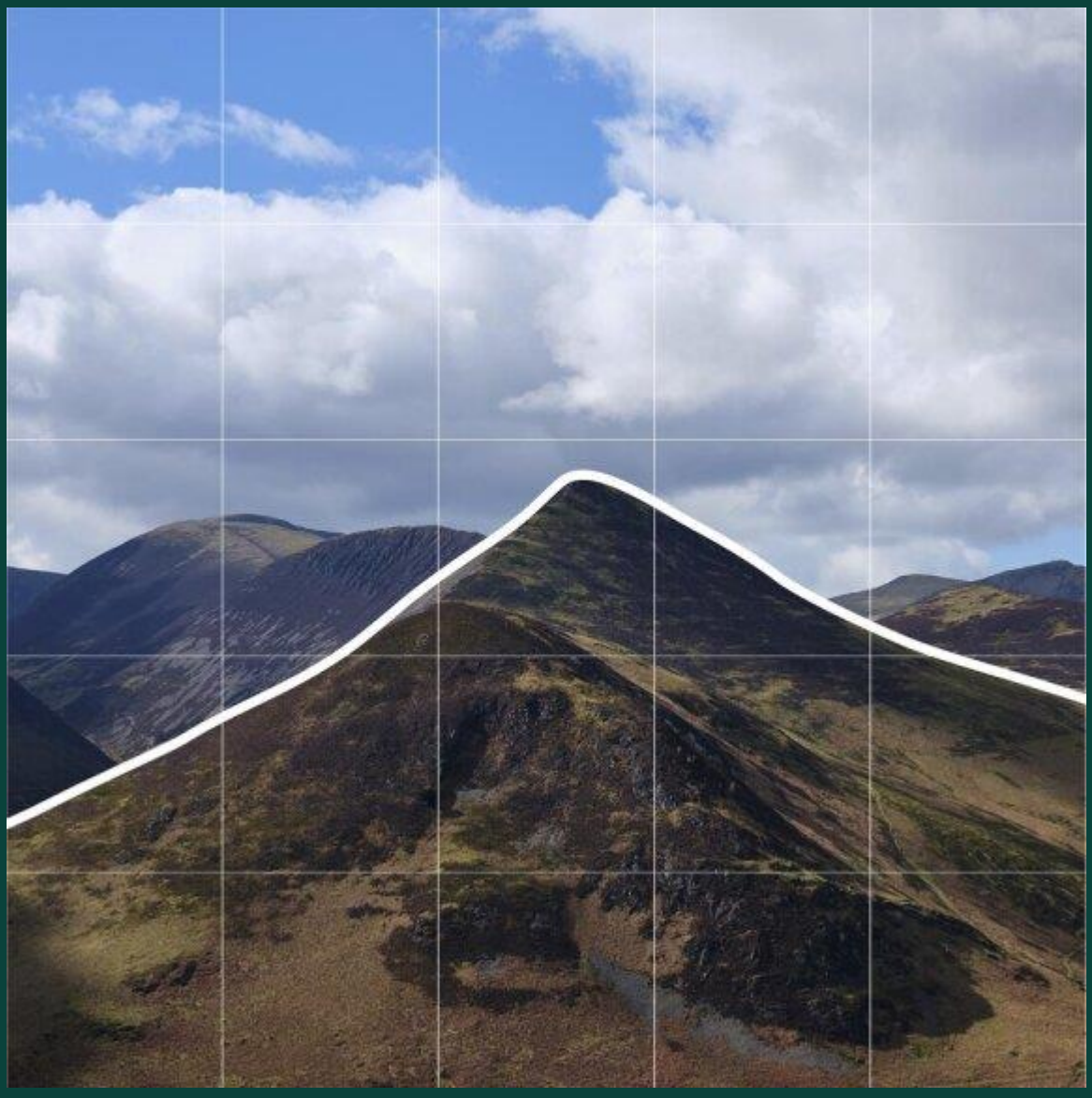
Nature Returns

Interim Report
May 2024



nature returns

Nature Returns is a partnership of government bodies, charities and other organisations working together to build the evidence for nature-based solutions to climate change at the landscape scale. Our science and green finance teams are working with local partners to test what works and what doesn't so we can help policy makers, land managers and investors to make good decisions for people and nature.

Further information

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Executive Summary

Nature Returns is a £17.5 m programme to pilot and test nature-based solutions for climate change at the landscape scale. It aims to build the evidence base on carbon storage and sequestration by species-rich habitats and better understand how green finance can support nature-based solutions. This will enable better decision-making by policymakers, land managers and investors and so contribute to meeting biodiversity and climate change goals.

The Programme is led by Natural England, working with the Environment Agency, Forestry Commission and Royal Botanic Gardens Kew, Wakehurst. It is sponsored by the Department for Environment, Food and Rural Affairs (Defra), Department for Energy Security and Net Zero (DESNZ) and HM Treasury.

Nature Returns is undertaking work in varied landscapes with a mixture of different habitats and land uses. It seeks to understand the practicalities of promoting nature-based solutions in these types of landscapes, which are typical of much of England. The Programme focuses on habitats with the potential to support both biodiversity and climate change mitigation but for which there are substantial evidence gaps. They include species-rich grassland, scrub, hedgerows, semi-natural woodland and wetland mosaics.

Six Local Partnership Projects (LPPs) have been established in contrasting areas across England, with funding for habitat creation and related activities provided to local partners; including non-government organisations (NGOs), a local authority and private landowners. Expertise and support are also provided to these local partners through the Programme. The projects were selected following a competitive application process.

Natural England scientists work at these sites to establish baseline information on carbon and biodiversity and compare different existing habitats. We have also sampled a number of additional areas where habitats have been created at different times in the past.

Environment Agency and Forestry Commission experts have been working with the Local Partnership Projects to understand opportunities and challenges for green finance, providing bespoke training and advice on carbon markets, and developing a process for Strategic Funding and Investment Plans for their catchments and landscapes.

Royal Botanic Gardens Kew’s field site at Wakehurst, Sussex, has been established as a site for research to understand carbon dynamics across the seasons and in different weather conditions and how carbon is exchanged between plants and soils, especially the key role of mycorrhizal fungi. Kew is also developing new

methodologies, testing existing ones and working with partners at Sussex University to develop tools for scaling up site scale findings to a landscape scale.

The current phase of the Programme is due to be completed in March 2025. By the end of March 2024, the following had been achieved:

- Across the six Local Partnership Projects, 628 ha of habitat and 9 km of hedgerow have been created
- Measurements of soil carbon, vegetation composition and, where possible, tree carbon and carbon fluxes (rates of uptake and / or loss) have been made in a range of key habitats at all Local Partnership Projects and five additional area where habitats have been created in the past.
- Carbon and biodiversity data from both aboveground and belowground, as well as fluxes, have been collected across a range of contrasting habitats at Wakehurst (broadleaf, conifer and coppice woodland, meadows and unimproved grasslands)
- A new methodology for estimating carbon in scrub and hedgerows using ground- based LiDAR has been successfully developed and tested
- Strategic funding workshops have been held at three of the Local Partnership Projects
- Reports on Governance of Blended Finance, The Aggregation of Ecosystem Services Suppliers and Carbon Prices in Voluntary Markets have been completed
- An independent Evaluation Report has been published to assess progress and capture lessons learnt to date.

A full report and papers will be published at the end of the Programme, however, emerging lessons learned include:

Partnership in Practice

- Natural England, Environment Agency and Forestry Commissions' advice is trusted and valued by local partnerships but requires good relationships that take time to develop. It is also important that advice is consistent between different bodies
- Extreme weather conditions such as a dry spring or wet autumn can set back the delivery of new habitats.

Carbon and Biodiversity Science

- Old grasslands in general store more carbon than those that are newly created on the same site, however there is large variation, the causes of which we are investigating
- Similar amounts of carbon are found in the top 30cm of soil in a woodland as in the trees themselves

- A small proportion of the largest trees (typically 5-10%) in broadleaf woodlands store more aboveground carbon than all the remaining smaller trees
- Estimates of carbon in woodland trees from basic measurement such as height and diameter vary greatly according to the methods used. These estimates are also different from those based on more detailed Light Detection and Ranging (LiDAR) scanning measurements
- Deoxyribonucleic acid (DNA) analyses show that there are more than 200 fungi forming ectomycorrhizas in the roots of the trees across our woodland habitats.

Landscape Scale Investment

- Developing strategic funding plans requires several conditions to be met, including a clear mandate, leadership, facilitation, trust and resources. It also requires appropriate governance
- Voluntary carbon markets have lower prices than compliance markets and can suffer from low confidence and fears of ‘greenwash.’

The Programme will continue over the next year, continuing to create new areas of habitat, collecting and analysing data and assessing progress with green finance. There will also be an increased focus on sharing the findings as well as the lessons learned from the Programme.

Contents

Introduction

The Context

The crises of biodiversity loss and climate change are fundamentally linked. Climate change increases the threat to biodiversity and ecosystem services, and the loss and degradation of ecosystems is a major contributor of greenhouse gas emissions (IPCC, 2019). Nature-based solutions (NbS) address these problems in joined up ways that provide multiple benefits both biodiversity and people (Dunlop and others, 2024).

Carbon storage and sequestration by natural and semi-natural habitats has attracted a lot of interest in recent years. Restoring natural vegetation cover can lead to an uptake of carbon dioxide from the atmosphere (sequestration) and storage in plants and soil. The best understood example of this is the creation of new woodland by planting trees, but a wide range of other habitats also take up and store carbon. In the UK, forest was the dominant natural land cover which developed after the last ice age and native woodlands are some of our most important conservation sites. Creating new native woodlands and expanding old ones are good ways of producing beneficial outcomes for both biodiversity and climate change.

Presently there are large evidence gaps in our knowledge of some habitats and the long-term trajectory of carbon (Gregg and others, 2021). This limits our capacity to make informed decisions or include many biodiverse habitats in the national greenhouse gas emissions inventory or develop green finance mechanisms to support them. These under studied habitats include scrub, hedgerows and mixed species native woodlands managed for conservation rather than timber. They also include species rich grasslands and wetland mosaic habitats which may have substantial soil carbon but when degrade can emit greenhouse gases.

Many of our most important habitats for conservation, such as species rich grasslands and hedgerows are the result of human and natural processes working together over millennia. It is important to understand the extent to which these habitats can also contribute to climate change mitigation by carbon storage and sequestration. However, this biodiversity is also important in its own right and brings many benefits to people.

There are multiple demands on our limited land area, in addition to supporting climate change mitigation and biodiversity. Developing a practical approach to nature-based solutions requires a good understanding of how habitat creation and restoration can be planned and delivered within complex landscapes. They need to be planned alongside food production and security, timber production, water resource and flood risk management with consideration of environmental, social, and economic benefits.

The deployment of NbS needs to be scaled up to play its part in meeting Net Zero, biodiversity and other objectives, but success is not guaranteed. NbS can be poorly

implemented by attempting to create habitats in places that would not naturally support them, resulting in poor value for money or adverse impacts on other public goods.

Achieving the Government's targets for private investment to support NbS delivery depends on giving confidence to investors, including evidence-based carbon sequestration estimates that are reliable. Understanding interactions between carbon markets and other markets, particularly for water, are also fundamental to encouraging investment. Further assurance for investors can be given by ensuring that governance structures for landscape scale NbS projects are robust and fit for purpose.

Newly planted orchard at Severn Solutions for Nature's Recovery. Photo credit: Hannah Bottrill, Gloucestershire Wildlife Trust

Nature Returns

The Nature Returns Programme started in 2021 in response to these challenges. It is piloting approaches for the implementation of NbS for climate change mitigation. The programme's linked research and development is also building the evidence to support decision making by policy makers, land managers and investors.

Nature Returns is led by Natural England (NE), in partnership with the Environment Agency (EA), Forestry Commission (FC) and Royal Botanic Gardens (RBG) Kew, Wakehurst (Kew, Wakehurst). It is co-sponsored by the Department for Environment, Food and Rural Affairs (Defra) and the Department for Energy Security and Net Zero (DESNZ) and is funded through the HM Treasury's Shared Outcomes Fund and the Defra Net Zero Research and Development budget.

A critical part is played by six Local Partnership Projects (LPPs) who were awarded grants by the Programme to test NbS practically, delivering a wide range of biodiverse habitats across England. NE scientists are also working in partnership with these projects to research how carbon accumulates or is released from different habitats in different circumstances.

The programme is also undertaking research at Wakehurst, Kew's wild botanic garden and living laboratory in Sussex, to better understand the ecological processes that control the carbon balance within and across habitats (in partnership with Royal Holloway, University of London, University of Sussex and Imperial College London).

EA and FC staff are working with the projects and their stakeholders to support their development of sustainable funding plans to deliver landscape-scale land use change and learn how best to blend public and private finance and the governance structures to support this.

The outcome of our work directly contributes to Government priorities, including Net Zero, the Environmental Improvement Plan (EIP), the Green Finance Strategy, Landscape Recovery, Land Use Framework, England Trees Action Plan, Peat Action Plan, the Plan for Water, and the 25 Year Environment Plan.

The Programme is scheduled to run until March 2025 and this Interim Report covers the period from October 2021 to March 2024.

Wye leaky dam at Derwent Living Forest. Photo credit Daniel Blake.

Partnership in Practice

Central to the success of the Nature Returns Programme is a series of landscape scale ‘Local Partnership Projects’ sited across England. These six projects were awarded grants in 2023 following a competitive bidding process, details of which can be found in Appendix 1.

Purpose

The Local Partnership Projects are vital to Nature Returns because they are both delivering nature-based solutions and providing test sites for scientific and practical research. They are improving our understanding of which ‘solutions’ work best in different landscapes and supporting the programme’s objectives in the following ways:

Partnership in Practice: They are working effectively in partnership with us and their local communities to pilot the delivery of nature-based solutions for climate change mitigation at a landscape scale.

Carbon and Biodiversity Science: Collectively, they form a hub of research sites giving our scientific teams access to historic and new habitat interventions to deliver critical carbon and greenhouse gas research.

Landscape Scale Investment: Large scale nature recovery projects are frequently delivered by a group of organisations or ‘landscape partnerships.’ These partnerships typically need to attract private funding to sustain their projects in the long term. Through our Local Partnership Projects we are developing case studies to understand and share best practice for project governance and blended finance. This will enable us to support and increase the implementation of landscape scale projects.

Progress

In just over twelve months, they have jointly delivered 628 ha of habitat and over 9km of hedgerow. A further 240 ha of habitat, 6.5km of hedgerow and 3.8km of watercourse improvements is expected before the end of March 2025. More detailed Progress reports from each of the projects can be found later in this section.

Local teams from Natural England, Forestry Commission and the Environment Agency have worked in partnership with the projects at every stage. Working together, we are experiencing the opportunities and challenges faced in delivering these complex projects. We are learning from this experience to improve the way we collaborate.

Over the last year the Local Partnership Projects have actively engaged with the communities around them by holding a variety of community events, such as guided walks and photography competitions.

They have also recruited hundreds of community volunteers to support them in their restoration work and provided work experience opportunities. They have encouraged under-represented urban communities to access green spaces and worked with us to better understand the multiple benefits of their work by completing a natural capital assessment.

Volunteers scything and raking at Pea Pits Copse, within National Trust's Buscot and Coleshill Estate. Photo credit: Freshwater Habitats Trust

Early Insights

In November 2023 we commissioned a study ('Partnership Working in a Place') to consolidate what we have learned to date and to make recommendations for change. The study will be published shortly but some early insights are:

Successes

- Named contacts within NE, EA and FC, working together and in collaboration with the Local Partnership Projects has enabled more efficient delivery by providing simultaneous and coordinated feedback on proposals.
- When public bodies such as NE, EA and FC work with a shared vision for a project, our advice is more consistent, and delivery is more efficient.
- The advice our Local Area teams give to these (and similar) projects is trusted and valued.

Challenges

- Public bodies do not always provide consistent advice to establish the best intervention in a particular location
- Public bodies do not always value the time their staff need to build relationships with these projects
- Public bodies need to manage staff turnover to provide consistency when dealing with complex, long-term projects
- Habitat delivery plans can be severely impacted by extreme weather events

More information

More information can be found in the Appendix 1. The ‘Partnership Working in a Place’ Report is published on the Nature Returns Access to Evidence page Nature Returns Programme

The Local Partnership Projects

Introduction

Since receiving funding in February 2023, the six Local Partnership Projects have been delivering against their agreed plans. An outline of both successes and challenges follows.

Further background for each project can be found in Appendix 1. Case studies to illustrate what we have learned with each project will be developed and published over the next year.

Project 1 – Wild Exmoor Carbon Sequestration

The National Trust was awarded almost £850,000 to deliver targeted, nature-based solutions across its 670 ha Watersmeet estate, which includes an area of nationally important Atlantic Temperate Rainforest.

The project has a focus on creating a wetter and wilder landscape with more trees and scrub in a mosaic of habitats. As well as increasing carbon sequestration, it is hoped that these interventions will reduce the risk of flooding in nearby villages and towns by reducing water flow rates in the landscape.

Tree planting at the Watersmeet Estate. Photo credit: Celia Jennings

The project has also encouraged these communities to take part in the habitat creation work and be ‘part of the solution.’

To date, the project has:

- Created / restored 80 ha of wood pasture, 4 ha of broadleaved woodland and 8 ha of species-rich grassland
- Held several volunteering events including tree planting and wildlife surveys, with over eighty people attending

Exmoor is a protected landscape which already has several important habitats and supports rare species, as well as well as more degraded areas and working around the need to protect these existing priorities is a key challenge for this local project.

The National Trust have collaborated with the Plymouth project (project 3 below), and in September 2023 hosted a group of young people from Plymouth for a week who had not previously experienced ‘wild’ environments. Activities included wild camping and undertaking habitat management work on the estate – this collaboration has proved beneficial for all involved and is ongoing.

Looking ahead, the project will be creating and restoring over 28 ha of wood pasture and 45 ha of heathland, alongside ongoing community engagement work.

