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Fellowship to Map the Evidence Base on the Costs of Action and Inaction in a Changing Climate

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Executive Summary

Background

Human-induced climate change is driving increasingly severe weather in the UK, threatening the long-term viability of Scotland's land-based industries. To remain resilient and competitive, these sectors must urgently adopt climate adaptation and mitigation strategies, including Nature-based Solutions (NbS), which are central to emerging policy and funding frameworks. We take a broad definition of NbS that includes any form of land management that utilises natural or nature-like process to provide adaptation outcomes, this includes where land is being primarily managed for productive purposes, e.g through changing production methods to include elements of NbS. This report investigates the state of knowledge on the relationship between NbS and the productive land use sectors of agriculture and forestry in Scotland.

Approach

The research questions guiding this work are:

1. What is the **state of knowledge** on the relationship between **nature-based solutions, risk and resilience for the productive land management sectors** of agriculture and forestry?
2. Based on the state of knowledge, how **effective** are NbS at **mitigating** and helping land use sectors to **adapt** against the UKCP18 climate change scenarios? How will the effectiveness of interventions be impacted by climate change?
3. What are the **costs** and **risks** of **maintaining the status quo**?
4. What are the **environmental, economic, and social trade-offs and synergies** to implementing NbS, and how might these inform expected **barriers to uptake**?

Key Findings

A Rapid Evidence Assessment yielded 1,820 results. Fifty-two pieces of evidence were included in the final review. The limitations and conditions of success of 54 NbS measures across 8 sources of grey literature/case studies were reviewed. Stakeholder workshops with research and policy experts, provided a sense check of the evidence review findings and discussed NbS effectiveness as well barriers and opportunities for NbS uptake at landscape scale in Scotland. The results of scoring different NbS measures against a range of implementation criteria are summarised in ***Table E***1. This show high scores across our criteria for 'traditional' NbS that are directly associated with the water environment, but lower scoring of NbS in land uses such as agriculture and forest management.

We identified multiple costs of inaction including lost production, ecosystem degradation, damage to property and infrastructure, and increasing costs of mitigating lost ecosystem services. These were matched to adaptive strategies and associated implementation costs. The barriers and incentives for NbS uptake at different time stages out to 2050 are summarised in Table E2. The aim here is to identify the timeframes for necessary actions.

Discussion

This research confirms that continuing with current productive land management practices is not a low-risk option. Land management is not coordinated at catchment and landscape scales reducing the potential effectiveness of sustainable practices including NbS. Both our evidence review and stakeholder engagement point to growing costs of inaction—ranging from soil degradation, declining water quality, storm damage and deer overpopulation—that are already impacting public budgets, supply chains, and community resilience. NbS aim to embed natural processes within productive land use , but their effectiveness is limited when implemented in isolation or without addressing the fragmentation of land use management. To be fully effective NbS need to be implemented at a scale and spatial pattern that reflects the local context. The evidence gaps identified in this work—particularly around long-term and integrated assessments—highlight that NbS research must move beyond single-measure evaluations to understand how combinations of interventions function within whole landscapes. Critically, these findings show that inaction carries escalating and unevenly distributed risks, and that addressing the limits of current knowledge should be a key priority for Scotland's next Strategic Research Programme (SRP).

Table E1 Tabulation of scores by participants to assess NbS interventions based on a selected list of criteria

NbS measures	Urgency	Cost of inaction	Co-benefits	Scalability	Evidence quality
Floodplain reconnection	5	5	4	3	4
Floodplain wetlands	5	5	5	4	4
Offline storage	5	5	4	5	4
Temporary storage ponds on farms	5	5	5	4	4
Leaky barriers – linked with riparian planting	5	5	4	4	4
Intercropping	3	2	3	5	2
Hedgerows	5	5	3[f]	3	3
Buffer strips (grass)	3	2	2	1	4
Multi-paddock grazing	3	3	2	4	2
Mixed density stands	3	3	3	2	3
Multifunctional forest	3	2	4	2	4
Forest zoning	4	3	4	3	3
Natural regeneration	3	3	3	2	2
Continuous cover forestry	4	3	3	2	3
Conservation areas	5	5	4	2	4
Riparian woodlands	5	5	4	3	3

Colouring and numbers indicate the ranking of the interventions against each criterion, the higher the number (darker blue shading) indicates a higher degree of importance or effectiveness. Low numbers (darker red shading) indicate either lower importance, effectiveness or lower quality of evidence.

Table E2 Summary table of the barriers and opportunities for NbS implementation from 2025 to 2050

2025	
Barriers to uptake	Push and pull from the market on farmers, leading to uncertainty
	Not having contractors skilled for NbS projects and the contractor base being too small for the level of projects incoming
	Slow rate of change for forestry
	Regulatory conflicts between peatland restoration and tree removal limitations
	The assumption that only native species can contribute to natural woodland
	Natural tree regeneration limited by deer grazing pressure
Incentives for adoption	Politicians and public figures speaking out for nature and defending rules and resources related to NbS
	Supermarkets and big wholesale buyers engaged in delivering the route map to sustainable regenerative agriculture
	Appraising and publicising the balance of public and private costs and benefits delivered by the current mix of land management
	NFUS and other key players supporting and promoting regenerative agriculture
	Normalising regenerative agriculture as mainstream, via monitor farms, LEAF farms, what is required in agricultural policy
	Having a societally defined objective for allowable deer populations
2030	
Barriers to uptake	Businesses not perceiving NbS as an opportunity or a risk mitigating tool for future profits
	Not enough technological advancement for agricultural productivity
	Lack of certainty and vision for the long term NbS land use plan
Incentives for adoption	Greater agri-environment scheme support for NbS
	Next Scottish Biodiversity Strategy delivery plan in place and the journey to NbS normalisation has begun
	More evidence of NbS being cost-effective
	Markets for sustainable agricultural products exists
	Regulators have made and had accepted policy changes necessary for the rate and type of change, especially in Forestry
	Higher disposable household income with lower energy bills
	More deer management operators, facilities, and outlets for venison
2040	
Barriers to uptake	Land managers do not fully understand the climate risks they are likely to be exposed to and what the solutions might be

Incentives for adoption	Successful delivery of Scottish Biodiversity Strategy actions at scale across habitats
	Successful implementation and delivery of NBF4 - damage and loss to irreplaceable habitats has been stopped
	Simplification of incentives and regulations for land managers to implement NbS
	Incentives to support farmers to deploy regenerative agriculture
	Pilot initiatives are fully implemented to grow the evidence base of NbS
	There is economic evidence in support of NbS
	Riparian woodland is well established, and we can see measurable changes in freshwater temperature reduction
	NbS requirements are included in agri-environment schemes
	Woodland creation and restocking has become much more diverse in terms of species, genotypes, and silvicultural practices
	Enforce abstraction allowances for agriculture
	Biosecurity is embedded into land management
	Sectorial change in species choice for forest planting is in place at scale
	Accepting and expecting novel ecosystems
	Insurers and lenders take account of nature and climate-related risks for land-based businesses
	Give the RLUP's 'teeth' by having leverage over agricultural subsidies
	Viable business models for different land management contexts
	Increased duties of local government and NHS to allocate resources for green infrastructure
	Viable nature markets for private investment
	Develop a large-scale strategy/tool to prioritise the application of NbS in land use
	Societal awareness and transparency about how public sector budgets are spent, highlighting the costs of the status quo (e.g. deer management)
	Change in climate change plan that removes perverse policies that are non-compatible with each other (e.g. peatland restoration vs. control of woodland removal policy)
	Deer allowance in wider landscape reduced to less than 5 per km^2
	Conversations around land management that acknowledge the diverse objectives of land use, whether for commercial productivity or ecological conservation

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Abbreviations

ARP – Agricultural Reform Programme
FGS – Forestry Grant Scheme
ICF –Institute of Chartered Foresters
IPCC – Intergovernmental Panel on Climate Change
IPM – Integrated Pest Management
NbS – Nature-based Solutions
NFM – Natural Flood Management
NWRM - Natural Water Retention Measures
REA – Rapid Evidence Assessment
SRP – Strategic Research Programme
WWNP – Working with Natural Processes

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Introduction

Background and policy context

The scale and impacts of human-induced global warming are undeniable. The UK Government's seventh carbon budget, published in February 2025, explicitly states that greenhouse gas emissions are entirely responsible for the observed long-term rise in global temperatures.[1] Extreme weather events, such as heatwaves and floods, are no longer rare occurrences but regular fixtures in the UK. The economic and environmental costs of these disasters are enormous, and as greenhouse gas emissions continue to accumulate, these events will only intensify in both frequency and severity. 'Business as usual' might continue but it will become increasingly unpredictable, riskier and costlier.

Since 2022, the Intergovernmental Panel on Climate Change (IPCC) has formally acknowledged the essential role that human behaviour plays in addressing the challenges of the Anthropocene. Integrating proactive climate adaptation and mitigation strategies into everyday practices is increasingly viewed as vital. Without such integration, the consequences of inaction are projected to escalate, potentially exceeding current estimates. Globally, key stakeholders, including insurance companies, risk management consultancies, international organizations, and policymakers, are increasingly acknowledging the severe economic and environmental consequences of delaying action. According to a report by the Boston Consulting Group, if global warming reaches 3°C by 2100, it could reduce cumulative economic output by 15–34%. In contrast, investing just 1–2% of global GDP in mitigation and adaptation could limit warming to 2°C and significantly reduce economic damages to 2–4%.[2] Acting now is not only more cost-effective than responding to escalating crises but, for many businesses, essential for survival.

In Scotland, mainstream land use has traditionally centred around agriculture, forestry, and other land-based industries, with an emphasis on economic productivity, including the production of food, timber, and fibre.[3] These practices have typically operated under the assumption of a stable and predictable climate, with land management focused on maximising yields and economic returns.[4] However, as the impacts of climate change become more apparent, this conventional approach is increasingly being challenged. Extreme weather events, fluctuating temperatures, and changing precipitation patterns are becoming more frequent, disrupting traditional agricultural and forestry cycles.[5] In this rapidly evolving context, the risks to both production activities, such as crop and

[1] Climate Change Committee. (2025). *The seventh carbon budget*.

[2] Boston Consulting Group. (2024, December 11). *The cost of inaction: Recognizing the value at risk from climate change*. https://www.bcg.com/press/11december2024-climate-risk-cost-of-inaction.

[3] ClimateXChange. (2020). *Impacts of climate change on Scottish agriculture and forestry*. https://www.climatexchange.org.uk.

[4] Forestry and Land Scotland. (2020). *Managing Scotland's forests and land for climate change*. https://forestry.gov.scot.

[5] Scottish Government. (2020). *Scotland's land use strategy 2021-2026*. https://www.gov.scot.

livestock yields, and ecosystem services such as water management, soil health, and biodiversity, are escalating.[6] Mainstream land management practices, particularly those focused on short-term gains, are finding it harder to adapt to the unpredictable climate, highlighting the need for more resilient and adaptive approaches.[7] Addressing these risks involves recognizing the vulnerabilities inherent in traditional practices and shifting toward policies and practices that enhance long-term resilience, safeguard ecosystem services, and build adaptive capacity to a more volatile climate.[8]

It is imperative for Scotland's land-based industries to integrate adaptation and mitigation strategies to manage risk and ensure the long-term productivity and viability of both the sector and the natural environment it depends on. A crucial step in this process is internalising the cost of climate-related events into business models. Without proactive measures, the status quo will increase financial and operational risks to agriculture and forestry in Scotland, including:

- **Increased vulnerability to extreme weather –** Scotland is experiencing more frequent floods, intense rainfall, and droughts. These events are disrupting crop cycles, damaging infrastructure, and reducing profitability in farming and timber industries. The economic toll is already evident: in 2017-2018 alone, extreme weather cost Scottish farmers an estimated **£161 million** due to livestock losses and lower crop yields. [9] Future climate projections suggest even greater losses if adaptation measures are not implemented.
- **Soil degradation and declining productivity –** Intensive farming and overgrazing are leading to soil erosion, compaction, and reduced fertility, diminishing long-term yields. A 2020 study estimated that soil erosion costs Scotland between **£30 million and £50 million annually,** as a result of a decline in agricultural and forestry yields, the cost of replaced losses in soil-based nutrients and minerals, declines in water quality, and the release of greenhouse gas emissions. [10] Additionally, Scotland's peatlands—critical carbon sinks that store vast amounts of carbon—are increasingly at risk due to climate change and land-use pressures.[11] The loss of peatland function not only exacerbates emissions but also threatens the water retention capacity of the landscape.
- **Spreading pests and diseases –** Rising temperatures and shifting precipitation patterns are accelerating the spread of crop pests and forest diseases. Ash dieback is expected to cost the UK economy **£15 billion over the coming**

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[6] Scottish Government. (2021). *Climate change adaptation and Scotland's environment*. https://www.gov.scot.

[7] Scottish Natural Heritage. (2021). *The role of natural heritage in Scotland's climate resilience*. https://www.nature.scot

[8] NatureScot. (2021). *Building climate resilience: The role of nature-based solutions*. https://www.nature.scot

[9] WWF Scotland. (2023). *The impact of extreme weather events on Scottish agriculture*.

[10] Rickson, R. J., Hann, M., Drake, N. A., & Graves, A. R. (2020). *Developing a method to estimate the costs of soil erosion in high-risk Scottish catchments: Final report*. Scottish Government.

[11] ClimateXChange. (n.d.). *Land use*. https://www.climatexchange.org.uk/policies/land-use/.

decades, with Scotland's forestry sector bearing a significant portion of these losses.[12] Other threats, such as Dothistroma needle blight and bark beetle infestations are at risk of becoming more prevalent, endangering commercial timber plantations and native woodlands.[13]

- **Rising operational costs** – Extreme weather events and disrupted supply chains are increasing the costs of livestock feed, fertilizers, and transportation, as well as increasing damage to homes and other personal assets.[14] In the forestry sector, major storms have caused **volumes of timber in excess of 1 million m^3 to be damaged at least 5 times in the last 50 years.**[15] Such volatility makes long-term production planning more difficult and threatens sector-wide financial stability.
- **Market and policy shifts** – Retailers, investors, and consumers are demanding stronger sustainability commitments, and businesses that fail to adapt risk losing market access.[16] Additionally, the Scottish Government is shifting financial incentives towards climate-conscious land management. Policies such as the **Agricultural Reform Programme (ARP)** and the **Forestry Grant Scheme (FGS)** are prioritising sustainability measures. Farms and forestry businesses that do not transition to lower-carbon, climate-resilient practices may lose eligibility for funding, making adaptation an economic necessity rather than a choice.

To address these challenges, policy frameworks are increasingly using Nature-based Solutions (NbS) as a key strategy for building resilience in the land-use sector. NbS harness natural processes to mitigate climate risks, enhance biodiversity, and improve land productivity, through actions such as restoring peatlands to capture carbon, expanding woodland cover to enhance biodiversity and provide sustainable timber, reintroducing native species like the beaver to improve wetland ecosystems, and implementing agroforestry practices to boost soil health and reduce flood risks. Crucially, they acknowledge that economic stability is inseparable from a healthy, functioning environment. The natural world underpins the productivity and sustainability of agriculture, forestry, and other land-based industries. Without investing in measures to reverse environmental degradation now, the long-term costs will be far greater, both economically and ecologically.

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[12] University of Oxford. (2019, May 8). *Ash dieback is predicted to cost £15 billion in Britain*.

[13] BBC News. (2012, September 19). *Tree disease hits Scottish forests*. https://www.bbc.co.uk/news/uk-scotland-19652046.

[14] Adaptation Scotland. (n.d.). *Impacts of climate change*. https://adaptation.scot/scotland-and-climate-change/impacts-of-climate-change/.

[15] Nicoll, B., Hale, S., & Locatelli, T. (n.d.). *Tree stability and wind risk to forests*. Forest Research.

[16] ClimateXChange. (2023, May). *The evidence for private sector drivers in the Scottish agricultural supply chain*. https://www.climatexchange.org.uk/wp-content/uploads/2023/12/CXC-The-evidence-for-private-sector-drivers-in-the-Scottish-agricultural-supply-chain-May-2023.pdf.

The Scottish Government and various agencies have integrated NbS into policies and strategies spanning land management and biodiversity conservation. Key initiatives include:

- **Scottish Climate Change Plan:** Sets a target for net zero by 2045, incorporating NbS as a central pillar of carbon reduction and resilience-building efforts.
- **Scottish Biodiversity Strategy to 2045**: outlines the country's commitment to a "nature-positive" future by 2030, emphasising the need to halt biodiversity loss through ecosystem restoration, enhance carbon sinks such as peatland and forests to mitigate climate change, support sustainable land management practices that integrate NbS, and align policy and funding mechanisms that integrate NbS.
- **National Planning Framework 4:** Embeds NbS into urban and rural planning, mandating nature-positive infrastructure.
- **Scottish Land Use Strategy**: Promotes an integrated, "natural capital" approach to land management, ensuring productive land sectors benefit from NbS.
- **Peatland ACTION Programme**: Aims to restore 250,000 hectares of degraded peatland by 2030, supporting both climate mitigation and water management.

In addition to the Agri-Environment Climate Scheme, Scotland also has established targeted funding mechanisms to accelerate NbS adoption:

- **Nature Restoration Fund**: Provides financial support for habitat restoration and biodiversity projects.
- **Forestry and Land Scotland Initiatives**: Expand woodland cover while integrating sustainable land use practices.
- **River Basin Management Plans**: Encourage natural flood management and wetland conservation.

Nonetheless, while widely recognised as a vital tool, challenges remain in defining and upscaling NbS implementation effectively within agricultural and forestry systems.

Aims and Objectives

The primary audience for this work is the Scottish Government's forthcoming SRP, particularly in guiding whether future research should focus on:

a) the efficacy of NbS,
b) the risks and resilience associated with mainstream farming and forestry practices,
c) or both—potentially through approaches such as adaptive learning.

Closely linked to this is a primary policy-making audience, with the understanding that effective policy must also be practical and deliverable on the ground.

This report examines the current state of knowledge on the relationship between NbS and the productive land-use sectors of agriculture and forestry in Scotland. Given the ambiguity surrounding the classification, effects, and large-scale implementation of NbS, we assess the existing evidence base and how it has been applied in Scotland.

Additionally, key knowledge gaps are identified regarding NbS as a tool for climate change mitigation and adaptation and explore the steps needed to integrate them more effectively into policymaking and land management practices. Addressing these gaps is essential to reducing the cost of inaction and mitigating the increasing economic and environmental impacts of climate change and nature-related disruptions.

Finally, this research aims to explore evidence gaps concerning NbS policymaking and implementation, namely that the status quo, or 'do nothing' scenario is not stable nor risk free in the context of a climate that is becoming increasingly chaotic.

Based on our consultation with the project steering group, the research has been split into three separate parts, guided by the following questions:

1. What is the state of knowledge on the relationship between NbS, risk and resilience for the productive land management sectors of agriculture and forestry?
2. Based on the state of knowledge, how effective are NbS at mitigating and helping land use sectors to adapt against the UKCP18 climate change scenarios? How will the effectiveness of interventions be impacted by climate change?
3. What are the costs and risks of maintaining the status quo?
4. What are the environmental, economic, and social trade-offs and synergies to implementing NbS, and how might these inform expected barriers to uptake?

Explained further in the **Methodology** section, question 1 was answered through a Rapid Evidence Assessment (REA) of the SCOPUS database, question 2 was addressed in a workshop with research experts, while questions 3 and 4 were discussed in a workshop with policy experts.

We included two research scope sections at the outset, one defining NbS and the other outlining climate change scenarios, to establish a shared understanding of these foundational concepts, clarify their relevance to land use and resilience, and provide essential context for interpreting the findings and recommendations throughout the report.

Research Scope I – NbS

The definition guiding our research was drawn from the IUCN Global Standard for NbS in relation to its 8 criteria for NbS:

1. addresses societal challenges (this includes: climate change mitigation and adaptation, food security, water security, disaster risk reduction, human health, economic and social development, environmental degradation and biodiversity loss

2. is designed at landscape scales
3. enhances biodiversity
4. achieves economic feasibility
5. works inclusively and transparently
6. balances trade-offs equitably
7. is managed adaptively with evidence
8. is sustained and mainstreamed.

