Leverhulme Centre for Nature Recovery

Developing a high-integrity nature-based carbon sequestration strategy for Oxfordshire

A report from the Enabling nature-based carbon offsetting in Oxfordshire project, funded by Innovate UK

Leverhulme Centre for Nature Recovery

School of Geography and the Environment, University of Oxford

Report author
Alison Smith, Leverhulme Centre for Nature Recovery

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Project partners
Oxfordshire Local Nature Partnership
Cherwell District Council
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Project Lead: Dominic Lamb, South & Vale District Councils
Contributors: Rocey Belandria, Tatiana Bell, Jessie Fieth, Hannah Kenyon, Jo Miskin, Kim Hall, Matt Whitney, Katie Fenton

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Report Summary

This report assesses options for developing an integrated nature and climate strategy in Oxfordshire, based on Oxfordshire's Local Nature Recovery Strategy (LNRS).

By combining the LNRS map with the high-resolution Agile Opportunity Map of Oxfordshire developed by the University of Oxford, we developed a detailed spatial scenario for habitat restoration within the LNRS network, removing constraints such as buildings, roads, water, existing woodland and other priority habitats. We prioritised potential measures to maximise carbon sequestration while still creating a balanced mix of habitats in line with the LNRS priorities. The scenario included restoration of woodland, grassland, wetlands, heathland and tree-grass-scrub mosaics, as well as an increase of 40% in hedgerow length, widespread adoption of silvopasture and silvoarable agroforestry on farmland, and measures to improve soil health and enhance soil carbon on arable land. Urban habitats and ponds were out of scope for this study, and peatland was not considered as there is only 17 hectares in Oxfordshire.

We show that a high-integrity nature-based carbon strategy could increase carbon storage in Oxfordshire by up to 28% (6 million tonnes of carbon) once habitats are mature (e.g. 100 years for woodlands). Over the next 30 years, this strategy could sequester over 180,000 tonnes of carbon annually, offsetting **18%** of Oxfordshire's 2023 emissions. However, only 38,000 tonnes of this total estimated sequestration is covered by existing or emerging market mechanisms (Wilder Carbon, the Woodland Carbon Code, and estimated units under future Soil, Agroforestry and Hedgerow carbon codes), offsetting **4%** of emissions. This is because these market schemes set aside risk buffers of up to 40% of the estimated carbon savings, and do not issue carbon units in advance for all habitat transitions. The most notable missing marketable transition is restoration of intensively cultivated grassland to semi-natural grassland, as well as restoration of wetland and heathland on mineral soils. However, these can be claimed in retrospect under the Wilder Carbon scheme, following implementation and verification of the actual carbon gain, provided good baseline measurements have been taken.

Extending hedgerow and soil carbon restoration to the whole county rather than just within the LNRS network could increase sequestration to offset 20% of emissions, of which 7% are currently marketable. These broad estimates are subject to high levels of uncertainty and represent upper limits, as they assume almost complete conversion or enhancement of low-grade farmland within the LNRS network over the next few decades, which is unlikely to occur in practice.

If emissions continue to decline as planned, the share of residual emissions that could be offset through nature-based solutions could increase significantly, although the sequestration rate will decline as restored habitats mature. Sequestration from nature-based solutions can therefore play an important role, especially in the next 100 years, but this must be accompanied by continued strong measures to reduce emissions from fossil fuels and land-use.

As well as playing a key role in delivering both nature recovery and net zero objectives, this strategy would also deliver multiple benefits for climate change adaptation, helping to reduce the impacts of floods, droughts and heatwaves, and would help to support human health and well-being through

improving air quality and providing nature-rich green spaces for recreation and relaxation. It can help to support more resilient food production, by boosting populations of pollinators and pest predators, and protecting from soil erosion. In contrast, other carbon sequestration options such as fast-growing non-native plantations generally deliver little or no benefit for biodiversity, while the impacts of biochar are highly dependent on the biomass source.

However, this strategy would have trade-offs for food production, as farmland is converted to woodland or less productive grassland options. This is minimised through avoiding conversion of Grade 1 and 2 land to non-agricultural use, but it would still lead to leakage of emissions due to food production in other areas, unless policies also encourage a shift to more plant-rich diets that require less land area.

Delivery of this strategy depends on strong national and local support mechanisms, including adequate carbon prices and payments or incentives for wider benefits, such as through agri-environment schemes. Restored habitats must be protected from development and other threats, and managed sensitively to deliver long-term benefits for carbon, nature and people. Alongside restoring habitats, it is also vital to protect existing habitats for their stored carbon as well as biodiversity and ecosystem services. With good support from both national and local policy mechanisms, this high-integrity policy can play a key role in delivering multiple benefits for carbon, nature and people in Oxfordshire.

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1 Introduction

This report assesses the potential for a high-integrity nature-based carbon strategy for Oxfordshire. The research was commissioned from the Leverhulme Centre for Nature Recovery at the University of Oxford by Oxfordshire's district councils (Cherwell, South Oxfordshire & Vale of White Horse, and West Oxfordshire). It is part of a project funded by Innovate UK, which aims to investigate the potential for high-integrity nature-based carbon markets in Oxfordshire. All outputs can be found on the website of the Oxfordshire Local Nature Partnership.

We aimed to develop a strategy for identifying nature-based solution opportunities that could maximise both carbon sequestration and nature recovery, in line with Oxfordshire's Local Nature Recovery Strategy (LNRS) which was released in November 2025.

The study aimed to:

- **Assess current carbon stocks and sequestration rates** in the mapped LNRS network.
- **Develop a high-integrity nature-based carbon scenario** that optimises carbon storage and sequestration potential alongside protection and enhancement of biodiversity, based on the priorities and potential measures identified in the LNRS.
- **Estimate the outcomes for carbon** storage and sequestration
- **Consider delivery of wider county objectives** for nature recovery, climate adaptation and community benefits, using the Environmental Benefits from Nature Tool.

Section 2 of this report presents the rationale for developing an integrated carbon and nature strategy and explains the significance of the LNRS. Section 3 summarises the mapping approach used for the spatial analysis, which combines the LNRS map with a more detailed land-use map for fine-scale analysis of constraints and opportunities. The remaining sections present the method and results to address each of the aims listed above, and the report concludes with a discussion of key findings and caveats.

2 Why develop an integrated nature and carbon strategy?

Nature-based solutions are defined as actions to protect, restore or sustainably manage natural or human-modified ecosystems to address societal challenges, with benefits for both people and biodiversity (UNEA, 2022). Interest in the role of nature for carbon storage and sequestration has skyrocketed in recent years, with a heavy reliance on offsetting to meet national or corporate Net Zero strategies. However, this has previously led to poorly designed projects predominantly focused on tree-planting, such as monoculture plantations of non-native species, or tree-planting on existing biodiverse grassland, heathland or peatland. Some projects have also been accused of land-grabbing – displacing local communities or indigenous peoples who depend on forests for their livelihoods.

In response, a coalition of environment and development organisations developed four guidelines for high-integrity nature-based solutions for climate change mitigation:

1. NbS are not a substitute for the rapid phase-out of fossil fuels
2. NbS involve a wide range of ecosystems on land and at sea
3. NbS are designed by or in partnership with local communities
4. NbS are explicitly designed to support or enhance biodiversity

These guidelines complement the more detailed IUCN Global Standard for NbS, which also emphasises the need for community participation and biodiversity benefits (IUCN, 2020). They are based on the understanding that high-integrity NbS that support and enhance biodiversity and benefit local communities are more resilient to future environmental and socio-economic change, and thus more likely to deliver long-lasting carbon storage and sequestration (Seddon et al., 2021). For example, monoculture tree plantations can be vulnerable to pests and diseases (Wingfield, 2015) and climate change (e.g. Hutchison et al., 2018), while water-hungry fast-growing non-native tree species can exacerbate water shortages in drought-prone regions (Chausson et al., 2020). In contrast, healthy, biodiverse and well-connected ecosystems are expected to be more resistant to climate change pressures such as floods, heatwaves and droughts (e.g. Bai and Tang, 2024; De Keersmaecker et al., 2016; Lawson et al., 2023; Oliveira et al., 2022; Wang et al. 2025).

In England, the emergence of Local Nature Recovery Strategies (LNRS) provides a key opportunity for ensuring that NbS can be designed to deliver genuine benefits for biodiversity and people. LNRS are a statutory requirement of the Environment Act 2021 and must be produced by all Responsible Authorities (typically county councils or unitary authorities) in England. Together, they are intended to provide a nationwide nature recovery network, as a crucial step towards meeting the Environment Act 2021 targets to halt and reverse biodiversity loss in England, in line with the UK's commitment under the Global Biodiversity Framework.

Oxfordshire's LNRS was developed through a process of intensive engagement with local stakeholders and biodiversity experts from 2023-2025 (see LNRS website, including the consultation report by Smith et al., 2025). It forms a network throughout the county, linking high-value biodiversity sites such as nature reserves and ancient woodlands via linear features such as river valleys and the chalk downland of the Ridgeway (Figure 1).

The LNRS lists 128 Potential Measures (PMs) to enhance biodiversity (Appendix 1). Of these, 80 are mapped to specific locations in the county. These include 37 mapped measures to create new habitats or enhance existing habitats such as native woodland, semi-natural grassland, heathland, scrub, wetlands, hedgerows, ponds and rivers. A further 43 mapped measures identify locations to support local species that require specific conservation actions not covered by the general habitat creation and enhancement actions, such as managing chalk grassland for Monkey Orchids, creating patches of bramble and honeysuckle in woodlands for White Admiral butterflies, or conserving deadwood in orchards for the Noble Chafer Beetle. Finally, there are 48 unmapped measures which could be implemented in many locations throughout the county, such as planting hedgerows, agroforestry or urban trees, maintaining patches of scrub on grasslands, and improving the health of farmland soils.

Because the LNRS has been tailored by local experts to support important local species and habitats, it is the ideal basis for developing an integrated carbon-nature strategy. Directing carbon offset funding towards actions that support the LNRS can help to deliver Oxfordshire's Net Zero and Nature Recovery strategies at the same time, thus providing greater value for money. It can also avoid conflicts where one strategy undermines the other, such as if trees are planted on a site which is an important opportunity for wetland or grassland creation.