Project 2 – Wansbeck Restoration for Climate Change

Just over £600,000 has been awarded to Groundwork Northeast and Cumbria to deliver this project, which aims to explore how nature-based solutions can thrive in a farmed landscape. The project builds on priorities identified during the Local Nature Recovery Strategy Pilot led by Northumberland County Council, with Natural England providing support, which took place in Northumberland in 2020-21.

The project is working across ten sites with multiple ownership to restore over 144 ha of mixed habitats including grasslands, wetlands and woodlands. They also plan to build on their experience to encourage neighbouring landowners to implement similar schemes and build the overall impact of the interventions, including with specific case studies.

Harwood Burn leaky dam. Photo credit: Groundwork North East and Cumbria

To date they have:

- Created and restored 17 ha of species rich grassland
- Restored 8 ha of blanket bog
- Created and restored over 19 ha of floodplain wetlands
- Improved 55 ha of wetland mosaic habitats
- Restored over 6.5 km of hedgerows
- Created a video to support their work with landowners
- Held an indoor and outdoor photo exhibition which over 900 people attended.

Looking ahead, they will continue to work with the National Trust and their tenant farms to restore or create the following five habitats:

- Over 4 km of new hedgerows
- Over 3 km of river restoration
- 22 ha of floodplain wetland habitat
- 98 ha of lowland wet heath
- Over 7 ha of peatland restoration

Project 3 – Plymouth’s Natural Grid

Plymouth City Council was awarded nearly £1m. The project is a collaboration between Plymouth City Council and the National Trust with a focus on creating nature-based solutions in and around an urban environment. They are creating a wide range of habitats, from wood pasture to floodplain mosaic at several sites across the city.

They have extensive experience of community engagement and have worked over the last year with a variety of community groups to complete the restoration work and inspire more people to become involved. They are seeing a positive impact on mental and physical health among their volunteers, which are some of the wider benefits of nature-based solutions. They have also implemented a digital badge scheme, which young volunteers can earn through their ongoing volunteering and learning about conservation.

Over the last year, they have:

- Created or restored 6.67 ha of wood pasture
- Created 1.47 ha of semi-natural grassland
- Created 29.69 ha of broadleaved woodland
- Created 6.74 ha of floodplain mosaic habitat
- Created 0.17 ha of fen
- Planted or restored 1.7 km of hedgerows
- Held nearly 200 hours of public engagement activities
- Released a film about their experiences as part of a campaign to recruit more volunteers and promote nature-based solutions.

Planting trees for South Devon Community Forest, Plymouth’s Natural Grid. Photo credit: Chris Parkes

They are currently surveying the new areas of habitat to evaluate how effective their work has been. Early signs are that solutions like leaky dams have already led to a 23% reduction in peak flow rate in Bircham Valley Local Nature Reserve (LNR), an extension project site.

Looking ahead they will be:

- Restoring over 7.00 ha of semi-natural grassland
- Restoring over 2.00 ha of floodplain wetlands
- Restoring and / or planting over 1.8 km of hedgerow

Project 4 – Derwent Living Forest

Derbyshire Wildlife Trust has been awarded over £560,000 for its Derwent Living Forest project (formerly the Derwent Forest project). The project stretches along the entire Derwent catchment from the edge of Derby into the Peak District.

Tree planting at the Derwent Living Forest project. Photo credit: George Jones

This project focuses on natural processes to create a broad range of habitats and deliver valuable ecosystem services. Also important is the project's work to develop an economically viable programme to support landowners to create and expand nature-based solutions.

Over the last year they have:

- Undertaken site preparation work, such as fencing and planting, to allow natural regeneration of over 200 ha of a variety of habitats and restored 600 m of hedgerow
- Produced guidance for landowners on natural flood management interventions and woodland planning/creation
- Scoped and delivered a number of natural flood management projects.
- Completed a willow tit study to support introductions and habitat improvement in the area
- Started a 3 year beaver feasibility and consultation study based on the findings from this project and overseen by the BFAI (Beaver Feasibility Assessment Initiative).

Looking ahead, they will be:

- Developing a sustainable roadmap for species recovery and reintroduction
- Delivering 44.12 ha of nature-based solutions across three sites.

Project 5 – The Oxfordshire and Buckinghamshire Freshwater Network

This project, run by the Freshwater Habitats Trust, was awarded over £780,000 to work in wetland and floodplain areas across Buckinghamshire and Oxfordshire with activities taking place at six different sites.

The project has a focus on wetlands. It is exploring the role the restoration of smaller wetlands, floodplains, grasslands, and waters plays in carbon capture and biodiversity. Freshwater habitats are vulnerable to biodiversity loss from a wide range of factors, including changes in land management and alterations in hydrology both off and on site.

The charity is also experienced in working with community groups to increase awareness of the benefits of regeneration and habitat creation. We are learning from their experience and sharing ideas for community engagement across the six projects.

Over the last year, the project has created or restored:

- 6.90 ha of species rich grassland
- 9.05 ha of floodplain wetlands
- 8.30 ha of fen.

They are also running a successful volunteer campaign ‘GroWet’ which harvested seeds and recruited volunteers to grow rare species of wetland plants at home for reintroduction as part of habitat restoration. Volunteer training days on scything and fen management have also been held.

GroWet volunteers with Community Engagement Officer Lizzie Every at a planting event. Photo credit: Freshwater Habitats Trust

This project has experienced challenges from which we are all learning. They do not directly own sites where works have taken place. This means they have been reliant upon third parties to consent to the planned work. Changing priorities for landowners during the year has led to challenges securing agreement, which has reduced the planned habitat delivery.

Exceptionally wet weather during the autumn of 2023 impacted the completion of floodplain works and the amount of habitat delivered because machinery could not access the floodplain sites. As a result we have learned the importance of scheduling works to mitigate for potential extreme weather events.

Looking ahead, they will be restoring:

- 2 ha of fen
- 1.5 ha of floodplain wetland
- 8 ha of floodplain grassland

Project 6 – Severn Solutions for Nature's Recovery

Gloucestershire Wildlife Trust has been awarded nearly £500,000 to work with the Hasfield Court Estate to restore a 500 ha estate in the Severn Vale. The site was chosen because it will deliver biodiversity improvements, enhance connectivity between existing pockets of priority habitat and restore historic landscapes including traditional orchards.

The project also directly borders the proposed Eelscapes Landscape Recovery Project in the Severn Vale, and opportunities for collecting and sharing carbon data across both projects have been identified.

To date they have:

- Planted 6.88 ha of traditional orchards around the estate to enhance biodiversity, and recreate a landscape characteristic of the area
- Established 14.14 ha of species rich grassland, aiming to increase connectivity between existing pockets
- Created 23.4 ha of wood pasture to encourage a continuous open woodland habitat across the landscape

The benefit of these actions is to create and link habitats for important pollinator species, nesting opportunities for farmland birds and foraging habitat for bat species.

Wood pasture habitat creation. Photo credit: Hannah Bottrill, Gloucestershire Wildlife Trust

They have experienced numerous challenges with extreme weather patterns resulting in additional actions such as an intensive watering regime of the newly planted trees across the orchards and wood pasture areas to ensure their survival.

Looking ahead, they will be:

- Planting a further 1.27 ha of wood pasture
- Creating 0.6 ha of scrub
- Seeding a further 4.09 ha of species rich grassland
- Restoring approximately 1.5 km of hedgerows across the estate

Carbon and Biodiversity Science

Introduction

Nature-based solutions offer real potential to contribute to both climate change mitigation and nature recovery. However, that does not mean that all habitat creation will automatically increase carbon uptake or decrease greenhouse gas emissions. Neither does it mean that biodiversity will necessarily be high in high carbon habitats.

There are large evidence gaps for many habitats, particularly over the long timescales needed to understand carbon and biodiversity in ecosystems and there are increasingly well documented examples of poor NbS outcomes in many parts of the world (Parmesan and others, 2022).

Nature Returns is seeking to improve the evidence base to enable better decision-making by government, local communities, land managers and investors. Natural England and Kew Wakehurst are jointly leading the carbon and biodiversity science work.

Natural England's science team is comparing carbon stored in different habitats and locations, measuring rates of carbon uptake and release and how it changes over time following habitat creation. They are also recording the species composition and structure of vegetation as a key element of biodiversity. Natural England is establishing carbon and biodiversity baselines before and after landscape changes at the Local Partnership Project sites, which will allow us to track how these habitats develop in future.

Kew Wakehurst is focusing on developing detailed methodologies to test existing assumptions and algorithms for estimating carbon. They are simultaneously integrating different data from Kew Wakehurst to comprehensively understand carbon dynamics across the seasons and in different weather conditions on multiple habitats without landscape interventions. They are also integrating this detailed research on how carbon is exchanged between plants and soils and the key role of mycorrhizal fungi in this.

The teams from Natural England and Kew Wakehurst have complementary work programmes with methodologies aligned where possible. Their overarching aims are as follows:

- To provide better estimates of carbon storage and sequestration in different habitats, particularly those which have been under-studied in the past. This will enable us to determine which habitats store most carbon both above and below ground. Habitats under study are primarily:
    - semi-natural woodlands
    - species rich grasslands
    - scrub
    - hedgerows
    - wetland mosaic habitats

- To establish a carbon and biodiversity baseline for future research and monitoring: This will allow us to test how quickly carbon increases in newly created habitats and how these changes over time.

- To understand the processes that control carbon storage and sequestration and their relationship to biodiversity in different habitats: understanding processes will enable policy makers and land managers to make better decisions to benefit both biodiversity and climate change mitigation.

- To develop and implement better methods for estimating carbon particularly in understudied habitats and systems: Test new methodologies to practically estimate carbon in scrub and hedgerows using (LiDAR) techniques. Test how much carbon is stored in woodlands, scrub, hedgerows, and grasslands both above and belowground. Developed new methods to measure and understand the contribution of mycorrhizal fungi to carbon storage/sequestration in different habitats.

- To investigate the co-benefits and trade-offs of NbS: to test the relationship between biodiversity and carbon in different habitats.

Progress to Date: Comparative measurements of carbon and biodiversity across habitats and sites

Introduction

Field data collection by the Natural England team began in summer 2022, alongside extensive field methodological development. Between summer 2022 and the present, we have collected over 1200 soil samples, conducted approximately five hundred vegetation surveys and measured greenhouse gas fluxes approximately 1100 times.

Our research has spanned all six Local Partnership Projects across England. We have also used an additional five ‘chronosequence’ sites where habitat creation has taken place in the past (Figure 1). These chronosequence sites give the opportunity to assess the rates at which carbon builds up in habitats and how biodiversity changes over the same time intervals.

Figure 1. Location of Local Partnership Projects (numbered blue circles) and chronosequence sites (orange circles) sites across England. The sites are as follows: 1 = Wild Exmoor Carbon Sequestration, 2 = Wansbeck Restoration for Climate Change, 3 = Plymouth’s Natural Grid, 4 = Derwent Living Forest, 5 = The Oxfordshire and Buckinghamshire Freshwater Network, 6 = Severn Solutions for Nature’s Recovery. a) = Cumbria, b) = Lincolnshire, c) = Wessex, d) = Oxfordshire, e) = East Kent

We are collecting data from randomly allocated plots within different sites (such as fields) at each location. The same basic approach to data collection is used to provide a baseline for measuring future change, compare different habitats and assess differences between habitats of different age. The main data we are collecting are as follows. Not all measurements are carried out in all locations and additional contextual information (such as soil pH and description) are also being collected:

- Species composition and structure of vegetation
- Soil carbon at 0-15 and 15-30 cm depth
- Carbon in trees, estimated using measurements of tree height and diameter of stems
- Flux (emission or uptake) of carbon dioxide and methane from vegetation canopies and soils
- Carbon in hedgerows and scrub using LiDAR method developed with Kew

To ensure comparability across the different habitats, we carried out an extensive survey design process, aligning our approach both between habitats and with other landscale scale work. Our approach is published in a field methodology guide (Elias and others, 2024). Further information can also be found in Appendix 2.

Field data collection methods for carbon science. Top left, clockwise: Species composition and structure of vegetation, soil carbon at 0-15 and 15-30 cm depth, carbon in trees, estimated using measurements of tree height and diameter of stems, carbon dioxide and methane flux from vegetation canopies and soils and carbon in hedgerows and scrub using LiDAR method developed with Kew. Photo credit from top left clockwise: Tamsin Lockwood, Celia Jennings, Tamsin Lockwood, Celia Jennings, Becky Davess

Early Insights

Up to now, the priorities have been to develop methodologies, conduct field work and laboratory analysis. Data analysis is underway, and this section presents a first look at of some of the headline findings, particularly from the chronosequence sites, which were measured at an earlier stage in the project.

The results presented here should not be taken as final or used for making decisions. Further statistical analysis is on-going, and more results will become available over the coming year. The results will be written up fully in a final report and for publication in peer-reviewed scientific journals.

- **Grassland soil carbon tends to be higher in older grasslands than more recent ones, but with considerable variation.** Across all chronosequence sites, increases in carbon stocks in the 0-15cm and 15-30cm depths can be seen with increasing age (Figure 2). The rates of increase are highly variable, ranging from roughly a 25% increase in carbon stock to a 0.5% increase. Further statistical analyses will investigate the nature of this increase in carbon stock, and assess which factors cause the variability between and within sites.

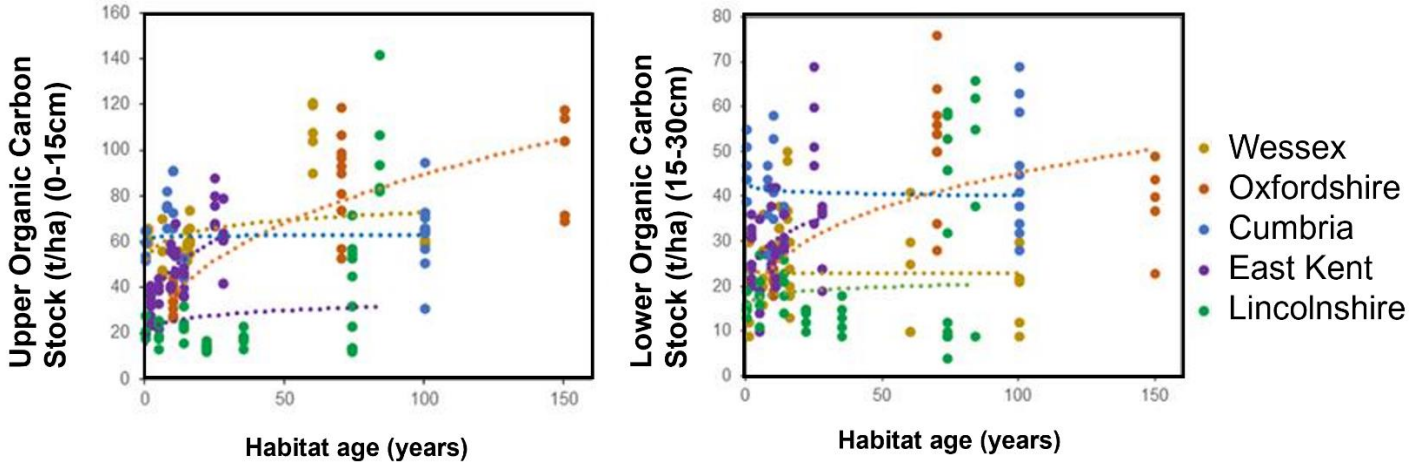

Figure 2. Relationship between soil carbon and age of grassland at (a) 0-15 cm depth and (b) 15-30 cm depth

- **Species composition of grasslands develops with age.** Our chronosequence sites show a pattern seen in earlier studies with the early stages of grassland with more weedy (‘ruderal’) species found in young grasslands where as older grasslands have a higher proportion of ‘stress tolerant’ species, which are often those most important for conservation (Figure 3).

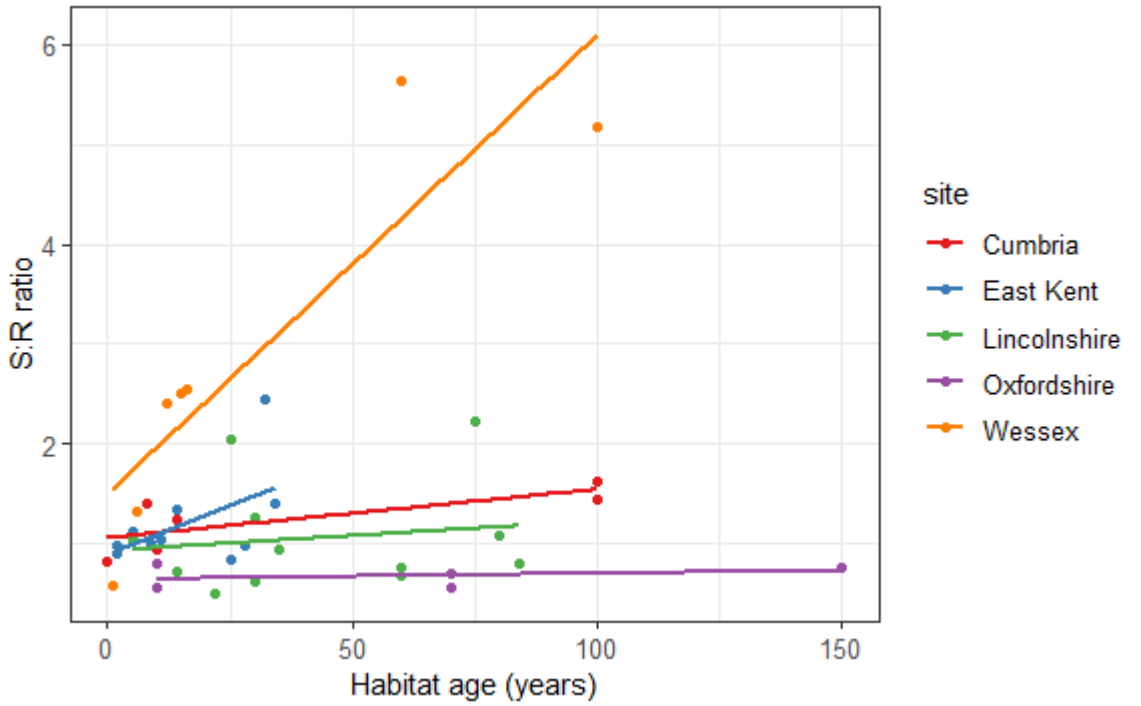

Figure 3. Changes in the ratio of stress tolerant: ruderal species (S:R) at different sites in grasslands of different ages

- **There can be similar amounts of carbon in the soil and the trees in woodland**. Much of this soil carbon is in the top 15 cm (Figure 4).