The core aim of NbS is to enhance ecosystem integrity while simultaneously addressing major societal challenges.

However, we acknowledge multiple definitions of NbS exist within environmental policymaking, reflecting the broad and interdisciplinary nature of the concept. Many other sustainable land management interventions fall under this scope, even if they use different terminology. For instance, Working With Natural Processes (WWNP) refers to measures that protect, restore, and emulate natural ecosystem functions, closely aligning with agroecology and regenerative agriculture principles, which emphasise ecological processes for sustainable food production. While WWNP specifically targets the functions of catchments, floodplains, rivers, and coastal systems to reduce flood risk, NbS is a broader framework that addresses a wider range of societal challenges through nature-based interventions.

Actions can often overlap across these categories. However, the primary goal of NbS is not limited to a single benefit such as flood risk mitigation, carbon sequestration, or biodiversity enhancement—rather, NbS integrates multiple functions that restore ecosystems while generating co-benefits for both human well-being and biodiversity. Conversely, certain nature-based improvements in agricultural or forestry systems may not always result in NbS outcomes. As a result, some studies identified in our scoping exercise also align with WWNP, regenerative agriculture, or agroecology.

To categorise and assess relevant NbS, we used ARP measures[17] as the foundation for our NbS typology. These served as a reference point for identifying and narrowing down measures found in the literature, ensuring alignment with Scottish policy and supporting future considerations for the SRP.

To supplement this, we incorporated evidence from DEFRA's report on evaluating agroecological farming practices[18]. ARP measures that were not identified through our screening process and lacked additional supporting evidence from the DEFRA report were excluded. The scope of these measures ranged from interventions in cultivated soils and field margins to uncultivated, permanent habitats. While ARP measures

[17] Rural Payments and Services – Agricultural Reform List of Measures (2023)

[18] Burgess. P.J., Redhead, J., Girkin, N., Deeks, L., Harris, J.A., Staley, J. (2023) Evaluating agroecological farming practices. Report from the "Evaluating the productivity, environmental sustainability and wider impacts of agroecological compared to conventional farming systems" project SCF0321 for DEFRA. 20 February 2023. Cranfield University and UK Centre for Ecology and Hydrology.

provided initial guidance, our analysis was not limited to the listed measures but also picked up broader examples of NbS on productive landscapes in Scotland. For the forestry sector, we referred to the EU's Natural Water Retention Measures (NWRM) platform to identify relevant NbS interventions. Measures initially included in our list but lacking mapped evidence based on our scoping criteria were omitted, while any additional interventions highlighted during the scoping exercise were incorporated.

Research Scope II – Climate change pathway scenario

A +4-degree future is not off the table as a possible climate scenario. On a high emissions pathway, global temperatures would rise 1.5°C by around 2026, 2°C by around 2039, 3°C by around 2060 and 4°C by around 2078.[19] Policies in place would put temperatures on track for around 2.6°C, but possibly as high as 3.5°C by 2100.[20] If certain climate 'tipping points' are reached or surpassed, this could lead to higher temperature levels than modelled as part of the status quo. Additionally, the IPCC predicts that climate-related extreme events will become more frequent and severe around the world, affecting multiple sectors and causing systemic failures across Europe, creating greater economic losses.[21]

Models such as UKCP18 predict that gradual shifts in weather patterns alongside an increasing frequency of extreme events will significantly impact productive land use over the next 50–70 years.[22] For instance, 50th percentile projections of summer and winter temperature variations highlight periods of heightened risk for flooding and drought, emphasising the urgent need to integrate climate realities into NbS planning.

Therefore, this report adopts a high emissions scenario from the projections of UKCP18 RCP8.5 (an average increase of 4.3˚C by 2081-2100) as the business-as-usual outcome to capture the shift in weather patterns and more frequent extreme events. These scenarios can be read about in further detail in

[19] Comparing climate impacts at 1.5°C, 2°C, 3°C and 4°C | UN Climate Summit News - COP29

[20] UNEP: Current climate commitments are 'weak promises, not yet delivered' - Carbon Brief

[21] European Environment Agency-Economic losses from weather- and climate-related extremes in Europe (2024)

[22] Modelling results vary based on emissions scenario pathways, geography, and percentile ranges.

Appendix 1 - Climate Scenarios in Scotland**.**

Methodology

To assess the current evidence base on NbS in Scotland and identify knowledge gaps, we conducted a REA, supplemented by two stakeholder workshops. Our research focused on evaluating NbS effectiveness in mitigating climate change impacts and extreme weather events, as well as identifying barriers and opportunities for their adoption in both the near and distant future.

Rapid Evidence Assessment – academic and grey literature

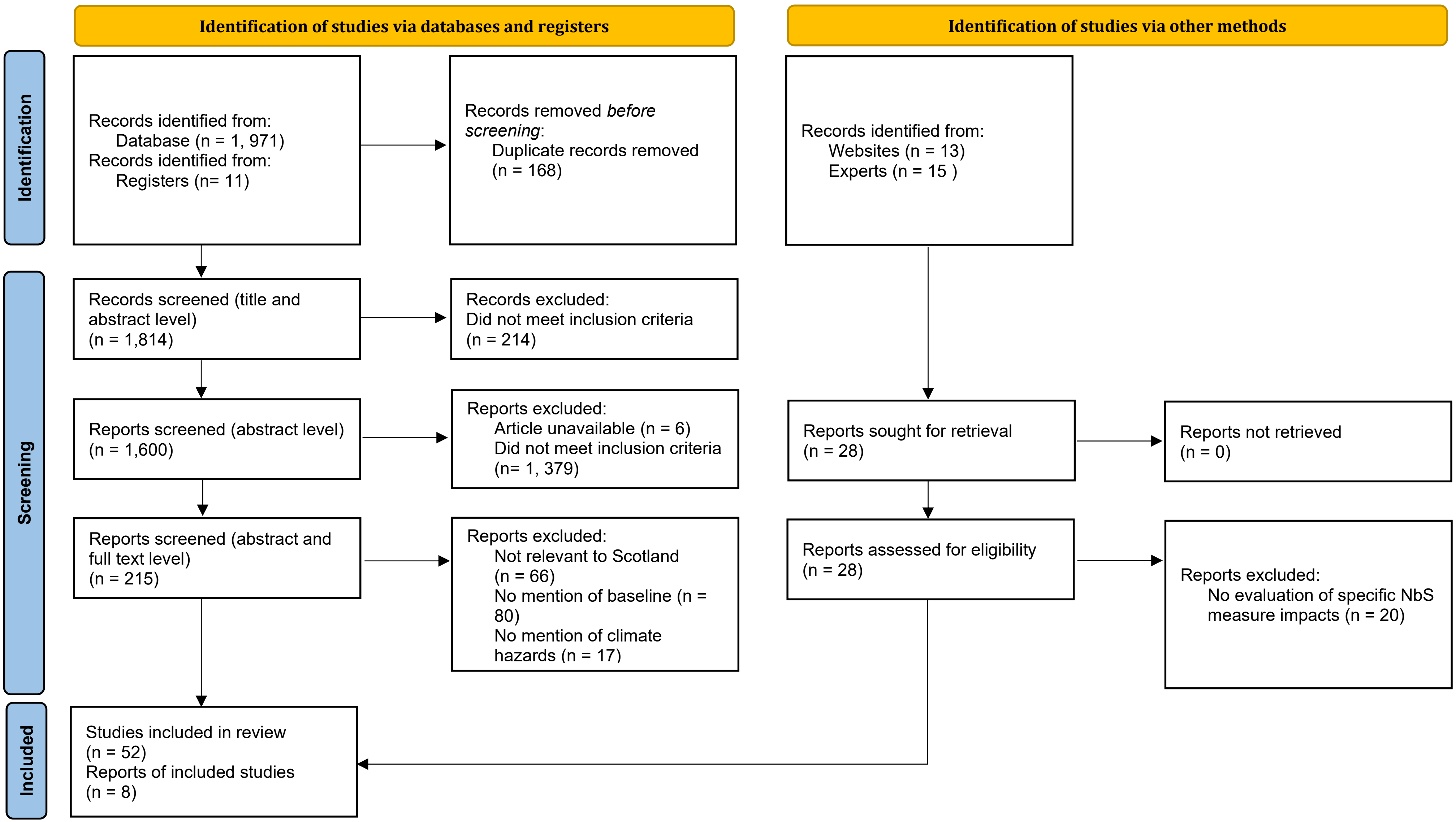
The initial stage of REA was conducted using the SCOPUS database, with a focus on interventions most relevant to Scotland's productive agriculture and forestry sectors. Search terms were structured using the PICO framework, as detailed in **Appendix 2 - REA search strings.** We deliberately employed narrower, NbS–specific terms to target studies that explicitly reported on NbS-related outcomes. Broader search terms based on intervention types were avoided, as they were likely to yield a high volume of studies lacking clear relevance to NbS objectives.

In order to answer our first research question, what the state of knowledge on the relationship between NbS, risk and resilience for the productive land management sectors of agriculture and forestry is, we developed a log to extract relevant information from each piece of evidence, namely:

a) The study area scale: individual plot, field/farm, or catchment/landscape scale. This allowed us to compare the findings and applicability of each measure at the relevant scale of land management, giving insights on whether the NbS impacts are scalable and transferrable across other agricultural and forestry systems.
b) Timescale of study: the effectiveness of NbS often depends on long-term ecological processes. Capturing timescales allows us to assess whether the evidence focuses on short term vs. long term benefits and whether conclusions are based on immediate observations or long-term data.
c) Type of data (empirical or modelled): empirical data provides real world evidence on how NbS function, while modelled studies help predict future scenarios, including climate adaptation potential.
d) Climate risk that is addressed: identifying which risks are studied help clarify where knowledge gaps exist in relation to the role of NbS in delivering resilience.

The full evidence log is included in **Appendix 3.1 – NbS from SCOPUS Literature.**

Figure 1: PRISMA 2020 flow diagram for new systematic reviews which included searches of databases, registers, and other sources.



Source: Page MJ, et al. BMJ 2021;372:n71. doi: 10.1136/bmj.n71.

Our initial search yielded 1,971 records as depicted in **Figure 1**, of which we were then able to remove 168 duplicates. We screened the first batch of evidence by title and abstract, screening for key words related to forestry and agriculture and the NbS measures we shortlisted from the ARP and NWRM, allowing us to exclude a further 214 due to lack of access or relevance after skimming the abstract. Of the 1,600 reports we sought for retrieval, we used the inclusion and exclusion criteria listed in **Table 1** when scanning the title or the abstract in more detail to understand whether the intervention did/did not occur in a productive landscape, if the NbS was being studied as an additional intervention on an existing area or landscape, and the measure being studied was applicable to the Scottish context. If all the above were true, the report was included in our final evidence review. We repeated this process iteratively and cross-referenced findings and were ultimately left with 69 reports. During the evidence logging process, a further 17 reports were excluded, resulting in the final total being **52 articles.** We also identified an additional 8 studies from websites and desk-based online search and recommended resources by participants from the workshops.

Table 1: inclusion and exclusion criteria used to peer-reviewed journal articles.

Inclusion criteria	Exclusion criteria
The intervention occurs in a productive landscape, such as forestry or agricultural land.	Studies that are not applicable to Scotland (e.g., due to differences in climate, soil, or crop type).
The NbS intervention is an "additional" activity or active action.	Interventions that do not take place in productive agricultural or forestry landscapes.
The study includes a timeline covering both pre- and post-intervention to assess impact.	Studies that do not evaluate NbS intervention outcomes in terms of ecosystem services or climate change adaptation and mitigation
The research is conducted in Scotland or is contextually relevant to Scotland.	

Secondly, we incorporated expert-recommended grey literature recommended to us in **Workshop 1** alongside the academic research. This enabled us to explore case studies relevant to NbS implementation in Scotland, complementing our initial mapping of the academic evidence base. By integrating both perspectives, we gained a more comprehensive understanding of the knowledge landscape and practical challenges, stakeholders to scale up NbS for climate adaptation and mitigation. We logged evidence for **54 NbS measures across 8 sources** from this stage of the REA.

The selection of grey literature is not exhaustive. It includes publications authored by the researchers we consulted, sources they recommended, and additional materials identified through targeted web searches that were deemed relevant. Given the wide range of topics covered in the grey literature—particularly concerning NbS case studies and their effectiveness—we organised the evidence log by type of NbS. This approach allowed us to disaggregate the studies and draw out key findings within each category.

The log of findings from the grey literature can be found in **Appendix 3.2 – NbS from Grey Literature,** which for every source logs:

a) Title, publication date, publication organisation, and sector,
b) NbS intervention,
c) Climate change outcomes mentioned,
d) Limitations of NbS implementation –to identify barriers to implementation, enabling conditions, and potential trade-offs. This helps provide a realistic picture of how NbS contribute to resilience in practice, rather than relying on generalised assumptions,
e) Conditions of success.

Workshops: Stakeholder research and policy sector

Of the three total workshops conducted, one stakeholder workshop focused on sense checking the academic findings and helping to assess the effectiveness of selected measures in mitigating climate change scenarios relevant to Scotland in the next 50 years. The second and third workshops explored barriers to uptake with regards to implementation of NbS at landscape scale, as well as evaluate the economic and social trade-offs of implementation within agricultural and productive forestry landscapes.

Workshop 1 was held on 28 January 2025 with six participants consisting of researchers and practitioners of NbS in Scotland. The second set of workshops were held on 17 and 20 February 2025 with a total of eight participants and consisted of policy and advisory staff from government and relevant agencies, as well as land managers. All workshops were hosted online via Microsoft Teams using Miro as a collaborative platform.

Findings: Evidence Mapping

An evidence gap matrix was developed to assess the current state of knowledge across academic and grey literature concerning the role of NbS in enhancing climate resilience for Scotland's agriculture and forestry sectors. The analysis aims to guide research priorities toward interventions that could be scaled across landscapes to prevent the most severe climate-related impacts, and to reinforce the recognition that maintaining the status quo carries its own risks. These findings are compiled in **Figure 2**.

The matrix is intended to identify where existing research is concentrated and where key evidence gaps persist. It consists of 38 interventions grouped into 10 thematic packages. The matrix cross-references:

- **Nature-based Interventions;** Identified through national frameworks (ARP, DEFRA agroecological measures, NWRM) and filtered for relevance to Scottish land use.
- **Outcomes**: Climate-related (e.g., wetter, drier, windier conditions) and secondary outcomes (e.g., biodiversity, GHG sequestration, water quality).

Each cell in the matrix represents the presence of mapped evidence linking an intervention to an outcome. Evidence is categorized by:

- **Volume**: Represented in the matrix by the relative size of the bars, visualising the number of studies associated with each cell.

A total of **60 unique sources** were mapped (52 academic, 8 grey literature).

Figure 2: Evidence Gap Matrix of academic and grey literature exploring NbS in the context of climate change

Measures highlighted in purple indicate no mapped evidence were found based on our criteria for NbS. Measures in green are additional and were not originally scoped from initial policy frameworks. The evidence matrix is coded red for no studies with blue bars indicating the number of studies where there was an evidence link. Note that an apparent evidence gap may mean that there is no mechanistic link between a measure and particular outcome.

		Outcomes - Climate					Outcomes - More broadly					Unspecified	
Package	**Nbs Interventions**	Resilience against rainfall and flooding - wetter conditions	Resilience against drought and heat stress - drier conditions	Resilience against storm and wind damage	Resilience against soil degradation	Resilience against pests, disease, and invasives	Biodiversity loss and/or habitat change	Economic productivity	Changing perceptions of climate change	Water quality/depth	GHG emissions and policy pressures	Unspecified	**Totals**
Agroforestry	Tree inter-cropping (incl. alley cropping and alternative native perennial tree belts)	0	0	0	0	0	1	0	0	1	0	0	2
Agroforestry	Tree crops (incl. short-rotation coppice and woody polycultures)	1	0	0	1	0	1	0	1	1	1	0	6
Agroforestry	Multistrata agroforestry	0	1	1	1	0	0	1	0	0	1	0	5
Continuous soil cover	Soil aeration and subsoiling	1	0	0	0	0	0	0	0	0	0	0	1
Continuous soil cover	Conservation tillage	2	0	0	1	0	0	0	0	1	0	0	4
Continuous soil cover	Cover crops	0	1	0	0	0	0	0	0	0	1	0	2
Continuous soil cover	Organic mulching	0	0	0	1	0	1	0	0	0	0	0	2
Crop diversity	Intercropping	0	0	0	1	1	0	1	1	1	1	0	6
Crop diversity- arable	Integrating livestock into cropping systems	0	0	0	0	0	0	0	0	0	0	0	0
Crop diversity- grassland	Multi-paddock grazing	0	0	0	0	0	0	0	0	0	0	0	0
Crop diversity- grassland	Pasture-fed livestock systems	0	0	0	0	0	0	0	0	0	0	0	0
Crop diversity- grassland	Livestock stocking density	2	0	0	0	0	0	0	0	0	0	0	2
Crop diversity-grasslands	Silvopasture	2	1	0	0	0	2	0	0	0	0	0	5
Crop diversity-grasslands	Integrating crops into livestock systems	0	0	0	0	0	1	0	0	0	0	0	1
Efficient/Reduced use of synthetic inputs	Organic farming systems	0	0	0	0	2	0	0	1	1	0	0	4
Efficient/Reduced use of synthetic inputs	Diversified crop rotations	2	1	1	0	2	1	0	1	1	2	0	11
Efficient/Reduced use of synthetic inputs	Organic livestock systems	0	0	0	0	0	1	0	0	0	1	0	2
Efficient/Reduced use of synthetic inputs	Extended crop rotations	0	0	0	0	0	0	0	0	0	0	0	0
Restore and Manage Nature Rich Habitats	rich gralssland, rewilding, and land abandonment)	0	1	0	0	1	2	0	0	0	2	1	7
Restore and Manage Nature Rich Habitats	On-farm afforestation	1	0	0	1	0	0	0	0	0	1	1	4
Retain and enhance field/permanent habitat margins	Field margins (incl. conservation areas, grass strips, and flower strips)	1	0	0	2	0	3	2	0	1	1	0	10
Retain and enhance field/permanent habitat margins	Reduced mowing (incl. delayed cuts)	0	0	0	0	0	2	0	0	0	0	0	2
Retain and enhance field/permanent habitat margins	Buffer strips bordering water bodies (incl. riparian planting)	4	0	0	2	0	1	0	0	3	1	0	11
Retain and enhance field/permanent habitat margins	Hedgerows	0	2	0	1	2	3	1	0	0	2	0	11
Forest management	Multifunctional forest (incl. targeted tree plantin and mixed species forest stands)	1	0	0	1	1	1	1	0	0	1	0	6
Forest management	Natural regeneration (inc. tree planting and removing conifers for natural colonisation)	2	0	0	1	0	3	0	0	0	1	0	7
Forest management	Mixed density forest stands (including forest thinning)	2	0	1	0	0	1	0	0	0	0	0	4
Forest management	Sustainable cutting (stem and branches, above ground)	0	0	0	1	0	0	0	0	1	0	0	2
Forest management	Forest zoning	0	0	0	0	0	1	0	0	0	0	0	1
Forest management	Continuous Cover Forestry	0	0	0	0	0	1	0	0	0	0	0	1
Forest management	Set aside/conservation area	1	0	0	1	1	5	1	0	0	3	2	14
Water management	Altered hydrological regimes (incl. paludiculture)	0	0	0	0	0	0	0	0	1	0	0	1
Water management	Runoff attentuation features	2	0	0	0	0	0	0	0	0	0	0	2
Water management	Temporary storage areas (incl. river woodlands, bunds, ponds, floodplains, barriers and dams)	7	1	0	0	0	1	0	1	0	1	0	11
Water management	River restoration	1	0	0	0	0	0	0	0	1	0	0	2
Species management	Species reintroduction (e.g. beavers)	2	0	0	1	0	0	0	0	0	0	0	3
Unspecified	Unspecified/metastudy	1	2	1	0	0	0	0	0	1	0	0	5
	Totals	35	10	4	16	10	32	7	5	14	20	4	

The **most frequently studied outcomes** were rainfall and flooding - wetter conditions (n= 35), and biodiversity loss and/or habitat change (n=32).