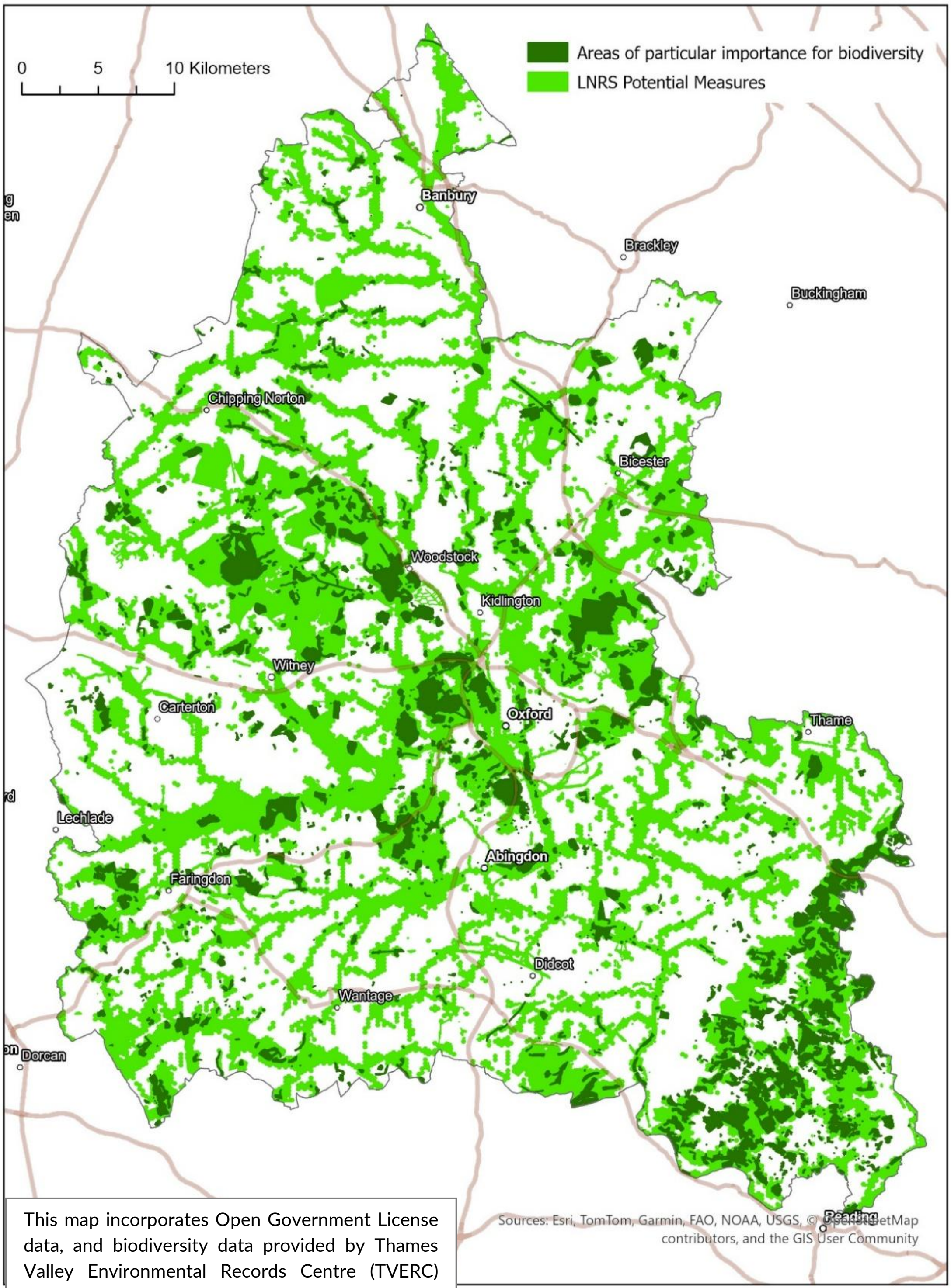
Proposed principles for carbon offsetting in Oxfordshire aim to prioritise emission reduction, deliver offsetting locally, and maximise co-benefits for biodiversity and local people (Fieth and Hall, 2025). This aligns well with the NbS Guidelines. Oxfordshire's local authorities are already making ambitious efforts to cut emissions from fossil fuels (Oxfordshire County Council, 2024), thus meeting NbS Guideline 1. However, there will still be a need to offset residual emissions at least up to the Net Zero target date.

Integrating the carbon offsetting strategy with the LNRS enables the remaining three guidelines to be met:

- the LNRS aims to restore a wide range of local habitats (Guideline 2),
- it has been developed in consultation with local stakeholders (Guideline 3), and
- it is targeted at delivering benefits for biodiversity (Guideline 4).

We therefore used the LNRS as the starting point for developing an integrated nature-climate strategy.

Figure 1. Oxfordshire's Local Nature Recovery Strategy map, showing core areas of particular importance for biodiversity (APIBs) and the target recovery zone for potential measures to improve biodiversity.



This map incorporates Open Government License data, and biodiversity data provided by Thames Valley Environmental Records Centre (TVERC) which is copyright to TVERC and its partners.

3 Spatial analysis

3.1 The LNRS map

The LNRS map identifies broad areas where the different Potential Measures (PMs) could be applied. In most locations there is a choice of several overlapping PMs, allowing landowners to choose a measure which fits with their requirements and with the local context. However, the LNRS is not intended as a detailed land-use map. For example, fine-scale constraints such as roads, houses and water have not been removed from the opportunity areas. Also, habitat creation opportunities were derived largely from Natural England's national map of Nature Recovery Networks for different habitats, but took a very inclusive approach by including existing and associated habitats as well as restoration opportunities (Bell, 2025) and did not take account of additional factors such as the location of flood zones (for creation of wet habitats). Therefore, to estimate carbon sequestration potential more precisely, the LNRS map of PMs was intersected with the Agile Nature-based Solution and Nature Recovery Opportunity Map for Oxfordshire.

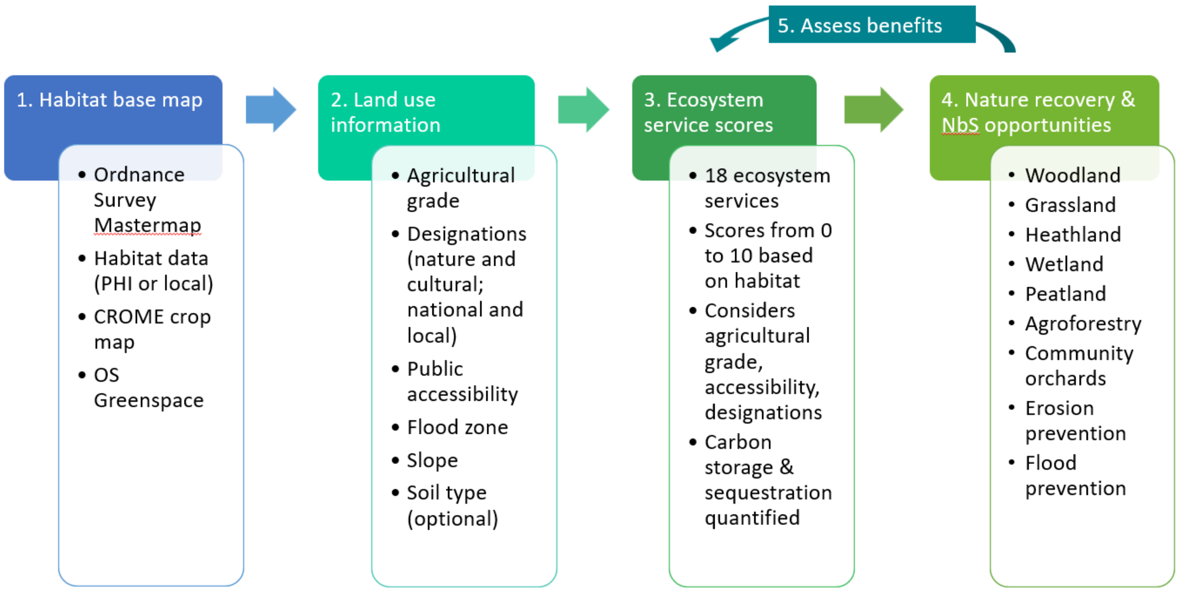
3.2 The Agile nature recovery opportunity map

The Agile mapping system, developed by the Agile Initiative at the University of Oxford, combines spatial datasets from multiple sources to produce a highly detailed land-use map that can be used to support nature recovery decision-making by local stakeholders (Smith, 2024). The maps show areas which are potentially suitable for specific types of interventions, such as creating woodlands, grasslands and wetlands and restoring peatlands, based on a series of simple rules. They are intended to encourage the siting of interventions in the most suitable locations to maximise benefits and minimise trade-offs.

The Agile maps integrate the following information (Figure 2):

- Habitat, based on information from OS Mastermap, Natural England's Priority Habitat Inventory or local data, CROME crop map of England and OS Greenspace data.
- Agricultural land classification, Designations and Public accessibility
- Scores from 0 to 10 for 18 ecosystem services, and a similar score for biodiversity
- Estimates of carbon stored and sequestered per hectare (which can be used to estimate totals for the area)
- Opportunities for nature recovery and nature-based solutions: creation or restoration of woodland & scrub, grassland, heathland and wetland; peatland restoration; agroforestry opportunities (silvoarable or silvopasture), community orchards, erosion prevention (on steep slopes and erodible soils) and natural flood management (on poorly drained soils).

Figure 2. How the Agile maps integrate multiple data sources to map habitats, assign ecosystem service scores, and identify nature recovery opportunities