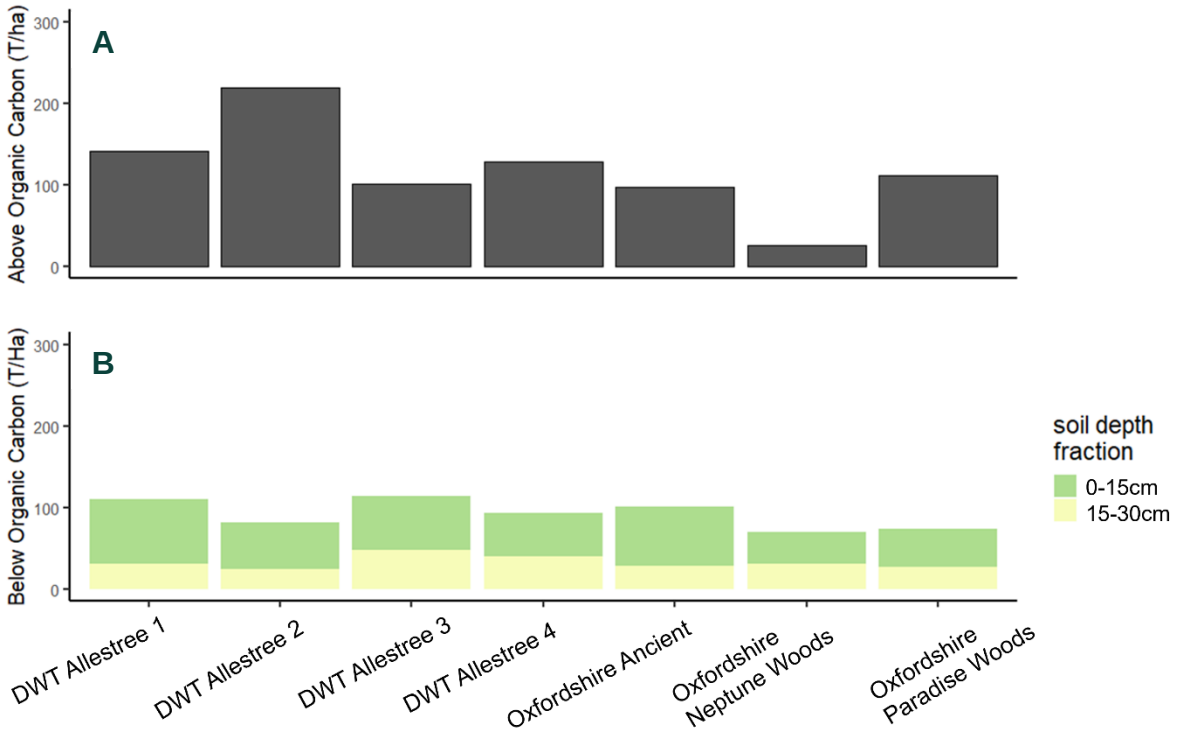

Figure 4. Total organic stock carbon in tonnes per hectare in A) trees and B) soil at a range of different woodland locations at the Derwent Living Forest Site – Derbyshire Wildlife Trust (DWT) site and the Oxfordshire chronosequence site

Progress to Date: Carbon processes and upscaling

Introduction

Over the past three years, scientists at Kew Wakehurst have amassed a wealth of carbon and biodiversity data. This data has been meticulously gathered from aboveground and belowground, as well as fluxes, within our targeted habitats at Wakehurst (broadleaf, conifer and coppice woodland, meadows and un-improved grasslands) and elsewhere in the wider South-East of England.

This comprehensive effort aims to unravel the intricate processes of carbon capture, storage, and release, while also delving into the temporal and spatial dynamics of carbon fluctuations, in conjunction with biodiversity variations, both across and within habitats.

We have developed methods to calculate carbon as we move through different scales (i.e., individual tree to habitats to landscapes), for above and belowground carbon. We test existing allometric algorithms for estimating carbon and biomass in trees (Jenkins and others, 2018; Gonzalez-Akre and others, 2022; and Réjou-Méchain and others, 2017) compared to our more detailed and accurate measurements (Disney and others 2018).

We are extrapolating carbon estimates to the wider landscapes, and with data collected at different scales to gain an understanding of the natural variation and precision. We are mapping the correlations between carbon levels and various recorded variables (such as land use, tree height, soil texture, pH), which will be integrated into our landscape modelling tool.

Fieldwork and data collection methods. Top left, clockwise: terrestrial LiDAR scanning of coppice woodland, soil sampling in meadows, root selection and DNA analysis in the laboratory, drone surveys, and gas flux stations in meadows. Photo credit RBG Kew

Our partners at the University of Sussex are developing a landscape modelling tool, which will build on the data collected, integrating ecological, social, and economic data to visualize and analyse the benefits and trade-offs of different NbS. This tool will provide policy makers and land managers with a visual understanding of how carbon functions in the landscape, helping decision making regarding investment in natural carbon and biodiversity within landscapes.

The integration of these objectives facilitates the assessment of carbon and biodiversity metrics and provides novel insights to how carbon functions in multiple UK habitats.

A comprehensive aboveground baseline has been produced using high-resolution drone and LiDAR technologies, supplemented by destructive biomass measurements when possible. Field collection data is collected with high locational accuracy, into electronic field data forms.

Each of the Wakehurst habitats have been fitted with a network of four semi-permanent, solar-powered CO_2 gas flux stations, recording net ecosystem exchange (NEE), and soil respiration (SR) to capture data at least every 60 minutes. Additionally, we use a portable unit to target whole ecosystems and to complement and calibrated against the continuous sampling, allowing the capture of variability in gas fluxes over space and time. The soil samples taken during these surveys form the basis of our below ground assessment of biodiversity and carbon for Mycorrhizas and plant roots.

As well as working at Wakehurst, we also gathered hedgerow and scrub data with destructive samples from multiple sites in southeastern England. Initially they were scanned with handheld LiDAR units and weighed wet and dry to calculate biomass. Soil samples from Wakehurst were also analysed, consistent with detailed belowground surveys.

We are now in the early stages of data analysis, the insights below are from preliminary analysis of our data and should not be taken as final or used for making decisions. Further analysis is ongoing, and the results will be written up fully in a final report and for publication in peer-reviewed scientific journals. Additional background can be found in Appendix 3.

Early insights

- **Giant sequoias are a rapidly growing feature of the UK landscape and capture large amounts of carbon during their long lives.** This is a spinout from our LiDAR research with University College London (UCL). Recently published detailed study shows that imported giant sequoia trees are well adapted to the UK, growing at rates close to their native ranges and capturing large amounts of carbon during their long lives (Holland and others, 2024)

- **Our hedgerow and scrub biomass method development suggests that terrestrial LiDAR scanning (TLS) could improve carbon storage estimation**. Through comparing destructive samples taken at Wakehurst and across the SE

of England, handheld TLS methods using voxels (3d pixels) estimations were more accurate than height-based only biomass estimation.

- **A small number of older trees play a greater role in carbon sequestration than a larger number of younger trees.** A small proportion of the largest trees (typically 5-10%) in broadleaf woodland habitats store more aboveground carbon than all the remaining smaller trees. This agrees with a recent study at Wytham Woods, Oxford (Calders and others, 2022). Additionally, conifer woodlands exhibit lower biodiversity (both above and belowground) than native mixtures, potentially reducing resilience to climate change.

- **There are widely varying results between LiDAR scanning methods and allometric methods for estimating carbon aboveground.** Comparing aboveground carbon at the tree level (a highly accurate method using terrestrial LiDAR scanning; Figure 5) to allometric estimates shows widely varying estimates across species and habitats. This will have important implications for natural carbon accounting, but calculating localised allometric equations can greatly reduce this variance (Vorster and others, 2020 and Holland and others, 2024).

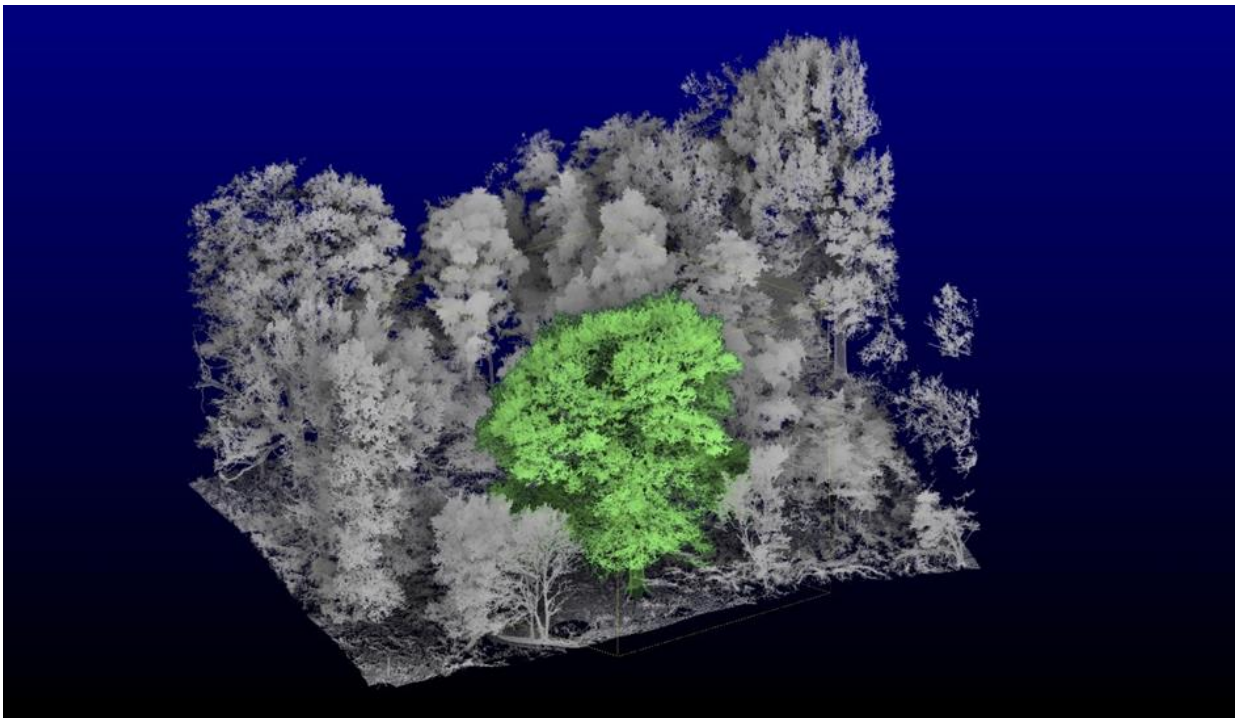

Figure 5. LiDAR scan of broadleaf woodland plot, tree highlighted in green is segmented for further analysis

- **Continuous gas flux monitoring helps create a baseline for carbon when combined with above and belowground methods.** We have collected two years of gas flux measurements across our four focal ecosystems to build a high-resolution baseline of the timing and magnitude of greenhouse gas release and uptake (Figure 6). By combining these data with soil biogeochemistry, above- and below-ground productivity, biodiversity, and climatic variables we will

bring together spatially explicit gas flux data with the drivers of change to understand the mechanisms for carbon uptake and release.

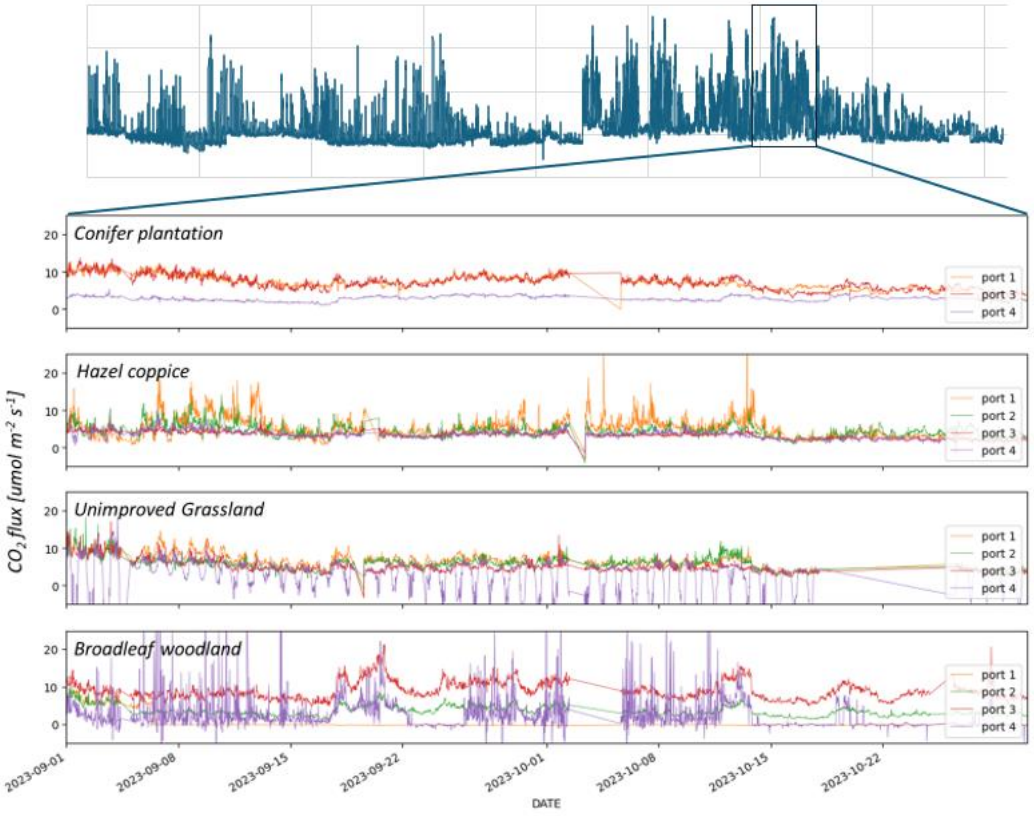

Figure 6. Temporal flux CO_2 data showing the gas exchange from soils to the atmosphere. Top; over two years of continue monitoring (meadows), bottom; detail of gas exchange for two months across four habitat

- **Belowground carbon stock is comparable in different habitats at Wakehurst, despite wildly varying ecosystem composition.** Preliminary results of belowground data at Wakehurst show that the difference in carbon stock at 0-15cm and 15-30cm is similar across woodland and meadow (Figure 7).

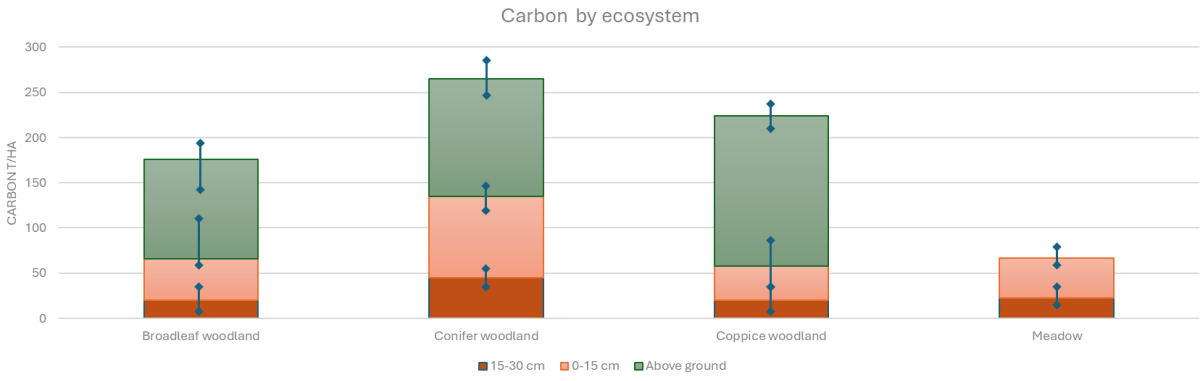

Figure 7. Carbon stock by habitat at Wakehurst, aboveground (green) and belowground (dark and light orange)

- DNA analyses show that there are more than 200 fungi forming ectomycorrhizas in the roots of the trees across our woodland habitats. Preliminary analysis of a large subset of DNA sequences obtained from roots shows more than 200 fungi (basidiomycetes and ascomycetes; Figure 8) forming ectomycorrhizas across the four woodland habitats. The two broadleaf woodlands (broadleaf and hazel coppice habitat) harbour more ectomycorrhizal fungi than the two conifer woodlands. Further links between taxonomic and functional diversity of mycorrhizal fungi and above and belowground factors including carbon stocks will be explored.