The **interventions most commonly studied in relation to the climate outcomes** include set-aside/conservation areas (n= 14), temporary storage areas - a broad category spanning several water-based interventions (n=11), hedgerows (n=11), buffer strips bordering water bodies (n=11), field margins (n=10), and diversified crop rotations (n=11). It should be noted that some sources link interventions to multiple outcomes, so counts per row do not equal the number of unique studies.

Five interventions had no mapped evidence based on our criteria for NbS, these being integrating livestock into cropping systems, multi-paddock grazing (e.g. high-density, short duration, rotational grazing sometimes called 'mob grazing'), pasture-fed livestock systems, integrating crops into livestock systems, and extended crop rotations.

Wind and storm-related impacts were notably underrepresented in the literature, compared to the other main climate outcomes. **Seven new measures not scoped from initial policy frameworks were added** during review due to their emerging relevance, including soil aeration and subsoiling, livestock stocking density, altered hydrological regimes, runoff attenuation features, temporary storage areas, river restoration, and species reintroduction.

Additionally, an intervention labelled as "**Unspecified**" was added, to capture two academic studies, of which one is an NbS meta study and the other focuses on the methodology of suitability mapping in relation to drought as opposed to the impacts of an NbS intervention.

The matrix reveals **a disproportionate focus on a limited set of interventions and outcomes,** with much of the literature addressing flooding and biodiversity. While this reflects important areas of risk, it underscores the need for a broader research agenda.

- **Evidence clustering** around a few outcomes and interventions suggests a limited research focus — potentially driven by ease of implementation, visibility, or historical funding priorities.
- **Notably absent evidence** for many integrated and livestock-based interventions signals areas ripe for further research — especially if these approaches align with agroecological or regenerative land use models.
- Policymakers should consider **supporting studies in underexplored areas**, especially those that integrate productivity, biodiversity, and resilience goals.
- The studies were not assessed for size, replicability or variability – future research should include a **review of evidence quality**.
- Research strategy should acknowledge that agriculture and forestry are not separate from nature — interventions must consider co-benefits and trade-offs across systems.

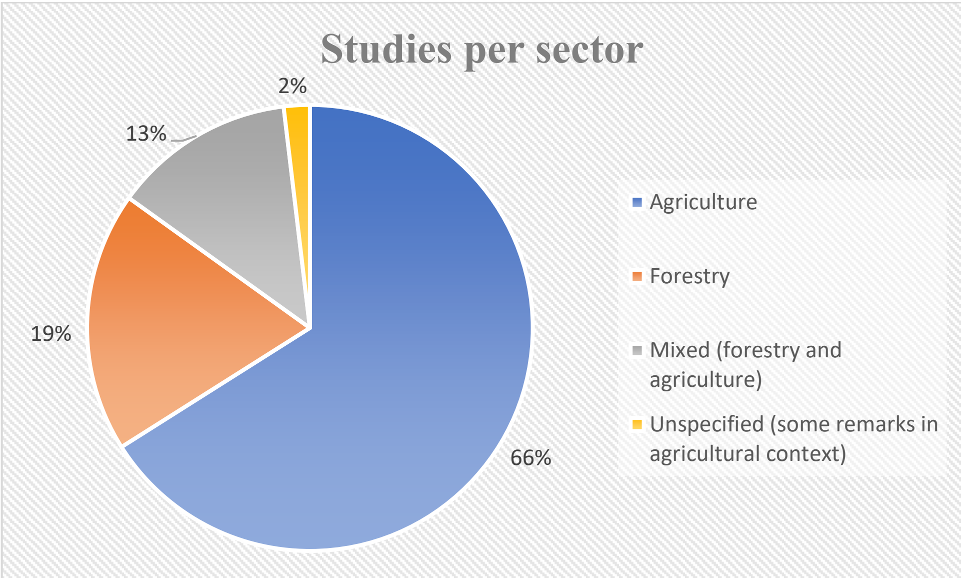
Academic Literature on SCOPUS – primary & secondary data

For the academic evidence collected through the SCOPUS database, we explored the spread of evidence over sector, timescale, study area scale, and any additional overarching findings.

Number of studies by sector

The majority of studies (n=34/52) are agricultural, whereas ten are forestry-related **(Figure 3).** Seven cover a mix of forestry and agriculture.[23] One study took place in an unspecified context, but with agricultural remarks.[24] Of all 52 studies, only six studies took place in the UK, and two in Scotland.[25]

Figure 3: percentage of evidence found per land management sector



The majority (n=48/52) of the evidence are empirical studies or models that measure outcomes against a baseline. Nine studies assessed the impact of NbS qualitatively[26], of which 5 are meta studies and evidence reviews and 4 conducted primary data collection through methods such as interviews, surveys, workshops, and Q methodology. One study employed both qualitative and quantitative methodologies.[27]

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[23] Brumberg et al., 2021; Digiovinazzo et al., 2011; Fennell et al., 2022; Truax et al., 2015; Vanneste et al., 2021; Vicarelli et al., 2024; Yimer et al., 2024.

[24] Roberts et al., 2023.

[25] Fennell et al., 2022 on runoff attenuation features, and Holstead et al., 2024 on criteria that affect farmer's uptake of natural flood management interventions.

[26] Fennell et al., 2023; Roberts et al., 2024; Walpole et al., 2017; Pereponova et al., 2023; Lovell et al., 2017; Iversen et al., 2022; Himanen et al., 2016; Holstead et al., 2017; Vicarelli et al., 2024.

[27] Roesch-McNally, 2018.

Number of studies by timescale

Table 2 depicts how studies were categorised, according to whether they measured NbS impacts in the short term (over a period of 10 years or less), the medium term (between 10 and 50 years), and over the long term (more than 50 years). Seven studies did not specify any timescale.[28] 29 out of 52 studies measured impacts in the short term, with the majority of these being 3 years or less (n=23/52). Seven studies mentioned impacts in the medium term, and nine studies mentioned impacts in the long term, with only one of these observing impacts over a timescale that was longer than 100 years.[29] Of the forestry studies, the majority looked at impacts over a long timescale of over 50 years (n=7), whereas the majority of agricultural studies measured impacts in the short term (n=24). All nine long-term studies that took place in a timescale of 50 years or more were conducted using modelling methodologies. Additionally, 5 studies measured impacts over a timescale of multiple or a range of years.[30]

Table 2: studies by timescale.

Years	Agriculture	Forestry	Mixed	Unspecified	Total
≤3	17	3	3	0	24
3 - 10	6	0	0	0	6
<50	5	0	1	1	7
50-100	2	6	0	0	8
>100	0	1	0	0	1
Unspecified	4	0	3	0	7
Total	**34**	**10**	**7**	**1**	**52**

The three studies that collected empirical data over the longest timescales were 8, 11, and 13 years long.[31] The first surveyed freshwater biodiversity for NbS measures in agricultural catchments, the second surveyed the change in diversity of field margin metacommunities, and the third conducted an alley field trial incorporating different combinations of belt width, alley width, and revegetation density to test water recharge control and asses the recovery of ecosystem services.

Number of studies by study area scale

Studies were categorised by scale, either at individual plot level, farm/field level, landscape/catchment level, or N/A if no scale was specified or the study was qualitative **Table 3.** We classified scale according to the following - Individual plots were studies where experiments were conducted on an area less than 100 hectares, at farm/field

[28] Truax et al., 2015; Brumberg et al., 2021; Falloon et al., 2004; Digiovinazzo et al., 2011; Davies et al., 2008; Chappell & Beven, 2024; Holstead et al., 2017; Yimer et al., 2024.

[29] Rossetti & Bagella, 2014.

[30] Ssegane et al., 2016; Rossetti & Bagella, 2014; Pereponova et al., 2023; Cordonnier et al., 2008; Coppini & Hermanin, 2007.

[31] Williams et al., 2020; Alignier, 2018; Noorduijn et al., 2010.

studies were done on an area between 100-500 hectares, and at landscape/catchment scale studies looked at an area of 500 hectares or more. Additionally, where a study was focused on individual plot experiments within a wider landscape, the evidence was organised under 'landscape/catchment.'

Table 3: Studies by scale.

Scale	Agriculture	Forestry	Mixed	Unspecified	Total
Individual plot	8	2	1	0	11
Farm/field	9	1	1	0	12
Landscape/ catchment	9	6	4	1	20
N/A	8	1	1	0	10
Total	**34**	**10**	**7**	**1**	**52**

A little less than half of the studies (n=20/52) are at landscape/catchment scale, whereas 11 studies measure NbS impacts at farm/field level and 11 studies at individual plot level. 10 studies do not specify at which scale they measure impacts. All catchment and landscape studies were modelled, except for two studies- one that looked at historical data of 62 years on land-use impacts on natural regeneration of oaks.[32] As for smaller scale studies, majority (n=7/9) used empirical data whereas two studies modelled data. The duration of these were 10[33] and 100 years.[34]

Additional observations during the screening and exclusion of articles during Stage 1

General observations show that there is a lack of empirical evidence for long-term studies at larger catchment or landscape scale. During this stage of the screening process, which only included title and abstract of journal articles, the following additional observations were noted from articles that were ultimately excluded from our final selection:

- Few studies were identified that examine NbS specifically at the landscape scale. Studies that do address broader landscape dynamics tend to focus on the valuation and distribution of ecosystem services across varying land uses or agricultural systems, often through ecosystem service mapping, land-use impact assessments, or modelling approaches.
- Within agricultural contexts in the UK, there is a greater volume of evidence related to field margins and buffer strips. In contrast, silvopastoral systems and

[32] Petersson et al., 2019.

[33] Dodd et al., 2014.

[34] Peringer et al., 2016.

rotational grazing, despite being included in the ARP measures, are more commonly studied in Mediterranean regions.

- In the forestry sector, most research identified relates to harvesting techniques and management of stem density, with a geographical concentration in Sweden, Finland, and Canada.
- Some recent literature on farmer adoption of NbS and behavioural responses to climate change was not retrieved through the SCOPUS search but was noted during the initial stakeholder workshop

Grey Literature and Case Studies

On the state of NbS Scotland, there are several examples in the space of natural flood management (NFM) at landscape scale. One notable publication is the Working with Natural Processes – Evidence Directory[35], published by the UK Environment Agency in 2017. A list of 45 UK case studies were compiled in which 3 featured Scotland, that is the Eddleston, Upper Bowmont and Allan Water catchment **(Table 4).**

Table 4: Summary of Scottish case studies identified from Environment Agency's Working With Natural Processes evidence directory and grey literature search

Case Study	NbS Interventions	Findings	Uncertainties and Knowledge Gaps
Eddleston Catchment (70 km^2)	River re-meandering, flow-restricting log jams, native riparian woodland planting, stormwater ponds	Empirical evidence shows a 29% reduction in annual high flow frequency over a 7-year post-intervention period compared to an 8-year baseline. Co-benefits included enhanced biodiversity in flood storage ponds. Broadleaf woodland on hillslopes contributed to rainfall infiltration and reduced runoff during storm events.	Woodland plantations did not demonstrate the same improvements in soil permeability. Further targeted studies are needed to confirm the differential effects of woodland types and placement on runoff mitigation.
Upper Bowmont Catchment (86 km^2)	Leaky barriers, native riparian and floodplain forest	Leaky barriers captured small amounts of sediment. Limited sediment trapping due to porous design and small size.	The planting area was small relative to the catchment size, making it unlikely to affect flood hydrology at scale. Quantitative assessments are lacking to evaluate the

[35] Environment Agency (2025) – Working with natural proceses: Evidence directory update

			broader hydrological impacts of these measures.
Dunruchan Farm, Allan Water (Knaik subcatchment, 39 km²)	Upland blanket bog peatland restoration	Post-restoration monitoring results have not been publicly reported.	No data available on downstream flood risk impacts. Empirical research is needed to assess the hydrological benefits of peatland restoration in this context.
River South Esk Catchment	Riverbank restoration, riparian tree planting, wetland habitat creation	Modelled results suggest a localised positive effect on flood mitigation. Biodiversity surveys show a positive impact on invertebrate populations.	Model-based results have not been validated with empirical flood data. Biodiversity benefits are indicative, requiring further research to confirm.

Another notable NbS evidence mapping exercise was published by The British Ecological Society in 2022[36] and Riverwoods for Scotland Report by the Riverwoods Science Group,[37] which examines the evidence base in the UK, and draws on international examples where UK evidence is limited. Other evidence reviews that were included were ClimateXChange's publication on carbon sequestration from nature-based solutions in Scotland[38].

Some of the notable headlines and topics evidenced by these publications are discussed below.

Evidence for NbS to mitigate wetter conditions and flood risk

There is comparatively stronger representation in the literature on NbS interventions aimed at mitigating flood risk in the UK, particularly through natural flood management (NFM) measures **(Figure 2).** These interventions are often designed for specific objectives, but the literature also reports a range of co-benefits, including improvements in water quality, biodiversity, soil structure, and carbon sequestration. Although the Environment Agency's review assigns confidence levels to these findings, it also notes that the effectiveness of NbS is highly context-dependent—determined by

[36] British Ecological Society (2021) Nature Based Solutions for Climate Change in the UK

[37] The Riverwoods Science Group (2022) Riverwoods for Scotland I Report on Scientific Evidence

[38] Baggaley, N., Britton, A., Sandison, F., Lilly, A., Stutter, M., Rees, B., Reed, M., and Buckingham, S. (2022) Understanding carbon sequestration from nature-based solutions

factors such as intervention design, catchment location, land use, and hydrological dynamics.

The Riverwood Science Group report highlights relatively high confidence in the evidence base for the flood mitigation role of woodlands—ranging from afforestation to more targeted tree planting in riparian areas and across catchments[39]. These interventions are also associated with biodiversity conservation through habitat connectivity[40]. However, the outcomes are influenced by variables such as management approach, tree species, forest age, and the proportion of forest cover. Some studies also note that afforestation on high-biodiversity grasslands or shallow peatlands may lead to adverse ecological impacts[41]. Additionally, deer grazing is identified as a barrier to woodland establishment and persistence in parts of the UK.

In Scotland, NFM measures such as offline storage areas, river restoration, leaky barriers, and beaver reintroduction are supported by a smaller number of case studies. While this indicates emerging interest and experimentation with these approaches, it also points to a relatively limited volume of context-specific research.

Beyond flood mitigation, there is broader UK-wide evidence for interventions such as field margins and buffer strips[42]. Studies indicate that wooded buffers and hedgerows can enhance soil structure, support biodiversity, manage flood risks, and contribute to soil carbon retention. As with other NbS, effectiveness appears closely linked to spatial design: for example, wider buffer strips, structurally diverse hedgerows, and three-dimensional buffer zones tend to demonstrate stronger benefits. However, this review identified only limited evidence specific to the carbon sequestration potential of these interventions in Scottish soils.

Evidence for NbS to mitigate drier conditions and drought risk

The reviewed evidence base contains relatively few studies that examine the effectiveness of NbS in addressing drought or water scarcity risks **(Figure 2).** Among the measures for which some evidence is available, offline storage areas and runoff management are noted most frequently. However, the quantity and consistency of research evaluating these measures in drought contexts remain limited.

Some recent studies suggest that river restoration may have minimal impact on water retention at scales sufficient to mitigate the effects of drought[43]. Similarly, while riparian and floodplain woodlands are often cited as NbS interventions with multiple

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[39] The Riverwoods Science Group (2022) Riverwoods for Scotland I Report on Scientific Evidence

[40] British Ecological Society (2021) Nature Based Solutions for Climate Change in the UK

[41] Peringer et al., 2016.

[42] Stutter, M., Ohuallachain, D., Baggaley, N., Costa, F.B. Lilly, A., Mellander, P., Wilkinson, M. (2022) Database of sixteen riparian management measures - Mendeley Data

[43] Environment Agency (2025) – Working with natural processes: Evidence directory update

hydrological benefits, current evidence provides only limited insight into their capacity to significantly influence or maintain low flows during periods of water scarcity. We were unable to find evidence with a Scottish context.

Available findings indicate that native broadleaved tree species are unlikely to have a substantial effect on annual average water yield at the catchment scale in Scotland[44]. However, no conclusive evidence was found to confirm a consistent positive impact of woodland interventions on drought resilience. This highlights a gap in context-specific, empirical research on the water storage and flow-regulation functions of such interventions, particularly under conditions of prolonged dry weather.

Evidence for soil and agronomic NbS to climate outcomes

Across multiple reviews, including those conducted by the British Ecological Society[45], the Environment Agency[46], and DEFRA[47], the current evidence base for the climate-related benefits of agronomic measures such as cover crops, reduced or no tillage, crop rotations, intercropping, and adjustments to livestock stocking density remains limited—particularly with respect to their application in Scottish soils. While some global studies report variable outcomes, peer-reviewed evidence quantifying impacts on flood risk mitigation and carbon sequestration in Scotland is scarce.

The DEFRA review provides one of the more comprehensive assessments of agroecological practices, focusing on outcomes such as soil carbon, biodiversity, and yields. However, this review also notes a lack of strong evidence linking these practices to flood or drought resilience. While some studies suggest that cover cropping may reduce groundwater recharge[48], the available data does not paint a conclusive picture and is context dependent.

Additional NbS priorities have been identified in the ClimateXChange publication, (footnote 39) which highlights the potential role of sward composition and structure in delivering greenhouse gas (GHG) mitigation and biodiversity benefits, particularly within intensively managed grasslands. Similarly, the composition of soil communities is recognised as a potentially important factor influencing the climate mitigation potential of field margins—through effects on decomposition processes, organic matter

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[44] The Riverwoods Science Group (2022) Riverwoods for Scotland I Report on Scientific Evidence

[45] British Ecological Society (2021) Nature Based Solutions for Climate Change in the UK

[46] Environment Agency (2025) – Working with natural processes: Evidence directory update

[47] Burgess. P.J., Redhead, J., Girkin, N., Deeks, L., Harris, J.A., Staley, J. (2023) Evaluating agroecological farming practices. Report from the "Evaluating the productivity, environmental sustainability and wider impacts of agroecological compared to conventional farming systems" project SCF0321 for DEFRA. 20 February 2023. Cranfield University and UK Centre for Ecology and Hydrology.

[48] Burgess. P.J., Redhead, J., Girkin, N., Deeks, L., Harris, J.A., Staley, J. (2023) Evaluating agroecological farming practices. Report from the "Evaluating the productivity, environmental sustainability and wider impacts of agroecological compared to conventional farming systems" project SCF0321 for DEFRA. 20 February 2023. Cranfield University and UK Centre for Ecology and Hydrology.

formation, and GHG sequestration. However, the overall impact of soil biota on GHG outcomes remains unquantified.

Measures aligned with integrated pest management (IPM), such as those that aim to support natural predator populations, also remain under-evidenced. The interventions that were referenced the most in relation to IPM included hedgerows, organic farming systems, and diversified crop rotations **(Figure 2),** all referenced by academic pieces of evidence[49] rather than Scottish-specific case studies. Further research is required to better understand their effectiveness and broader implications for climate adaptation and mitigation.

[49] Aviron et al., 2014; Boinot et al., 2024; Roesch-McNally et al., 2018; Collar ed al., 2018; Storkey et al., 2014.

Findings: Stakeholder Engagement

Workshop 1: Researcher insights on NbS effectiveness

Activity 1: Mapping interventions against climate scenarios

To sense-check the findings from the REA, the NbS interventions scoped from the literature were displayed on a Miro canvas. In the first activity, research experts were asked to match NbS interventions with climate scenarios, explaining why they thought specific interventions would be particularly well suited to mitigate against outcomes associated with the given scenario. The climate change scenarios that we asked participants to comment on are based on the UK Climate Projections (2018) [50], assuming a high-emissions scenario (RCP8.5) for Scotland.