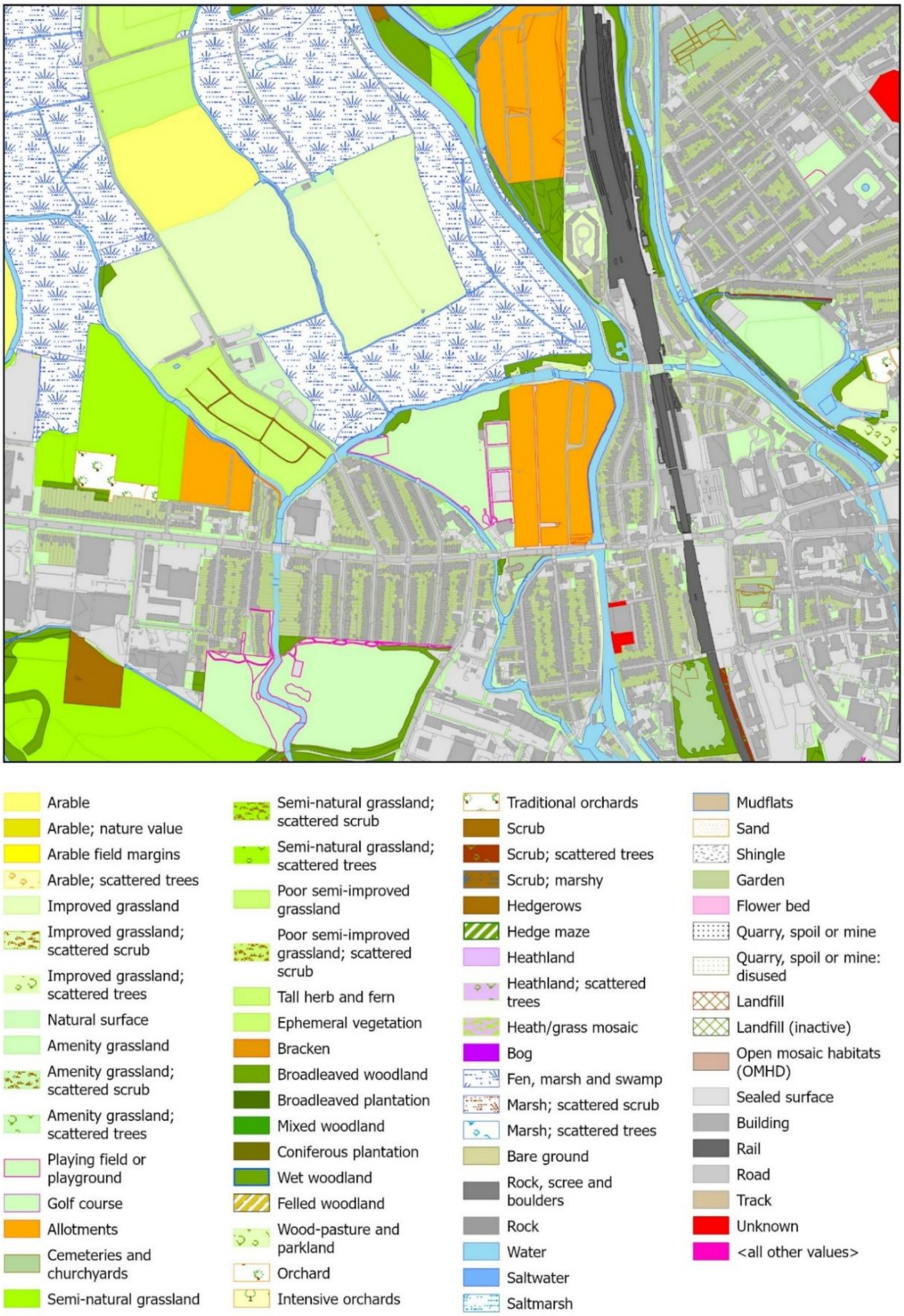


Because the Agile maps are based on Ordnance Survey Mastermap (OSMM), they provide complete, detailed land cover maps with no gaps or overlaps. They are vector maps, not raster maps, so they show detail of roads, buildings, gardens, urban greenspace such as allotments and cemeteries, and even roadside verges (Figure 3). The polygons match OSMM boundaries except where additional boundaries have been added during the integration of local habitat data. The full map is shown in Figure 4.

For this project we updated the Agile map of Oxfordshire using the latest OSMM and OSMM Greenspace data, downloaded in November 2025, and the most recent (May 2025) local habitat data from Thames Valley Environmental Records Centre (TVERC), under license. The TVERC data is more up to date than Natural England's Priority Habitat Inventory, the default source for the Agile maps, but many of the habitat observations are several years old and/or are based only on aerial photo interpretation rather than site visits. Therefore, although the Agile opportunity maps are a powerful tool for strategic analysis at the county scale, they should always be used in conjunction with ground-truthing and consultation with local experts (Warner and Smith, 2024), as part of a process of participatory engagement with local stakeholders (Hafferty, 2023).

The Agile map incorporates scores for 18 ecosystem services, based on habitat type, agricultural land class, public accessibility and designations, and estimates of carbon stored and sequestered for each habitat. Habitat areas, ecosystem service scores and carbon values were exported to an Excel spreadsheet for analysis, producing a habitat inventory for Oxfordshire and for the LNRS network (Figure 5, Table 1) and estimates of current carbon stored and sequestered in Oxfordshire (Section 4).

Figure 3. Extract from the Agile habitat map showing complete and detailed coverage including greenspace



Created using Agile Opportunity Maps software from the Oxford Martin School. This map incorporates OS data (© Crown Copyright and database rights 2025 Ordnance Survey AC0000851941), Open Government License data, and biodiversity data provided by Thames Valley Environmental Records Centre (TVERC) which is copyright to TVERC and its partners.

Figure 4. Habitat map of Oxfordshire

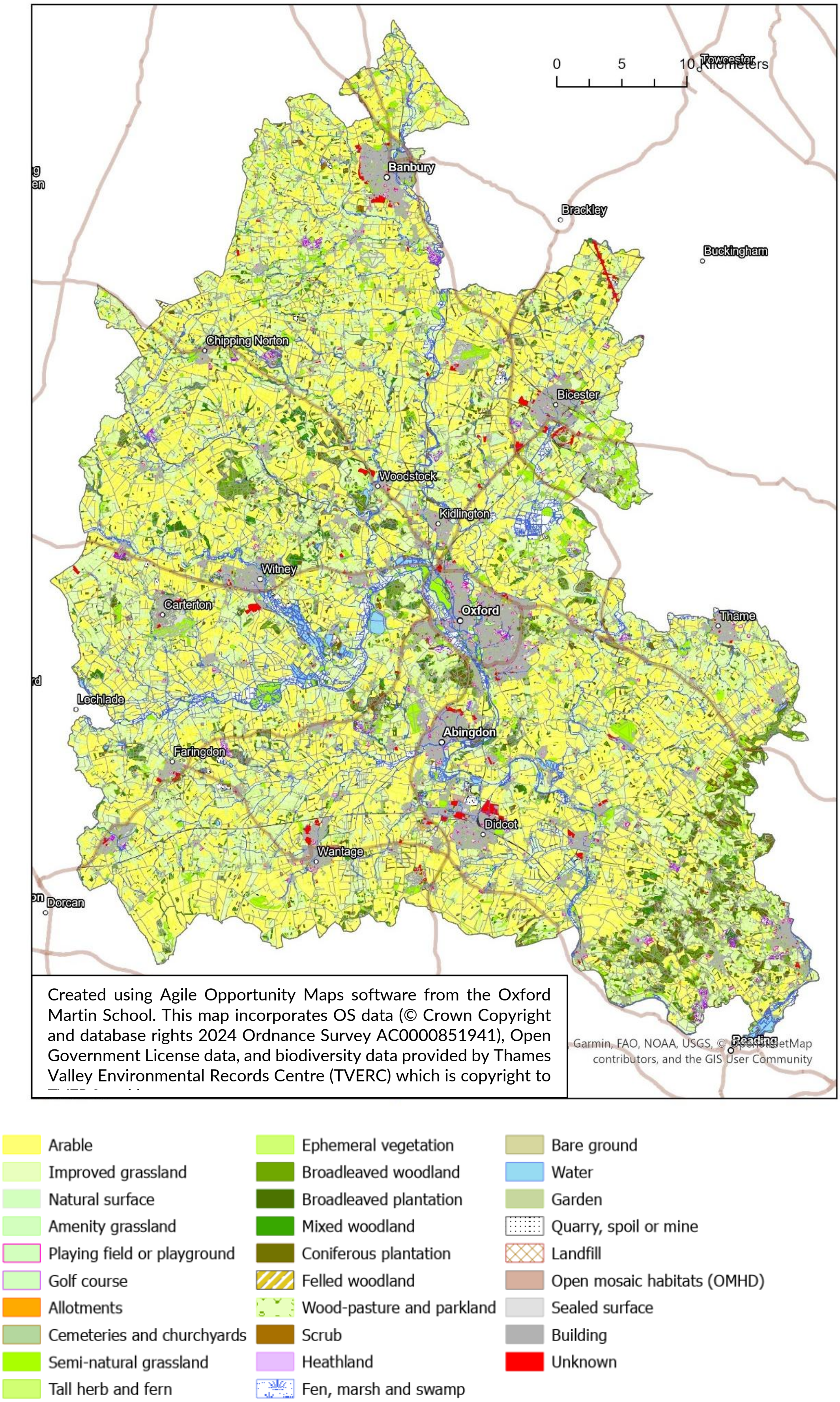
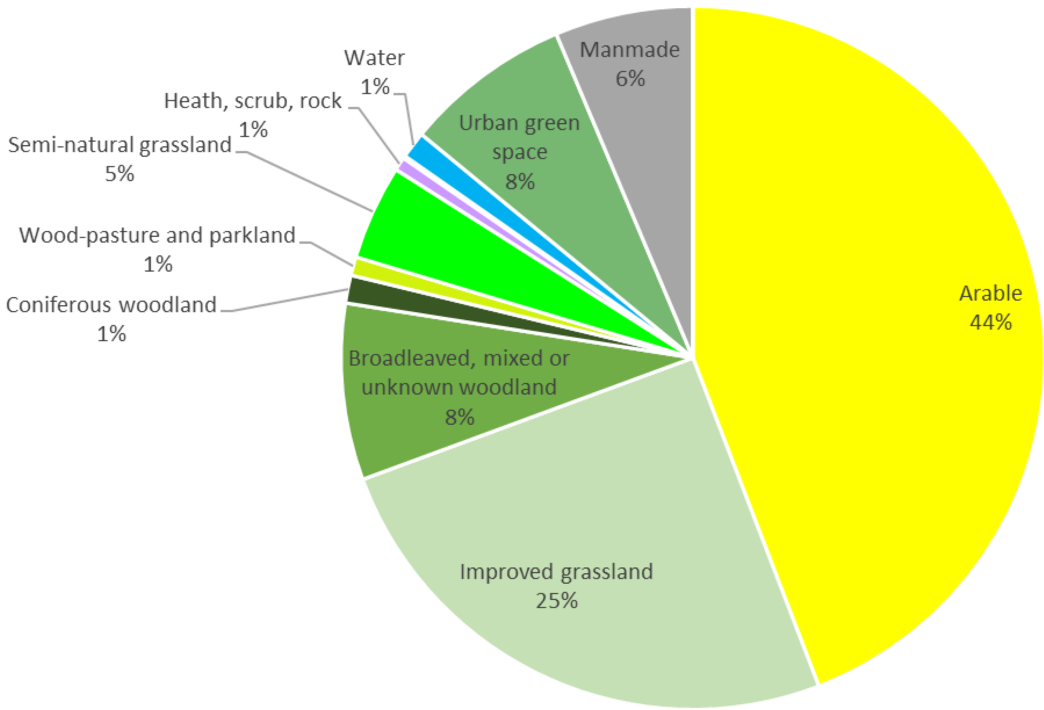


Figure 5. Breakdown of broad habitat types in Oxfordshire (top) and the LNRS network (bottom)