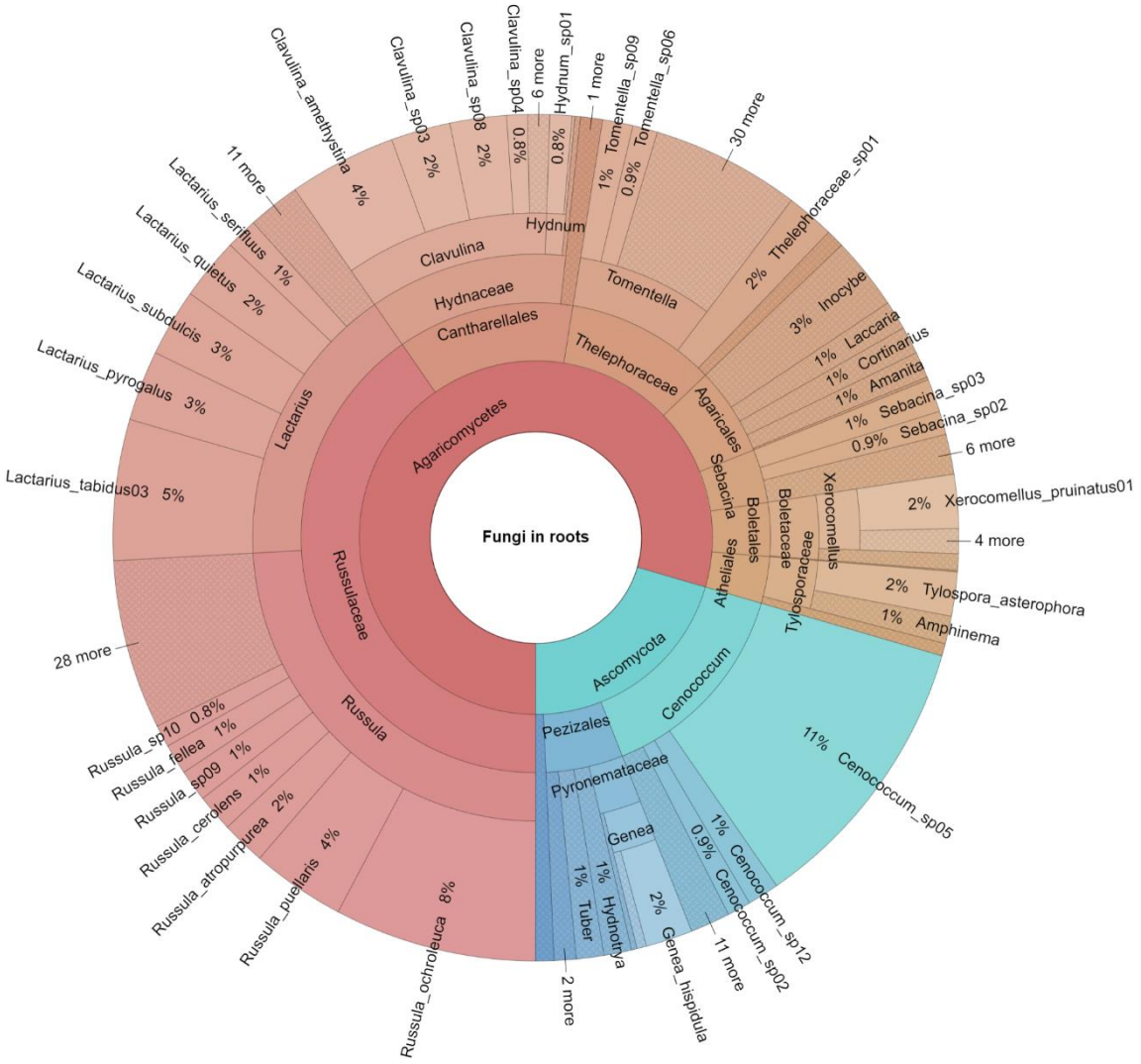

Figure 8. Chart showing ectomycorrhizal taxa identified using DNA across habitats at Wakehurst. It displays the percentage of root tips colonised by each fungus at the species level (at the outer edge of the chart, %) but also at genus, family, order, and phylum levels moving towards the centre of the chart. What stands out is not only the vast number of species (approximately 200) but also the significant proportion that cannot be assigned a species name and therefore are potentially new to science or still undescribed.

- **Decision making tools need to articulate uncertainty.** In the initial stages of developing the Landscape modelling tool, it became evident that addressing and visualising uncertainties in carbon modelling across the landscape was needed for informed decision-making. We are adapting methods from IPCC reports and mapping to this end.

Landscape scale Investment

Introduction

Over the last year, Nature Returns has been exploring the required steps for bringing landscape scale nature-based solutions projects to an implementation-ready stage, and how to ensure their long-term success through future funding and extended financing.

This section describes how the Programme is working with external partners to better understand the requirements and enablers for collaboration between multiple landowners and delivery partners, as well as how to blend public and private finance to make these complex projects viable in the long term.

Purpose of this work

Collaboration and Governance

Delivering nature-based solutions at a landscape scale across land that is owned and managed by multiple parties presents numerous challenges. Developing appropriate legal and governance structures to bring these parties together in a project is not new but there are limited examples of it in practice, such as the Community Forests.

Nature Returns is seeking to better understand these challenges and identify opportunities for bringing people together to effect positive change in our landscapes; with the goal of seeing more partnerships between NGOs, landowners, land managers and local government, as well as securing buy-in from the community and private finance.

Securing in private finance

Landscape-scale change cannot be delivered without long-term funding. To date, government funding has supplied much of the financial resource for the delivery of environmental benefits. New mechanisms, such as nature markets, are emerging to enable the private sector to get involved but are still in the early stages of development.

We know that leveraging private finance for the environment, or ‘green finance,’ will be key to delivering environmental outcomes in the future. The Government’s ambition is to bring £500m of private investment into nature every year by 2027, increasing to £1bn per year by 2030 (Nature Markets, 2023), but there is limited understanding of how this can best be achieved, or measured.

A landscape-scale approach to NbS means coordinating planned actions across different landowners, local communities, and stakeholders. It requires technical and scientific input in both policy development and implementation.

Through Nature Returns, we are supporting our Local Partnership Projects to think strategically about the nature-based solutions needed to solve the environmental problems their specific landscapes face, and to use this information to develop strategic funding plans to leverage private investment.

Nature Markets

Nature markets provide a mechanism for generating revenue streams from nature-based solutions. However, these markets alone will not deliver the scale of land use change needed without collaborative action.

The early development stage of these markets also means that higher levels of engagement and support are needed to help them function and there is no clear, overarching process for an eNGO (Environmental Non-governmental Organisation) or other partnership to enter a nature market at the current time.

Government departments and public bodies have a role to play in helping develop this market (Young and others, 2022; UK Government, 2023): co-creating and enabling place-based investable projects, facilitating the coordination of public funding, providing regulation, as well as testing and evaluating these ideas to monitor the benefits that they provide.

Our Approach

Through Nature Returns, we are exploring cross-government department approaches to using blended funding to achieve the environmental outcomes we need, including commissioning research to support development of these approaches. We are also working with three of our Local Partnership Projects to develop strategic funding plans for delivering place-based environmental action. Through working with our partnership projects, we will develop a replicable process for others to follow.

Working across government

Collaboration across government bodies is critical to delivering the objectives of Nature Returns. Over the last year, we have worked in partnership with other Defra programmes developing green finance approaches, such as the Natural Environment Investment Readiness Fund (NEIRF), Landscape Recovery, and Local Investment in Natural Capital (LINC) to share experience, knowledge and understanding.

We are also working closely with other colleagues across government and public bodies to ensure there is no duplication of effort and share our experiences, specifically with Nature Markets, Nature Recovery, Land Use Framework, and the Plan for Water.

Over the next year, we will continue to work with these programmes and develop case studies to support the expansion of nature-based solutions.

Developing strategic funding plans

Landscape and catchment partners are already working together with our Local Partnership Projects and others across the country to develop projects to deliver habitat restoration. This collaboration between partners is vital both to achieve the scale of change needed and to attract the necessary investment to support landscape scale restoration over many years.

The development of strategic funding plans for the environment, which we are developing through Nature Returns, will drive collaborative decision making about the nature-based solutions needed, and minimise the siloed nature of funding bids by focusing on multiple benefits.

The EA, together with external consultants, have facilitated workshops with three of our Local Partnership Projects to support them in the development of these strategic funding plans These workshops are being followed by direct support from green finance specialists within EA, and will continue through the final year of the project.

A board from a facilitated workshop with one of the Local Partnership Projects. Photo credit: Eunomia Research & Consulting Ltd

As well as providing practical support to the Projects, we are gaining a first-hand understanding of how public and private funding can work together in practice, and at a landscape scale, and the role collaboration between our Defra, its ALBs and external stakeholders plays in driving investment.

In developing strategic funding plans, our Projects are thinking through the:

- Vision they are collectively trying to achieve
- Actions needed to achieve this vision
- Resources needed to fund and deliver the actions

- Other partners needed to make this a success
- Timescales for delivery.

We believe this approach will give the Projects greater bargaining power with potential investors and lower transaction costs.

Ultimately, however, success relies on a partner to ‘take the lead’ as a convenor to bring partners together and drive the process forward. These collaborations may eventually be formalised by a governance structure, such as a community investment company, however our previous research shows that these develop at a later stage, once the programme is better developed, as ‘form follows function.’

Independent Research

The Environment Agency and the Forestry Commission are working with external specialists to carry out independent research projects looking beyond our Local Partnership Projects. Our objective is to further develop our understanding of the following aspects of green finance and nature markets:

- Governance structures to support landscape-scale action and investment
- Benefits and needs of effective place-based collaboration
- Investor and buyer motivations in nature markets
- Carbon prices in voluntary markets
- Land use decision making tools.

Knowledge sharing

Through regular contact with the Local Partnership Projects, we are exchanging knowledge and learnings from across the Programme on collaborative working (e.g. governance structures, aggregation mechanisms) and green finance.

We are supporting them to increase opportunities to secure private funding in their projects by identifying knowledge and capacity gaps. We are then offering training and support to fill these gaps.

The programme has hosted regular virtual and in-person events to bring representatives from the six projects together, providing opportunities for them to share their experience with each other and to hear more about the wider findings from Nature Returns and beyond.

Early insights

Developing Strategic Funding Plans

Over the last two months, we held individual workshops with three of our Local Partnership Projects. These workshops were intended to kickstart proactive thinking

about how best the catchment or landscape partnerships can work together to plan, deliver and fund the environmental interventions needed to build climate and nature resilience.

More workshops will be held in the upcoming year, and ultimately, we will develop a process for creating strategic funding plans that can be used by others.

Findings from these workshops include:

- **A clear mandate for landscape-scale nature-based solutions is needed.** While most participants recognised the need, planning strategically across the catchment or landscape was not foremost in people's minds.
- **People are ready for the challenge.** Despite the ambitious workshop objectives, participants were excited about the prospect of transforming their landscapes. They also welcomed the opportunity to have space and time to think strategically about what their area needs.
- **Not all organisations want to lead.** Development of strategic funding plans requires an organisation to take on the convening role (referred to as the convenor) - bringing other partners together and driving development of the collaborative approach. While many of the participants were keen and support the ambition, most were pleased that someone else is stepping into the leadership role of driving the collaboration forward. More understanding of these motivations is needed.
- **Facilitation to fill gaps in experience and draw together people's objectives is critical.** In each workshop, participants were thankful for the facilitation provided, and the effort made to bring people together. Comments were made regarding the benefits of facilitation for these discussions (providing headspace, having a neutral party in the room), and the need for resource to support facilitation. This facilitation role is likely different to the convening role (or bringing partners together) but must work together with the convening partner.
- **Trust needs to be built.** Planning for delivery of landscape scale nature-based solutions, supported by strategic funding plans needs to be tailored to the partnership. Trust between the partners is critical, especially in the early stages of collaboration when organisational motives may differ, and ways or working not captured in legal agreements.
- **Resource is needed** to provide the facilitation and time for strategic planning to support the convening organisation, and to support the change from competition for grant funding, to collaboration and blended funding. Funding for the strategic planning element is not readily available, and most eNGOs do not have the available resources to cover these costs without additional funding.

Collaboration and Governance for Action at Scale

Nature Returns has assessed and gathered examples of good governance for planning and delivery of landscape scale nature-based solutions, such as Water Resources East (Water Resources East, 2023) and Natural Course (Natural Course - Our Water. Our future), and the mechanisms that drive their development.

These governance structures can help support collaborative working by provide a legal framework to work withing. Learning from these examples and research we have commissioned (Eunomia, 2022; Eunomia 2023a; Eunomia 2023b) shows that:

- **Integrated land and water governance promotes a more holistic and strategic approach to managing the environment,** which can improve delivery of policies, such as the Environmental Improvement Plan.

- **Appropriate governance to support joint investment and action amongst partners is required** for place-based, integrated approaches to be effective.

- **Appropriate governance is key to convening partnerships and balancing risks**, ensuring a fair distribution of responsibility and benefit.

- **Successful finance schemes develop with collaboration and partnership working**, as part of a place-based approach, based on examples and evidence outside the Nature Returns programme (such as Water Resources East, Natural Course).

- **Eight key ingredients underpin integrated environmental management:** leadership; decision-making structures; sufficient and connected resources; ownership and buy-in from organisations with the power to change; broad and diverse stakeholder engagement; a collaborative mindset; working at meaningful scale; and testing, learning and evaluation.

- **Form follows function** when it comes to decision making about appropriate legal structures to support collaboration and partnership. Often, a structure is chosen only once an organisation has determined the function or key strategy of their project, and this function influences the funding sources.

- **Multiple examples of aggregating ecosystem service suppliers are in practice,** with a range of risks and benefits depending on the desired outcomes. There is not one example that is appropriate in all situations. Those interested in aggregating ecosystem service suppliers should consider the scale, risks and benefits of the various models previously used to determine whether these examples provide a replicable model for their situation.

Investor and Buyer Motivations in Nature Markets

A significant hurdle to bringing greater amounts of private finance into nature recovery is establishing the demand from the private sector. Our research (North Star Transition, 2023) into institutional investor motivations shows that:

- Institutional investors are interested in high quality, well-structured projects that balance the risks and benefits of investors, buyers and suppliers and share benefits with local communities.

Carbon Prices in Voluntary Markets

Despite launching in 2011 and 2015 respectively, prices paid for carbon units from the Woodland Carbon Code and Peatland Code have never been published, as they are traded through private arrangements.

Nature Returns has funded stakeholder engagement that encouraged market participants to anonymously disclose pricing data to an online hub, providing the UK voluntary carbon market (VCM) with a pricing benchmark for the first time. Our research has shown that:

- **Compliance markets drive higher prices than voluntary markets for carbon units.** Our research shows that average prices paid for units from the Woodland Carbon Code have increased from £14.93 in 2021, £19.13 in 2022, and £25.36 in 2023, an increase of approximately one-third year-on-year. In contrast, carbon credits sold in the UK Emissions Trading Scheme (UK ETS) – a compliance market – are sold for around three times the price of units sold in the voluntary market, at £83.03 per credit in 2023. However, most of the units sold in the VCM are ex-ante (they are yet to be delivered), whilst credits sold in the UK ETS are ex-post (they have already been delivered).

- **Low prices and not having a price guarantee contribute to a lack of confidence from potential suppliers.** The Woodland Carbon Guarantee was launched in 2019 and operates by providing reverse-auctions to enable suppliers of Woodland Carbon Units (verified by the Woodland Carbon Code) an option to sell their units to government on a 35-year contract at an agreed index-linked rate, should they not find a buyer on the private market. While some suppliers have taken advantage of this, the number of projects registering with the Woodland Carbon Code and its Guarantee is still relatively low compared to the volume of woodland creation taking place.

- **Perceptions of the voluntary carbon market are often characterised by fears of greenwash.** Regulation of buyers of carbon units to ensure that they are using offsets as part of a wider strategy to reduce their avoidable emissions could help to raise the profile of the UK VCM.

Nature Returns – The Year Ahead

Over the next year, we will continue to collaborate with the Projects and support them in delivering against their habitat targets. We will bring them together to maximise the potential for learning from their experiences.

We will work together to share our discoveries with a wider audience and demonstrate the value of implementing Nature-based solutions. We will embed the recommendations made in the Partnership Working study in our organisations.

Our key areas of focus for the next year are:

Partnership in Practice

- **Delivering a further 200 ha** of nature-based solutions.
- **Increasing public engagement and access to nature** by creating and improving access, highlighting habitat restoration methods to increase understanding and interaction with nature and providing volunteering opportunities.
- **Reducing flood risk** by installing targeted interventions to slow the flow of water during peak flow periods.
- **Improving habitat connectivity** between sites by increasing habitat corridors.

Carbon and Biodiversity Science

- **Rolling out our new methodology** for assessing carbon in hedgerows and scrub across the Local Partnership Projects.
- **Extending our carbon research** in understudied habitats including species rich woodlands, flood plain mosaics and wetlands and starting measurements of methane emissions.
- **Extending our work** to understand the processes contributing to carbon sequestration in soils.
- **Publishing our methodologies** for measuring carbon and biodiversity in a landscape over time (temporal/spatial).
- **Publishing our evidence** about (the processes contributing to) carbon sequestration and storage in under-researched habitats and soils.

Landscape Scale Investment

- **Continuing to develop strategic funding plans** with at least three of our Projects to help them expand their financing for future delivery of nature-based solutions.
- **Delivering and sharing governance** models and best practices.
- **Supporting the development** of collaboration and partnership learning and development with CIWEM (Chartered Institution of Water and Environmental Management)

- **Supporting the design** of a green finance community of practice.
- **Testing and developing land use modelling tools** to support decision-making for landscape scale land use change.
- **Testing methodologies of emerging carbon codes** in real-life settings
- **Scoping sites to test the methodology** of the Woodland Water Code

Building the evidence and sharing what works will help us to put nature-based solutions at the heart of what we do. We will demonstrate how nature recovery can lead to tangible returns in the form of carbon sequestration and increased biodiversity to accelerate Nature's return.

For more information or to follow our progress, please visit Nature Returns Programme (naturalengland.org.uk).

References

Calders, K., Verbeeck, H., Burt, A., Origo, N., Nightingale, J., Malhi, Y., Wilkes, P., Rau monen, P., Bunce, R. G. H., & Disney, M. 2022. Laser scanning reveals potential underestimation of biomass carbon in temperate forest. *Ecological Solutions and Evidence*. 3, e12197. doi.org/10.1002/2688-8319.12197.

Disney MI., Boni Vicari M., Burt A., Calders K., Lewis SL., Raumonen P., Wilkes P. 2018. Weighing trees with lasers: advances, challenges and opportunities. *Interface Focus.* 8: 20170048. doi.org/10.1098/rsfs.2017.0048.

Dunlop, T., Khojasteh, D., Cohen-Shacham, E., Glamore, W., Haghani, M., van den Bosch, M., Rizzi, D., Greve, P. and Felder, S. 2024. The evolution and future of research on nature-based solutions to address societal challenges. *Communications Earth & Environment*. 5(1), p.132. doi.org/10.1038/s43247-024-01308-8.