A summary of participants' feedback is presented in **Table 5** below.

[50] UK Climate Projections: Headline Findings (2022) – Met Office

Table 5: Collated feedback by participants and NbS measures to address corresponding climate scenario

UKCP18 Scenario	NbS intervention chosen	Feedback by participants
Drier summer, wetter winter	Temporary Storage Areas	Temporary storage on farmland plays a crucial role in mitigating floods, droughts, and improving water quality. While many NbS measures provide valuable benefits, several key measures needed to address larger floods are currently lacking. These include: 1) floodplain reconnection, 2) floodplain wetlands, 3) offline storage, 4) temporary storage ponds on farms, and 5) leaky barriers. These measures are particularly relevant in farming contexts, especially in upland agricultural areas, and they are considered more effective than other measures in these settings.
	Buffer strips bordering water bodies (long term)	Should only if it considers more structure in buffer strips – such as 3D buffers. Grass buffers are the least effective of 16 types of riparian margins[51].
Increase in rainfall events	Intercropping	Reasonable evidence that diverse crop mixtures enhance field drought resilience. Best hedging (risk mitigation) strategy in unpredictable climates is well known benefit of intercropping.
	Multi-paddock grazing	Has an impact on surface flow and mitigates flooding. Flooding events will be coming from River Wyre[52] come end February, change in uplands farming will affect this.
Frequent drought	Set aside/conservation area (near term)	Focus on non-productive species.
Higher risk of fluvial flooding	Forest zoning (long term)	Zoning for targeted flood mitigation.
Risk of pest and disease outbreak	Mixed density forest Stands (including forest thinning) (long term)	Reducing density and increasing structural diversity to encourage airflow and potential predators of pest species.

Some additional comments were posted relating to a NbS measures and their effectiveness in climate change mitigation and adaptation in Scotland, out with the structure of the Miro activity. These are displayed in **Table 6.**

[51] This is evidenced in Database of sixteen riparian management measures (Stutter et al., 2022). Other than wide (>10 m) grass buffers, there is limited ability for this measure to sufficiently retain dissolved nutrients, especially groundwater nitrate flows. Subsurface artificial drainage pathways can readily pass through buffers and undermine their effectiveness.

[52] Wyre Rivers Trust (2024) website

Table 6: Additional feedback on NbS measures during activity 1.

NbS intervention	Feedback from participants
Multi-paddock grazing	There is a real shortage of evidence on multi-paddock grazing, lots of theory.
Intercropping	One of the benefits of intercropping is the yield boost - x1.25 on average. This strategy could free up land.
Cover crop	Not sure about 'substantial' carbon increase through cover crop. Need to consider trade-offs with GHG from fuel, tractor passes.
Nature rich habitats	Restoring wetlands in catchments is a good way of reducing flood peaks and maintaining low flows, especially flood plain wetlands.
Field margins	Effectiveness is highly location dependent, and whether they will have their desired impact on flood and drought mitigation, or water quality improvement.

Overall, participants found the mapping exercise counterintuitive, as there was no clear "problem" to match with a nature-based "solution." They noted that the broad climate scenarios made it challenging to pinpoint specific interventions, given that NbS effectiveness is highly context dependent. Rather than being inherently beneficial, outcomes depend on the design and placement of interventions. Although we did not have time to probe these issues further during the workshop, we can speculate as to why evidence of effectiveness is limited. NbS may be a relatively recent motivation for many measures, so although well studied, the focus of research has not been on NbS outcomes. Experimental applications have not been at the scales relevant to NbS. Interactions between multiple NbS measures have not been evaluated. And, catchment level evidence is context specific (climate, soils, topography, land use etc.) and results may not be transferable.

Activity 2: Ranking NbS interventions

Similar concerns about the goal were expressed in the second activity, where assessing the effectiveness of NbS was not straightforward without further context (e.g. the exact problem that needs to be addressed, placement and design of measures). Participants were asked to rank interventions on a scale of 1 to 5 (1 being lowest and 5 highest) based on a set of criteria; (i) how **urgently** the NbS should be adopted, (ii) the **cost of inaction** if the NbS is not implemented, (iii) the **co-benefits** the NbS delivers, (iv) the **scalability** of the NbS to a wider landscape/area, and (v) the **quality of the evidence** that exists for that NbS. The outputs are shown in **Table 7.**

It was noted by one participant that soils are integral within these measures, and soil management is crucial to unlock the benefits of interventions.

Table 7: Tabulation of scores by participants to assess NbS interventions based on a selected list of criteria

NbS measures	Urgency	Cost of inaction	Co-benefits	Scalability	Evidence quality
Floodplain reconnection	5	5	4	3[a]	4
Floodplain wetlands	5	5	5	4[b]	4
Offline storage	5	5	4	5	4
Temporary storage ponds on farms	5	5	5	4	4
Leaky barriers – linked with riparian planting	5	5	4[c]	4	4
Intercropping	3	2	3	5[d]	2[e]
Hedgerows	5	5	3[f]	3	3
Buffer strips (grass)	3	2	2	1	4
Multi-paddock grazing	3	3	2	4	2[g]
Mixed density stands	3	3	3	2	3
Multifunctional forest	3	2	4	2	4
Forest zoning	4	3	4[h]	3	3
Natural regeneration	3	3	3	2	2
Continuous cover forestry	4	3	3	2	3
Conservation areas	5	5	4	2	4
Riparian woodlands	5	5	4	3	3

Colouring and numbers indicate the ranking of the interventions against each criterion, the higher the number (darker blue shading) indicates a higher degree of importance or effectiveness. Low numbers (darker red shading) indicate either lower importance, effectiveness or lower quality of evidence.

[a] "not large enough most cases"

[b] "need to be linked into changing land use"

[c] "depends entirely on design"

[d] "Easy"

[e] "for Scotland and crops used here"

[f] "depends on hedgerow management"

[g] "little evidence and much theory/hyperbole"

[h] "depending on location"

Workshop 2: Policy insights on NbS implementation

In the second workshop, public sector policy experts and policymakers were invited to discuss the environmental, economic, and social synergies of NbS implementation at landscape scale in the context of productive land management, keeping in mind the goal of increasing the land's resilience to climate shocks. Participants were initially asked to share their thoughts on what they believed the biggest risks to land management will be in the next 50 years. Then, participants were asked to give comment on a future landscape vision that integrates NbS in catchment that also continues producing economic outputs. After refining the future vision, participants were asked to backcast from 2050, the year in which we decided the hypothetical future vision was set, back to the present day, indicating the barriers and opportunities for achieving the vision in each decade. The purpose of backcasting is to identify the steps or pathways that need to be in place at different stages to achieve the desired future vision.

Activity 1: Conceptualising the cost of inaction

To get participants stimulated and thinking early on about what the cost of inaction means to them particularly for productive land use management, they were asked to write on sticky notes their thoughts to the following question:

"Based on the state of NbS implementation and current climate projections, what will be the biggest risks to land management for food and timber in the next 50 years?"

Table 8 summarises the qualitative responses participants gave when asked what the biggest risk to productive land management would be, alongside the subsequent cost of inaction, potential adaptative management strategy and what the cost of that strategy would be. Quantifying these costs would give a more robust picture of how the costs of action now, weigh up to the cost of inaction, later.

Table 8: Perceived risks and associated costs of inaction, alongside adaption strategies and sources of costs

Risk and adaptation	Cost of (in)action
Risk: Increased threat from pests, pathogens, and invasive species	**Cost of Inaction:** Loss of crops, forests, and ecosystems, escalating environmental damage, and economic losses due to crop failures.
Adaptive Strategy: Implement diversified crop and tree species to build resilience against pests and pathogens. Training land managers in adaptive techniques to continually refine practices based on changing environmental conditions.	**Cost of adaptive strategy:** Initial costs may include research, implementing, and monitoring of biodiversity measures. Costs of (re)training land managers.
Risk: soil degradation and water scarcity	**Cost of Inaction:** Soil erosion and degradation reduce agricultural productivity, leading to higher costs for water treatment and soil restoration. Water scarcity disrupts agricultural activities and increases economic burdens.
Adaptive Strategy: Implement soil conservation techniques (e.g., riparian buffer zones, cover cropping) and water management practices such as rainwater harvesting or wetlands restoration.	**Cost of Adaptive Strategy:** Requires investment in new infrastructure and potentially reduces short-term agricultural output while restorative practices take effect. However, long-term benefits include enhanced land productivity and savings in water management costs.
Risk: increased flooding and wildfire risks	**Cost of Inaction:** Increased flood damage to crops, wildfire damage to land, and higher recovery costs due to extreme weather. Also results in increased insurance premiums.
Adaptive Strategy: Adopt NFM measures, such as restoring wetlands, reforesting floodplains, and implementing firebreaks.	**Cost of Adaptive Strategy:** Implementing NbS like wetland restoration and forest management will require upfront costs, including land restoration and maintenance, but will reduce the long-term economic costs associated with flooding and wildfires.
Risk: Loss of ecosystem services - pollination, water purification, etc.	**Cost of Inaction:** Increased financial burden on society to replace lost ecosystem services with artificial solutions. Greater dependency on costly human interventions.
Adaptive Strategy: Restore ecosystems using NbS such as creating pollinator	**Cost of Adaptive Strategy:** The initial cost involves land restoration projects

habitats, enhancing wetlands for water purification, and planting trees for carbon sequestration.	and establishing long-term monitoring systems. However, over time, ecosystem services will become more self-sustaining and reduce reliance on costly substitutes.
Risk: changing land suitability and loss of agricultural productivity	**Cost of Inaction:** Declining agricultural output, loss of viable crop types, and economic uncertainty as climate shifts make traditional practices unsustainable.
Adaptive Strategy: Shift to diversified land-use practices that integrate a wider range of tree species, crops, and livestock. Encourage sustainable farming techniques suited to changing climate conditions.	**Cost of Adaptive Strategy:** Transitioning to new agricultural practices may reduce short-term yields and require financial investment in new technologies, training, and infrastructure. However, this strategy will future-proof land management and increase long-term sustainability.

A recurring theme was that **risk aversion in policymaking** is a major obstacle to change. Participants noted that decision-makers are often hesitant to commit to new strategies out of fear of getting it wrong. Yet, they pointed to examples like the Scottish timber industry, where long-term reliance on a single commercial species has created rigid path dependencies, leaving the sector vulnerable to pests, diseases, and ecological stress. This, they argued, shows how inaction and resistance to change can result in higher long-term risks and reduced resilience.

Participants warned against oversimplified interpretations of NbS, such as planting trees for carbon credits without considering ecosystem diversity or functionality. They emphasized that **true NbS must be designed to deliver multiple co-benefits**, enhancing both biodiversity and landscape resilience. Failing to do so risks wasting resources on ineffective solutions that may not deliver long-term value.

Participants also highlighted the **hidden and cumulative costs of the status quo.** For example, many restoration projects have been undermined by high deer populations, which limit tree growth and reduce carbon sequestration potential. These challenges are often not factored into traditional cost-benefit models, but participants felt strongly that such issues need to be better quantified and mapped to reveal the true societal costs of failing to adapt.

Several participants also acknowledged that adaptive management does come with its own costs—including the **potential for short-term productivity losses** or the need to shift away from familiar practices. But they argued that these costs must be seen in context. For instance, diversifying crops or tree species might reduce yield in the short term but would ultimately increase long-term sustainability and reduce exposure to systemic risks like pest outbreaks or soil degradation.

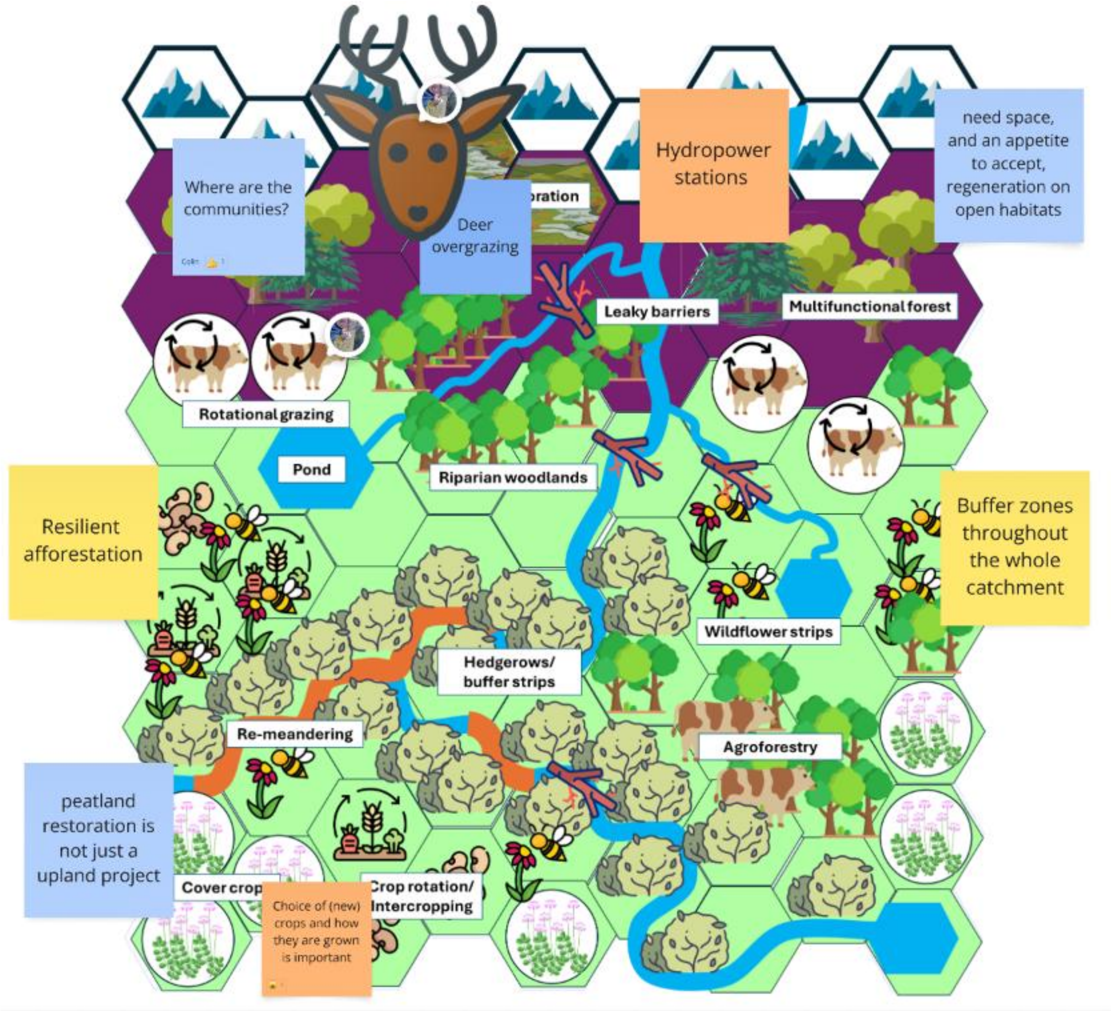
Finally, participants stressed the importance of **equity in adaptive land management**. Larger landowners, pension funds, and commercial forestry enterprises may have the capacity to take on more risk and innovate, but smaller landholders and communities often lack this flexibility. There was a strong call for supportive policy frameworks that enable more equitable participation in adaptation strategies, particularly through capacity-building, financial support, and knowledge sharing.

In addition to findings from the workshop, we have also supplemented these risks with additional evidence from the literature in **Appendix 4 – Further costs of inaction.**

Activity 2: painting the 2050 future vision

Backcasting from the future to the present, a map was developed to illustrate a potential land-use landscape that integrates productive agriculture, forestry, and NbS interventions. Although simplified and gamified, the map presents a vision of landscape features across lowland, midland, and upland contexts. By offering a visual representation, the intention was to spark discussion on what might be missing from this vision and what additional elements could contribute to a resilient future. **Figure 4** presents the map alongside participant feedback on missing elements in an integrated land-use scenario. Many participants highlighted the absence of human settlements and their influence on future land use. Other notable contributions included a forestry sector participant suggesting productive woodland shouldn't be confined to upland areas, as less land would be required to grow productive trees in fertile areas. An agricultural sector participant emphasized the necessity for regenerative agricultural approaches across the entire landscape, particularly advocating for diverse, multi-year crop mosaics beyond just hedges and field edges. A participant who specialises in community approaches and value conflict, noted the inclusion of upstream hydropower dams on the map, highlighting these will continue to influence water flow into the future. While some may be decommissioned, they will likely remain essential to the energy landscape through tunnels and reservoirs. These structures have the ability to disrupt sediment transport, impact habitats—especially migratory fish—and alter landscapes, affecting recreation and downstream land use.

Figure 4: Mapping output of what a resilient landscape could look like in the future



Activity 3: Achieving the vision – actions and barriers

In exploring what conditions need to be established by 2040 to enable an ideal future, participants were asked to identify relevant policies, technological and cultural drivers, stakeholder roles, and social, financial, or regulatory incentives. These ideas were initially recorded on sticky notes and then placed on a matrix assessing *uptake* (ease of implementation) against *impact* (level of influence). This exercise aimed to help prioritise policy changes, funding mechanisms, and land management practices that should be scaled up. Most suggestions fell within the high-impact, high-uptake quadrant. Ideas classified as high impact, but low uptake often represented previously trialled measures that had limited success. However, interpreting the matrix proved challenging due to inconsistent placement caused by spatial constraints and overcrowding on the board. **Table 9** provides an overview of the constraints and enablers participants identified in 2025, 2030, and 2040 that could either help achieve or delay the 2050 vision.

Table 9: Summary table of the barriers and opportunities for NbS implementation from 2025 to 2050

2025	
Barriers to uptake	Push and pull from the market on farmers, leading to uncertainty
	Not having contractors skilled for NbS projects and the contractor base being too small for the level of projects incoming
	Slow rate of change for forestry
	Regulatory conflicts between peatland restoration and tree removal limitations
	The assumption that only native species can contribute to natural woodland
	Natural tree regeneration limited by deer grazing pressure
Incentives for adoption	Politicians and public figures speaking out for nature and defending rules and resources related to NbS
	Supermarkets and big wholesale buyers engaged in delivering the route map to sustainable regenerative agriculture
	Appraising and publicising the balance of public and private costs and benefits delivered by the current mix of land management
	NFUS and other key players supporting and promoting regenerative agriculture
	Normalising regenerative agriculture as mainstream, via monitor farms, LEAF farms, what is required in agricultural policy
	Having a societally defined objective for allowable deer populations
2030	
Barriers to uptake	Businesses not perceiving NbS as an opportunity or a risk mitigating tool for future profits
	Not enough technological advancement for agricultural productivity
	Lack of certainty and vision for the long term NbS land use plan
Incentives for adoption	Greater agri-environment scheme support for NbS
	Next Scottish Biodiversity Strategy delivery plan in place and the journey to NbS normalisation has begun
	More evidence of NbS being cost-effective
	Markets for sustainable agricultural products exists
	Regulators have made and had accepted policy changes necessary for the rate and type of change, especially in Forestry
	Higher disposable household income with lower energy bills
	More deer management operators, facilities, and outlets for venison
2040	
Barriers to uptake	Land managers do not fully understand the climate risks they are likely to be exposed to and what the solutions might be

Incentives for adoption	Successful delivery of Scottish Biodiversity Strategy actions at scale across habitats
	Successful implementation and delivery of NBF4 - damage and loss to irreplaceable habitats has been stopped
	Simplification of incentives and regulations for land managers to implement NbS
	Incentives to support farmers to deploy regenerative agriculture
	Pilot initiatives are fully implemented to grow the evidence base of NbS
	There is economic evidence in support of NbS
	Riparian woodland is well established, and we can see measurable changes in freshwater temperature reduction
	NbS requirements are included in agri-environment schemes
	Woodland creation and restocking has become much more diverse in terms of species, genotypes, and silvicultural practices
	Enforce abstraction allowances for agriculture
	Biosecurity is embedded into land management
	Sectorial change in species choice for forest planting is in place at scale
	Accepting and expecting novel ecosystems
	Insurers and lenders take account of nature and climate-related risks for land-based businesses
	Give the RLUP's 'teeth' by having leverage over agricultural subsidies
	Viable business models for different land management contexts
	Increased duties of local government and NHS to allocate resources for green infrastructure
	Viable nature markets for private investment
	Develop a large-scale strategy/tool to prioritise the application of NbS in land use
	Societal awareness and transparency about how public sector budgets are spent, highlighting the costs of the status quo (e.g. deer management)
	Change in climate change plan that removes perverse policies that are non-compatible with each other (e.g. peatland restoration vs. control of woodland removal policy)
	Deer density in wider landscape reduced to less than 5 per km^2
	Conversations around land management that acknowledge the diverse objectives of land use, whether for commercial productivity or ecological conservation

The following paragraphs provide an additional qualitative summary of key findings and participant discussions related to sticky note placement.