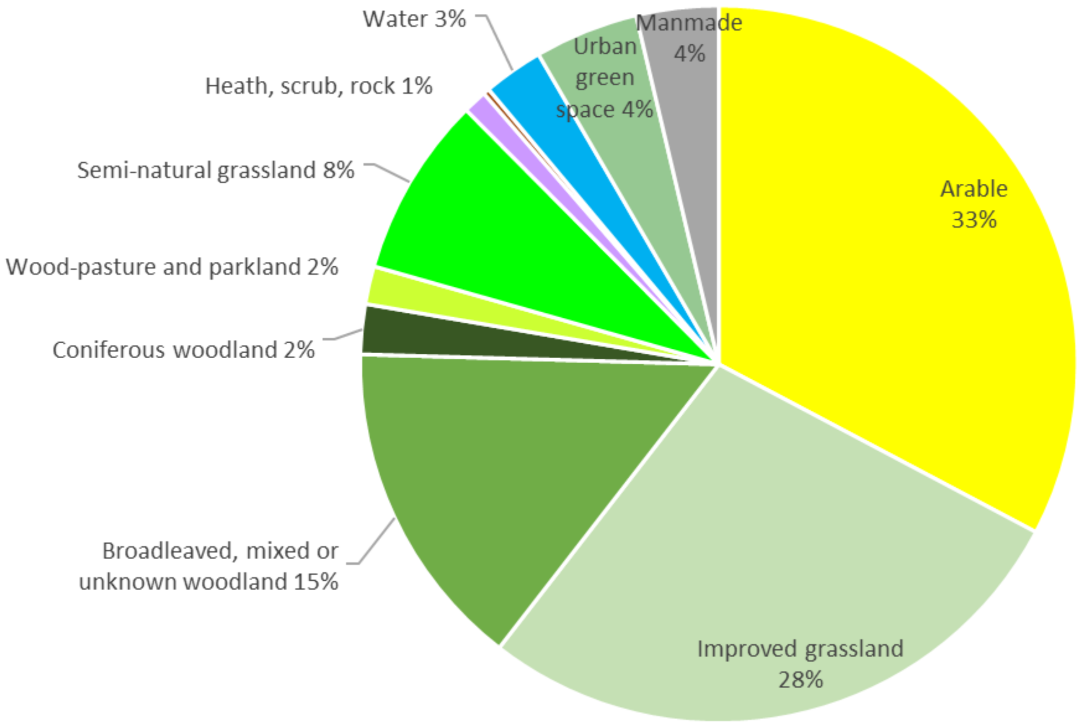


Table 1. Breakdown of habitats in Oxfordshire and in the LNRS network, from the Agile maps

	Oxfordshire		LNRS network	
Habitat	**ha**	**% of total**	**ha**	**% of total**
Arable	114,825	44%	34,503	33%
Improved grassland	65,685	25%	29,410	28%
Intensive orchards	12	0%	2	0%
Total intensive farmland	**180,522**	**69%**	**63,914**	**60%**
Coniferous plantation	3,322	1%	2,370	2%
Mixed woodland	3,102	1%	2,305	2%
Broadleaved woodland	18,049	7%	13,541	13%
Traditional orchards	284	0%	208	0%
Total woodland	**24,757**	**9.5%**	**18,424**	**17%**
Wood-pasture and parkland or scattered trees	2,219	1%	1,813	2%
Scrub	1,592	1%	1,113	1%
Heathland	4	0%	4	0%
Semi-natural grassland	7,766	3%	5,087	5%
Fen, marsh and swamp	3,932	2%	3,845	4%
Open mosaic habitats (OMHD)	196	0%	131	0%
Total non-woodland semi-natural habitats	15,709	6%	11,993	11%
Total semi-natural habitats excl. water and conifer plantations	**37,144**	**14%**	**28,047**	**26%**
Rivers and streams	1,171	0%	1,112	1%
Lakes, reservoirs and ponds	2,045	1%	1,757	2%
Water	**3,216**	**1%**	**2,869**	**3%**
Building	4,418	2%	656	1%
Road	4,141	2%	976	1%
Other sealed surfaces	6,682	3%	1,865	2%
Manmade unsealed surface (e.g. quarry, landfill, felled woodland)	669	0%	352	0%
Unknown (usually building sites)	1,013	0%	191	0%
Total buildings and manmade surfaces	**16,925**	**6%**	**4,041**	**4%**
Garden	10,879	4%	1,913	2%
Amenity grassland, golf courses, playing fields, etc.	8,199	3%	2,715	3%
Allotments	263	0%	93	0%
Cemeteries and churchyards	123	0%	33	0%
Total gardens and urban green space	**19,464**	**7%**	**4,754**	**4%**
Total urban (buildings, manmade and green space)	**36,388**	**14%**	**8,795**	**8%**
Total	**260,592**	**100%**	**105,996**	**100%**

3.3 Combining the LNRS and Agile maps

Before combining the Agile map with the LNRS map, we pre-processed the overlapping layers of LNRS potential measures into a single layer, using an adapted module from the Agile mapping software, and created an extra attribute that concatenated all the LNRS PMs into a single string, separated by commas.

This layer was then intersected with the Agile map in ArcGIS, producing a dataset with 929,000 rows (polygons). The ArcGIS Summarise function was applied to this layer to create a table of key attributes which included the detailed Agile habitat classification, Agricultural Land Class, Flood Zone, soil type, key designations, the Agile opportunity zones for peatland, grassland, woodland etc, and the attribute containing all the LNRS PMs. Using this large number of attributes meant that very few rows had exactly the same attributes, resulting in a very large 'summary' table of 340,000 rows, which was exported to Excel for further analysis. The Excel file was converted to a binary workbook to reduce the size and make analysis more manageable.

The analysis involved creating additional columns in this spreadsheet to define the integrated carbon-nature scenario based on the existing habitat, LNRS PMs and Agile opportunity zones, as described in Section 5, and then assessing the outcomes of this land-use change for carbon storage and sequestration (Section 6), and biodiversity and ecosystem services (Section 7).

3.4 Hedgerows

Hedgerows are not included in the Agile map, as they are line features (not polygons), so they were analysed separately. We considered three different hedgerow datasets that provide differing estimates of hedgerow length in Oxfordshire (Table 2). Each of these has different issues affecting the accuracy, largely arising from the method of creating the datasets by overlaying remote sensing data with maps of field boundaries, which may miss or double-count features. The datasets considered were:

- **UKCEH**; a line dataset of hedgerows and hedgerow trees based on intersecting LIDAR data on vegetation height with field boundaries (UK Centre for Ecology & Hydrology, 2024). This records the height of features and whether they are alongside a road, or whether they are part of a 'double hedge' (e.g. two sides of a track). However, as the field boundaries are based on the UKCEH Land Cover Map which has simplified field boundaries, they do not match actual boundaries on the ground. This means that some features are omitted during the overlay process, leading to an underestimate.
- **RPA**: a line dataset of hedgerows, hedgerow trees and lines of trees produced by the Rural Payments Agency and provided to the University of Oxford under license via the Ordnance Survey for research purposes only. This has proved reasonably accurate in limited comparison with aerial photos. While we cannot share the underlying spatial data, we can use the overall hedgerow length.
- **Google**: the beta-testing version of a raster dataset of hedges, woodland and individual trees developed by Google in partnership with the University of Oxford, based on aerial photos taken between 2018 and 2021. This was converted to a vector (polygon) dataset by the author and intersected with field boundaries from OSMM to estimate hedgerow length. This is an excellent dataset but the intersection with field boundaries can lead to double counting where the tree canopy overhangs more than one boundary feature, e.g. two sides of a track. Also, woodland boundaries have not been excluded, so it may give an over-estimate.

We concluded that the RPA dataset could provide the most accurate estimate of current hedgerow length. This dataset distinguishes hedges and lines of trees along woodland boundaries, but these may not be distinct from the woodland edge so they were excluded, giving an estimate of around 12,000 km of hedgerows and lines of trees in Oxfordshire and 4,300 km in the LNRS network.

Table 2. Estimates of current hedgerow length in Oxfordshire

Length, km	Oxfordshire			LNRS network			Notes
	Hedges	Lines of trees	Total	Hedges	Lines of trees	Total	
UKCEH	4,774	3,938	**8,712**				Underestimate, as field boundaries are based on UKCEH LandCover Map which is simplified and does not match actual boundaries.
OS/RPA	9,564	2,591	**12,155**	3,499	768	**4,267**	Excluding 'woodland boundaries'
Google beta version	6,160	11,545	**17,705**				May include woodland boundaries May double count if double track boundaries overlap a single feature

4 Current carbon storage and sequestration in Oxfordshire

The Agile opportunity maps include estimates of carbon storage and sequestration for each habitat, based on a range of literature sources and assumptions (Appendix 2). These estimates are based on a few key sources for broad habitat types (including semi-natural broadleaved woodland, coniferous plantation, scrub, semi-natural grassland, heathland, bog, arable land and improved grassland). Values for related habitats are then derived based on scores from zero to 10 that rank habitats in the correct order based on understanding of the key factors affecting carbon storage and sequestration from an extensive literature review of over 700 papers (Smith et al., 2017). Further values for composite habitats (such as grassland with scattered trees) are then calculated based on combinations of the major habitats.

For this project, we conducted a brief review of recent academic and grey literature to determine whether improved data had become available. We also compared the Agile values to the findings of the comprehensive review of carbon sequestration and storage potential for habitats relevant to Oxfordshire that was produced as part of this project (Thomas, 2025).

We determined that although some updated sources are now available (notably the Natural England report by Gregg et al 2021, which updates the report by Alonso et al 2012 that was used to derive some of the initial values), these do not provide internally consistent values. For example, Gregg et al 2021 warns that the values for grassland habitats are based on different soil depths, whereas the values used by Agile are all based on 30cm depth. Also, in Gregg et al (2021) semi-natural grassland is assigned zero sequestration whereas improved grassland sequesters carbon, implying that a transition from semi-natural to improved grassland could result in a carbon gain. This conflicts with evidence from the wider literature which shows that ploughing, reseeding and fertilising grassland is likely to lead to loss of soil carbon (Anderson, 2024; Loges et al., 2024), while restoring improved grassland to semi-natural grassland is likely to enhance carbon storage (De Deyn et al., 2011). Several mechanisms underpin this observation: deep-rooted species in semi-natural grassland transfer soil carbon lower in the soil profile (Jackson et al., 2017); slower-growing species like sheep's fescue and harebell decompose more slowly, (Anderson, 2024); greater species diversity promotes microbial activity, soil carbon formation and stability (Yang et al., 2019), and greater structural diversity of grasses and flowering plants leads to 'niche complementarity', whereby resources (water, sunlight, nutrients) can be more efficiently exploited (Tilman et al., 2001). We therefore conclude that for the purposes of this project, the Agile values are still the most internally consistent and comprehensive dataset available, providing full coverage of all habitat types, although there is scope for a more detailed updating exercise in future work.

Maps of carbon storage and sequestration based on the Agile values are shown in Figure 7 and Figure 8, highlighting the importance of the carbon-rich core LNRS APIB areas which include most of Oxfordshire's ancient woodlands, meadows and wetlands. (The LNRS recovery zone is not shown on these maps as it is too complex and obscures the map detail.)

Total carbon storage and sequestration in the whole of Oxfordshire and in just the LNRS network is summarised in Table 3. This shows that although the LNRS network covers just 41% of the county it stores 51% of the county's carbon and sequesters 81%, largely due to the core APIB areas. The recovery zone, as expected, currently only stores and sequesters very slightly more than the county average, as it consists mainly of intensive farmland, giving high potential for enhancement.