Elias, J.L, Davess, B., Kemp, H., Lockwood, T., Izard, N., Hartill, J., Mason, E., Stone, M., Spiers, M., Cooper, A. and Morecroft, M., 2024. Nature Returns: Field survey methodology for comparative assessment of carbon and biodiversity. Nautre Returns. Natural England Technical Information Note [TIN220] Natural England, York.

Eunomia Research and Consulting, 2022. Governance of Blended Finance: Governance structures and corporate entities for partnerships. Report produced for the Environment Agency. 111pp. Available at: GFI Investment Readiness Toolkit (Accessed: 09.05.2024).

Eunomia Research and Consulting, 2023a. Green Finance, Flood and Water Governance. Report commissioned for the Environment Agency. 70pp.

Eunomia Research and Consulting, 2023b. The Aggregation of Ecosystem Services Suppliers. Report commissioned for the Environment Agency. 50pp. Available at the GFI Investment Readiness Toolkit (Accessed: 09.05.2024).

Gonzalez-Akre, E., Piponiot, C., Lepore, M., Herrmann, V., Lutz, J. A., Baltzer, J. L., Dick, C. W., Gilbert, G. S., He, F., Heym, M., Huerta, A. I., Jansen, P. A., Johnson, D. J., Knapp, N., Král, K., Lin, D., Malhi, Y., McMahon, S. M., Myers, J. A., and Anderson-Teixeira, K. J. 2022. *allodb*: An R package for biomass estimation at globally distributed extratropical forest plots. *Methods in Ecology and Evolution*. 13(2), 330–338. doi.org/10.1111/2041-210X.13756.

Gregg, R., Elias, J.L., Alonso, I., Crosher, I.E., Muto, P., and Morecroft, M.D. 2021. Carbon storage and sequestration by habitat: a review of the evidence (second edition) *Natural England Research Report NERR094*. Natural England, York.

Holland, R, Castro, G., Chavana-Bryant, C., Levy, R., Moat, J., Robson, T., Wilkinson, T., Wilkes, P., Yang, W., and Disney, M. 2024. "Giant sequoia (*Sequoiadendron giganteum*) in the UK: carbon storage potential and growth rates." *Royal Society Open Science.* 11, no. 3, 230603. doi.org/10.1098/rsos.230603.

IPCC, 2019: Summary for Policymakers. In: *Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems* [Shukla, P.R., Skea, J., Calvo Buendia, E., Masson-Delmotte, V., Pörtner, H.- O.,

Roberts, D. C., Zhai, P., Slade, R., Connors, S., van Diemen, R., Ferrat, M., Haughey, E., Luz, S., Neogi, S., Pathak, M., Petzold, J., Portugal Pereira, J., Vyas, P., Huntley, E., Kissick, K., Belkacemi, M., and Malley, J. (eds.)]. doi.org/10.1017/9781009157988.001.

Jenkins, T. A. R., Mackie, E. D., Matthews, R. W., Miller, G., Randle, T. J., and White, M. E. 2018. FC Woodland Carbon Code: Carbon Assessment Protocol (v2.0). Available at www.woodlandcarboncode.org.uk. (Accessed: 02.05.2024).

Natural Course - Our Water. Our future). Available at www.naturalcourse.co.uk. (Accessed: 02.05.2024).

Nature Markets. 2023. *A framework for scaling up private investment in nature recovery and sustainable farming*. UK Government. London. Available at www.gov.uk/publications. (Accessed: 02.05.2024).

North Star Transition, 2023. *Aggregation and Investment for Nature. A report for the Environment Agency*. 23pp.

Parmesan, C., Morecroft, M.D., Trisurat, Y. R., Adrian, G.Z., Anshari, A., Arneth, Q., Gao, P., Gonzalez, R., Harris, J., Price, N., Stevens, and Talukdarr, G.H. 2022. Terrestrial and Freshwater Ecosystems and Their Services. In: *Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 197–377. doi:10.1017/9781009325844.004.

Réjou-Méchain, M., Tanguy, A., Piponiot, C., Chave, J., and Hérault, B. 2017. Biomass: an r package for estimating above-ground biomass and its uncertainty in tropical forests. *Methods in Ecology and Evolution*. 8(9), 1163–1167. doi.org/10.1111/2041-210X.12753.

UK Government. 2023. *Mobilising Green Investment, 2023 Green Finance Strategy*. UK Government, London. Available at: www.assets.publishing.service.gov.uk (Accessed: 02.05.2024).

Vorster, A. G., Evangelista, P. H., Stovall, A. E. L., and Ex., S. 2020. Variability and uncertainty in forest biomass estimates from the tree to landscape scale: the role of allometric equations. *Carbon Balance and Management.* 15: 1-20. doi.org/10.1186/s13021-020-00143-6.

Water Resources East, 2023. Regional water Resources Plan for Eastern England. Available at www.wre.org.uk. (Accessed: 02.05.2024).

Young, D., Aboobakar, A., Curtis, T., Draisey, Z., Fitton, R., Grundmann, L., Higgs, R., Howard, B., Macedo, C., McAleese, L., Pinkerton, V., Shah, R., Tremolet, S., and Twining, S. 2022. *Financing Nature Recovery UK: Scaling Up High-Integrity Environmental Markets Across the UK.* London, United Kingdom.

Glossary

Term	Definition
Allometric algorithm	An equation describing how characteristics of living organisms change with size. I.e. tree biomass from diameter
Biodiversity	The collection of all living things on Earth
Biomass	The total mass of an organism or organisms in a given area.
Carbon dioxide (CO_2)	A greenhouse gas with a chemical compound comprising one carbon atom and two oxygen atoms.
Carbon sequestration	The rate at which carbon is captured and stored from the Earth's atmosphere.
Carbon stocks/carbon storage	The amount of carbon that is stored within a habitat, object or system.
Chronosequence	A series of sites similar in characteristic that vary in age, enabling an assessment of change through time.
Department for Energy Security & Net Zero (DESNZ)	A government department concerning energy security and net zero and is the former Department for Business, Energy and Industrial Strategy (BEIS).
Deoxyribonucleic acid (DNA)	The molecule that carries genetic information for the development and function of an organism
Emissions	The production and discharge of a substance. In this report, emissions refer to carbon dioxide and/or methane.
Flux	The different between the rate of emissions to the atmosphere and the amount taken up by ocean or land masses.
Greenhouse gas (GHG)	Gases in the Earth's atmosphere that trap heat and contribute to climate change. The primary greenhouse gases

Term	Definition
	described in this report are carbon dioxide and methane.
Hectares (Ha)	A unit of measure to describe the size of a land area. One hectare is equal to 10,000 square metres.
International Union for Conservation of Nature (IUCN)	An international body working to address nature conservation for the sustainable use of natural resources.
Light Detection and Ranging (LiDAR)	A method for determining the range of an object or surface, by measuring time taken for the laser to return back to the scanner.
Methane (CH_4)	A greenhouse gas containing one carbon atom and four hydrogen atoms. Methane is at least twenty-eight times more potent than carbon dioxide.
Mycorrhizal fungi	Fungi which are associated with the roots of a host species, creating a relationship which benefits both, in a process called ‘symbiosis’.
Natural habitat	An ecosystem where its natural processes have not been significantly impacted by human activities
Nature-based solution (NbS)	Actions that address challenges in society through the protection, sustainable management and restoration of natural and modified ecosystems. These actions benefit people and nature simultaneously.
Net Ecosystem Exchange (NEE)	Net exchange of carbon between the atmosphere and the ecosystem being measured.
Net Zero	A UK government target whereby carbon being released into the atmosphere equals that being removed from the atmosphere, by 2050.
Semi-natural habitat	An ecosystem with most of its natural processes and biodiversity intact, but has

Term	Definition
	been somewhat altered by human activities.
Site of Special Scientific Interest (SSSI)	An area of water or land containing wildlife geology, landform or other natural heritage of a special interest.
Shared Outcomes Fund (SOF)	A funding initiative set up by HM Treasury to incentivise cross-departmental collaboration to address challenging policy areas.
Soil respiration (SR)	A measure of the carbon dioxide released from soil.
United Nations Environment Assembly (UNEA)	A decision making body environmental matters, involving all United Nations member states.

Appendix 1 – Partnership in Practice

Grant Application Process

The six projects receiving funding were selected through a competitive application process that ran over the course of the Summer and Autumn of 2022.

Application documents and guidance were prepared and issued to provide applicants with information on the habitats being prioritised for further research to benefit the climate science. This was accompanied by explanations of the level of detail required and how applications would be assessed to ensure a transparent process. These are our priority habitats:

- Woodlands established by natural colonisation rather than planting.
- Mixed species and broadleaved woodlands
- Wood pasture
- Hedgerows
- Scrub
- Heathland
- Species rich grasslands
- Small areas of peat within a wider landscape (‘peaty pockets’)
- Reversion of plantation forestry on peat back to semi-natural peatlands
- Floodplains including floodplain mosaic habitats, flood plan grazing marsh conversion of cropland back to semi-natural floodplain

These habitats are based on evidence gaps identified in a Natural England report on Carbon Storage and Sequestration by Habitat. Available here: http://publications.naturalengland.org.uk/publication/5419124441481216

A total of nine applications were received, and these were assessed by an expert panel to evaluate the::

1. Project Vision
2. Detailed plans
3. Permissions, Regulations and Access
4. Project Funding and management
5. Project legacy and future funding.

Following this exercise, the top five scoring projects were awarded the funding that had been applied for, with the sixth awarded a smaller amount to use all the funding available.

Habitat Creation Summary

A habitat summary detailing the wide range of habitat creation across all projects can be found in Table 1.

Table 1. Summary of habitat creation across the six projects from February 2023 to the end of March 2024

Habitat Type	Target (ha)	Completed to 31/03/24 (ha)	% of target complete
Wood Pasture	185.03	138.01	74.59
Orchard	6.80	6.88	101
Species-rich grassland	134.0	76.05	65
Mature deciduous woodland	77.93	77.93	100
Deciduous wood and scrub – natural regeneration	11.71	11.71	100
Mosaic grass and scrub – natural regeneration	74.56	74.06	99
Mosaic grass, wetland and scrub – natural regeneration	9.64	9.64	100
Mature deciduous wood – natural regeneration	35.45	25.95	73.20
Scrub – including natural regeneration	7.86	7.86	100
Open water	5.31	5.31	100
Wetland	4.82	4.82	100
Broadleaved woodland	34.75	34.29	98.7
Floodplain wetland mosaic	43.55	38.06	87.4
Mixed native woodlands	1.31	1.1	83.97
Peaty pockets (*ref)	74	55.00	74.3
Heathland	23.90	-	0
Fen	8.47	8.47	100
Saltmarsh	0.26	-	0
Semi-natural grassland	1.44	1.44	100
Pond	3.8	3.80	100

Habitat Type	Target (ha)	Completed to 31/03/24 (ha)	% of target complete
Riparian woodland	0	0.6	100
Blanket bog	0	8.00	148
Hedgerow	9,690m	9,035m	93

*- Peaty pockets are grassland areas with small pockets of deeper peat randomly dispersed within the soils

Project 1 – Wild Exmoor Carbon Sequestration Project

This project, which is being run by the National Trust (NT), has been awarded almost £850,000 to undertake works in partnership with the Exmoor National Park Partnership, Woodland Trust and Plantlife.

The Wild Exmoor Carbon Sequestration Project is the second phase of the wider Reconnecting West Exmoor Coastal Project. The long-term vision of this project is to create a more dynamic mosaic landscape, dotted with more trees, scrub and water, where natural processes are healing the previously overworked and stripped back landscape. The project also continues the legacy for the Atlantic temperate rainforests and will also create new areas of public access space.

Wild Exmoor Carbon Sequestration Project fencing. Photo credit: Stewart Wesley

The Wild Exmoor Carbon Sequestration Project aims to deliver the vision across the National Trust's 670 ha Watersmeet Estate and will:

- encourage a complex, more resilient and dynamic landscape, underpinned by sustainable land management and the restoration of natural processes
- restore wetland habitats and slow the flow of water by increasing its retention on site
- use a mix of carefully controlled grazing, rootling, and wallowing animals to encourage natural regeneration and scrub to form

- increase understanding in carbon sequestration within the natural environment
- create new and improved access to help grow the economic benefits to the local community.

Habitat Creation

Land designated for habitat creation and management is shown in the maps below. These show the areas of land proposed at the commencement of the project but certain areas have since been removed. This includes the area of Kipscombe (heath) which was a 26 ha area of proposed heathland mosaic creation from grassland (Figure 9).

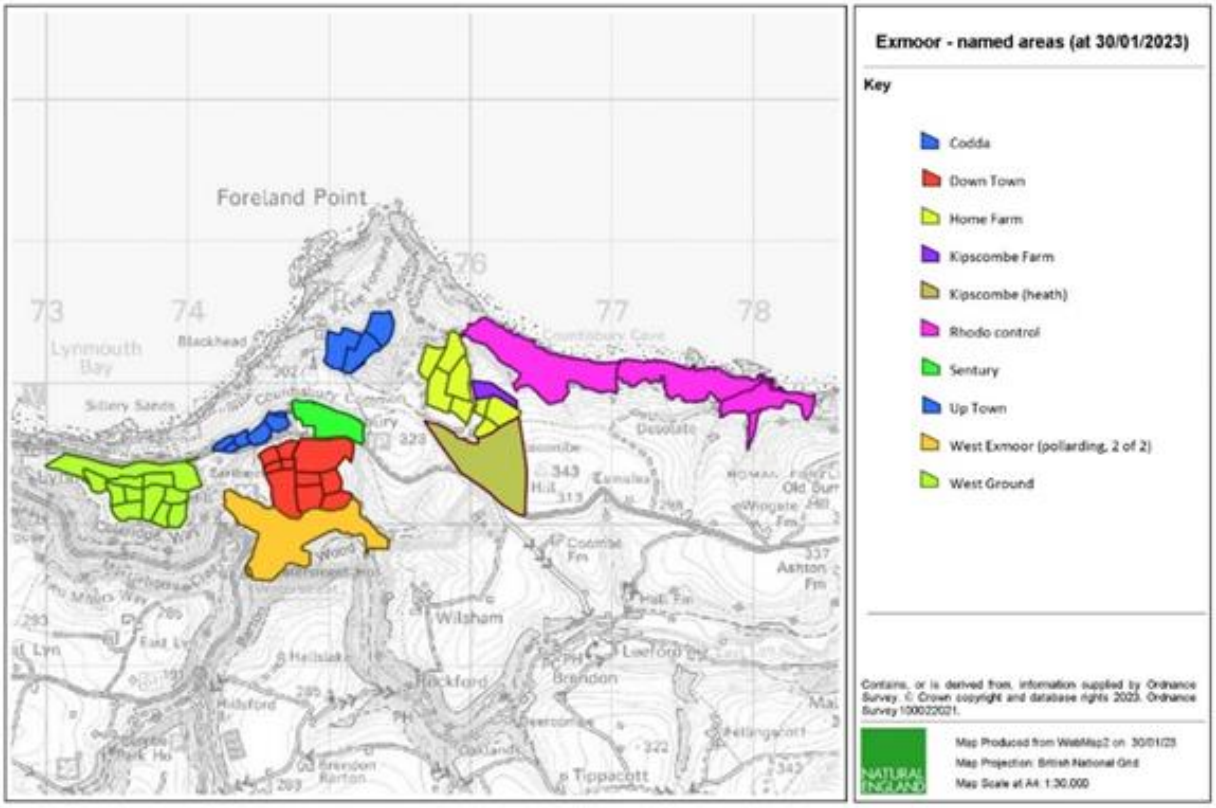

Figure 9: Map showing sites within the Wild Exmoor Carbon Sequestration project on the east side of the project area

Through eDNA surveys and fruiting body surveys, it has been determined that this area is of national importance for waxcaps and other grassland fungi, and that the heathland creation as proposed may impact this value. Natural England specialists and the National Trust project team are meeting to determine what habitat creation can be undertaken on this site, and to begin to come to conclusions on how similar areas throughout the country can be managed in the future.

Areas of habitat created are shown in the Habitat Creation table shown earlier in this Appendix. Habitats have been created to focus on breaking up the extensive areas of grassland and blur the edges between heathland, field and woodland, creating a habitat mosaic across the site. New broadleaf woodland has been planted as a buffer and to aid habitat connectivity.

The National Trust team have undertaken a full suite of baseline habitat assessments, which are in addition to soil and vegetation measurements taken by the NE field team. This has included:

- Restoration of 8.7 ha of species rich grassland as a donor site for future interventions
- Baseline monitoring including habitat assessments, sampling, and wildlife monitoring, aligned with Defra natural capital programme. Monitoring will include species diversity, including birds, invertebrates and vascular plants, trophic complexity, pollinators, habitat assessment and soils.

Additional non-carbon benefits:

- Creating new and improved access to help grow the economic benefits to the local community

Green Finance

The National Trust are currently developing a ‘best in class’ biodiversity/ carbon/ nutrient offsetting product, with UNESCO North Devon World Biosphere and Finance Earth Ltd, connected to the Natural Capital Marketplace. This will be taken to market c. 2025.

Project 2 – Wansbeck Restoration for Climate Change

This project, run by Groundwork North East and Cumbria, has been awarded just over £600,000 to undertake works in partnership with The National Trust and associated farm tenants, as well as two other local landowners.

Works included in their Nature Returns project will contribute to the delivery of proposals included in the Northumberland Local Nature Recovery Strategy (LNRS). The Northumberland LNRS was led by Northumberland County Council and supported by Natural England. It developed a strategic, landscape scale plan for nature recovery priorities throughout the Wansbeck catchment.

Their vision is to create an exemplar project for nature recovery around the River Wansbeck, demonstrating how nature recovery can thrive in a semi-natural habitat, highlight how different landowners can collaborate to fight climate change, reduce greenhouse gas emissions and promote carbon sequestration, in a way that benefits nature and society.