Path dependencies of policy in forestry

Forestry operates on much longer timescales than agriculture, where change can happen more immediately. Currently, only 1–2% of commercial timber is felled and replaced annually, meaning that without significant intervention, the forestry landscape in 2040 will remain almost identical to that of 2025. Historically, major shifts in land-use policy have taken decades. The ongoing debate over deer management, for instance, has been active for over 20 years, with meaningful progress only now being made. Often, change occurs only in response to crises—such as the 25,000 hectares of commercial conifers lost to storms in Ireland. Policymakers may not act until a significant disruption forces them to reconsider.

Shifting toward more diverse, nature-based forestry solutions requires early intervention, but the nursery sector, which supplies seedlings, needs five to ten years to adjust. Any large-scale transition would also require ministerial and industry-wide support, including key organizations like Confor and the Institute of Chartered Foresters (ICF).

The next window for significant policy-driven changes is already approaching the 2030s, making it difficult to meet 2040 targets unless action is taken now. Furthermore, the national forestry strategy is not set for renewal until 2049. Implementing meaningful change before then would require ministerial intervention, but with an election year approaching, political appetite for major policy shifts is low. For some in the forestry sector, reducing regulatory barriers would be more impactful than financial support. For example, easing restrictions around land management could make a significant difference. On the other hand, financial incentives have proven to be strong drivers of change, as demonstrated by the surge in Scots pine planting following an increase in grant rates. This highlights a clear role for government—not only in signalling which activities it wants to encourage but also in disincentivizing those that are less desirable.

Despite the slow-moving nature of forestry policy, action must begin immediately to achieve the desired landscape in 2040. There is a risk of complacency—assuming there is time to act later—when in reality, long lead times mean today's decisions shape the future. Without proactive planning, the necessary changes may remain stuck in discussion rather than implementation.

Controlling deer populations

Managing Scotland's deer population currently costs around £10 million per year, largely due to the absence of natural predators and an expensive, stalker-based control model. The financial return on culling deer is minimal—while it costs roughly £250 to shoot a deer, the carcass is worth only £70–£80, making it economically unviable for many land managers. As a result, deer management remains a significant drain on public funds—resources that could instead support nature restoration and riparian woodland planting.

Effective deer control also requires cooperation among land managers, but this is not happening at the necessary scale. Some landowners are failing to take adequate measures, contributing to population growth and exacerbating environmental damage.

Without collective action, deer numbers will continue to impact woodland regeneration and biodiversity efforts.

One potential solution is to implement allowable maximum deer populations, like the model used in Norway. There, strict population limits are enforced alongside structured training, support, and regulation, ensuring that deer numbers remain at ecologically sustainable levels. A similar framework in Scotland could provide clear guidelines, proper oversight, and financial incentives, making deer management more effective and economically viable.

Providing the right financial levers and incentives

Some participants mentioned that current agri-environment schemes lack clear direction and effective implementation when it comes to NbS. Farmers face uncertainty about expectations, and existing policies do not provide the necessary funding or guidance to ensure successful adoption. If NbS are to be widely implemented, policymakers must establish clear objectives, funding mechanisms, and practical guidelines to help farmers integrate these approaches effectively.

Financial institutions, including insurers and lenders, can play a key role in promoting sustainable land use by aligning incentives with climate resilience. For instance, lenders may be more inclined to finance farms that implement risk-reduction strategies, while insurers could offer lower premiums to those adopting climate-smart practices. On the other hand, businesses that pursue unsustainable investments may face financial disincentives, reflecting the growing economic risks associated with climate change. Many companies rely on healthy natural systems to buffer against threats like flooding and extreme weather, even if this dependence is not yet fully integrated into their business models. However, mounting financial pressures, such as rising insurance premiums, may prompt a shift. As climate-related risks become more immediate, nature restoration is likely to be seen less as a peripheral concern and more as a core investment strategy.

Easing requirements and regulatory flexibility

One participant discussed how excessive planning, preparation, and legislative compliance can slow down necessary environmental action. While these regulations aim to prevent negative consequences, the risk of delayed action often outweighs the risk of implementing imperfect solutions quickly. Acting sooner allows for early course correction, whereas waiting too long to empower people to make large-scale changes could lead to far greater consequences.

There is growing recognition that protected areas should be managed with greater diversity and flexibility rather than a one-size-fits-all approach. Instead of requiring every landowner to follow identical guidelines, policymakers could offer a menu of options, ensuring that no single option is overwhelmingly easier or harder than the rest.

This approach reduces regulatory complexity while allowing for a broader range of positive ecological outcomes.

Regulatory bodies like SEPA have successfully shifted toward self-regulation in some areas, such as compliance with water discharge regulations. Businesses with a strong track record of compliance undergo less monitoring, allowing regulatory bodies to focus enforcement efforts on those with poor compliance histories. This tiered approach could be applied more broadly to nature management, balancing flexibility with accountability.

A major challenge in environmental management is the fear that greater discretion and flexibility will lead to abuse. However, a hybrid system—where certain core requirements remain mandatory while other elements are optional or selectable from a range of choices—could create a more adaptive and effective regulatory environment. Importantly, oversight bodies must retain the power to intervene if needed, ensuring that flexibility does not come at the expense of ecological integrity.

Building Investor Confidence in NbS

Despite growing interest NbS, investment remains low compared to the scale of the challenge. While the goal is to scale up these initiatives alongside public funding, private investors need a clearer path to profitability. Currently, carbon prices are too low, and there is no widely accepted mechanism for monetising improvements in water quality or biodiversity at a level that drives significant private investment. There is also a need to build the economic case with relevant evidence for NbS to give more clarity that NbS is a viable and profitable approach, with well-defined outcomes that justify their financial commitments.

By 2040, a stronger policy framework is essential to boost investor confidence and incentivise NbS. This includes public policies that actively promote and reward nature-based interventions, rather than simply maintaining traditional agricultural subsidies that sustain the status quo. If policy remains unchanged, progress will be limited and exposure to risks will magnify. Establishing robust market mechanisms, reducing uncertainty around returns, and aligning policy with long-term environmental goals will be critical in unlocking the necessary scale of investment.

The Link Between Food Prices, Carbon Budgets, and Market Power

The UK government has focused on keeping food prices low due to household budget pressures. However, if the carbon budget targets set by the UK Climate Change Committee are met, household electricity bills could decrease, freeing up income for more sustainably produced food. This shift will take time, but policymakers and businesses should prepare now to ensure regenerative food options are available when consumer spending capacity increases.

Supermarkets and large buyers play a dominant role in shaping farmer decisions, particularly in annual food production. Farmers often feel they are reacting to government regulations, supermarket demands, and market pressures rather than making independent, proactive choices. For example, the barley market—essential for the distilling industry—is controlled by just seven major buyers in the UK, giving them significant power over farming practices.

Government reluctance to allow food price increases while energy bills remain high is understandable. However, in four to five years, lower electricity costs could create headroom for higher food spending. If the industry does not prepare now, other sectors may absorb this extra disposable income, missing a critical opportunity to drive demand for sustainable, high-quality food.

Integrating NbS policy with other priorities- Biodiversity Strategy and Scottish National Adaptation Plan

The uptake of NbS can be integrated with ongoing work to deliver Scotland's Biodiversity Strategy. Many of the ambitious ideas being proposed today take five years or more to materialize, making early engagement crucial. The Biodiversity Strategy is backed by a Delivery Plan, which outlines specific actions and assigns responsibility to relevant stakeholders. Additionally, there has been a clear alignment between the Biodiversity Strategy and the Scottish National Adaptation Plan (SNAP 3), ensuring a coordinated approach to biodiversity and climate resilience. Some existing actions within the current biodiversity delivery plan could already help achieve higher uptake goals for NbS—if they are prioritised now.

Summary and Knowledge Gaps

Knowledge Gaps

- **Approaches to Evidence Generation and Synthesis**: The scoping approach we took relied heavily on institutional publications and peer-reviewed journal articles from sources like SCOPUS, but this type of resource is often inaccessible to land managers who tend to rely more on case studies and place-based evidence from local organisations. It is important to also consider evidence generated from the ground up, focusing on what is practically applicable and contextually appropriate to local conditions.

- **Limited UK and Scotland Evidence**: While academic literature in the UK and Scotland is limited, a wealth of practical insights can be found in grey literature and case studies. Case studies highlight the active work being done on field, but more formal research is needed to better understand long-term effectiveness with empirical data.

- **Wider understanding of contexts and scale of implementation**: With multiple NbS measures and strong context dependencies, increasing case study examples, particularly at larger scales, can help to build the evidence base and identify best practice.

- **Better understanding of the economics and uncertainties of interventions**: In addition, with growing influence of the private sector in funding NbS, there is a need for evidence on the economic case for NbS to justify investments and improve certainty among investors.

- **Trade-offs in NbS Effectiveness:** The implementation of NbS often involves trade-offs between competing objectives. For instance, while measures like leaky dams may enhance biodiversity, they could also negatively impact water quality. Balancing these trade-offs, such as prioritising biodiversity over water quality or flood control over carbon sequestration, presents a significant challenge in the design of NbS interventions. It's important to recognise that the benefits of NbS measures may conflict or complement each other when considered at a larger scale. For example, flood control measures could reduce the capacity for carbon sequestration or biodiversity enhancement. Therefore, trade-offs must be carefully weighed, with research focused on understanding how different measures interact within the broader landscape. This approach will help ensure that NbS interventions address multiple risks (e.g., flooding, drought, soil erosion, biodiversity loss) while optimizing their overall effectiveness.

- **Future crop and land suitability:** Currently crop breeding mainly focuses on yield and disease resistance, and the multiple effects from climate change are not generally considered. With longer thermal growing season and warming and more chaotic climate, changing patterns of land capability and crop suitability across Scotland need to be understood better.

Areas for Further Research

Adopting an integrated assessment of NbS

The emphasis on placement and context of NbS measures contrasts with the approach taken in much of the existing literature. For example, NFM measures at the catchment scale require a combination of individual measures (e.g., leaky barriers, riparian planting, and offline ponds) to deliver flood risk benefits. However, evidence reviews and studies typically assess these measures individually or in a site-specific context. There is a need for evidence reviews to adopt an integrated approach that combines multiple measures, such as runoff pathway management, which assesses the effectiveness of hedges and buffer strips alongside runoff attenuation features like swales, ponds, and bunds.[53]

Limited long term empirical and wider scale evidence

There is limited empirical evidence regarding the effectiveness of NbS in mitigating climate risks in Scotland. Aside from the Eddleston case study, positive outcomes for NbS implementation, particularly NFM measures (riparian woodlands, runoff attenuation features) at a catchment scale, are primarily based on modelled results from small catchments over short timescales. These findings often focus on interactions between woodland, water flows, and sediment, using modelling to understand their effects at the catchment scale. Even well-researched NbS measures like riparian woodlands show less certain effects at larger scales or in mitigating extreme events. This is reflected in the Working with Natural Processes directory, where evidence on flood risk mitigation is site-specific and harder to predict for wider catchments. This uncertainty is compounded by responses to land use management changes, as well as variability in environmental conditions across catchments. Additionally, there is a lag period before measures reach full capacity—up to 100 years for a well-established riparian forest to deliver the hydraulic resistance required for NFM. Furthermore, there is a need for more evidence on how reductions in flood peak flows translate to actual flood risk reductions. Results from the Eddleston case study are not easily comparable to other catchments, as implementation in these catchments is still too early to produce significant effects and will require longer-term data for analysis.

[53] Environment Agency (2025) – Working with natural processes: Evidence directory update

Given the identified costs of inaction, waiting for evidence from long-term and wide-scale applications is not an option. 'No regret' options should be identified with research also exploring new modelling and monitoring technologies including remote sensing such as forthcoming national LIDAR surveys.

Limited evidence on NbS effectiveness in a rapidly changing environment

It is uncertain how adaptable river woodland tree species are to long term drought in Scotland. This will depend on their adaptative mechanisms (such as deep penetrating roots) and the timing and frequency of droughts over time[54]. There is a need to understand the effect of floodplain woodlands on low flow and droughts as well. Drier conditions can affect the effectiveness of hedgerows, buffer strips, and grasslands, which is why diversity of species will be crucial to remain resilient to changing conditions[55]. The benefits of all species and types of woodlands declines as flood magnitude increases, and it is uncertain how significant sediment mobilisation (from extreme events) would affect their ability to modify or reduce sediment pathways[56]. Additionally, there is a gap in understanding whether land management alone can reliably mitigate flood risk at a catchment scale, given the increasing frequency and magnitude of extreme rainfall events due to climate change projections. Offline ponds, for example, can shift between being sources or sinks of CO_2 if they dry out, although diverse vegetation appears to reduce this effect.[57] Moreover, there is a knowledge gap regarding the impact of beaver landscape engineering on low-flow conditions and wetland maintenance.

Understanding drivers and obstacles to behavioural change

The combination of a changing and uncertain land use policy environment, increasing climate risks and uncertainty over NbS effectiveness creates multiple obstacles to behaviour change. Research should explore NbS adoption decisions and identify how barriers can be addressed.

Measures that are achievable at individual level

While the literature emphasises the interdependence of measures with other contextual factors, some measures show potential for delivering broader benefits, regardless of surrounding land use. This insight could support further uptake, as these measures would be easier to implement. For example, pond sediments store high levels of organic carbon when paired with diverse vegetation and are less influenced by surrounding

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[54] The Riverwoods Science Group (2022) Riverwoods for Scotland I Report on Scientific Evidence

[55] British Ecological Society (2021) Nature Based Solutions for Climate Change in the UK

[56] Environment Agency (2025) – Working with natural processes: Evidence directory update

[57] Nikki Baggaley, Fiona Fraser, Paul Hallett, Allan Lilly, Mohamed Jabloun, Kenneth Loades, Thomas Parker, Mike Rivington, Amin Sharififar, Zulin Zhang, Michaela Roberts (2024). Assessing the socio-economic impacts of soil degradation on Scotland's water environment. CRW2022_04. Centre of Expertise for Waters (CREW)

land use. Although further research is needed to substantiate these findings, they suggest that offline storage ponds on farmland could be more widely adopted.

Other points participants identified as being critical for achieving an integrated landscape, which need to be explored in further depth, included:

- **Shifting mindsets toward risk-spreading,** relying more heavily on adaptive practice and learning and a suite of measures rather than rigid land-use practices.
- **Addressing deer overpopulation** as a major barrier to afforestation goals, recognising deer management as a powerful lever for landscape restoration and severely impeding riparian planting and restoration efforts at the moment.
- **Increasing on-farm water storage** during dry periods to reduce reliance on abstraction.
- **Reintroducing keystone species** and considering species translocation to restore ecological balance.
- **Recognising the tourism benefits of natural capital and NbS**, integrating tourism with land management for nature rather than treating them as separate. For example, around 20% of forestry income comes from recreation and tourism.
- **Reframing "native" vs. "natural" woodlands**, allowing flexibility in woodland restoration based on biodiversity benefits rather than strict adherence to historical species.
- **Acknowledging the footprint of communities in the landscape**, as policymakers will prioritise their needs when considering land management changes.
- **Improving community engagement**, questioning *why* and *how* communities are involved in NbS design and implementation. Some are well-equipped to engage, while others need guidance. In the Highlands, for example, communities affected by land-use changes may live far from the impacted areas. A broader definition of "community" could include all stakeholders with a legitimate interest in a place.
- **Balancing local authority power in decision-making**, ensuring they represent diverse interests rather than just the most vocal and powerful regional stakeholders. Strengthening local governance could enhance decision-making at the appropriate scale.

Policy design and recommendations

The workshop discussions identified solutions that should be considered in policy-making to address the multiple barriers in the uptake of NbS landscape-wide. These include:

- **Adaptive management:** Supporting diversified, locally adapted solutions that embeds risk of failure. Financial incentives remain influential in directing implementation on the ground. However, they can be repurposed to minimise risk on land managers and encourage more integrated, coordinated approaches to NbS. Rather than a flat payment, incentives should support long timescales, multifunctional measures (e.g. 3D buffer strips), and support spatial connectivity. There should also be an allowance or support for failure to enable learning and changes to lower the risk perception among land managers. Easing regulatory requirements, a lever with minimal onset financial cost, can be relevant to encourage adaptive management and adoption of NbS as well. A core strength of adaptive management is that diversity builds resilience. By maintaining a varied portfolio of NbS strategies, land-based sectors can better respond to emerging threats—such as increased pesticide pressure, drought, or shifting climate baselines—that may currently seem distant but could escalate in the future. To enable this, financial incentives should move beyond flat payments and instead reward long-term, multifunctional, and spatially connected measures (e.g., 3D buffer strips). Regulatory flexibility and support for trial-and-error approaches can also lower the perceived risk of adopting NbS and encourage wider uptake across Scotland's landscapes.

  An important aspect of adaptive management is appropriate baselining, monitoring and measurement. These should meet the needs and resources of both land managers and regulatory agencies.

- **Coordinating action with wider policy to mitigate path dependency:** Integrating NbS with wider SNAP3 priorities and the Scottish Biodiversity Strategy, and utilising channels that foster landscape-wide collaboration such as Regional Land Use Partnerships, will help in streamlining efforts and funding for NbS implementation.

- **Reduce grazing pressure on woodlands:** Our workshops emphasise that deer grazing pressure will remain a prominent threat in the uptake and success of woodland NbS measures. This will likely remain a significant barrier.

Appendix 1 - Climate Scenarios in Scotland

The UK Climate Projections, UKCP18 (updated in 2022)[58], are the most recent UK-wide probabilistic projections for future temperature and precipitation relative to a 1981 to 2000 baseline. Four scenarios are modelled covering low (RCP2.6), medium (RCP4.5 and RCP6.0) and high (RCP8.5) emissions pathways[59]. The probabilistic element of the projections means that the modelling results are reported over different percentiles. These effectively give central projections with potential ranges out to the 5th and 95th percentiles. Modelling results are available at multiple scales including UK country, regions and river basins. The UKCP headline findings key results[60] are used here to identify potential climate changes over Scottish river basins, which are the small aggregate geographies reported by UKCP. These are illustrated in **Figure 5**, noting that although the river basins correspond with agricultural regions, some will include large variations in landscapes and land uses, or include part of England such as the Solway basin.