Table 3. Estimated carbon storage and sequestration in soils and vegetation in Oxfordshire and in the LNRS network at present, showing the difference between the core APIB areas and the LNRS recovery zone

	Area, ha	Carbon stored, tC	Carbon sequestered, tC/y	Average C storage tC/ha	Average C sequestration tC/ha/y
Oxfordshire	260,592	22,023,103	102,904	85	0.39
LNRS (whole)	105,996	11,172,704	83,195	105	0.78
LNRS core (APIB)	16,064	3,266,269	45,358	203	2.82
LNRS recovery zone	89,932	7,906,434	37,838	88	0.42
LNRS as % of county	41%	51%	81%		
APIB as % of LNRS	15%	29%	55%		
APIB as % of county	6%	15%	44%		

To put this in context, the total net emissions from all sources for Oxfordshire was estimated as 3,833,000 tCO_{2e}/y in 2023, equivalent to 1,045,000 tC/y (DESNZ, 2025). Thus annual sequestration by soils and vegetation currently removes 10% of current emissions, but the carbon stored in soils and vegetation is equivalent to 20 years of current emissions (Figure 6). This highlights the need to protect stored carbon as well as restoring habitats to enhance storage and sequestration. It also shows that nature-based carbon sequestration cannot be a substitute for emission reduction, but is a complementary strategy.

Figure 6. Comparison of carbon stored and sequestered in Oxfordshire's ecosystems with annual emissions from all sources

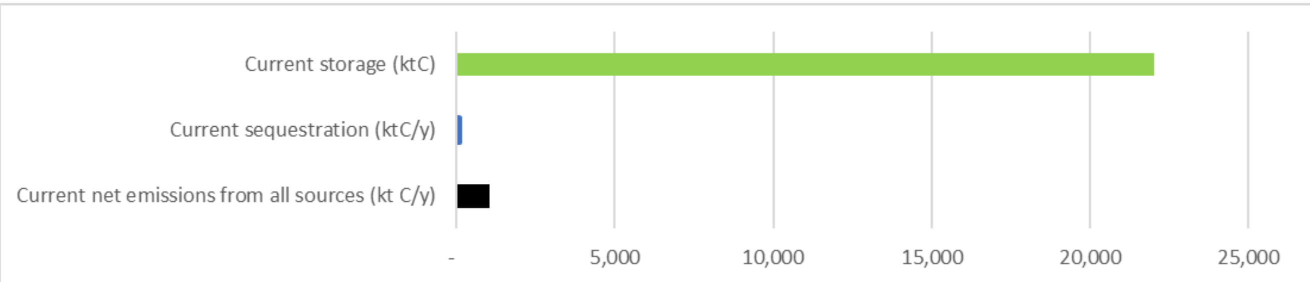


Figure 7. Current estimated carbon storage in Oxfordshire, showing the LNRS core areas (APIBs)

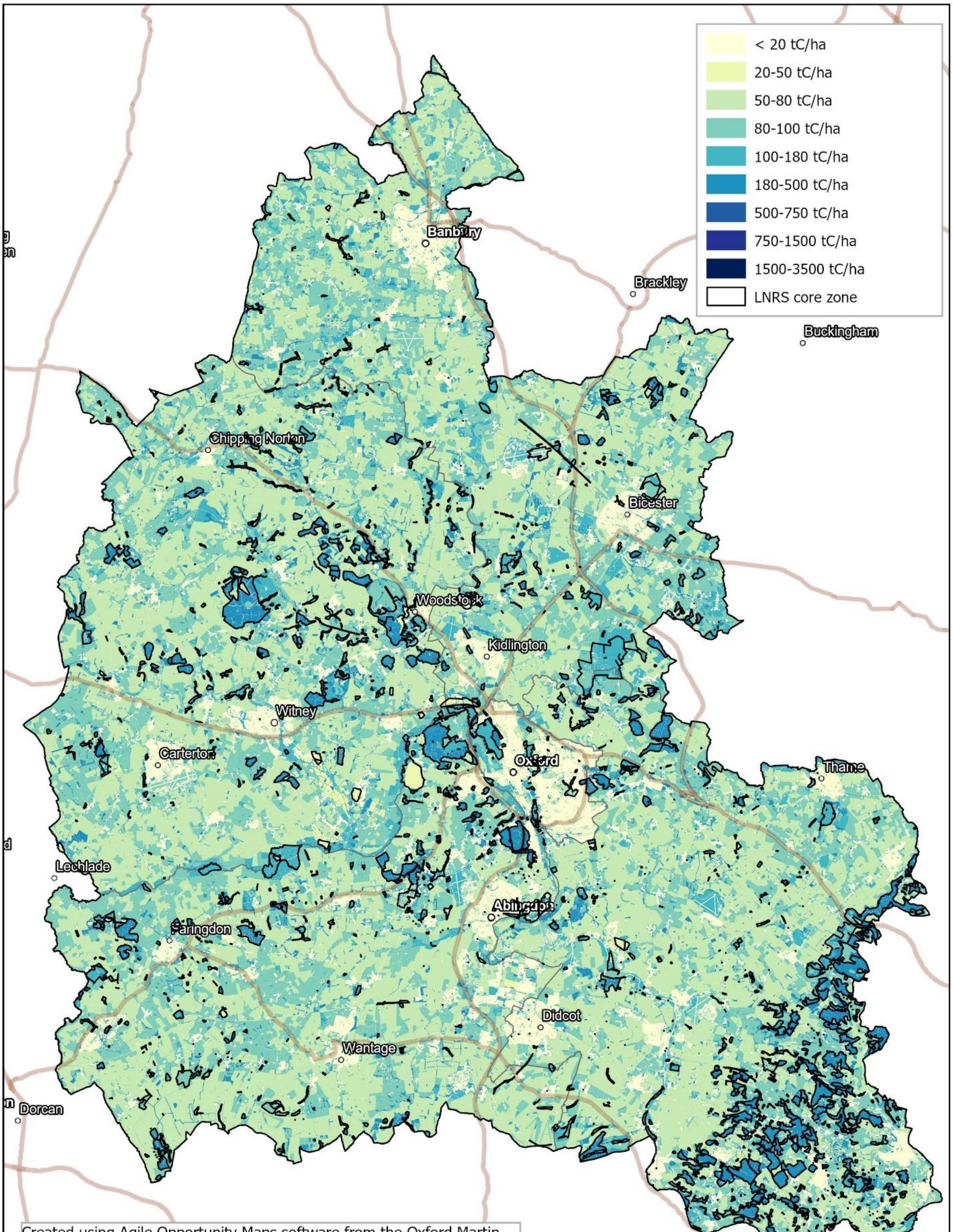
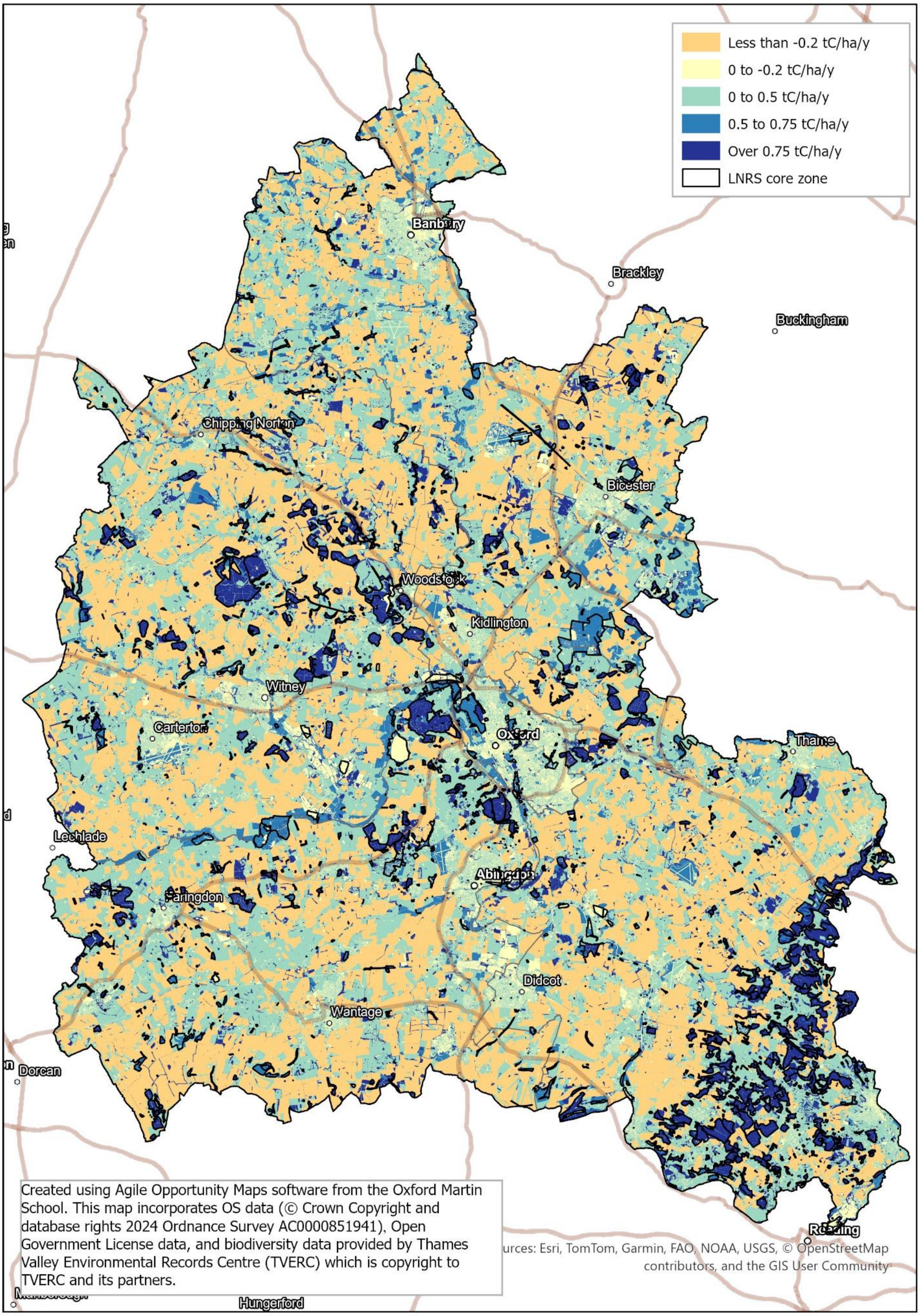


Figure 8. Current estimated carbon sequestration in Oxfordshire, showing the LNRS APIBs



5 Developing an integrated carbon and nature strategy

5.1 Identifying potential measures to include

We aimed to develop a scenario to optimise carbon storage and sequestration potential alongside protection and enhancement of biodiversity, based on the priorities and potential measures identified in the LNRS.

We focused on the potential measures for creating new habitats, rather than enhancing existing habitats, as these are likely to have the greatest carbon impacts. However, we also considered the potential for soil carbon enhancement on farmland.

The parallel report on carbon markets for this project (Thomas et al. 2025) identifies a range of priority interventions for Oxfordshire including hedgerow expansion, river floodplain restoration, regenerative agriculture, and selective woodland planting, all of which deliver co-benefits for biodiversity, flood management and soil health, reducing climate and ecological risk simultaneously. While woodlands are important carbon sinks, other options including grassland restoration, floodplain re-naturalisation, and hedgerow expansion are also important for both carbon and biodiversity, and are easier to scale up within Oxfordshire's agricultural landscape.