Hedgerow planting at Middleton North. Photo credit: Groundwork North East and Cumbria

To realise their vision, they are delivering river and habitat restoration on three estates, with 144.1 ha of direct habitat creation/restoration, and a further 6,303 ha of river catchment restoration. Their objectives are to:

- Develop an integrated approach to catchment delivery of nature-based solutions.
- Improve water quality in the River Wansbeck catchment.
- Improve natural processes in the River Wansbeck catchment.
- Improve business resilience for enterprises who use Wansbeck's natural, cultural and built heritage
- Support the agricultural sectors by facilitating access to new funding including green finance and future land management schemes.

Sites being restored are shown in Figure 10. This includes the six sites proposed at the beginning, all works have been completed or are in progress. In addition, a seventh site has been added to the project.

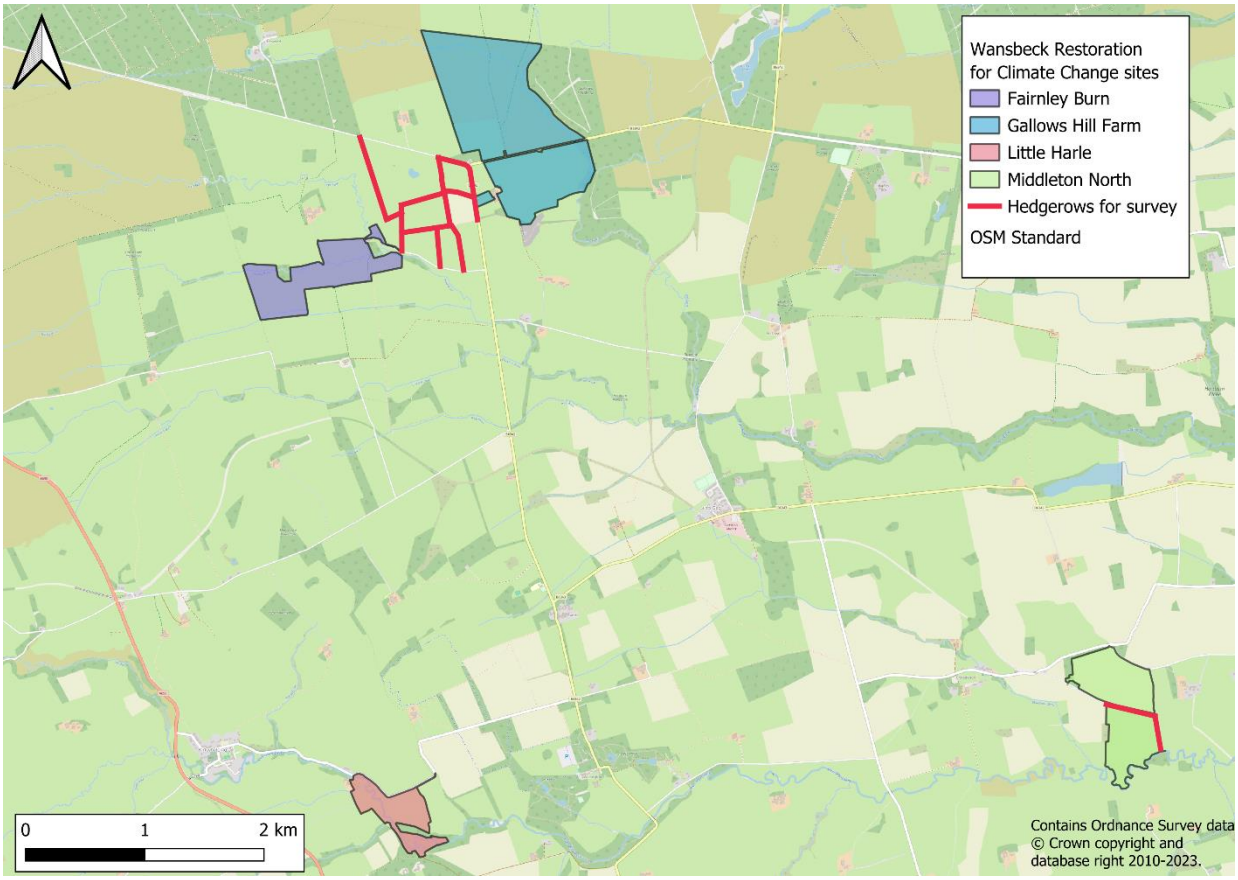

Figure 10: Map showing the seven sites being restored as part of the Project. Credit: Groundwork North East and Cumbria.

These works have involved the restoration of an area of peat bog from previously felled Forestry England (FE) land within Harwood Forest. The area had been felled of trees some 10-12 years ago and FE assessment had determined that the area should not be restocked with trees. The works have consisted of ‘smoothing’ the area by pushing high areas and associated tree stumps into the deep ditches and flattening the area. Some bunding has also been provided around the edges of the area to retain water within the area, increasing the likelihood of the peat restoration on the site. These works have restored an additional 8ha of blanket bog habitat in the Wansbeck catchment.

The only other main change to the proposals was the reduction in area of floodplain mosaic habitat to be restored at Little Harle, with the landowners not agreeing to the full proposals on the site. Other changes have occurred to the works proposed at Middleton North, including the replacement of an area of river restoration with riparian woodland creation, the replacement of a woodland strip with wood pasture cages due to heritage reasons and the removal of an area of woodland strip to prevent issuing with an existing land management scheme.

Progress to date:

Habitat creation and restoration

A considerable proportion of the works have been completed at the time of writing, including all the floodplain mosaic, peaty pockets, heathland and bog works. All hedgerow and species-rich grassland work have been completed. Riparian woodland, wood pasture and other tree planting have recently been finished.

Reconnected floodplain at Harwood Burn. Photo credit: Groundwork North East and Cumbria

Community Engagement

Gaining a good baseline of data and engagement are key points for the team, and they are therefore also planning a Bioblitz of one of the sites to increase data gathered and public involvement in the project. Other engagement works have included numerous talks held and events attended, many with local farmers and landowners. In addition, they hosted a wildlife photography course, which has resulted in a photography exhibition being held first at the National Trust Wallington site, and now Kirkharle Courtyard.

Monitoring and Research

The Groundwork team have undertaken extensive soil and vegetation surveys on the Nature Returns sites and additional sites in the local area to act as control points. They have used the same vegetation survey methodology so that results are comparable.

In addition the Groundwork team have undertaken breeding and wintering bird surveys and are undertaking Fixed Point Photography assessments to give a visual representation of the habitat changes from their interventions.

Project 3 – Plymouth's Natural Grid

Plymouth's Natural Grid (PNG) has been awarded approximately £1m to support Plymouth City Council (PCC), in collaboration with the National Trust (NT), to restore natural habitats and create local solutions to climate change in the urban environment. The project is located within the Plymouth and South Devon Community Forest (PSDCF) landscape as seen in Figure 11, and aims to create and restore 99.7 ha of priority habitat across eight sites:

- Fen creation/restoration - 0.17 ha
- Floodplain mosaic habitat creation/restoration - 6.74 ha
- Hedgerow creation - 1785.3 m
- Saltmarsh restoration - 0.26 ha
- Scrub creation - 0.26 ha
- Semi-natural grassland creation - 1.44 ha
- Wood pasture creation - 61.11 ha
- Broadleaved woodland creation - 29.69 ha

Sites have been selected to offer a diversity of habitats for biodiversity, significant carbon sequestration potential and the potential for innovative funding (e.g. through Biodiversity and Carbon credits).

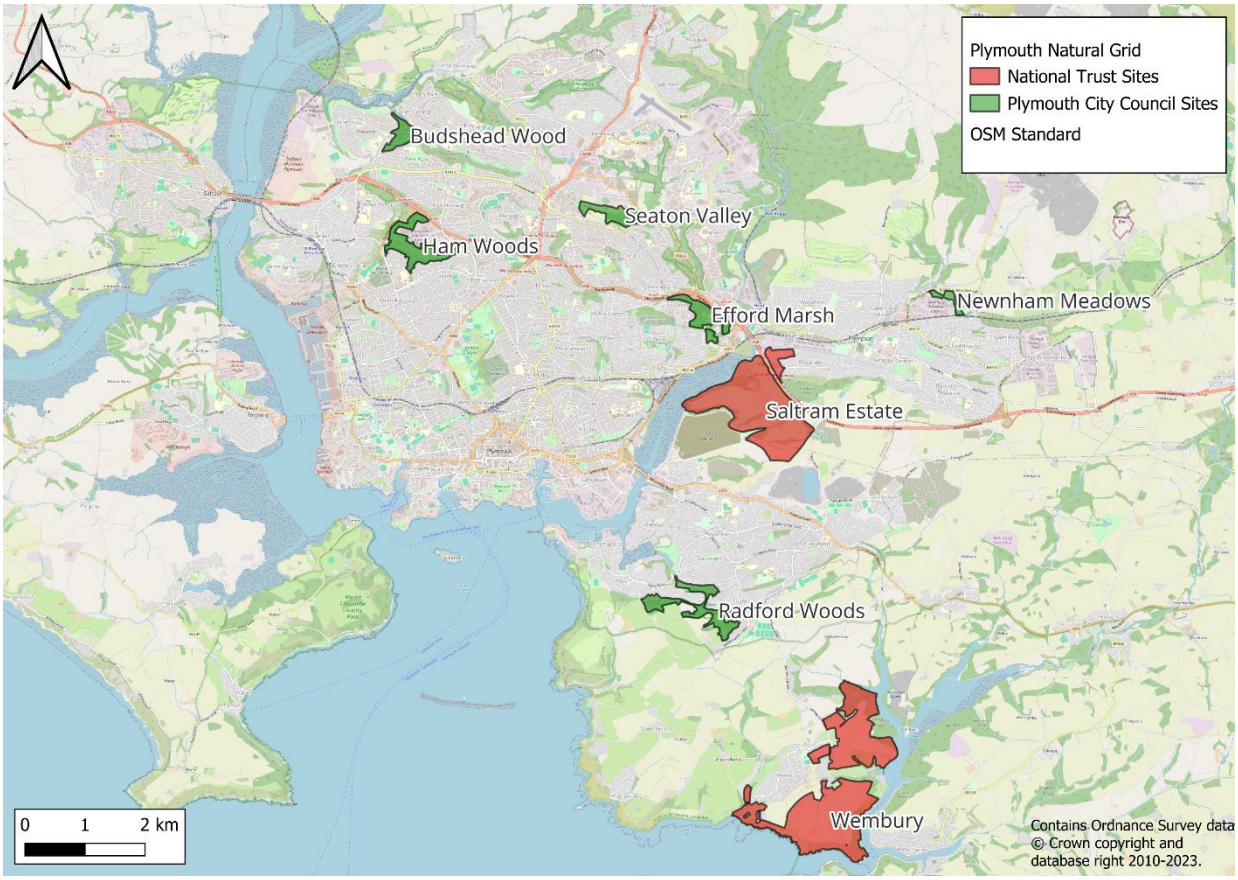

Figure 11 Map provided by Plymouth Natural Grid showing location of project sites; Budshead Wood, Ham Woods, Seaton Valley, Efford Marsh, Newnham Meadows, Saltram, Radford Woods and Wembury

The project includes a programme of community engagement activities, with an interest in the benefits of NbS in an urban context including; improving health and wellbeing, improving air quality, water management and managing heat stress of residents.

Progress to date

Habitat creation and restoration

- 0.17 ha of fen habitat has been created at Radford Woods.
- Floodplain mosaic habitat creation and restoration activities took place across a total area of 6.74 ha at Budshead Wood, Efford Marsh, Ham Wood, Seaton Valley, Newnham Meadows and Radford Woods. Activities include selective thinning of trees to open closed canopy and allow light into the channel. Natural Flood Management (NFM) interventions such as the installation of leaky woody dams (using wood from thinned trees) designed to slow the flow of water during high flows while allowing fish to pass underneath, as well as flow deflectors and the creation of shallow pools and scrapes. Additionally, the removal of non-native invasive *Impatiens glandulifera* (Himalayan Balsam) by project staff and volunteers at Ham Wood and Newnham meadows took place as part of habitat restoration works.
- Saltmarsh- materials for saltmarsh creation works at Saltram have been procured, and work will commence in Summer 2024. This includes sediment trapping and planting.
- 0.26 ha of scrub restoration and management has taken place at Ham Woods and Radford Woods, through bramble management; selective thinning, scalloping of edges and varying the age structure of the bramble by cutting on a multi-year rotation.
- 1.47 ha of Semi-natural grassland habitat have been created at Ham Woods using seed harvested from local donor sites and cutting patches of bramble scrub.
- 6.67 ha of wood pasture habitat has been created at Seaton Valley through tree planting, installation of fencing, tree guards and shelters to protect newly planted trees from deer, rabbits and livestock. Additional clusters of scrubby understory have been planted around trees to mimic natural woodland regeneration and provide further protection to trees from grazing. Planting of hedgerow and plans to install stock fencing are underway in Seaton Valley.
- Further wood pasture habitat creation works are in progress at Wembury to be completed before the end of March 2024, and 29.69 ha of broadleaf woodland habitat creation has been completed.
- 29.69 ha Broadleaf woodland creation at Wembury completed using match funding.

Community Engagement

PCC and NT have conducted a programme of engagement activities delivering over 200 hours of volunteering, and 1,483 number of people engaged with nature. Activities included practical volunteering days, Junior Urban Ranger and green digital badge scheme.

Monitoring and research

- Baseline water flow monitoring by Exeter University of NFM structures in Seaton Valley, with plans to continue monitoring
- Fish, butterfly and Bryophyte and visitor number surveys

Project 4 – Derwent Forest Project

This project, which is being run by Derbyshire Wildlife Trust, has been awarded over £550,000 to undertake works in partnership with Derby City Council and The Chatsworth Estate.

Tree nursery at Derwent Living Forest. Picture credit: George Jones

The works to be undertaken as part of the Nature Returns programme form part of a much wider vision in which DWT aim to create a connected landscape throughout the Derwent Catchment, linking the Northern Forest and the National Forest. Derbyshire lies at an important junction between upland and lowland England, and is seen as an important site to allow movement of species north in response to climate change. The long-term vision of the project is to create 30,000ha of woody habitats (woodland, orchards, hedgerows, parkland and agroforestry). Where possible this will be delivered

through natural regeneration and re-wilding, using large herbivores to create dynamic, mosaic habitats.

The current stage of the project being delivered under the Nature Returns programme includes nine sites. These range from Allestree Park, a former golf course in the city of Derby, to Ladybower Wood in the High Peak area of the Peak District. Habitats to be created will cover 268.18 ha and will:

- Sequester carbon in new woodlands and increased organic matter in soils
- Improve water quality through removal of sediment, phosphates and nitrates
- Help to develop a nature-based economy, working with the nationally significant tourism economy in the catchment (Peak District National Park and Derwent Vally Mills World Heritage Site)
- Improve health and wellbeing through being one of the seven Green Social prescribing pilot projects across the country
- Reduce flood risk in the region which has significant and increasing flood risk with Matlock having had four ‘1 in 100-year’ floods in the past three years

Progress to date

Habitat creation and restoration

The nine sites being restored under the Nature Returns programme are shown in Figure 12. Works on all nine sites is continuing, though some changes have been made to the proposals since the start of the project.

The aims for what will be achieved in terms of habitat creation on the site have not changed, but the methods of doing this will now need to be mechanical and driven by the local community.

The proposed community orchard has also been removed from the proposals at this site. Consent applications for NFM (Natural Flood Management) works have been submitted which would guarantee an all year round water supply and facilitate more flexible grazing options.