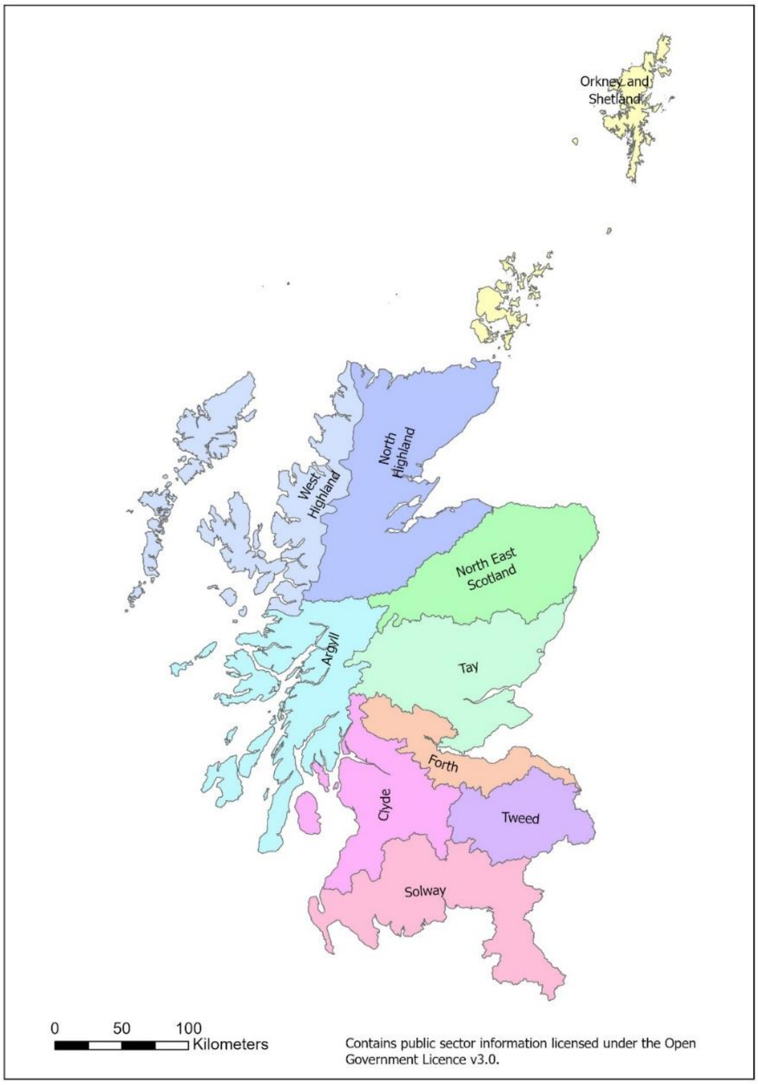
There are many possible combinations of climate variables, emissions scenarios and probabilistic projections. In this section we present a summary of the 50th percentile projections of variations in precipitation and temperature in both summer and winter. These are likely to capture the important extremes of climate change covering the times at highest risk of events such as flooding and drought.

[58] Met Office (2022) UKCP headline findings

[59] Representative Concentration Pathways are based on future greenhouse gas concentrations using assumptions about economic, social and environmental changes. For more information see here.

[60] Met Office UK Climate Projections 2022 version (Excel database)

Figure 5: Map of the UKCP(18) Scottish River Basins



Precipitation:

- Across all the river basins there is **a gradual increase in variation** relative to the baseline over the time slices, these average the predicted variation over 20 years.
- In each river basin **mean summer precipitation is predicted to decline**.
- The largest reductions are expected in the **eastern river basins**, with the lowest in the north-west and northern isles.
- **Winter precipitation is expected to increase** across all river basins and by similar magnitudes

Temperature:

- Both summer and winter mean temperatures are predicted to increase across all river basins.
- In the high emissions projections for both seasons, the higher temperature increases will occur in the **south and south-east.**

Extreme events:

- Cotterill et al. (2021) define **extreme rainfall** as days of **more than 50mm**, using UKCP18 data to estimate the number of days per year exceeding this level. They predicted an **increase in frequency of 85%** between 2019 and 2080 based on the RCP8.5 high emissions pathway.
- Increasing frequency of extreme rainfall **is predicted across all regions** and are significantly more likely in **western areas** including the west coast of Scotland.
- Drought Severity Index (DSI) is a measure based on the accumulation of monthly rainfall deficits over 3, 6, 12 and 36 month periods. Hanlon et al. (2021) estimate that there will be statistically **significant increases in drought severity across the UK** with global temperature increases above 1.5°C.
- In Scotland, there will be an **east-west split** with drought less frequent in the west and more frequent in the east, particularly for 12 and 36 month periods.
- High impact rainfall events (triggering thresholds for fluvial flooding and severe weather warnings) were predicted to i**ncrease in frequency in northwest, south and east of Scotland.**
- Hanlon et al. (2021) were not able to detect a climate change signal in the **variation in maximum wind gust speed.**
- Potential climate positives are **increased thermal growing season** and **reduced frost days** (Hanlon et al., 2021), although these may need to be **tempered against the role of cold and frost in moderating pests and diseases.**

Appendix 2 - REA search strings

We developed our search strings based on the PICO framework used in the Biodiversa+ Scoping Review[61], as shown in **Table 10.** The search query selected all fields for each row in SCOPUS, except for the lines in bold where the query was limited to "title" only to narrow down our screening to journal articles that conducted experiments or comparative studies.

Table 10: Key terms used in search query on Scopus following the PICO framework

Population	farm* OR "land manage*" OR forest* OR agricul* OR estate OR
Intervention	eco* OR ecosystem OR "eco* based" OR "community-based" OR (nat* OR eco* AND manage*) OR sustainable OR environment* OR restoration OR protect* OR conserva* resilien* OR sustainable OR ecolog* OR climate* OR "adaptation services" OR agroforest* OR agro-forest OR "re-vegetat*" OR revegetat* OR afforest* OR "land management" OR reforest* OR rehabilit* OR "agro-pastoral" OR agropastoral OR silvopastoral OR "regenerative agriculture" OR "regen* ag*" OR "low carbon" OR "net zero" OR "nature positive" OR "nature-positive" green OR blue OR "natural resource*" OR biodiversity OR "natural capital" OR "ecosystem service*" OR ecosystem forest* OR wood* OR riparian OR estuar* OR lake* OR stream* OR aquifer* OR marsh* OR catchment* OR floodplain* OR "flood plain*" OR peatland* OR saltmarsh OR "salt marsh*" OR shrub* OR intertidal OR field* OR wildlife OR livestock* OR arable OR crop OR upland OR lowland
Context	landscape OR catchment OR "landscape scale" OR "catchment scale" OR landscape-scale OR catchment-scale **evidence OR result* OR study OR experiment OR trial – title only**
Outcome	adapt* OR vulnerab* OR resilie* OR "food securit*" OR "water securit*" OR mitigat* OR reduction OR protection OR "risk mitigation" OR climate OR carbon OR co2 OR greenhouse OR "well-being" OR wellbeing OR alleviat* OR control OR biodiversity OR income OR development OR econom* OR cost OR benefit

[61] Biodiversa+ (2023), Scoping Review: what is the state of the knowledge on the role of biodiversity in design, delivery and benefits of Nature-based Solutions?

Appendix 3.1 – NbS from SCOPUS Literature

Table 11: Evidence log of SCOPUS studies

No	Title, Link	Author, Year, Source	NbS intervention	Location, Sector	Method	Timescale, Period	Scale, Size	Climate scenario addressed
1	A fuzzy logic-based approach for evaluating forest ecosystem service provision and biodiversity applied to a case study landscape in Southern Germany	Biber et al. (2021), SCOPUS	Multifunctional forest (tree planting), Set Aside, Production Oriented, Hedgerows and linear features on arable land, permanent grassland	Sourthern Germany, Forestry	Quantitative, Modelling	100 years	Landscape/ catchment, 120,000 ha sized area with 53,000 ha forest cover	Biodiversity loss, Pest resilience
2	Balancing food production and biodiversity conservation in arable landscapes: Lessons from the Farm4Bio experiment	Storkey et al. (2014), SCOPUS	Organic farming (4 agroecological measures) on cropped land, Conventional farming (with uncropped area)	Wessex and the South East of England, Agriculture	Quantitative, Empirical (survey)	2 years	Farm/field, 100 ha, 12 farms	Pest resilience
3	Changing land use and increasing abundance of deer cause natural regeneration failure of oaks: Six decades of landscape-scale evidence	Petersson et al. (2019), SCOPUS	Natural regeneration in Broadleaf dominated forest, Natural regeneration in conifer dominated forest	Southern Sweden, Forestry	Quantitative, Empirical (historical data)	62 years	Landscape/ catchment, 85,000 km2	Biodiversity loss

4	Comparison of Genetic Diversity in Naturally Regenerated Norway Spruce Stands and Seed Orchard Progeny Trials	Ruņģis et al. (2019), SCOPUS	Naturally Regenerated Norway Spruce Stands, Seed Orchard Progeny Trials	Latvia, Forestry	Quantitative, Empirical	1 year	Farm/field, sample	Biodiversity loss
5	Comparison of the interest of four types of organic mulches to reclaim degraded areas: a field study based on their relative attractiveness for soil macrofauna	Leclercq-Dransart et al. (2020), SCOPUS	Organic mulches, plastic sheeting, bare soil	Northern France, Agriculture	Quantitative, Empirical (survey)	2 years	Individual plot, 4400m2 plot	Soil surface temperature rise, biodiversity loss
6	Connectivity of cropped vs. semi-natural habitats mediates biodiversity: A case study of carabid beetles communities	Aviron et al. (2018), SCOPUS	Woody habitat (hedgerows/woodlands) at field edges, Crop habitat (conventional farming with asynchornous crop)	Brittany, France, Agriculture	Quantitative, Empirical (sampling)	1 year	Field/farm. 1km2 plot	Pest resilience
7	Delaying mowing and leaving uncut refuges boosts orthopterans in extensively managed meadows: Evidence drawn from field-scale experimentation	Buri et al. (2013), SCOPUS	Delay first cut by one month, Limit to two cuts per year (inaction), Set aside uncut grass	Switzerland, Agriculture	Quantitative, Empirical (sampling)	2 years	Individual plot, 0.8ha per meadow	Biodiversity loss
8	Experimental evidence that even minor livestock trampling has severe effects on land snail communities in forest remnants	Denmead et al. (2015), SCOPUS	Livestock access to forest remnants on farmland	Northern New Zealand, Agriculture	Quantitative, Empirical (sampling)	6 weeks	Individual plot, 12x30m plot	Biodiversity loss

9	The economics of transformation toward sustainable hill country land use: Whatawhata case study	Dodd et al. (2014), SCOPUS	Afforestation (130ha) on farmland	New Zealand, Agriculture	Quantitative, Modelling	10 years	Field/farm, 296ha	Unspecified
10	Flower strips, conservation field margins and fallows promote the arable flora in intensively farmed landscapes: Results of a 4-year study	Wietzke et al. (2020), SCOPUS	Agri-environment strips, Conventionally managed field edges	Germany, Agriculture	Quantitative, Empirical (survey)	4 years	Individual plot, 67 sites of 400-6200m2	Biodiversity loss
11	How Are Landscapes under Agroecological Transition Perceived and Appreciated? A Belgian Case Study	Boeraeve et al. (2020), SCOPUS	Agroecological landscape, Conventional farming landscape	Belgium, Agriculture	Quantitative, Empirical (survey)	1 year	N/A, 13 participants	Climate change
12	How can the forest sector mitigate climate change in a changing climate? Case studies of boreal and northern temperate forests in eastern Canada	Moreau et al. (2022), SCOPUS	Increase conservation (reduce harvesting by 11.1% to 49.8%), Increase harvesting by 6.3% to 13.9%, no management	Eastern Canada, Forestry	Quantitative, Modelling	80 years	Landscape/ Catchment, Montmorency Forest (37,050 ha) and the Hereford For est (5,668.75 ha)	GHG emissions
13	Impacts of forest biomass removal on soil nutrient status under climate change: a catchment-based modelling study for Finland	Aherne et al. (2011), SCOPUS	Whole tree harvesting, stem only harvesting, Stem plus branches harvesting, Above Ground harvesting, BAU (increasing growing stock)	Finland, Forestry	Quantitative, Modelling	60 years	Landscape/ Catchment, 1066 lake catchments	soil and water quality

14	Impacts of Forest Management on Forest Bird Occurrence Patterns-A Case Study in Central Europe	Pedro et al. (2022), SCOPUS	Continuous cover, multifunctional, wood production, habitat tree, set-aside	Switzerland, Forestry	Quantitative, Modelling	100 years	Landscape/ Catchment, 1,729 km2	biodiversity loss
15	Integrated nutrient transport modelling with respect to the implementation of the European WFD: The Weiße Elster Case Study, Germany	Rode et al. (2008), SCOPUS	Organic farming share 5%- 30%, BAU (9% agricultural land reduction), Status Quo (45% agricultural land reduction)	Germany, Agriculture	Quantitative, Modelling	9 years	Landscape/ Catchment, 5300 km^2	Water quality
16	Landscape-scale simulation experiments test Romanian and Swiss management guidelines for mountain pasture-woodland habitat diversity	Peringer et al. (2016), SCOPUS	Pastoral woodlands-low, medium, higher intensity	Switzerland, Agriculture	Quantitative, Modelling	100 years	Field/farm, 111 ha	Drought
17	Nature based measures increase freshwater biodiversity in agricultural catchments	Williams et al. (2020), Independent search	Earth-bunded ditches and stream, Interception ponds, Clean water ponds, Debris dams	England, Agriculture	Quantitative, Empirical (survey)	8 years (2010-2018)	Landscape/ Catchment, 10km2	Biodiversity loss
18	Assessing the role of location and scale of Nature Based Solutions for the enhancement of low flows	Fennell et al. (2022), Independent search	Runoff Attenuation Features	Scotland, Mixed (forestry and agriculture)	Quantitative, Modelling	2 years (2018-2020)	Landscape/ Catchment, Upland Scottish catchment (0.9 km2)	Flooding
20	Hedgerow structural diversity is key to promoting biodiversity and ecosystem services:	Kratschmer et al. (2024), Independent search	hedgerows	Central Europe, Agriculture	Qualitative, Evidence Review	48 years (1974-2022)	N/A, meta study	Biodiversity

	A systematic review of Central European studies							
21	Temperature effects on forest understorey plants in hedgerows: A combined warming and transplant experiment	Vanneste et al. (2021), SCOPUS	Efficiency of hedgerows in supporting forest plant persistence and migration in agricultural landscapes	Everbeek, Belgium and Vasterstad, Sweden, Mixed (forestry and agriculture)	Quantitative, Empirical (survey) and modelling	2 years	Individual plot	Temperatur e change
22	Multiple-Use Zoning Model for Private Forest Owners in Agricultural Landscapes: A Case Study	Truax et al. (2015), SCOPUS	Forest zoning separating the land base in three zones that have different management objectives: conservation, ecosystem management, intensive productions	Quebec, Canada, Mixed (forestry and agriculture)	Quantitative, Empirical (sampling)	Unspecifie d, 1-2 years	Field/farm, 216ha privately owned property	Biodiversity protection, increasing multi-functional land use.
23	Shared visions, future challenges: a case study of three Collaborative Forest Landscape Restoration Program locations	Walpole et al. (2017), SCOPUS	Collaboration for landscape-scale forest ecosystem management and large scale ecological restoration	United States, Forestry	Qualitative, Empirical (semi-structured interviews)	1 year	N/A	Reducing conflict over environmen tal restoration goals
24	The economics of growing shrub willow as a bioenergy buffer on agricultural fields: A case	Ssegane et al. (2016), SCOPUS	Landscape design for growing bioenergy crops, using short-rotation willow	United States, Agriculture	Quantitative, Modelling	13 and 22 years - Investment timeframes	Landscape/ catchment	reducing fertiliser use, water resources, NO3 export,

	study in the Midwest Corn Belt							reducing GHG emissions
25	Trade-offs between grassland plant biodiversity and yields are heterogenous across Germany	Schulz et al. (2024), SCOPUS	Effects of mowing frequency	Germany, Agriculture	Quantitative, Modelling	3 years	Field/farm	Biodiversity loss
26	Mediterranean Quercus suber wooded grasslands risk disappearance: New evidences from Sardinia (Italy)	Rossetti & Bagella (2014), SCOPUS	Wooded grasslands - testing the compatibility of management type (grazed, grazed and tilled wooded grasslands, non-grazed woodlands) for tree regeneration	Italy, Agriculture	Quantitative, Empirical (surveys) and modelling	Multiple, 50, 75, 100, and 125 years	Landscape/ Catchment, 230 km sq	Biodiversity loss - long term conservation through tree regeneration
27	Barriers to implementing climate resilient agricultural strategies: The case of crop diversification in the U.S. Corn Belt	Roesch-McNally et al. (2018), SCOPUS	Factors that influence adoption of cropping system diversity	United States, Agriculture	Quantitative and qualitative, Empirical (interviews and surveys)	5 years	Landscape/ Catchment, 80 acres across 20 watersheds	Agrosystem and pest resilience, extreme and variable weather
28	Sustainable transformation of agriculture requires landscape experiments	Pereponova et al. (2023), SCOPUS	Examination of the existing methods in field and landscape experimentation and identifying the major constraints in field experimentation,	Unspecified, Agriculture	Qualitative, Evidence Review	Multiple, 1-2 years	N/A, meta study	Potential for landscape-scale transformation

29	Water table response to an experimental alley farming trial: dissecting the spatial and temporal structure of the data	Noorduijn et al. (2010), SCOPUS	Alternating native perennial tree belts with mono-species agriculture within the tree belt alleys	Western Australia, Agriculture	Quantitative, Empirical (sampling)	13 years (1995-2008)	Field/farm, 21 plots	Biodiversity loss, water table depth groundwate r recharge
30	Temperate agroforestry research: considering multifunctional woody polycultures and the design of long-term field trials	Lovell et al. (2017), SCOPUS	Multifunctional woody polycultures	France and United States, Agriculture	Qualitative, Evidence Review	20 years	Field/farm, 45ha and 270 ha	carbon sequestratio n, water quality, adaptation to climate change, and biodiversity
31	Why and how we should study field boundary biodiversity in an agrarian landscape context	Le Cœur et al. (2002), SCOPUS	Field boundary diversity	Western France, Agriculture	Quantitative, Empirical (sampling)	2 years	Landscape/ catchment 500 to 700 ha	species dispersal
32	Why understanding stakeholder perspectives and emotions is important in upland woodland creation-A case study from Cumbria, UK	Iversen et al. (2022), SCOPUS	Understanding value conflict in upland woodland creation	Cumbria, UK, Forestry	Qualitative, Empirical (Q methodolog y)	1 year	Landscape/ Catchment Howgill Fells Natural Character Area, 10360ha	GHG emission reduction, biodiversity loss
33	Species rich, perennial wildflower mixtures for the production of biogas enhance biodiversity in the agricultural landscape by providing floral resources and habitat continuity – results from several field experiments;	Carlsson et al. (2016), SCOPUS	Wild plant mixes in energy crop cultivation	South and west Sweden, Agriculture	Quantitative, Empirical (sampling)	3 years	N/A	GHG emissions

34	Riparian buffer length is more influential than width on river water quality: A case study in southern Costa Rica	Brumberg et al. (2021), SCOPUS	The minimum riparian forest buffer width necessary to maintain tropical river water quality	Costa Rica, Mixed (forestry and agriculture)	Quantitative, Empirical (sampling)	Unspecified	Landscape/ Catchment, 4200 km2	Water quality
35	Release of dissolved phosphorus from riparian wetlands: Evidence for complex interactions among hydroclimate variability, topography and soil properties	Gu et al. (2017), SCOPUS	vegetated buffer zones in riparian wetlands	France, Agriculture	Quantitative, Empirical (sampling)	3 years (2015-2018)	Landscape/ Catchment, 5 km2 headwater catchment	Soil structure and phosphorus concentrations
36	Managing field margins for biodiversity and carbon sequestration: a Great Britain case study	Falloon et al. (2004), SCOPUS	Field margin scenarios with the highest carbon mitigation potential	UK, Agriculture	Quantitative, Empirical (sampling)	Unspecified	Individual plot, 12 ha	Carbon sequestration
37	Mixed effects of ecological intensification on natural pest control providers: a short-term study for biotic homogenization in winter wheat fields	Elek et al. (2020), SCOPUS	Establishing new, semi-natural habitats by setting aside fields next to agricultural areas	Hungary, Agriculture	Quantitative, Empirical (sampling)	3 years	Individual plot, 1.98 to 5.43 ha	Pest resilience, biotic homogenisation
38	Scenarios to reduce forest fragmentation and improve landscape multifunctionality: a study from Northern Italy	Digiovinazzo et al. (2011), SCOPUS	Woody patches	Italy, Mixed (forestry and agriculture)	Quantitative, Modelling (GIS)	Unspecified	Landscape/ Catchment, suburbs of Milan, 1982 km sq	Biodiversity loss