The LNRS includes a wide range of relevant habitat creation measures (. For this study, we did not consider unmapped LNRS measures outside the network, although these are very important and could deliver further benefits for both carbon and biodiversity (see Section 8.5). We also did not consider pond creation, because no carbon data is yet available, although ponds are also a vital measure for nature recovery. Finally, urban areas are also very important both for wildlife and people but were excluded because the focus was on creating larger habitat areas.

Table 4). The full list is in Appendix 1, including unmapped and species-focused measures. For this study, we did not consider unmapped LNRS measures outside the network, although these are very important and could deliver further benefits for both carbon and biodiversity (see Section 8.5). We also did not consider pond creation, because no carbon data is yet available, although ponds are also a vital measure for nature recovery. Finally, urban areas are also very important both for wildlife and people but were excluded because the focus was on creating larger habitat areas.

Table 4. Relevant LNRS Potential Measures (PMs) for habitat creation in Oxfordshire

PM number	Description
PM_5	Create areas of calcareous species-rich grasslands in suitable locations, particularly slopes
PM_6	Create areas of neutral species-rich grasslands in suitable locations
PM_7	Create areas of species-rich acid grasslands in suitable locations
PM_9	Create new areas of lowland meadow by creating and restoring meadows in suitable locations (particularly on floodplains)
PM_22	Create new areas of heathland on suitable soil types
PM_29	Create (and manage) areas of new parkland and wood pasture, planning to produce future ancient and veteran trees
PM_30	Create new areas of habitat that contain a matrix of habitat types including small woodland patches, scattered trees, scrub, and grassland
PM_38	Create new woodland by planting trees (or enabling their natural regeneration) using species that are suited to the soil type and site conditions

PM_40	Create new areas of wet woodland along rivers, river corridors, and riparian land as appropriate
PM_54	Create wetland habitats that contain a matrix of various habitat types suitable for the site (e.g. wet grassland, ponds, ditches, hedgerows, trees, or wet woodland)
PM_58	Create areas of new good quality grazing marsh and enhance (or maintain a good condition) of existing floodplain grazing marsh

5.2 Excluding constraints

As described in Section 3, we intersected the LNRS map with the detailed Agile opportunity map to ensure that constraints on habitat creation were excluded. For example, the LNRS identifies 24,800 ha of land with potential for woodland creation; this consists of 8,112 ha of broadleaved woodland (PM 38) and 17,453 ha of wet woodland (PM 40) with some overlap between the two. However, removing constraints (buildings, roads, rail, water, existing woodland, biodiverse grassland) reduces the woodland opportunity area to 22,000 ha. Of this, a further 1,600 ha is high grade farmland, where planting trees is likely to result in displaced impacts elsewhere, leading to emission 'leakage' (e.g. though deforestation in other countries supplying food or feed to the UK; see Section 8.4). This is not in line with high-integrity carbon removal practice, so these areas were excluded, reducing the available area to 20,400 ha. A further 450 ha has competing land uses: private gardens, golf course fairways, allotments, cemeteries, churchyards and playing fields; excluding these would reduce the total to 19,940 ha. Finally, around 2,800 ha is rough and/or marshy grassland, scrub and scattered trees, which may be better used for grassland, wetland or mosaic habitats. Excluding this would reduce the woodland creation opportunity area to 17,100 ha.

As the LNRS can offer a choice of up to 15 potential measures in any one location, we needed to narrow this down to specific measures so we could estimate carbon benefits. We therefore opted to develop two scenarios, reflecting minimum and maximum potential carbon benefits.

5.3 Minimum carbon scenario

The minimum carbon scenario simply assumes that the option with the lowest carbon benefit is implemented in each location. This is creation of grassland: either calcareous grassland on calcareous soil, or neutral grassland elsewhere. While this uniform grassland-only approach would not be in line with the need to create a diverse mix of habitat types, it reflects a 'worst case' scenario which has some basis in reality, as recent unpublished assessment of biodiversity net gain projects indicates that many farmers prefer grassland creation options. This is because grassland is a) more reversible than tree, scrub or wetland creation and b) allows food production (grazing) to continue.

5.4 Maximum carbon scenario

For the maximum carbon scenario, we took the following approach.

1. **Peatland restoration** is prioritised where possible (this only affects 17 ha).
2. **Broadleaved native semi-natural woodland** creation takes place where LNRS PM 38 intersects the Agile map 'no constraints' zone for woodland creation (i.e. excluding buildings, roads, rail, water, existing semi-natural habitats, existing plantations and Grade 1 and 2 farmland), and the area is not on the floodplain.
3. **Wet woodland** creation takes place where LNRS PM 40 intersects the Agile map top priority zone for woodland creation (within 200m of existing woodland and no constraints on woodland creation, as above), and the area is on the floodplain (but not on 'marshy grassland'

which may have existing biodiversity value and/or is considered more suitable for other floodplain habitats). Wet woodland was restricted to only the top priority Agile zone because otherwise woodland would occupy a third of the floodplain, leaving little space for floodplain meadows, wetlands, and grazing marsh (see Section 5.5 for more information).

4. **Wood-grass-scrub mosaics** were created where LNRS PM 30 intersects the Agile map zones where both woodland and grassland creation are possible (no constraints, as listed above). Creation of wood-pasture and parkland (PM29) was not modelled separately, for simplicity, but it would be suitable in similar locations and would have similar outcomes for carbon, biodiversity and ecosystem services.
5. **Other habitats are allocated in order of scarcity**: heathland, acid grassland, lowland meadows (if on the floodplain and no existing scattered trees or scrub), lowland fens, calcareous grassland, neutral grassland, traditional orchards, silvopasture, silvoarable. In each case, suitability was determined using the Agile map opportunity zones to rule out constraints.
6. **High grade farmland** (Grade 1 or 2) was allocated to silvoarable or silvopasture.

Trial and error was used to develop this approach, with the aim of ensuring a balanced mix of habitats. The resulting new habitats created are shown in Table 5, and the changes compared to existing habitats are shown in Table 6 and Figure 9.

Table 5. New broad habitat areas created under the maximum carbon-nature scenario

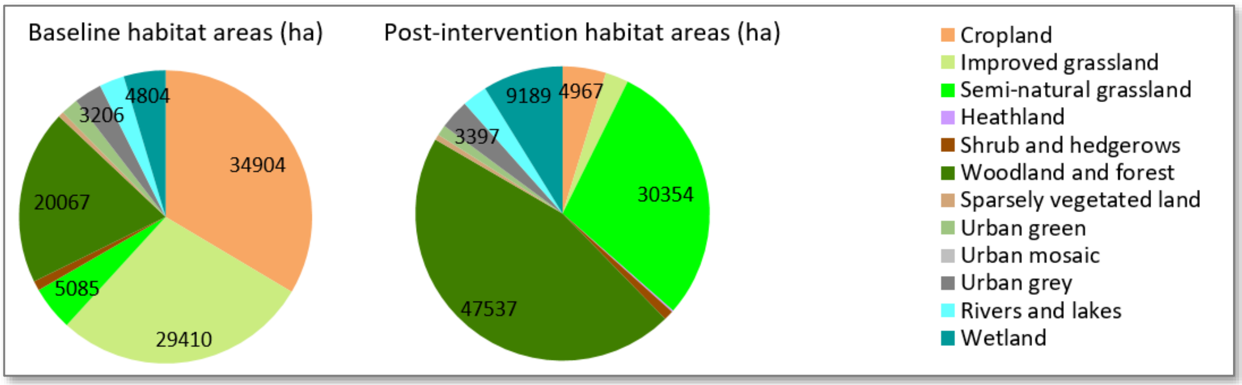
New habitat created	Ha	% of total created
Broadleaved woodland	7,481	11%
Wet woodland	4,004	6%
Semi-natural grassland	25,197	38%
Acid grassland	*674*	*1%*
Calcareous grassland	*10,342*	*16%*
Neutral grassland	*13,224*	*20%*
Lowland meadows	*1,139*	*2%*
Tree-grass-scrub mosaic	16,003	24%
Heathland	170	0%
Fen, marsh and swamp	5,344	8%
Silvoarable	4,331	7%
Silvopasture	2,605	4%
Traditional orchards	355	1%
Grand Total	65,671	100%

Table 6. Existing and new habitat areas in Oxfordshire and in the LNRS network area under the maximum carbon-nature scenario (simplified habitat categories)

Area, ha	Oxon existing	LNRS existing	Max Carbon LRNS	Max Carbon Oxon	%Oxon existing	% Oxon Max Carbon	Change in % Oxon
Acid grassland	65	57	723	731	0.03%	0.28%	0.26%
Allotment	263	93	93	263	0%	0%	0%
Amenity grassland	3,349	941	1	2,408	1%	1%	0%
Arable	114,814	34,494	70	80,391	44%	31%	-13%
Arable; nature value	11	9	-	2	0%	0%	0%
Bare ground	48	24	24	48	0%	0%	0%

Area, ha	Oxon existing	LNRS existing	Max Carbon LRNS	Max Carbon Oxon	%Oxon existing	% Oxon Max Carbon	Change in % Oxon
Bracken	24	23	-	2	0%	0%	0%
Broadleaved plantation	1,519	1,006	1,006	1,519	1%	1%	0%
Broadleaved woodland	16,369	12,375	19,856	23,849	6%	9%	3%
Wet woodland	162	159	4,163	4,166	0%	2%	2%
Building	4,418	656	656	4,418	2%	2%	0%
Calcareous grassland	1,148	954	11,296	11,491	0%	4%	4%
Cemeteries & churchyards	123	33	33	123	0%	0%	0%
Coniferous plantation	3,322	2,370	2,370	3,322	1%	1%	0%
Ephemeral vegetation	19	19	19	19	0%	0%	0%
Felled woodland	17	17	-	0	0%	0%	0%
Fen, marsh and swamp	248	245	4,386	4,389	0%	2%	2%
Garden	10,879	1,913	1,913	10,879	4%	4%	0%
Golf course	1,260	620	620	1,260	0%	0%	0%
Heathland	4	4	174	174	0.0%	0.1%	0%
Improved grassland	65,685	29,410	34	36,310	25%	14%	-11%
Intensive orchards	12	2	2	12	0%	0%	0%
Landfill	76	59	59	76	0%	0%	0%
Marshy grassland	3,622	3,542	3,542	3,622	1%	1%	0%
Mixed woodland	3,102	2,305	2,305	3,102	1%	1%	0%
Natural surface	2,163	796	0	1,367	1%	1%	0%
Neutral grassland	5,665	3,467	16,691	18,889	2%	7%	5%
Open mosaic habitats (OMHD)	196	131	131	196	0%	0%	0%
Playing field / playground	1,409	339	339	1,409	1%	1%	0%
Poor semi-improved grassland	141	97	10	54	0%	0%	0%
Purple moor grass and rush pastures	7	7	7	7	0%	0%	0%
Quarry, spoil or mine	524	251	251	524	0%	0%	0%
Reedbeds	55	51	51	55	0%	0%	0%
Rock, scree and boulders	0	-	-	0	0%	0%	0%
Saltmarsh	1	0	0	1	0%	0%	0%
Sand or shingle	2	1	1	2	0%	0%	0%
Scrub	1,592	1,113	1,113	1,592	1%	1%	0%
Sealed surface	9,671	2,239	2,239	9,671	4%	4%	0%
Semi-natural grassland	709	479	16,357	16,587	0%	6%	6%
Silvoarable			4,331	4,331	0%	2%	2%
Silvopasture			2,605	2,605	0%	1%	1%
Tall herb and fern	14	11	11	14	0%	0%	0%
Track	1,152	602	602	1,152	0%	0%	0%
Traditional orchards	284	208	563	639	0%	0%	0%
Tree-grass-scrub mosaic			16,003	16,003	0%	6%	6%
Unknown	1,013	191	191	1,013	0%	0%	0%
Water	3,216	2,869	2,869	3,216	1%	1%	0%
Wood-pasture & parkland	2,219	1,813	1,813	2,219	1%	1%	0%
Total	260,592	105,996	105,334	259,930			

Figure 9. Broad habitats in the LNRS network before and after implementation of the maximum carbon-nature scenario (output from the EBNT, see also Section 7.2)



5.5 Floodplain habitats

Floodplain habitats such as meadows and wetlands are particularly important in Oxfordshire, with the floodplain covering 12% of the county – 30,184 ha. A large part of the LNRS is on the floodplain - partly because river valleys were used as a connecting feature when creating the network, and partly because the network was targeted towards lower-grade agricultural land, which is often found in the flood zone. We therefore carried out additional checks to make sure suitable habitats were being allocated to floodplain areas.