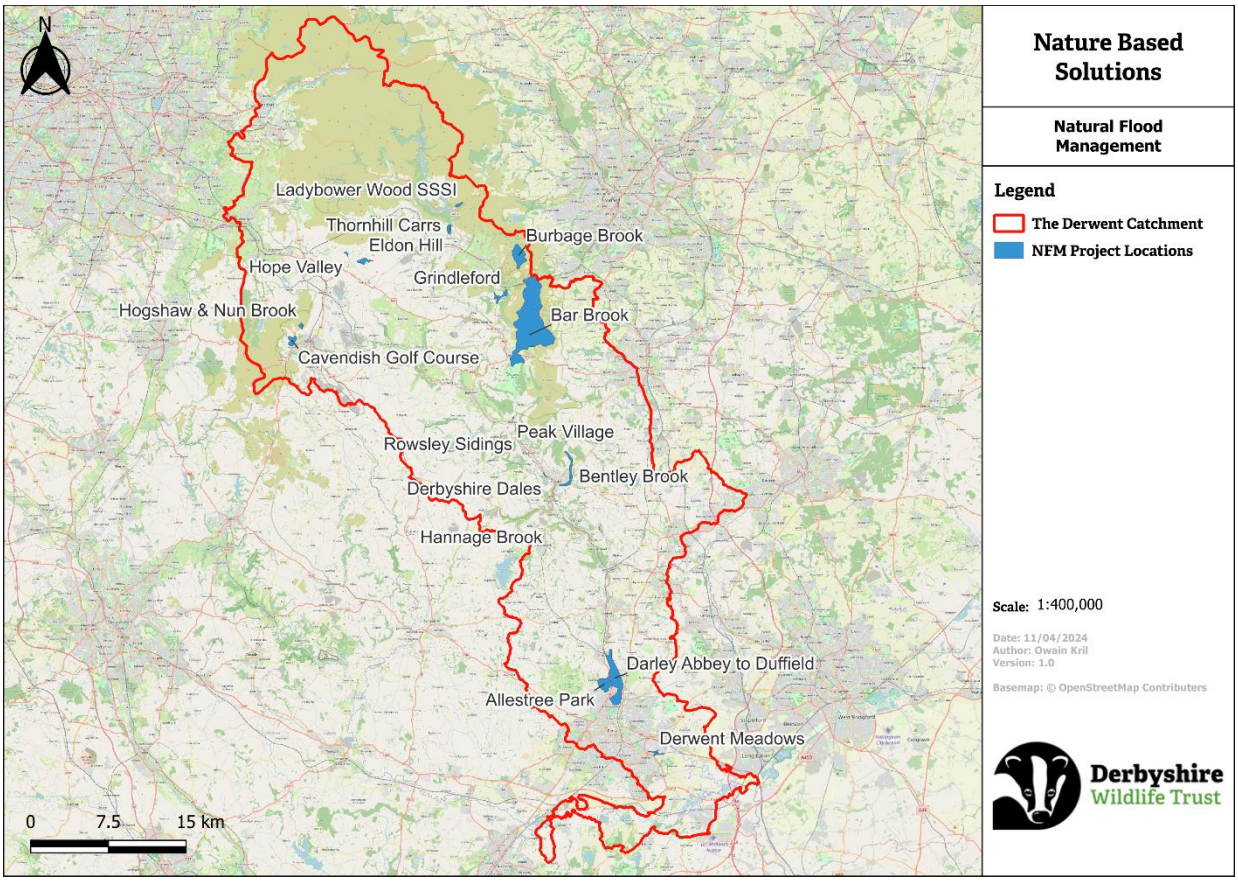

Figure 12: Map showing the nine sites being restored as part of the Derwent project

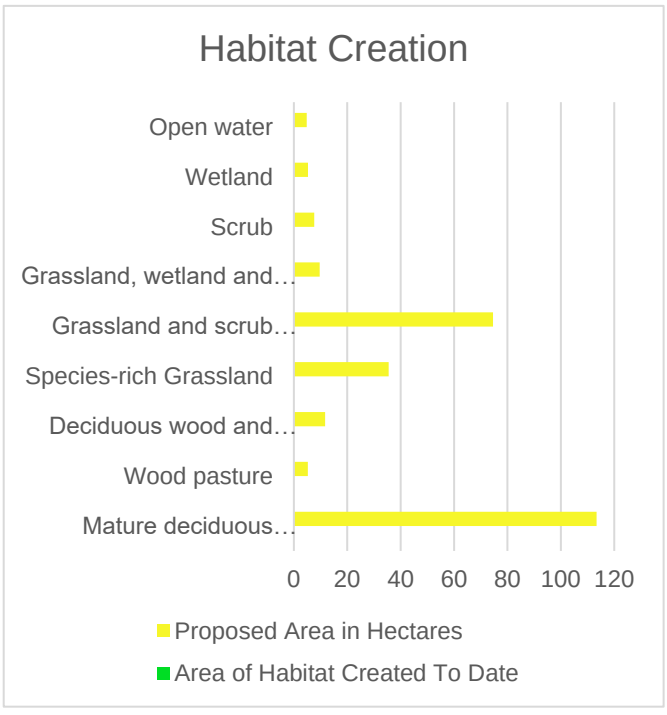

Figure 13: Showing the proposed habitat creation (ha) for the Derwent project to date

Areas of habitat creation, and that completed at the time of writing, are as shown in Figure 13. It should be noted that none of the habitats show any as having been created at this time, but this is due to the proposed method of natural regeneration which will only begin at the end of the project when large herbivores are introduced to the sites.

Extensive works have been undertaken in installing fencing, water features for livestock and items such as cattle corrals which will allow these large herbivores to be used on these sites.

Livestock will be moved on to these sites between late February and March 2024 to begin the process of creating new mosaic habitats. In this respect, habitat creation works are on track and due to complete by the end of March 2024.

‘Be a Jay Day’ community engagement day. Photo credit: George Jones

Community Engagement

Engagement is a significant element of the project for DWT with volunteers used widely for their work, including for an important element of dry-stone walling within this project. To date, they have established seven publicly run tree nurseries which will help supply trees to be planted throughout the area to achieve their goals of increasing woody vegetation. In addition, they have run a series of ‘Be a Jay Days’ aimed at increasing awareness amongst children and families of the benefits of trees, and which include significant tree planting during the event. This is in addition to a number of talks and presentations to the public and councillors on the benefits of nature-based solutions and NFM measures.

Monitoring and Research

It should also be noted that the areas provided for habitat creation are expected values based on knowledge of the methods being used and the sites within the project. However, given the process on all sites except Allestree Park will be led by natural regeneration, the specific habitats being created and quantities of each cannot be guaranteed.
In response to additional budget for proposed works at Allestree Park being made available due to the changes in methodology there, a Fixed Point Photography and Point Sightings System has been devised and is being implemented on all the Nature Returns site. In addition to taking regular photographs at fixed points on the sites, the system will allow members of the public to submit photographs to an app, which will increase public engagement and provide further evidence on the habitat changes on

site. The system aims to show the changes in time that occur from natural regeneration of a site, and the benefits this can have for ecosystems and biodiversity. In addition to the FPP system above, the DWT team are also undertaking other baseline assessments, which are in addition to soil and vegetation measurements taken by the NE field team. This has included:

- Habitat assessment using UKHab
- Defra Metric calculation
- Use of NFM Hub to monitor flood data
- Monitoring of wellbeing of volunteers
- Drone survey to give a visual representation of carbon in woody vegetation

The surveys aim to quantify the benefits of dynamic transitional habitats (terrestrial and wetland mosaics) for biodiversity, carbon, water quality and natural flood management, in addition to assessing the benefits of natural habitats to the wider public.

Project 5 - The Oxfordshire-Buckinghamshire Freshwater Network

Background

The Oxfordshire-Buckinghamshire Freshwater Network, led by the Freshwater Habitats Trust (FHT), has been awarded over £780,000 to focus on the role played by smaller, peat-dominated wetlands, floodplains, wet grasslands and waters in sequestering carbon in the landscape. These habitats are of exceptional importance for freshwater biodiversity, which is in rapid decline. The project will help to better understand the role that these habitats can play in carbon sequestration. It will also help Freshwater Habitats Trust build the Freshwater Network – a national network of wilder, wetter, cleaner and connected freshwaters.

FHT are working with landowners, conservation charities and public bodies to create and restore freshwater habitats across six sites in Oxfordshire and Buckinghamshire:

- Fens - 8.3 ha
- Floodplain Wetland Mosaic -14.54 ha
- Species-rich grassland - 6.9 ha

The funding will also allow the continuation of FHT's GroWet initiative, where volunteers grow rare wetland plants at home before being introduced to wetlands sites across Oxfordshire and Buckinghamshire.

The funding has also facilitated the production of 3 videos showcasing the restoration work at fens and floodplains as well as the community side of the project through the GroWet initiative. Links to the videos:

- Floodplains: https://www.youtube.com/watch?v=LEPjzXJuN60&ab_channel=FreshwaterHabitatsTrust
- Fens: https://www.youtube.com/watch?v=mUk340LI2hM&ab_channel=FreshwaterHabitatsTrust
- GroWet: https://www.youtube.com/watch?v=jb5pCupzNqs&t=5s&ab_channel=FreshwaterHabitatsTrust

Progress to date

Restoration works to reinstate alkaline valley fen habitat has taken place at three sites across Oxfordshire; Middle Barton Fen SSSI, Hinksey Heights Farm and National Trust Buscot and Coleshill Estate. Restoration activities include scything, raking, scrub clearance and invasive plant management by volunteers and contractors. Where inappropriate planting of trees has taken place, these have been cleared, including felling of Ash affected by *Hymenoscyphus fraxineus* (Ash dieback), creating new areas of open ground. FHT are scoping grazing opportunities on restored fen areas as part of the ongoing management of the restoration sites, to supplement works already carried out by volunteers.

Volunteers scything and raking at Hinksey Heights fen. Photo credit: Freshwater Habitats Trust

Floodplain Wetland Mosaic creation at two sites is complete, Methods include reverting arable land in the floodplain to pasture, creating a range of wetland pools of varying sizes, depths and water sources through excavation and drain blocking to re-initiate peat formation. 6.9 ha of species-rich grassland have been created across three sites in Oxfordshire Buckinghamshire, through spreading of green hay collected from local donor sites.

FHT partnered with sixteen ‘hubs’ including libraries, community centres and public spaces across main towns in Oxfordshire, to distribute GroWet plant packs to volunteers for growing wetland plants at home. Plants grown by volunteers were collected and over 1,000 rare or endangered plants have been introduced at three receptor sites. To date FHT have engaged with more than 550 volunteers through the project and 120 people through events, including through art workshop and visits to wetland sites.

Floodplain Conservation Officer Ellie MacDonald showing the recently created wetlands in an engagement event with farmers. Photo credit: Freshwater Habitats Trust

Botanical surveys of fen and floodplain wetland mosaic sites have been completed. Inspection of previous GroWet planting sites in August 2023 found that over 90% of introduced plants have survived and grown considerably since they were planted out in October 2022. FHT are in the process of drafting a monitoring plan for the GroWet plants that planted during the grant period and are planning to collect seeds to germinate from plants including Endangered species such as Creeping Marshwort (*Helosciadium repens*) and Fen Violet (*Viola stagnina*).

Freshwater Habitats Trust installed hydrological monitoring equipment at fen sites, with preliminary ground investigations undertaken to inform their installation and design. Long-term hydrological data will help FHT to assess the success of restoration and to inform future management actions.

Water chemistry sampling was carried out at all the sites covered by the project, which were analysed by the UK Centre for Ecology and Hydrology (UKCEH) to study the water quality and build a comprehensive dataset of water quality in newly created wetlands and how this changes with the feature's age. The extent to which they can become more enriched is particularly interesting on sites flooded regularly from by rivers.

Green hay spreading at National Trust Buscot and Coleshill. In the background, wetland created with funding from GRCF and Nature Returns. Photo credit: Ellie MacDonald, Freshwater Habitats Trust

Project 6 – Severn Solutions for Nature's Recovery

Background

Severn Solutions for Nature's Recovery (SSNR) is a project led by Gloucestershire Wildlife Trust (GWT) in partnership with Hasfield Court Estate (HCE), a 500 ha site located in the Severn Vale in Northern Gloucestershire. GWT has been awarded just under £500,000 to create 42.8 ha of semi-natural habitats across the mixed-farm landscape of the estate. The partnership's vision is to demonstrate and provide evidence of how the restoration of native habitats can provide nature-based solutions (NbS) that help adapt to climate change and tackle the ecological emergency.

23.4 ha of wood pasture, 6.8 ha of traditional orchard and 12.6 ha of species rich grassland.

Following detailed mapping of the site, these habitats were chosen to enhance landscape connectivity by linking up existing areas of remnant priority habitat. The project sits adjacent to a GWT nature reserve, Ashleworth Ham SSSI and the Landscape Recovery scheme project, Eelscapes, and will create new areas of habitat in the transition zone between the floodplain and areas of higher land, allowing better resilience to the effects of climate change.

SSNR's objectives:

- Enhance the extent, quality and climate resilience of the ecosystems through NbS
- Contribute to the delivery of nature's recovery within one of Gloucestershire priority nature recovery zones
- Create a coherent habitat matrix of sufficient size to support viable populations of functional species within the landscape
- Provide maximum ecosystem resilience to deliver a diverse landscape of geomorphic variation by adopting NbS
- Contribute to reversing the ecological and climate change emergencies through the creation of ecological networks and by storing/sequestering carbon
- Develop and carry out a monitoring programme based on ecological integrity principles which provide spatial and temporal data sets which demonstrate benefits of the project outputs
- Further understanding of carbon sequestration and storage value of NbS and develop evidence to support blended finance models.

Progress to date

Designs for wood pasture creation across five parcels of improved grassland were finalised in Q1 2023. The design process took into account existing features across the proposed area, identifying opportunities to connect priority ancient semi-natural woodland and hedgerow habitat. A species-mix composition of native broadleaved trees and scrub suitable for the local landscape were identified, aiming to create an open woodland mosaic habitat.

Planting was split into two seasons, with density and age structure of trees to be varied, and clusters of trees included in the design. Care was taken to minimise disruption to the views of the landscape from nearby houses following feedback from consultation with the local community. Trees were planted by GWT staff and volunteers over two planting seasons and completed by January 2024.

Livestock guards for the first season of planted trees have been installed, and interior boundary fences have been removed between wood pasture parcels to create an open woodland habitat. Installation of new way marking posts where these fences have been removed, and livestock guards for second season trees is in progress. A total of 23.4 ha of wood pasture has been established.

Tree planting overlooking the Severn Vale. Photo credit: Hannah Bottrill, Gloucestershire Wildlife Trust

Traditional Orchard planting and restoration plan across four parcels of improved and semi-unimproved grassland was completed in Q1 2023. These parcels were identified as orchards historically and contain remnant orchard trees, linking to existing priority habitat and forming part of a wider wooded landscape mosaic. Traditional and local varieties of apples, pears, plums and cherries were identified but due to the size that perry pears grow, most were incorporated into the wood pasture creation area (which has existing remnant perry pear trees present) and in the hedgerows across the estate. Planting of the orchard trees took place over two seasons and was completed in December 2023.

Due to hot and dry conditions during Spring and Summer 2023, continued watering of newly planted trees was necessary over the Summer period, which ensured minimal losses. A total of 6.88 ha of traditional orchard has been created/restored.

Baseline soil analysis surveys to determine the most appropriate seed mix for the species-rich grassland creation areas were completed in Q1 2023. Establishment across the chosen three filed parcels aims to connect up remnant surviving habitat and

will contribute to forming the mosaic of open habitat with existing priority woodland, wood pasture and orchard creation across the project area.

Delays to the start of the project and poor weather conditions caused significant issues with preparation of the seedbed and in establishing the species-rich grassland areas. Due to these extenuating circumstances GWT was awarded an additional £81,857.31 to undertake additional activities including the re-establishment of the seed bed in some of the species-rich grassland parcels. Vegetation has been cut and removed to reduce weed burden and additional seed sourced has been sourced for sowing into existing sward.

The project is on track to exceed target of 12.6 ha of species-rich grassland habitat, as additional seed has been undersown in the wood pasture and traditional orchard creation areas, which will bring total area to 14.14 ha.

An annual hay cutting regime will be conducted across the species-rich grassland parcels, as well as grazing with livestock across all three habitat types.
Monitoring and research activities undertaken to date:

- Dormouse surveys
- Environmental DNA (eDNA) soil surveys and analysis
- Spatial mapping using LiDAR
- Nature Reserve Condition Monitoring vegetation surveys across the project area-to be repeated annually to show change in vegetation communities over time
- Mapping of planted trees across the project area to provide spatial data set to evidence ecosystem integrity and connectivity
- Butterfly transect
- Breeding bird surveys
- Moth trapping
- Grassland fungi surveys

Livestock tree guards being installed. Photo credit: Hannah Bottrill, Gloucestershire Wildlife Trust

Additional monitoring and outputs:

- Extensive monitoring in the surrounding pockets of woodlands to the project area will be carried out. This will be to assess the carbon sequestration values of dead wood, coppice regimes and different age class/varieties of trees, adding value and comparison to that of the wood pasture, traditional orchard and scrub habitats.
- More eDNA soil surveys and analysis including the woodland and floodplain (Ashleworth Ham).
- Invertebrate monitoring using acoustic monitoring methodologies.
- Collaboration with various research institutions to provide more research opportunities and benefit form academic expertise.
- Carbon accounting - carry out a project specific carbon audit of the delivery stage of the pilot, with a report output which documents the carbon footprint to understand the carbon cost of the project.

Appendix 2 – Carbon and Biodiversity Science, Natural England

Methodological Development

Natural England's Science Team is providing a comparative assessment of carbon stocks, sequestration and biodiversity across a range of different habitats. Providing a direct comparison between habitats can be difficult; there are a huge range of habitats at each site, even within individual plots we see variability, which we refer to as mosaic habitats. To enable a comparison which is scientifically robust, we have carried out an extensive field design exercise, working closely with our pilot partners and aligning with published literature and other standardised methods. In doing so, we have produced a field survey approach which is representative of each of the habitats, and in a way which can be replicated in the future. A brief summary of our site selection and sampling criteria is included below. A full comprehensive description of our methodology has been published in the Technical Report "Nature Returns: Field Survey Methodology for Comparative Assessment of Carbon and Biodiversity" (Elias and others, 2024).

Plot Selection and Sampling Design

For relatively large portions of land, with vegetation that is largely homogeneous, we randomly allocate plots using QGIS, which provides five GPS locations to be navigated in the field. These five locations make up our sampling plots. Where mosaic habitats are present, we take a different approach to ensure that each habitat is captured. Here, we use a stratified randomised sampling approach. Where habitats change along a gradient, such as in a floodplain mosaic, we use a transect approach. To ensure comparability between our soil sampling and vegetation surveys, we aim to allocate soil and vegetation plots adjacent to each other.

Soil sampling for carbon stock assessment

To facilitate a robust baseline assessment, and to provide comparison across different habitats, we have taken a standardised approach to soil sampling. Across all of our habitats, we core to a depth of 30 cm, to account for disturbance from land management practices, and to account for more than the surface soil. By taking this approach, we can also ensure that our carbon stock assessments are not overestimated. We collect additional field data to later assess the relationships between field conditions and soil carbon stocks, including soil moisture, soil temperature and soil pH.

Vegetation species identification and biodiversity assessment

To explore the relationships between carbon and biodiversity in key habitats, we are collecting baseline evidence for vegetation biodiversity, before any conservation work beings, and we look to return over a time period to monitor changes in biodiversity. To do this, we lay quadrats adjacent to the soil plots, to record species, percentage cover and any other features (ant hills, litter, moss, dead wood etc). We have added a further dimension to the vegetation surveying through an assessment of invertebrate proxy. This gives an indication of how varied the vegetation structure is and to what extent it might be used by invertebrates. This has the potential to inform us of how much that habitat might support other taxonomic groups such as birds and mammals, and so help develop a broader understanding of diversity in that landscape.

Carbon dioxide and methane flux

Greenhouse gas work in the Nature Returns project seeks to understand the behaviours of carbon dioxide and methane on land undergoing change and establish baseline flow rates for key habitat evidence gaps. Evidence already available indicates very high variability within a site, even in a homogeneous habitat. We therefore require a high number of replicates, both spatially (within a site) and temporally (through time).