39	Measurement of flood peak effects as a result of soil and land management, with focus on experimental issues and scale	Deasy et al. (2014), SCOPUS	Arable in-field mitigation treatments: minimum tillage, contour cultivation, no tramlines in fields	Leicestershire, UK, Agriculture	Quantitative, Empirical (sampling)	1 year (2007-2008)	Individual plot, 17 unbound hillslopes, 70-100m long	Arable diffuse pollution mitigation, flood peak
40	Making agricultural landscapes more sustainable for freshwater biodiversity: a case study from southern England	Davies et al. (2008), SCOPUS	Buffer strips and farmland water bodies	UK, Agriculture	Quantitative, Empirical (sampling)	Unspecified	Landscape/ Catchment, 143 km2 of lowland agricultural landscape	Biodiversity loss - protection for freshwater biota
41	Permanence of resilience and protection efficiency in mountain Norway spruce forest stands: A simulation study	Cordonnier et al. (2008), SCOPUS	Individual tree and gap selection forestry in mountain silviculture, looking at forest stand structure (density), mean stem size, stem size distribution.	Norway, Forestry	Quantitative, Modelling (spruce stands dynamic model)	Range, 300-800 years	Individual plot, 1ha plot with a north facing slope	Protection against natural hazards such as snowfall and avalanches in the context of permanent cover forestry
42	Restoration of selective beech coppices: A case study in the Apennines (Italy)	Coppini & Hermanin (2007), SCOPUS	Restoring silvicultural systems on selective beech coppices that are in a state of prolonged abandonment	Italy, Forestry	Quantitative, Empirical (surveys) and modelling	Range, 30-70 years	Individual plot, 3 permanent sample plots with areas of 6000, 4000 and 1750 m sq	Intense rainfall and drought, retaining soil moisture, protecting against

								erosion on slopes
43	Restoration management of phosphorus pollution on lowland fen peatlands: A data evidence review from the Somerset Levels and Moors	Comber et al. (2023),	Altered hydrological regimes and plant biomass harvesting can be used to reduce eutrophication, and paludiculture (wet agricultural crops) and rewetting of peat bodies can help restore wetlands	UK, Agriculture	Quantitative, Empirical (sampling)	5 years	Field/farm, 1016ha, 226 ha, 9.3 ha, 200 ha	Water quality, runoff
44	Spatial organisation of habitats in agricultural plots affects per-capita predator effect on conservation biological control: An individual based modelling study	Collard et al. (2018), SCOPUS	Maintaining non crop plants in agrosystems	Unspecified, Agriculture	Quantitative, Modelling	1 day	Individual plot, 19.2 x 19.2 m	Pest control
45	Organic farming and semi-natural habitats for multifunctional agriculture: A case study in hedgerow landscapes of Brittany	Boinot et al. (2024), SCOPUS	Effects of the farming system (conventional vs. organic) and the total length of hedgerows in the landscape with their interaction on winter cereal fields	France, Agriculture	Quantitative, Modelling (space-for-time substitution)	1 year (2019)	Field/farm, crops between 5-50m away from field margins	Biodiversity conservation, nutrient cycling and soil structure, pest and disease regulation

46	Two decades of change in a field margin vegetation metacommunity as a result of field margin structure and management practice changes	Alignier (2018), SCOPUS	Diversity and composition of field margins	France, Agriculture	Quantitative, Empirical (surveys)	11 years (1994-2015)	Landscape/ Catchment, 309 field margins across three landscapes of around 650ha each	Species and plant diversity
47	Cover crop effects on maize drought stress and yield	Hunter et al. (2021), Independent search	Cover crops	United States, Agriculture	Quantitative, Empirical (surveys)	2 years (2013-2015)	N/A	Reduce drought stress by improving cash crop access to water or nitrogen
48	Engaging Farmers in Climate Change Adaptation Planning: Assessing Intercropping as a Means to Support Farm Adaptive Capacity	Himanen et al. (2016), Independent search	Intercropping	Finland, Agriculture	Qualitative, Empirical (workshop)	1 year	Participants, 30, of which 13 were farmers and 17 other rural stakeholders	Yield security, nutrient and protein self-sufficiency, soil conservation, reduced pathogen pressure, regulation of water dynamics
49	Nature-based solutions for effective flood mitigation: potential design criteria	Chappell & Beven (2024), Independent search	Potential design criteria for NbS features: planted woodlands, earth bunds on hillslopes or stone/wooden	Cumbria, UK, Agriculture	Quantitative, Modelling	Unspecified	N/A 7 NbS design criteria that NbS features and schemes should consider for	Magnitude of flood peaks during fluvial flooding

			structures in peat drains, leaky dams, aereated pastures, storage bunds on floodplains				flood peak reduction	
50	Natural flood management from the farmer's perspective: criteria that affect uptake	Holstead et al. (2017), Independe nt search	Farmer's perceptions of NFM	Scotland, Agriculture	Qualitative, Empirical (interviews and surveys)	Unspecifie d	Participants, 23 - scoping workshop held with 8 farmers and 15 semi structured interviews with farmers	Uptake of NFM measures for flooding on agricultural land
51	On the cost-effectiveness of Nature-based Solutions for reducing disaster risk	Vicarelli et al. (2024), Independe nt search	Evidence on the economic viability and equity impacts of ecosystem-based interventions	Global, Mixed (forestry and agriculture)	Qualitative, Evidence Review (metastudy)	21 years (2000-2021)	N/A 87 studies corresponding to 402 observations as part of a systematic review	The reviewed studies span 8 ecosystem types and 11 hazards
52	Framework for mapping large-scale nature-based solutions for drought mitigation: Regional application in Flanders	Yimer et al. (2024), Independe nt search	suitable detention basin (DB) and managed aquifer recharge (MAR) locations for drought mitigation	Belgium, Mixed (forestry and agriculture)	Quantitative, Modelling	Unspecifie d	Landscape/ catchment	Water scarcity, groundwate r recharge

Appendix 3.2 – NbS from Grey Literature

Table 12: Evidence log of NbS measures from case studies and grey literature

No	NbS intervention, Sector	Title	Publication organisation, date	Climate change outcomes	Limitations	Conditions for success
1	Afforestation (natural regeneration), Mixed	NATURE-BASED SOLUTIONS FOR CLIMATE CHANGE IN THE UK	British Ecological Society, 2021	GHG emissions, flood risk, soil erosion	Grazing pressure in the UK poses risks to woodlands, and current incentives for establishing woodlands for carbon sequestration are insufficient to drive widespread change, with only 266 projects registered under the Woodland Carbon Code. Impacts will likely be complex, depending on factors such as soil type, grassland type, and management practices.	Use native species to enhance genetic and species diversity, boost resilience to pests and diseases, improve structural diversity, and foster landscape-scale collaboration with land managers.
2	Tree planting to increase tree cover, Mixed	NATURE-BASED SOLUTIONS FOR CLIMATE CHANGE IN THE UK	British Ecological Society, 2021	GHG emissions, flood risk, soil erosion	Widespread woodland creation (by planting or natural colonisation) in the uplands and headwater gathering grounds can help to reduce runoff generation, though direct evidence shows an uncertain overall impact on flood flows.	Mixed-species planting, which leads to oak dominance over time, creates more durable carbon stores than conifer plantations. Studies in Europe show that mixed-species forests sequester carbon more quickly and are more climate-resilient, especially in regions with climate-related wood production limits.
3	Proforestation (Protecting existing forests),	NATURE-BASED SOLUTIONS FOR CLIMATE	British Ecological Society, 2021	GHG emissions, flood risk, soil erosion	Limited scope in UK due to few trees	

	Mixed	CHANGE IN THE UK				
4	Increasing cover of native woodlands, including productive woodlands, Mixed	NATURE-BASED SOLUTIONS FOR CLIMATE CHANGE IN THE UK	British Ecological Society, 2021	GHG emissions, flood risk, soil erosion	In one study, native birches and pines planted on organic soils were found to result in carbon loss from the soil which offsets carbon accumulation within living biomass, leaving no climate benefit of afforestation after 12 and 39 years.	Broadleaved woodlands store about 29% of the carbon in UK forest biomass and could sequester significantly more if established over sufficient scales. Control invasive species to support natural regeneration
5	Retaining permanent grassland in situ, Agriculture	NATURE-BASED SOLUTIONS FOR CLIMATE CHANGE IN THE UK	British Ecological Society, 2021	GHG emissions, biodiversity loss	Shallow rooting depths of sown species (e.g. annual ryegrass (Lolium perenne) and white clover (Trifolium repens)) constrain soil carbon and have low levels of species diversity. Capacity of UK grasslands to naturally adapt to climate change through increasing in species diversity is severely limited by the presence and connectivity of habitats including suitable species in the wider landscape.	More diverse permanent pastures which require lower levels of nutrients. Native species mixtures that include legumes has also been shown to benefit soil carbon sequestration. Higher species-richness increases the rate of carbon sequestration in grassland communities.
6	Grazing management - more diverse grazing species, rotational, mob grazing, Agriculture	NATURE-BASED SOLUTIONS FOR CLIMATE CHANGE IN THE UK	British Ecological Society, 2021	GHG emissions, biodiversity loss	Research needed to assist in transforming grassland management. Lack of understanding about the processes leading to carbon storage at depth, its relationship with biodiversity above and below ground and how it is affected by field management practices needs to be addressed.	
7	Hedgerows, Agriculture	NATURE-BASED SOLUTIONS	British Ecological Society,	GHG emissions, biodiversity loss	Hedgerows may provide landscape connectivity which enables dispersal opportunities for species across the	More diverse range of species and hedgerow species adapted to a wider range of

		FOR CLIMATE CHANGE IN THE UK	2021		landscape at a local to national level in response to a changing climate, although the effectiveness of these corridors is not yet established. Yield benefits may take time to accrue and habitat measures must be carefully designed for specific systems to avoid trade-offs.	climatic conditions can ensure climatic resilience.
8	Herbaceous Field Margins, Agriculture	NATURE-BASED SOLUTIONS FOR CLIMATE CHANGE IN THE UK	British Ecological Society, 2021	Flood risk, soil degradation	Yield benefits may take time to accrue and habitat measures must be carefully designed for specific systems to avoid a trade-offs.	
9	Conservation biological control. Agriculture	NATURE-BASED SOLUTIONS FOR CLIMATE CHANGE IN THE UK	British Ecological Society, 2021	Pest and disease	These benefits are not found in every circumstance and more research is needed.	Can be enhanced through a range of management approaches, with carefully engineered solutions such as combining trap and repellent plants and using attractant plants or chemicals such as pheromones to bring in natural enemies of pests, being among the most effective. Well-designed flower strips alongside arable fields also enhance natural pest control and can therefore reduce the need for insecticides.
10	Agroforestry, Agriculture	NATURE-BASED SOLUTIONS FOR CLIMATE	British Ecological Society, 2021	Soil degradation, wind, drought	Limited evidence in UK	When intercropped trees are less mature, yield may be improved in some situations.

		CHANGE IN THE UK				
	Cover cropping, Agriculture	NATURE-BASED SOLUTIONS FOR CLIMATE CHANGE IN THE UK	British Ecological Society, 2021	GHG emissions	Studies agree that cover crops enhance soil organic carbon sequestration, but their impact on direct GHG emissions varies.	Key considerations include managing cover crop residues, tillage, water, inputs, species, biome, and soil type. Short-term legume fallows (2-3 years) can reduce soil carbon losses, pesticide use, and GHGs by lowering the need for pesticide manufacturing
11	Intercropping, Agriculture	NATURE-BASED SOLUTIONS FOR CLIMATE CHANGE IN THE UK	British Ecological Society, 2021	GHG emissions	More evidence is required across globally distributed sites to draw clear conclusions.	There is some evidence that the benefits of intercropping come from improved nitrogen use efficiency, especially when legumes and non-legumes are mixed, and the potential for reduced fertiliser inputs if legumes are used. However more evidence is required across globally distributed sites to draw clear conclusions.
12	Ponds, Agriculture	NATURE-BASED SOLUTIONS FOR CLIMATE CHANGE IN THE UK	British Ecological Society, 2021	Changing rainfall patterns, flood risk	Ponds can quickly switch between CO2 sources and sinks if they dry, though diverse vegetation may reduce this. Evidence of their effectiveness is inconsistent, and it's unclear how long these rates persist, especially in shallow ponds under various pressure.	Mature ponds with higher rates of vegetation are more effective at sequestering carbon. Diverse vegetation appears to be the main factor driving higher storage, whilst surrounding land use is less important, suggesting that ponds could be effective across many different landscapes.

13	Runoff attenuation features and temporary storage ponds, Mixed	NATURE-BASED SOLUTIONS FOR CLIMATE CHANGE IN THE UK	British Ecological Society, 2021	Flood risk	Soil, wood, or stone barriers and removing river embankments can effectively manage small, frequent floods in small catchments. However, there are concerns about the scalability of these models, with limited empirical evidence for larger floods or catchments.	Empirical results from the Eddleston study show the impact of in-stream log structures and temporary storage ponds in delaying the rise in peak flood waters for a catchment of at least 25 km.
14	Re-introductions and species management (e.g. beavers), Mixed	NATURE-BASED SOLUTIONS FOR CLIMATE CHANGE IN THE UK	British Ecological Society, 2021	Flood risk, nutrient loss	Significant issues around trade-offs, with clashes between sectoral views of the damage caused to angling and farming interests, as well as observations that beaver ponds are significant sources of methane and nitrous oxide emissions.	Studies from the Scottish and Devon's River Otter show that beaver dams and activities reduce peak discharge by 30%, total discharge by 34%, and increase lag times by 29%. Beavers also impact wetland vegetation, reducing sediment, nitrogen, and phosphate.
15	River woodlands, Mixed	Riverwoods for Scotland Report on Scientific Evidence	The Riverwoods Science Group, 2022	Flood risk	Improved evidence at catchment scale and over longer timescales will improve confidence in river woodlands as a nature-based solution. Estimations on the time it takes for benefits to be realised will be valuable for catchment planning, for example in identifying future needs of drinking water supplies or flood risk changes.	Lower gradients and wider floodplains enhance woodland interaction with flood flows, slowing response times and increasing flood storage, while also promoting large woody material dams. The placement of riparian woodland within a catchment can influence peak flow magnitudes by synchronizing or desynchronizing sub-catchment flow responses.
16	Agroforestry, Agriculture	Understanding carbon sequestration	ClimateXChange, 2022	GHG emissions	Limited evidence in Scotland for carbon stocks	Impacts are site specific depending on the yield and species of trees which are a

		from nature-based solutions				function of soils, topography and local climate. Tree growth is dependent on soil, climate and topography meaning some land will be suitable for agroforestry and other areas will be less likely to support tree growth. A landscape scale approach to identifying sites suitable for agroforestry in Scotland is therefore needed.
17	Riparian buffer strips, Agriculture	Understanding carbon sequestration from nature-based solutions	ClimateXChange, 2022	GHG emissions	Limited evidence for carbon stocks and uncertainties with wider or narrow buffer zones of tree planting. Many riparian areas in Scotland that are intensively managed for agriculture comprise wet soils and are likely to be artificially drained. The impact of the management of subsurface drains on net GHG emissions is an area where research is lacking	There is limited evidence for the change in vegetation carbon stocks in riparian buffer zones but where trees have been integrated into the buffer there is some evidence of increasing stocks.
18	Hedgerows, Agriculture	Understanding carbon sequestration from nature-based solutions	ClimateXChange, 2022	GHG emissions	No Scottish evidence for carbons stock changes with hedgerows Vulnerable to warming and drier climate	Evidence suggests hedgerows in arable fields may sequester more soil carbon than those in grasslands, though SOC changes can vary. Effective management, including selecting drought-tolerant species, is crucial for maintaining hedgerow health and resilience against climate change and other pressures.

19	Species-rich grasslands, Agriculture	Understanding carbon sequestration from nature-based solutions	ClimateXChange, 2022	GHG emissions	Limited evidence in Scotland for carbon stocks Warming and drier climate can cause grasslands to be emitters	Vegetation and soil carbon stocks in seminatural grasslands vary by type and are influenced by soil, climate, and management. Reducing or removing grazing on upland acid grassland increases biomass and soil carbon stocks, while also reducing livestock emissions
20	River restoration, Unspecified	Working with Natural Processes – Evidence Directory	Environment Agency, 2025	Water quality, flood risk - medium confidence	Our understanding of the effectiveness of river restoration at larger catchments sizes may be limited due to the challenges of monitoring at larger scales. Additionally, there are few large-scale restoration projects in the UK, with most being smaller in scale. While it is thought that river restoration may improve resilience to droughts, new evidence suggests that it can have minimal impact on water resources. Does not work instantaneously, it takes time to adjust morphologically, and pace of adjustment will vary depending on flow and sediment supply	Can slow flows, delay peak flows and store water. However, effectiveness depends on: the length of the channel restored; with evidence suggesting it is more effective across entire river segments, catchment size; with evidence suggesting it is more effective in smaller catchments, the level of impoundment within the reach.
21	Floodplain and floodplain wetland restoration, Unspecified	Working with Natural Processes – Evidence Directory	Environment Agency, 2025	Flood risk, low to medium confidence	Can increase flooding downstream (for example, due to peak synchronisation in the river network) Does not usually work instantaneously, there can be delays before full floodplain connectivity is	Modelling shows floodplain restoration can reduce peak flow; this is consistent among the literature as reported by multiple studies, and the effect has also been noted over a variety of return

					re-established and it is able to attenuate peak flows Can reduce or delay flood peaks, but these benefits are site-specific and hard to predict.	periods. Design should reflect the typology of the catchment and local environment.. Can reduce flood risk, but the extent of this effect depends on the length of river restored relative to the catchment size, and the river and floodplain type
22	Leaky barriers Unspecified	Working with Natural Processes – Evidence Directory	Environment Agency, 2025	flood risk - medium confidence	Have limited effects on hydrological variables at low flows. Have limited long-term effects on water quality. Affect fish movement, which is dependent on the design of the leaky barrier	The potential for peak flow to align after the introduction of leaky barriers may increase with catchment size; making sure flood peaks are not synchronised across sub-catchments may improve the effectiveness of schemes using leaky barriers. Storage is dependent on design and site character, including structure, width of lower and lateral gaps, barrier height, and channel slope, bed roughness, and depth.
23	Species introduction-beavers Unspecified	Working with Natural Processes – Evidence Directory	Environment Agency, 2025	flood risk-medium confidence	Greater understanding of the impacts of beaver landscape engineering on low flow conditions and wetland maintenance during drought Evidence to suggest whether beaver dam analogues/leaky woody debris dams could function as ‘starter dams’ to encourage beaver damming in locations that optimise the potential	Dams work well in locations where they create complex wetlands, often in headwaters and tributaries and encompass benefits realised from leaky woody barriers, river and floodplain restoration, offline storage areas