There are a range of relevant PMs for floodplain habitats, including:

- PM 9 (create lowland meadows, especially on floodplains),
- PM40 (create wet woodland),
- PM54 (create wetland mosaics),
- PM55 (create ponds),
- PM56 (create floodplain grazing marsh).

To achieve a balanced mix of these habitats in the maximum carbon-nature scenario, we restricted creation of wet woodland to areas that were within 200m of existing woodland, as described above, resulting in an increase from 62 ha to 4066 ha. Next, we prioritised tree-grass-scrub mosaics in areas where both woodland and grassland opportunities overlapped, followed by other habitats in order of scarcity: acid grassland, lowland fen (as a proxy for floodplain mosaics), lowland meadows and calcareous grassland. This resulted in 17% of the floodplain being allocated to wet woodland, 23% to wetlands (lowland fen), 5% to tree-grass-scrub mosaics, and 12% to neutral grassland, including lowland meadows (Table 7). As 4% of the floodplain is currently broadleaved woodland, the total proportion of the floodplain that is wooded would increase from 4% to 21%, but there would also be big increases in wetlands and grasslands.

Table 7. Floodplain habitats created within the LNRS network in the maximum carbon-nature scenario. The total floodplain area in Oxfordshire is 30,184 ha of which 23,939 ha (79%) is in the LNRS.

Habitat	Existing ha	% of LNRS floodplain for existing habitats	Maximum carbon-nature ha	% of LNRS floodplain in maximum carbon nature	Change
Wet woodland	62	0%	4,066	17%	4,004
Tree-grass-scrub mosaic	-	0%	1,283	5%	1,283
Lowland fen	172	1%	5,516	23%	5,344
Neutral grassland / Lowland meadows	1,599	7%	2,867	12%	1,268
Calcareous grassland	23	0%	143	1%	120
Acid grassland	0	0%	45	0%	45
Silvoarable	-	0%	661	3%	661
Silvopasture	-	0%	626	3%	626
Total targeted habitats	**2,382**	**10%**	**15,732**	**66%**	**13,350**

5.6 Natural regeneration

For the woodland creation, we assume that half of the woodland is planted and half is naturally regenerated; this aligns with LNRS potential measure PM 39, 'Use low intervention woodland creation techniques including natural regeneration where appropriate, especially near existing ancient woodland'. Thomas (2025) also highlights the potential of natural regeneration to deliver carbon sequestration, citing research at Rothamstead (Anderson, 2024) and Knepp (Burrell et al, 2024). Natural regeneration can also deliver habitats that are better adapted to local conditions, more resilient to change, and support local species (Wang et al., 2023).

5.7 Hedgerows

As reported in Thomas et al. (2025), "*the Committee on Climate Change recommends increasing UK hedgerow length by 40% by 2050, with a 20% increase by 2035 (CCC, 2021). This would affect only around 11% of existing field boundaries in the UK, with relatively low impact on the area available for food production (Biffi et al., 2022). Natural England suggests an additional 335,000 km is needed to reach favourable conservation status (Staley et al., 2020), while the UK Government has committed to creating or restoring 72,420 km of managed hedgerow in England by 2050 (DESNZ, 2025).*"

We therefore assume a 40% increase in hedgerow length, based on the current total length of hedgerows and lines of trees. We assume that existing hedgerows are on average 1.5m wide; this is the minimum width based on 'good condition' for hedgerows in agri-environment schemes. However, we assume that newly created hedgerows will be 2m wide. If hedgerows are allowed to grow large and bushy, they may be far wider than this, so this is a conservative estimate of future sequestration potential. We assume that the allocation of new hedgerows to either arable or improved grassland is based pro-rata on the current ratio of these types of farmland: 64% arable in Oxfordshire, and 54% in the LNRS network, producing the estimates for areas of new hedgerows shown in Table 8.

Table 8. Assumed new hedgerow length and area under the maximum carbon-nature scenario, for a 40% increase in hedgerow length

	Oxfordshire			LNRS network		
Hedgerows created on:	**% of farmland**	**km added**	**ha added**	**% of farmland**	**km added**	**ha added**
Arable	64%	3,093	1,835	54%	921	562
Improved grassland	36%	1,769	1,050	46%	785	479
Total new hedgerow area		**4,862**	**2,885**		**1,707**	**1,041**

Spatial analysis of the hedgerow dataset from previous unpublished work indicated that only around 60% of field boundaries currently have hedges or lines of trees, leaving around 16,500 km of boundaries with no hedges or trees. Of these, 9,100 km (55%) are in areas identified as high priority, defined as being 100 m (1 ha) grid cells that have less than 100 m of existing linear woodland features along field boundaries and more than 100 m of field boundaries with no hedges. Therefore the target length of 4,900 km of new hedgerow in Oxfordshire appears to be feasible in theory.

In addition, we found that there are around 2,600 very large fields (defined as fields over 14 hectares; around twice the average field size in Oxfordshire) where there might be additional opportunities to restore mid-field hedgerows that have been removed over the last few decades. The average size of these fields is 24 ha, and if each of them was split into half with the creation of one additional hedgerow across the middle of the field, this could represent roughly an additional 1,290 km of new hedgerow opportunities.

5.8 Farmland soil

We assumed that soil carbon could be enhanced on arable land, in line with LNRS PM 71 ('increase the biodiversity in soils by choosing cultivation practices that can regenerate species and produce healthy soils'). This could include practices such as reduced tillage, addition of organic matter to the soil, and reduced synthetic inputs. We assumed a typical sequestration rate of 0.4 tC/ha/y which could be maintained for 30 years before saturation was reached (see Section 6.2, Soil carbon code).

6 Outcomes for carbon

6.1 Total carbon gains using Agile carbon estimates

We estimated carbon stored and sequestered under the carbon-nature scenario using a table of land-use transitions between the starting habitat and the final habitat, and the Agile estimates of carbon stored per hectare (Table 9). For each habitat transition, the estimated carbon gain at habitat maturity is simply the total carbon stored in the new habitat (area x tC/ha) minus the total carbon stored in the starting habitats that changed to that new habitat (sum of areas x tC/ha for each). This indicates that the maximum carbon-nature scenario could result in extra storage of 5 million tonnes of carbon once habitats have matured, or 6 million tonnes if hedgerow creation and soil carbon enhancement is extended to the whole county.

This simple approach does not account for avoided emissions when arable land is converted to a different habitat, but that is included in the estimates of carbon sequestration over the next 30 years in Table 17 (Section 6.3). Note that habitats that already had existing scattered trees or scattered scrub were assumed to retain this after transition to semi-natural grassland, e.g. arable with scattered broadleaved trees could transition to acid, calcareous or neutral grassland with scattered trees. The additional tree-grass-scrub mosaic is not split into acid, calcareous and neutral.

Table 9. Carbon gained at habitat maturity in the maximum carbon-nature scenario, based on the total carbon stored in new habitats created in the LNRS network minus the total carbon stored in the starting habitats, plus carbon sequestered in hedgerows and arable soils both in the LNRS network and the whole county

Habitat created		tC/ha at maturity	Area created ha	tC gained at maturity
Woodland: broadleaved, semi-natural		273	7,481	1,493,027
Wet woodland		333	4,004	1,030,868
Tree-grass-scrub mosaic		147	16,003	1,167,477
Acid grassland		110	675	24,691
Calcareous grassland		82	10,343	98,511
Neutral grassland		110	13,224	497,303
Lowland meadows		110	1,139	38,171
Heathland		109	169	5,908
Lowland fens		164	5,345	476,351
Traditional orchard		137	355	22,833
Silvoarable		93	4,331	116,668
Silvopasture		107	2,605	62,768
Total habitats created in LNRS network			**65,672**	**5,034,574**
Soil and hedgerows: LNRS network area				
Hedgerows		137	341	21,578
Soil carbon enhancement on arable land			4,042	48,508
Total with soil and hedgerows in LNRS			**69,924**	**5,104,660**
Soil and hedgerows: whole of Oxfordshire				
Hedgerows		137	972	62,985
Soil carbon enhancement on arable land			83,819	938,793
Total with soil and hedgerows in all Oxfordshire			**150,065**	**6,036,352**

6.2 Marketable carbon units

To indicate the quantity of carbon units that could be available via certified market mechanisms, we also estimated potential ‘marketable carbon units’ relevant to the main existing or emerging carbon market tools identified in the parallel report (Thomas et al., 2025). These cover only a limited selection of habitat transitions (Table 10). Notably, none of the codes currently provide figures for restoration of improved grassland to semi-natural grassland, perhaps reflecting the issues with the figures in Gregg et al (2021) noted above. Similarly, none provide estimates for transitions to wetland or heathland on mineral soils, or for creation of ponds. However, Wilder Carbon permit sale of units from restoration of these habitats after the project has been implemented and any carbon gain has been verified through on-site measurements (Wilder Carbon, 2025).