We take a minimum of 20 randomly allocates replicated across the selected sites, helping us to eliminate spatial bias and informs more powerful statistical analysis. We primarily collect ground level carbon dioxide measurements using two chambers; soil respiration and a canopy chamber, which allows plants to photosynthesise and therefore measure the net flux of carbon to or from the area of the chamber at a given time. Additionally, we can also measure methane, simultaneously with carbon dioxide using a trace gas analyser.

Carbon stock assessment for trees

For woodlands, we aim to explore the relationships between above-ground carbon stock in trees, including deadwood, with below-ground carbon stock in forest soil and plant diversity assessments. In doing so, we will be able to compare these relationships with the other key habitats being studied. We primarily focus on trees within woodlands, primarily of native broadleaf species. Our method for measuring trees outside of woodlands is currently under development.

For our assessment, we calculate the height of each tree within the pre-selected plot. We also take the diameter of each tree at breast height (DBH). All stems with DBH greater than 2cm are identified to species level where possible. We also record standing deadwood, measured in the same way as we measure the living trees.
Methods in development

We have several methods which are novel and are therefore under development. These are set to be rolled out on our pilot sites once the initial development stage has been complete. These methods include:

- Hedgerow carbon, including soil and vegetation biomass (partnered with Kew Wakehurst)
- Carbon stock assessment of scrub and hedgerow using LiDAR (partnered with Kew Wakehurst)
- Trees outside of woodlands

Appendix 3 – Carbon Science, Kew Wakehurst. Introduction, rationale and summary of methods

Introduction

This project was developed to understand how carbon functions in biodiverse landscapes, using high resolution research to quantify above and belowground carbon storage, gas flux and biodiversity across multiple habitats. The relationship between above and belowground carbon storage has largely been unstudied, causing the natural variation of carbon stores across landscapes and time to be poorly quantified. Our science aims to develop methods to evaluate carbon within nature, incorporating crucial belowground data, to aboveground measurements and the fluxes from soil to air for total carbon analysis across the Wakehurst landscape.

The Wakehurst landscape, a 200+ ha site which forms a microcosm of habitats across the UK, particularly southern England. Photo credit: Royal Botanic Gardens, Wakehurst

Over the last two years, our researchers have collected data aboveground, belowground, and fluxes to understand how carbon is captured, stored, and released in different habitats. We now have over four seasons of data; these in-depth data are essential to understand how carbon changes temporally and spatially across and within habitats. Using high-resolution data and correlations with mappable units, our partners at the University of Sussex are developing a flexible Landscape Modelling Tool (LMT) that will provide policy makers and land managers a visual understanding of how carbon functions in the landscape and the impact of landscape/land use change on carbon storage and biodiversity.
Our workstream (WS3) is divided for convenience (all groups are interlinked) into five research streams:

- 3.1 (A) Aboveground
- 3.1 (B) Hedgerows and scrubs
- 3.2 Ground level: carbon dioxide (CO_2) fluxes
- 3.3 Belowground

3.4 Integration and testing
3.5 Scaling up: Landscape Modelling Tool (LMT)

Our work is at multiple scales (from mm to tens of metres) which will give us a better understanding of how carbon is stored per unit area and provide the associated variability with precision, alongside change at different scales and with different datasets. This is especially important when extrapolating data collection to the wider landscape using different resolutions of data (i.e. satellites, aerial or drone derived data).
We are using Wakehurst (Kew's wild botanic garden of 210 ha) as our test landscape, concentrating our detailed studies (where all levels of data are collected) within five main habitats:

1. Meadow
2. Broadleaf woodland (SSSI)
3. Coppice woodland (hazel coppice)
4. Conifer woodlands (dominated by Norway spruce)
5. Hedgerow and scrub (both at Wakehurst and other sites)

Beyond these, additional habitats are being tested (within other projects and research), but not with all methodologies and not all at the systematic detail as above. These include wet woodland, parkland, horticulture bedding, unimproved grasslands, silva-pasture and non-native trees including giant sequoia. At the highest level, our findings are analysed by habitat and the chronosequence for these habitats will feed directly into evidence gathered from work in WS2 (characterising the impact of creating and restoring species-rich habitats).

Rationale: what and why?

Aboveground: Wakehurst

What: Informing and building the high-resolution baselines of aboveground biomass, biodiversity, structure, and composition of habitats, bringing together the spatially explicit belowground and gas flux elements.
Why: Spatial analysis and remote sensing will bring these measurements into one platform enabling projections of our findings to wider landscape scales. This will play a critical role for data management, monitoring, and understanding UK landscapes. The data gathered and inferences made from these methods will be used to inform carbon and biodiversity metrics, supporting extrapolation from Wakehurst to the wider landscape. Spatial data will be collected at multiple resolutions with multiple sensors.

Aboveground: Hedgerows and scrub (at Wakehurst and other sites)

What: Improve current estimation of aboveground biomass in hedgerows. Develop methods and proxies using allometric and/or terrestrial LiDAR for hedgerow and scrub biomass.
Why: While hedgerows likely provide long-term storage of carbon in UK landscapes, biomass calculations on hedgerows in the UK are extremely limited. Due being actively managed, their storage trajectories are unlikely to be represented by naturally existing scrub counterparts. Beyond carbon, hedgerows provide multiple ecosystems services and important social benefits.

Ground level: CO_2 flux

What: We measure spatial and temporal variability in GHG fluxes and gather data to understand underlying mechanisms of change. GHG fluxes are modified by site management, weather conditions, vegetation composition and chemistry, associated belowground communities and soil conditions.
Why: Understanding the mechanisms of change can inform management recommendations to reduce GHG emissions and increase the storage of carbon belowground. Relationships with weather can help us to project future GHG emission in a changing climate.

Belowground

What: Developing a methodology for measuring baseline soil carbon and fungal community data (with a focus on mycorrhizal fungi) in soil and roots across habitats that can be shared and scaled up and combined with gas flux and aboveground data.
Why: Most plants form mycorrhizas, mutualistic partnerships where the fungi explore the soil, more efficiently than roots and root hairs, and get carbon from plants in exchange for water and soil nutrients. Mycorrhizal fungi are therefore directly involved in plant nutrition and growth. Fungi, and in particular mycorrhizal fungi, are key players in the carbon and nutrient terrestrial cycles. Different mycorrhizal types contribute differently to ecosystem processes. Moreover, changes in fungal community composition affect mineral nutrition of plants. Understanding and measuring how mycorrhizal fungi contribute to carbon storage within and across habitats is key to predict and scale-up i) estimates of carbon stores on a landscape scale and ii) responses of different habitats to abiotic and biotic changes.

Integration and testing

What: Developing workflows and mathematical equations for carbon as we move through different scales (i.e. individual tree to habitats to landscapes), for both above- and below-ground carbon. Testing existing allometric algorithms for carbon and biomass.
Why: Nature is not homogeneous, and neither is carbon in nature and our landscapes; without good controls with precision and the propagation of this precision we cannot rely on carbon estimates. To extrapolate to wider landscapes and with data at different scales, we need correlates with observations (i.e. vegetation height to above ground carbon or ecosystem health and soil texture to belowground carbon) which can feed into landscape model tools.

Scaling up: Landscape modelling tool

What: The landscape modelling tool, developed by the University of Sussex, will incorporate RBG Kew's ecological data (and from others) with social and economic data. Using machine learning, it will help visualise and examine key benefits and trade-offs of different NbS approaches (e.g. carbon and biodiversity). It will integrate, build upon and complement existing spatial models designed to examine the costs and benefits of land use options.
Why: Tools are needed to visualize, quantify, and model where carbon and biodiversity sit within the landscape, but also how decisions can improve outcomes efficiently.

Sampling, field survey methods, and data collection

An overview of sampling methods is given below for each work stream. Here, we show the general rationale for sampling across our five target habitats. Our sampling extent is determined by time, methods as well as the ecosystems' extent and complexity (Figure 14)

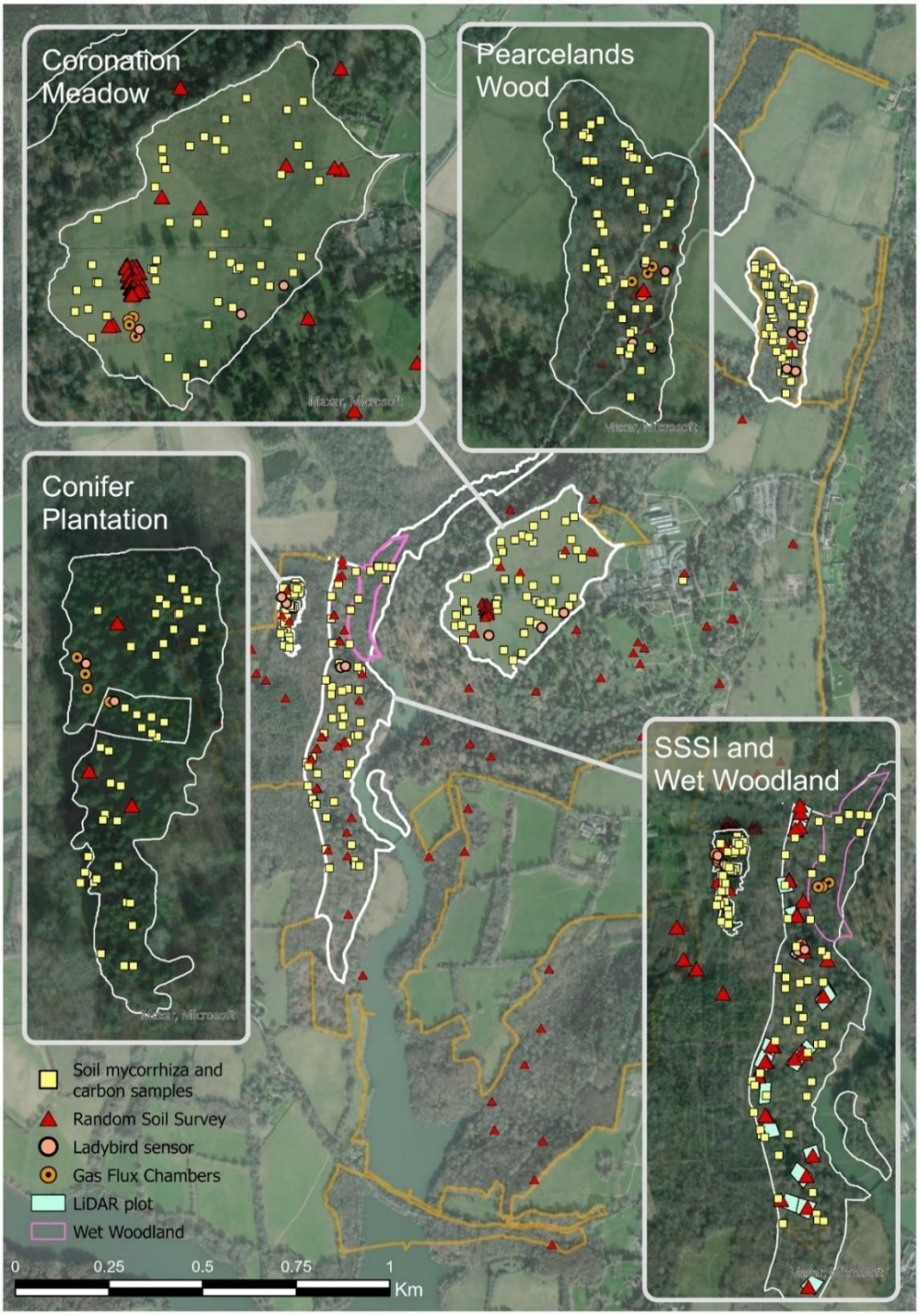

Figure 14. Overview of sampling for carbon pools and carbon fluxes across the Wakehurst Landscape. N.B. Pearcelands wood and the conifer plantation have been fully scanned with terrestrial LiDAR

Aboveground: Wakehurst

For each habitat we have multiple spatially explicit data sets, collected at differing temporal and spatial resolutions and sampling methods. Our site-wide aboveground dataset forms the baseline mapping for all other workstreams, comprised of high-resolution data collected for targeted ecosystems using drone and LiDAR (around these plots technologies. When available (i.e. removal) we have also collected destructive biomass weights (wet) and samples (dry for volume and density). Additionally, the aboveground group produced field collections forms (in Survey123), sampling and collating other groups' data spatially (Table 2).

Table 2. Summary of above ground data collected and methods at Wakehurst

Technology	Methodology
Fixed wing drones	Site wide (and surrounding area) data collection (~250 ha) at resolutions of 2-3cm using colour imagery from fixed wing drones (with RTK) for the whole Wakehurst site, at least for two seasons each year. For extra oversight, ground control locations (visible in the drone imagery) are collected with RTK GPS unit to an accuracy of 2-3cm.
Quad copter drones	Within targeted ecosystems areas of approximately one ha (centre around plots) are surveyed with low altitude quadcopter drones.
Terrestrial LiDAR	Ground surveys for all woodland areas are conducted using high resolution terrestrial LiDAR, with the smallest area unit of 0.09 ha (30 x 30m) in extensive woodland (broadleaf) with a network of eighteen plots. The conifer woodland (see xiv below) and coppice woodland at Wakehurst were surveyed using terrestrial LiDAR in their entirety.
Destructive sampling	These destructive samples harvested and weighed in builder's bags or tarps using hanging scales. In the field scrub microsamples (wet) were weighed using a hand scale. One metre sections of hedge were weighed with a hanging scale lifted with a tractor. Smaller samples of these samples (~1/10) were dried in an oven at 80 °C until the weight stopped reducing (~ 24-30 hours). The dry weight samples were extrapolated to the hedge sections or scrub area samples.
Species inventory	Inventory data of tree species and diameter at breast height has also been collected.

Aboveground: Hedgerows and scrub

While aboveground data collection detailed above is collected across the Wakehurst site, hedgerow and scrub data and samples were also collected from multiple sites from the SE of England. All sites were scanned with handheld terrestrial LiDAR units. Biomass samples, taken from small sections of shrubs or hedge are marked with poles to be visible in the LiDAR scans and are weighed wet and dry. These destructive samples harvested and weighed in builder's bags or tarps using hanging scales. In the field scrub microsamples (wet) were weighed using a hand scale. One metre sections of hedge were weighed with a hanging scale lifted with a tractor. Smaller samples of these samples (~1/10) were dried in an oven at 80 °C until the weight stopped reducing (~ 24-30 hours). The dry weight samples were extrapolated to the hedge sections or scrub area samples.

A laser scanning survey was performed across all sites to provide 3-D representation of the shrubs and hedgerow sections. These surveys aimed, as best possible, to cover all sides by movement around the hedge or shrub sections. Movement was staggered but followed a looping pattern as required for SLAM modelling.

In addition to the above ground samples, soil samples were taken at the Wakehurst site at two hedgerows. Soil samples were collected along transects that were perpendicular to the hedgerows at distances of 0, 1, 3, 9 and 15m and at two depths: 0-15 cm and 15-30 cm. The analysis of soil was consistent with the detailed belowground surveys.

Ground level: CO_2 flux

Moving to ground level data collection, each of our four Wakehurst habitats (Meadow, Broadleaf woodland, Coppice woodland and Conifer woodlands) have been fitted with a network of four semi-permanent, solar-powered CO_2 gas flux stations, recording net ecosystem exchange (NEE), and soil respiration (SR) at least every 60 mins (greater intervals in summer when solar power is more reliable) . Stations also simultaneously record air temperature, soil moisture and temperature, humidity, and photosynthetically active radiation.

Additionally, we use a portable unit, in conjunction with GPS, soil temperature and humidity were used to target whole ecosystems and to complement the continuous sampling, allowing the capture of variability in gas fluxes over space and time.

Belowground

For belowground data collection, soil and root sampling campaigns were conducted seasonally (spring, summer, autumn, and winter), collecting soil samples across the target habitats. Soil samples collection were randomised across the habitats in each season, rather than repeating samples in the same location, as the specific locations will be affected by previous sampling. Mobile gas flux readings were collected before the soil samples and the locations were determined with RTK GNSS.

Integration and testing

In addition to implementing the various aboveground carbon analyses (see above), we are developing the uncertainties (and variation) and their progression from

measurement to carbon values. The uncertainties will be progressed within the various models for carbon to be developed in the landscape modelling tool.

The belowground team will contribute to and review the correlation for belowground carbon and biodiversity, and explanatory variables, also to be developed into the landscape modelling tool.

Scaling up: Landscape modelling tool

The Landscape Modelling Tool (LMT) was developed with three main objectives in mind. Firstly, it prioritizes accessibility, ensuring users can access it without any restrictive hardware or software prerequisites. Secondly, it offers both mapping and computation tools, empowering users to explore and analyse data effectively. Lastly, it imposes no limitations on the scale of application, capable of operating on individual properties or at national levels with equal proficiency.

Employing a unified modelling methodology and consistent, high-resolution data sources enables seamless integration of local changes into broader regional contexts. This facilitates the modelling of potential impacts across vast landscapes with precision and ease, benefiting researchers, analysts, and planners alike. To meet these objectives, we designed a browser-based web application following a containerized three-tier architecture. A Postgres database stores essential application details, managed by a Ruby-on-Rails backend serving a React interface. Docker orchestrates operations, with a dedicated Caddy server acting as a reverse proxy for user interaction. Geoserver handles data storage and processing tasks like re-projection.

The LMT boasts flexibility in data inputs, engagement methods, and output formats, supporting various data types. It is built for open access while accommodating restricted channels for confidential data collaboration. Furthermore, it features an integrated annotation tool which can facilitating machine learning model training for customized land use/land cover characterization. This tool enhances recognition of landscape features like lone trees and hedgerows for carbon storage or habitats and species identification.

nature returns

HM Government

NATURAL ENGLAND

Environment Agency

Forestry Commission

Royal Botanic Gardens Kew

Derbyshire Wildlife Trust

Freshwater Habitats Trust

Gloucestershire Wildlife Trust

GROUNDWORK CHANGING PLACES CHANGING LIVES

National Trust

PLYMOUTH CITY COUNCIL

Working together to build the evidence for nature-based solutions to climate change and biodiversity loss