					benefits of beavers in NFM, while minimising the potential conflict	
24	Offline storage areas Unspecified	Working with Natural Processes – Evidence Directory	Environment Agency, 2025	flood risk- medium confidence	Water storage areas can overflow even in modest floods. More evidence is needed on how flood peak reductions translate into reduced flood risk, and how offline storage areas may aid in managing flood risks, including with engineered assets. There is limited data on their effectiveness at the catchment scale for larger floods and on their cumulative impact when scaled up	The design of offline storage areas can impact the measure's effectivenes- inlet-filling height, inflow management, drainage design, size of outflow pipes etc. Some studies found outlet design is important to ensure sufficient and timely drainage
25	Catchment woodland Unspecified	Working with Natural Processes – Evidence Directory	Environment Agency, 2025	flood risk - medium to high confidence	Evidence is needed on how flood peak reductions from catchment woodlands translate into reduced flood risks and assist with managing engineered assets. There is also a need to quantify how woodland type, placement, and catchment size affect flood risk. The impact of woodland creation in large catchments is less studied, with most research focused on small to medium-sized ones. In UK upland headwater catchments, woodland can take around 15 years to significantly reduce flows through soil changes.	The nature of woodland management impacts the efficacy of the measure (understory management, roads, ditches (particularly in peat catchments), soil health, grazing) Woodland can reduce peak flow and increase time to peak, and is more effective when a higher proportion of the catchment is afforested and in smaller events
26	Cross-slope woodland Unspecified	Working with Natural Processes – Evidence Directory	Environment Agency, 2025	flood risk - low confidence	Most studies look at smaller catchments, where percentage woodland coverage is higher; there is a lack of evidence for the efficacy in larger catchments. There are	There is an evidence gap in optimal soil, geological conditions, and locations for forest cover to impact catchment scale. More

					limited new studies, particularly including observed data	research is needed on how woodland design and management—such as size, width, type, density, and age—affect the effectiveness of cross-slope woodlands
27	Floodplain woodland Unspecified	Working with Natural Processes – Evidence Directory	Environment Agency, 2025	flood risk- low to medium confidence	Evidence is lacking on the impact of large floodplain woodlands on flood flows and protection across various catchment sizes. Further research is needed on how different effects of floodplain woodland (e.g., water use, soil infiltration, erosion, and sediment delivery) reduce flood risk, and how these vary by woodland and catchment type	Floodplain woodlands mainly impact flood flows by increasing surface roughness, slowing flow, and retaining water.
28	Riparian woodland Unspecified	Working with Natural Processes – Evidence Directory	Environment Agency, 2025	flood risk- medium confidence	Delay of 40-50 years between the initiation of riparian forest growth and the delivery of woody debris to the channel in a size that can enhance channel complexity and hydraulic resistance, or 100 years for establishment of new riparian forest to deliver full capacity of NFM	Mature trees can add large woody debris to watercourses, increasing hydraulic resistance and channel complexity. Tree species and canopy should be considered, as canopy height and density may impact hydraulic resistance
29	soil aeration and subsoiling Agriculture	Working with Natural Processes – Evidence Directory	Environment Agency, 2025	flood risk- low confidence	there was high confidence that soil aeration and subsoiling does increase the ability for water to infiltrate and be stored in soil, but there is currently low confidence in the measure itself significantly reducing flood risk downstream	More evidence (qualitative and quantitative) that takes into account the complexity of catchment hydrological connectivity, flood generating processes and land management across vast areas to determine the type of land management required

						to create an impact of flood risk on a catchment scale
30	for grassland systems - stocking density and vegetation cover Agriculture	Working with Natural Processes – Evidence Directory	Environment Agency, 2025	flood risk- low confidence	There were limited findings from scientific experiments showing the impacts of stocking/destocking on run-off generation. Findings from scientific studies on this topic were conflicting, in some cases, it is assumed that trampling will cause compaction and reduce infiltration, while in other studies no significant difference was witnessed between soil infiltration rates on grazed and ungrazed plot	Combining soil and land management measures with other nature-based solutions (NBS) leads to efficiencies, but improved soil management means that fewer run-off attenuation features (RAFs) will be required, as less run-off is generated to fill them according to a modelling study. Introducing a diverse mix of vegetation which builds a rough surface will help to restore unimproved grassland; a study on culm grassland, comparing improved and unimproved grassland found this
31	arable systems (including machinery use) Agriculture	Working with Natural Processes – Evidence Directory	Environment Agency, 2025	flood risk- low confidence	there was limited evidence or peer-reviewed literature from the UK which shows that changes in crop management reduce flood risk locally or at the catchment scale; the evidence that was available is also conflicting	
32	conservation tillage Agriculture	Working with Natural Processes – Evidence Directory	Environment Agency, 2025	flood risk- low confidence	soil cultivation or tillage can, in the short term, have positive effects on soil water retention capacity by decreasing soil bulk density and increasing porosity	
33	cover cropping	Working with Natural	Environment Agency, 2025	flood risk- low confidence	early sowing and cover crops have a flood risk benefit; however, there	

	Agriculture	Processes – Evidence Directory			was limited peer-reviewed literature available and it was conflicting	
34	crop rotations Agriculture	Working with Natural Processes – Evidence Directory	Environment Agency, 2025	flood risk- low confidence	There is strong evidence to suggest that seasonal changes in vegetation mean that overland flow peaks vary over the course of a year	
35	Run-off pathway management Unspecified	Working with Natural Processes – Evidence Directory	Environment Agency, 2025	flood risk- high confidence	Scaling up results from bunds on a sub-catchment to their impact on a full catchment may not show as high a reduction in peak flows, however, there has been limited new evidence regarding this	The location of RAFs and ponds in a catchment influences peak flow, and can sometimes increase it, so this must be considered in their design and modelling. Buffer strips reduce flood risk further when implemented over a greater area, integrated buffer zones (with storage and outflow) perform more effectively and wider buffer strips are more effective at reducing peak flow and time-to-peak
36	Upland woodland planting, Agriculture	Land management for increased flood resilience	CREW, 2015	Flood risk - farmers likely or highly likely to consider	Money is not always the determining factor	incentives at the average level of £69/ ha/yr. or higher would be sufficient to motivate some farmers to implement upland wood planting as a NFM measure, increasing as the compensation rises.
37	Blocking upland drains/moorland grips	Land management for increased	CREW, 2015	Flood risk - low support	Monetary value not sufficient, perception that such a widespread activity could take out large areas of	specific individuals may be willing to implement drain blocking given specific farm or farmer characteristics,

	Agriculture	flood resilience			land with relatively low levels of compensation	irrespective to some extent of the level of payment on offer.
38	Reducing stock numbers by 50% Agriculture	Land management for increased flood resilience	CREW, 2015	Flood risk - very low support	Reducing stock numbers on hill farms remains one of the least attractive NFM measures proposed	If implemented, could reduce soil compaction and surface water runoff
39	In bye woodland planting Agriculture	Land management for increased flood resilience	CREW, 2015	Flood risk - medium support		Incentives at £80/ha/yr. or higher are seen as being sufficient to motivate some farmers to implement in-bye wood planting
40	Tree planting in gullies Agriculture	Land management for increased flood resilience	CREW, 2015	Flood risk - low support	Many would not support at the lowest level of compensation	There is a greater willingness at the highest level of compensation than for woodland planting on in bye land
41	Cross-slope woodland shelter belts Agriculture	Land management for increased flood resilience	CREW, 2015	Flood risk - medium support		Incentives at £80/ha/yr. or higher are sufficient to motivate some farmers to consider implementing cross slope woodland shelter belts
42	Creating areas of 'sacrificial' wetlands Agriculture	Land management for increased flood resilience	CREW, 2015	Flood risk - low support	the exact location and deployment of such wetland areas across a catchment landscape would need careful planning to be effective	some farmers may be in unique or uncommon circumstances that allow them to consider this option so it should not be ruled out. Each catchment and farm circumstance should be assessed on its own merit, recognising potential benefits such as preventing soil erosion.
43	Removing flood banks and	Land management	CREW, 2015	Flood risk - low support	Removal of flood banks would increase the likelihood of river	At the average figure of £326/ha/yr., one of two

	switching to grass Agriculture	for increased flood resilience			flooding at times of high flow and require the farmer to switch the impacted areas to grass production, rather than stay in arable	farmers indicated "Likely" acceptance of the average incentive value.
44	Rural Sustainable Drainage Systems Agriculture	Rural Sustainable Drainage Systems: A Practical Design and Build Guide for Scotland's Farmers and Landowners	CREW & Abertay University, 2015	Reduce diffuse pollution		These physical barriers reduce agricultural diffuse pollution by capturing runoff, soil particles, nutrients, and pesticides. Low-cost, aboveground drainage structures, they prevent blockages and contribute to farm assurance schemes. In fields, they return fertile soil to farmland, enhancing resilience to climate change, and can save £88 per hectare annually
45	3D Buffer Zones Agriculture	3D Buffer Zones	FAS, 2023	Intercept agricultural pollution for atmospheric, surface, and subsurface pathways		3D buffers can be focused on targeting certain problem points, where water is more likely to flow due to field characteristics or types of soils that may be allowing more subsurface runoff to pass through them
46	Grass buffer Agriculture	Database of sixteen riparian management measures	Mendeley, 2022	Filter sediment, P, and to a lesser extent N and pesticides	Need time to establish grasses and stiffer vegetation to form a barrier to surface runoff. If placed in a livestock field these features need to be fenced. Reduces the size of field.	This measure requires relatively low management inputs but it still requires a certain level of effort to establish the buffer, for example to establish a grass sward.
47	Wildflower buffer	Database of sixteen	Mendeley, 2022	Erosion control	Establishment of wild flowers can be tricky amongst grasses that	Specialist wildflower seed mixes are available off-the-

	Agriculture	riparian management measures			outcompete them for light and other resources, necessitating ground preparation such as herbicide or physical cultivation.	shelf for different climatic regions and goals. Often competing vegetation must be mechanically removed to allow flowering plants to establish. pecial survey and planning may be required if diverse or mosaic vegetation on different soil moisture regimes is to be established, or trees and herbaceous mixtures.
48	wooded buffer Agriculture	Database of sixteen riparian management measures	Mendeley, 2022	Flooding, bank erosion, elevating water temperatures, lacking woodland connectivity	Flows can be bypassed at depth, although this can be reduced by tree rooting. Potentially needs access for management such as thinning and eventual harvesting. Potentially vulnerable to wind blow.	getting rid of grass and competing weeds at tree bases is recommended until canopy closure to help trees become established. Protection from deer is necessary. Access for harvesting machinery must be done with care not to destroy soil structure or leave preferential run-off paths and may give marginal returns on small areas relative to effort.
49	Magic margins Agriculture	Database of sixteen riparian management measures	Mendeley, 2022	Nutrient and soil runoff, habitat diversity	Timing of operations are important as to create bare soil and set up drills during the autumn/winter makes the soil erosion risk higher, thus acting as the cause of the very issue we aim to prevent. As a buffer strip designed to capture eroded soil and any leached nutrition, our	the margins would need to be cut periodically and the material removed to help control the build up of nutrients which encourage dominance by the more vigorous noxious perennial weeds. Cut material

					permanently established 'magic margins' are not suited to wildflower meadow-type management which requires lower soil fertility levels to allow annual flowers to flourish.	containing a diversity of plant species can contribute high quality organic matter to the system if returned to the field soil (either pre-composted or as a mulch)
50	Raised buffer: field runoff Agriculture	Database of sixteen riparian management measures	Mendeley, 2022	Field water runoff, storms	Sediment accumulations need to be managed. Space required, bund width is usually around 6 m to 8 m. Bund will require ongoing inspections, especially after storm events.	Wilkinson et al., (2013) showed that a raised bund buffer placed in a field margin (in the Belford catchment, UK) drained within 10h hours after mitigating runoff from an intense storm. It was estimated that the same feature captured ~1 tonne of sediment during a moderate rainfall event, the equivalent of 91kg/ha (Palmer, 2012). There is a potential to create a complex habitat mosaic from wetter and drier ground that elevates the terrestrial habitat potential and other field services such as pollinators, but this depends on design and management.
51	Raised buffer: overbank Agriculture	Database of sixteen riparian management measures	Mendeley, 2022	Flooding	Bund will require ongoing inspections, especially after storm events.	Nicholson et al. (2019) showed that 35 small ponds (eachof capacity 500 m3in series in a 5 km2 catchment area) could provide a 30% reduction in flood peak for an observedstorm estimated to represent a 1:100 year return

						period (Hewett et al., 2020). Meltcalfe et al., (2018) also showed runoff attenuation features could be used to mitigate flood peaks .
52	Sediment traps Agriculture	Database of sixteen riparian management measures	Mendeley, 2022	Improve water quality	Best with larger surface area, however, this takes a greater area of land. Sediment traps should not be used to collect dirty water such as silage leakage, slurry or effluents as these should be treated considerable distances away from the riparian zone. Sediment traps need management	The diversity of wetter and drier soil conditions around the features aids habitat diversity (varying vegetation communities).
53	Integrated buffer zone Agriculture	Database of sixteen riparian management measures	Mendeley, 2022	Soil loss control, P capture and retention, terrestrial habitat diversity, reduce runoff and flood risk	There is limited testing presently	Periodic biomass harvesting maintains nutrient offtakes and can offset management costs, especially if wood chip has local on-farm use. Alder may have 10-year coppice cycles, while willow cycles are 3-5 years. In high erosion areas, linear ponds may become sedimented, reducing retention time or blocking field drains, requiring manual sediment removal
54	Two stage channel Agriculture	Database of sixteen riparian management measures	Mendeley, 2022	Flooding, retained P, fish biodiversity	Costs can increase if excessive tree roots are encountered or excavated material has to be removed from site.	The optimal location to reprofile the ditch to a two stage channel is where naturally channel benches (shoulders) are forming anyway. The principles of design are that: the channel is

	sized to convey the effective discharge, the benches cut (the 'second stages') serve as the floodplain for the smaller inset channel and are adequate width to prevent flow overtopping the ditch and flooding surrounding land.

Appendix 4 – Further costs of inaction

Deer grazing pressure

Failing to address unsustainable deer populations in Scotland poses a significant threat to the success of NbS, particularly those involving trees such as riparian woodlands and the natural regeneration of native species. Without effective management, deer browsing jeopardises up to 150 million young trees, undermining efforts to enhance carbon sequestration, improve biodiversity, and reduce flood risk[62]. As the climate warms, reduced mortality and increased breeding rates are expected to worsen the issue, escalating both ecological and financial costs. In response, the Scottish Government awarded £6.6 million in 2023 for deer fencing, while Forestry and Land Scotland invests around £7 million annually in deer management[63]. However, these measures are reactive and resource intensive. Without more proactive, systemic solutions, the long-term cost of inaction—including diminished NbS efficacy in climate adaptation and broader ecosystem service loss—will likely continue to rise. Further research is urgently needed to assess the full scale of these impacts and inform more sustainable deer management strategies.

Soil degradation

The cost of inaction on soil health is already mounting and is projected to escalate as climate risks intensify. Across all three stakeholder workshops, poor soil health emerged as a major concern, linked to reduced crop yields, increased pollution, and downstream sedimentation. A 2024 report by the Centre of Expertise for Waters (CREW) estimates that compacted soils alone cost Scottish farmers between £15 and £209 per hectare in additional fuel use[64]. Yield losses—particularly from spring barley—are estimated at £16–49 million per year, with these figures likely to worsen under growing drought risks[65]. The consequences extend beyond agriculture: soil compaction also contributes to surface runoff, increasing flood risk by an estimated 1%, which could cost local authorities £2.6 million annually in flood-related damages. Insurance claims for flood events range from £57,000 to £76,000 per affected property[66]. In parallel, soil contamination from microplastics and organic pollutants

[62] Forestry and Land Scotland- Out of season deer control on Scotland's national forests and land

[63] Scottish Government (2025) Costs for the installation of deer fences: EIR release

[64] Nikki Baggaley, Fiona Fraser, Paul Hallett, Allan Lilly, Mohamed Jabloun, Kenneth Loades, Thomas Parker, Mike Rivington, Amin Sharififar, Zulin Zhang, Michaela Roberts (2024). Assessing the socio-economic impacts of soil degradation on Scotland's water environment. CRW2022_04. Centre of Expertise for Waters (CREW)

[65] Nikki Baggaley, Fiona Fraser, Paul Hallett, Allan Lilly, Mohamed Jabloun, Kenneth Loades, Thomas Parker, Mike Rivington, Amin Sharififar, Zulin Zhang, Michaela Roberts (2024). Assessing the socio-economic impacts of soil degradation on Scotland's water environment. CRW2022_04. Centre of Expertise for Waters (CREW)

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threatens both human and animal health, though the full extent of these risks remains poorly understood. Critical research gaps persist around how compaction and contamination affect soil biodiversity, which is fundamental to carbon storage and the long-term resilience of agricultural systems. Without coordinated action, the ecological and economic toll of degraded soils will continue to rise.

Storm

Ignoring the growing threat of storm surges poses serious economic risks, particularly for the forestry sector. Although not addressed in the UKCP18 land projections, storm surges were identified as a key concern by stakeholders—especially in light of events like Storm Arwen, which brought wind speeds up to 110mph and damaged over 8,000 hectares of Scottish forest[67]. The storm felled approximately one-third of the annual timber harvest[68], creating a sudden oversupply that drove down prices and diminished the market value of otherwise usable timber. This represents a significant opportunity cost for land managers, who must absorb both the financial loss and the longer-term disruption to forest planning and carbon sequestration targets[69]. Despite their increasing frequency and severity, the lack of formal recognition of storm surges in land-focused climate projections risks underestimating their impact and delaying the development of appropriate resilience strategies.

Loss of ecosystem services linked to biodiversity

Delaying the implementation of NbS risks accelerating biodiversity loss, particularly within monoculture systems, and significantly increases future costs. As climate impacts intensify, the capacity of natural systems to recover and provide essential ecosystem services will diminish, making restoration efforts more difficult and expensive. Many of these services, such as pollination and water purification, are irreplaceable without incurring substantial costs for artificial substitutes. Even then, man-made interventions typically address a single issue, whereas NbS offer a more cost-effective approach by delivering multiple co-benefits simultaneously. Prolonged inaction not only erodes natural resilience but also undermines the economic rationale for sustainable land management.

Water quality

Water quality issues, exacerbated by soil erosion, pesticide pressures, and water abstraction, particularly in Northeast Scotland, pose significant risks to access to clean water. Communities and supply chains rely heavily on this vital ecosystem service. The off-site costs associated with sediment and nutrient removal—necessary for water

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[67] Forest Research (2023) Annual Reports and Accounts 2022-2023

[68] Forestry and Land Scotland (2021) Storm Arwen: The aftermath

[69] Edwin Thompson- A Year in Review of Storm Arwen

treatment—are already substantial, amounting to £19 million annually in Scotland due to soil erosion and agricultural leaching[70]. By 2025, this figure is expected to rise to £24 million[71], adjusted for inflation. Agriculture is a major contributor to watercourse sediment, accounting for an estimated 75% of total sediment load in the UK[72]. Specific examples, such as the Ugie and Tweed catchments, highlight the financial burden: the Ugie catchment incurs £338,915 per year in water filtration costs, while the Tweed catchment faces £3 million annually[73]. Without effective action to reduce these pressures, these costs will only increase, straining both the economy and water quality management efforts.

Wildfire

Neglecting to address wildfire risks in upland forestry, particularly in Scotland's moorland regions, incurs escalating ecological and economic costs. Dry heath habitats, prevalent in eastern Scotland's moorlands, are increasingly susceptible to wildfires. While only 1.1% of these moorlands are currently affected by wildfires, climate change is expected to increase both the frequency and intensity of such fires, potentially causing deeper burns through vegetation layers, including soil[74]. This trend threatens biodiversity and disrupts essential ecosystem services. The James Hutton Institute's 2024 publication[75] underscores the growing wildfire risk in these areas, highlighting the need for proactive land management and conservation strategies to mitigate potential ecological and economic losses.

[70] Rickson, R.J., Baggaley, N., Deeks, L.K., Graves, A., Hannam, J., Keay, C and Lilly, A. (2019). Developing a method to estimate the costs of soil erosion in highrisk Scottish catchments. Report to the Scottish Government. Available online from https://www.gov.scot/ISBN/978-1-83960-754-7

[71] Rickson, R.J., Baggaley, N., Deeks, L.K., Graves, A., Hannam, J., Keay, C and Lilly, A. (2019). Developing a method to estimate the costs of soil erosion in highrisk Scottish catchments. Report to the Scottish Government. Available online from https://www.gov.scot/ISBN/978-1-83960-754-7

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[74] James Hutton Institute (2025) Wildfire risk in Scotland

[75] James Hutton Institute (2025) Wildfire risk in Scotland

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