supporting tools and evidence, such as evaluation methods and detailed maps and registers of natural capital assets and climate risk, to help inform adaptation planning that delivers co-benefits and avoids adverse side-effects. Funding needs to cover the costs of providing advice from ecologists to help inform the design of NbS so that they optimise benefits for biodiversity.

7.6 SUMMARY TABLE OF RECOMMENDATIONS FOR DIFFERENT TYPES OF NBS

Table 11.
Specific recommendations for scaling up high quality NbS for climate adaptation in the UK

NbS type	Recommendations
Marine and coastal NbS	- Streamline and simplify licensing arrangements for marine NbS including beneficial use of dredging material and seagrass restoration - Include targets and support for seagrass, kelp, sand dune and reef protection and restoration in NAP3 - Fund research to inform development of metrics on the performance of marine NbS, e.g. for flood protection and erosion stabilisation as well as carbon sequestration - Better enforcement of Marine Protected Areas
Natural Flood Management (NFM)	- Establish a requirement for partnership working to enable oversight and co-ordination between district, county and catchment / landscape scales (as legally required in Scotland) and develop a framework for collectively sharing responsibilities - Support catchment/landscape-level organisations as trusted intermediaries for NbS delivery - Allow consideration of co-benefits in appraisals for flood risk management funding, while recognising that further benefits will exist that cannot be meaningfully monetised. In England, this means that the Partnership Funding Calculator needs to be revised to take greater account of environmental co-benefits - Consider providing ring-fenced funding for NFM within appraisal of flood and coastal erosion risk management projects, to recognise the co-benefits of NbS that are currently excluded from the appraisal process - Develop mechanisms for blending finance from different beneficiaries and stacking and bundling benefits (flood protection, water quality, carbon, biodiversity etc), e.g. through a shared outcomes fund - Educate consenting authorities about NFM so that licensing and permissions can be simplified (e.g. not requiring permission for every leaky dam separately) - Provide guidance to Lead Local Flood Authorities in England and devolved nation equivalents on how to create high quality SuDS and NFM with biodiversity benefits - Scale up public funding beyond the pilot scale, support NFM in agri-environment schemes such as ELMS (vital given that 70% of UK is privately owned farmland) - Change OfWat rules to unlock further funding via water companies, who are currently not allowed to invest unless there is an economic return for their shareholders - Regulators need to understand and acknowledge that NFM involves a process of adaptive management ('managing for uncertainty') that has a larger envelope of variability than engineered infrastructure, but can still deliver sustainable and cost-effective outcomes
Woodland NbS	- Do not plant trees on biodiverse open habitats unless there are clear biodiversity benefits - Choose a mix of climate-resilient native species, and consider natural regeneration rather than planting, to allow a mosaic of shrubs, grass and woodland to form
Grassland NbS including floodplain meadows	- Explicitly include floodplain meadows in flood risk management, agri-environment and nature recovery plans. Protect existing 'Ancient Meadows' and set targets for floodplain meadow restoration, with long term funding (10-20 years) via agri-environment schemes or conservation covenants - Take land in the flood zone out of intensive agriculture and restore to floodplain meadows - Reconsider opportunity maps and grants for trees on floodplains, which may conflict with floodplain meadow restoration

NbS type	Recommendations
Peat and heathland NbS	- Strengthen action plans (including the England Peat Action Plan) to accelerate restoration of degraded peat, ban burning on all peat (not just protected areas) and end all peat extraction (both amateur and professional use) - Lowland peat: implement faster and more ambitious action to rewet lowland peatland with sustainable management to maximise NbS benefits, particularly control of water - Ensure the new UK Forestry Standard prohibits non-native tree-planting on shallow as well as deep peat, and on heathland
Slope stabilisation	- Consider whether there is greater potential to use native vegetation to stabilise embankments rather than always clearing vegetation as a hazard (following the example of Wales)
Agro-ecology	- Link baseline payments in agri-environment schemes to basic soil protection measures including maintaining cover, minimising tillage and avoiding synthetic fertilisers on permanent grassland - Provide support for organic farming. Organic certification could be used to target agri-environment schemes soil stewardship payments - Support regular monitoring of soil organic matter on farms; it should be a condition of farm tenancies that this is maintained or improved
Agroforestry	- Recognise the potential of agroforestry for increasing farm resilience to climate change in the next round of NAPs, and develop appropriate supporting policies to greatly increase the uptake of agroforestry by farmers - Fill the funding gap for agroforestry by providing long term financial support in post-Brexit agricultural policy at a high enough level to increase uptake. In England, for example, this can be achieved by supporting the development and adoption of an explicit agroforestry standard in ELMS, to provide clear guidance for farmers on what they need to do, together with inclusion of wood pasture as a component of the Nature Recovery tier of ELMS.[179] - Invest in knowledge exchange to help farmers understand and implement agroforestry techniques, through funding for agroforestry demonstration projects, peer to peer knowledge exchange, farmer-led research and innovation networks, mentoring, regional knowledge hubs, and specialist advisors who can work one-to-one with farmers.[177] - Help farmers and landlords to develop longer term tenancy agreements to make agroforestry investments worthwhile - Invest in processing capacity for lucrative agroforestry crops such as nuts.[178]
SuDS	In line with CCC recommendations:[231] - Remove the automatic right to connect surface water runoff from new developments to the sewer network in England (this has already been done in the other three nations) - Technical standards for SuDS should ensure that biodiverse open, vegetated systems are used which deliver multiple benefits for biodiversity, amenity and water quality, rather than tank and pipe systems. Adopt the revised technical standards for SuDS in England, and consider improving the standards in other countries where necessary, including through including multiple benefits in the Northern Ireland standard and tightening up the definition of 'maximising biodiversity' in the Welsh standards.[219] - Resolve barriers to the adoption of SuDS by local authorities and / or water companies

NbS type	Recommendations
Green roofs and green walls	- National level planning policy (for example the NPPF in England) should state an expectation that all flat roofs in new developments should be green or biosolar roofs unless there are good reasons why this is not appropriate. Local planning authorities can deliver this aim through local plans and associated planning policy and conditions. For example, in London this has been achieved through the use of the Urban Greening Factor with a minimum score of 0.4. - National and local planning policies should specify a minimum standard for green roofs to be 'Biodiverse green roofs' with adequate depth of substrate to deliver cooling and drainage services, as defined in the GRO code, and not thin sedum mats - Set a target and provide incentives to increase retrofit of green roofs and walls in existing developments
Urban trees and other green-blue infrastructure	- Recognise urban trees and other green-blue infrastructure as essential infrastructure alongside utilities, to be incorporated at the first stage of planning. [230] - Apply tools to value the benefits of urban trees, especially larger, older trees, to counteract the prevailing view of them as liabilities (e.g. iTree-Eco; CAVAT). - Maximise the adaptation benefits of urban green infrastructure through changes to conventional management, e.g. cut grass less and cut later in the year to give a denser and more biodiverse sward that has greater value for flood protection and pollination
UKOTs	- Provide additional funding for NbS in the Overseas Territories. Scale up funding for mangrove and reef restoration for coastal protection, and cloud forest protection and restoration for water security

Firs Farm Wetlands, Enfield, were restored by de-culverting a hidden river. They now protect 100 houses from flooding, filter out pollution from surface water runoff, and provide beautiful natural spaces for local people and wildlife

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Protecting and restoring coral reefs in the UK Overseas Territories can help protect communities from coastal floods, as well as supporting fisheries

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