Table 10. Existing and emerging carbon codes considered for estimating marketable carbon units

Carbon code	Habitat transitions relevant to Oxfordshire	Notes
Woodland Carbon Code (WCC)	Arable or grassland to woodland Agroforestry Traditional orchards	Applies a 20% deduction for data precision and a 20% risk buffer Units calculated over 100 years Used as basis for Agile woodland carbon sequestration values (Appendix 2)
Wilder Carbon	Arable to extensive grassland (M) Arable or improved grassland to woodland; planted or natural regeneration (H) Arable or improved grassland to scrub (M) Wood-pasture and parkland (10% of woodland, plus arable to grassland if starting from arable) (not used, but adapted for Tree-grass-scrub mosaic assuming 20% woodland, 20% scrub, 60% grassland)	Variable risk buffers based on confidence levels: H = high, 20% buffer, M = medium, 40% buffer Only 50% of units can be sold in advance; the rest after the first verification point Units calculated over 50 years Other habitat can be included post-restoration when carbon gain is verified. No distinction between acid, calcareous or neutral grassland.
Peatland Code	Arable or grassland to lowland fen (more appropriate than bog, for Oxfordshire)	Not implemented, due to the very small area of peat soil in Oxfordshire (17 ha)
Hedgerow Carbon Code (estimate)	Arable or improved grassland to hedgerow	Farm Carbon Calculator used, as hedgerow code not yet available
Soil Carbon Code (estimate)	Arable soil carbon sequestration through agroecological measures (e.g. cover crops; organic amendments; reduced tillage)	Farm Carbon Calculator used, as soil carbon codes are proprietary and require empirical measurements

Wilder Carbon

Wilder Carbon is identified by Thomas et al. (2025) as a key tool for delivering high-integrity nature-based carbon solutions, as it focuses on delivering a wide range of mixed native mosaic habitats, with a focus on natural regeneration, and ensuring that this is delivered alongside at least 50% biodiversity gain (Wilder Carbon, 2025a).

Carbon sequestration estimates are from various sources (Wilder Carbon, 2025b). For mineral soils, the main sources are the Woodland Carbon Code (for woodland and scrub) and Gregg et al (2021) for grassland. The calculations for specific habitat transitions can be demonstrated in the online 'Carbon+ Habitat' tool at https://webapps.kwtg.uk/public/app/carbon_plus_tool_public (Figure 10). The process, which was replicated for our analysis, can be summarised as:

1. Establish a carbon sequestration rate for the baseline habitat
2. Establish carbon sequestration rates for the transition from the baseline habitat to the new habitat in 10 year time periods up to 50 years after project start.
3. Establish how long the transition will take.
4. Carbon sequestration per year in the transition period is calculated as: Transition sequestration – Baseline habitat emissions (if any).
5. Carbon sequestration per year after the transition period is the avoided Baseline habitat emissions (if any), typically if the baseline is arable land or degraded peat.
6. Total sequestration is summed over 50 years
7. A 'risk buffer' is calculated based on the confidence in the carbon estimates for each transition. This is 20% for high-confidence and 30-40% for medium-confidence estimates.

8. The Estimated Issuance Units (expected total saleable units over 50 years) are the total estimated sequestration (in tonnes CO2e) minus the risk buffer, e.g. 60% of total estimated units for medium confidence transitions where the risk buffer is 40%.
9. In parallel, Biodiversity Net Gain units and Wilder Carbon Biodiversity Units are also calculated.

Figure 10. Screenshot of habitat transition examples from Wilder Carbon's online Carbon+Habitat calculator. Top: summaries for four habitat transitions (arable to lowland meadow, mixed scrub, natural regeneration or planted woodland). Bottom: detailed breakdown over time for a single transition (arable to calcareous grassland).

The Carbon + Habitat Tool

Carbon + Habitat Tool

About the tool

Area	Description	Soil	Baseline Habitat	Post-Intervention Habitat	Estimated Carbon Benefit (tCO2e)	Net Estimated Carbon Benefit (tCO2e)	Risk Buffer Contribution (tCO2e)	Estima Issuan Unit Contril (tCO2e
1	Arable	Mineral	Cereal crops	Lowland meadows	64.92	64.92	25.97	38.95
1	Arable	Mineral	Cereal crops	Mixed scrub	95.02	95.02	38.01	57.01
1	Arable	Mineral	Cereal crops	Lowland mixed deciduous woodland (natural regen.)	493.52	493.52	98.70	394.82
1	Arable	Mineral	Cereal crops	Lowland mixed deciduous woodland (planted)	539.42	539.42	107.88	431.54

Parcel Results

Area	Description	Soil	Baseline Habitat	Post-Intervention Habitat	Estimated Carbon Benefit (tCO2e)	Net Estimated Carbon Benefit (tCO2e)	Risk Buffer Contribution (tCO2e)	Estimated Issuance Unit Contribution (tCO2e)	DEFRA BNG Units	Wilder Carbon Biodiversity Units
1	test	Mineral	Cereal crops	Lowland calcareous grassland	64.92	64.92	25.97	38.95	1	5

Period Breakdown

Period	Estimated Carbon Benefit (tCO2e)	Net Estimated Carbon Benefit (tCO2e)	Risk Buffer Units	Estimated Issuance Units (EIUs)
Years 1-10	22.52	22.52	9	13
Years 11-20	22.52	22.52	9	13
Years 21-30	6.62	6.62	2	3
Years 31-40	6.62	6.62	2	3
Years 41-50	6.62	6.62	2	3

We replicated this approach for the following transitions:

- arable to semi-natural grassland
- arable or improved grassland to woodland or wet woodland (although wet woodland units can only be issued post-verification)
- arable or improved grassland to tree-grass-scrub mosaic, using the Wilder Carbon approach for wood-pasture and parkland (which assumes 10% woodland, plus arable to semi-natural

grassland if starting from arable). We assumed 20% naturally regenerated woodland, 20% scrub and 60% grassland, and disallowed felled woodland and any habitats that had scattered trees or scrub to start with (these were very small areas).

For the maximum carbon-nature pathway over the 30 years from 2025 to 2055, the results indicated total marketable units of almost 900,000 tC, averaging around 30,000 tC/y, but for the minimum carbon scenario this fell to around 160,000 tC and 5,000 tC/y, only 18% of the maximum value (Table 11).

Table 11. Marketable carbon units over 2025 to 2055 estimated from the Wilder Carbon methodology (including a 50% split between planted and naturally regenerated woodland)

	ha	tC	tC/y
Maximum carbon-nature scenario			
Arable to semi-natural grassland	13,074	-60,942	-2,031
Arable to woodland	3,924	-220,348	-7,345
Arable to wet woodland	1,533	-86,084	-2,869
Modified grassland to woodland	3,557	-199,696	-6,657
Modified grassland to wet woodland	2,470	-138,698	-4,623
Arable to tree-grass-scrub mosaic	8,432	-110,020	-3,667
Modified grassland to tree-grass-scrub mosaic	7,460	-74,053	-2,468
Total	**24,558**	**-889,841**	**-29,661**
Minimum carbon scenario			
Arable to semi-natural grassland	**30,101**	**-156,633**	**-5,221**

It is worth noting that Wilder Carbon take a very conservative approach. Other estimates may be higher, e.g. for arable reversion to grassland, the Knepp Wildland Carbon Project (2024) estimated an average sequestration rate of 3.04 $tCO_2e/ha/y$, compared to 1.59 $tCO_2e/ha/y$ for Wilder Carbon.

Woodland Carbon Code

The WCC is a well-established funding mechanism offering long-term permanence (secured for 100 years). The WCC calculator (WCC, 2024) projects future carbon sequestration from tree planting, based on tree species, spacing, yield class (productivity, dependent on climate and soil type), and management (thinning / harvesting). For the Pathways to Zero Carbon Oxfordshire (PAZCO) report in 2021 (Hampton, 2021; Smith, 2021), we developed a system for deriving average carbon sequestration factors over the period of interest (2020 to 2050) from the WCC calculator, based on typical tree species mixes and yield classes in Oxfordshire (see notes at end of Appendix 2). We use these factors to estimate the total carbon emissions in the Agile maps.

For this study, we downloaded the most recent WCC calculator (V3.0, released August 2025) and entered the relevant parameters to estimate total marketable carbon units for the maximum carbon-nature scenario. We made the following assumptions:

- Half of woodland is planted; half naturally regenerated.
    - In the WCC calculator, naturally regenerated woodland or scrub is only entered so that it can be claimed in future – it is not included in the calculations. Therefore we entered it as if it was planted woodland, in order to produce a sequestration estimate.
    - The WCC indicates that natural regeneration is unlikely to occur in very wet soils, meaning that this may not be feasible for Wet Woodland, although this raises the question of how wet woodlands are naturally self-sustaining.

- Credits can only be claimed for natural regeneration if there is evidence that seedling regeneration is currently being suppressed by browsing, which the project aims to tackle (e.g. by excluding browsers using fencing).
- Seedling spacing is 3m
- We assumed no mounding, ploughing, scarifying or subsoiling
- Planted woodland uses tree shelters but no fertiliser or herbicides
- Planted woodland is fenced in very large blocks (100 ha), to represent minimal fencing (in order to allow free movement of wildlife), with 2 gates per 1km fencing.
- We claimed soil carbon sequestration for the area planted on arable land, because we assumed minimal intervention (no thinning or clear-felling)
- We assumed low disturbance (hand screefing only) for planted woodland and no disturbance for naturally regenerated woodland. The WCC assumes no soil carbon emissions for both these options.
- We assumed no carbon leakage as the WCC states 'normally zero'. However, dietary change (to a lower meat diet) would be needed to achieve this in practice, to avoid exporting food production to other areas.
- We assumed no baseline emissions as the WCC states 'normally zero'. This therefore ignores ongoing emissions from arable cultivation, which are taken into account in the Wilder Carbon calculation – however, this can be offset against some of the other optimistic assumptions.
- Although a long list of possible broadleaf tree species is provided, these are all allocated to one of three models: beech, oak, or sycamore/ash/birch (SAB). We assumed that all wet woodland was SAB (this includes species such as black poplar, alder, willow, aspen, cherry, and shrubs such as blackthorn and hazel), and that dry woodland was 30% beech, 30% oak and 40% SAB. Beech and oak was assumed to end up at 5m spacing, yield class 6, and SAB at 3m, yield class 8. These spacings are relatively wide, to reflect the desired semi-natural woodland structure, giving trees space to reach a large size and allowing light to reach the forest floor. Yield classes vary considerably across Oxfordshire, so we selected central estimates.

The WCC subtracts initial establishment emissions and adds soil carbon gains from the proportion planted on arable land. It also subtracts 20% for model precision and a further 20% as a buffer.

The results indicate the potential to claim credits for sequestering 1.4 million tonnes of carbon in 100 years, or 755,000 tC in the first 30 years, averaging 25,000 tC/y (Table 12). This is a little more than the estimate from the Wilder Carbon methodology, which is 21,000 tC/y from transitions to woodland. Wilder Carbon is also based on the WCC, but the difference may be due to Wilder Carbon's additional 20% risk buffer (it is not clear whether this is applied on top of the WCC 20% buffer) or to different assumptions about tree spacing, species mix or yield class.

As the WCC does not allow units from natural regeneration to be issued in advance, most landowners would probably find Wilder Carbon more suitable for this option, with the option of using the WCC for planted woodland. We therefore also calculated the estimated carbon units for just the planted woodland, and for the dry and wet woodland separately (Table 12).

Table 12. Estimated marketable carbon units for woodland creation in the maximum carbon-nature scenario, from the Woodland Carbon Code calculator

	All woodland	Planted woodland	Planted dry woodland	Planted wet woodland
Total carbon gain at 100y, tC	1,446,668	717,224	388,499	328,719
Average sequestration rate over 100y, tC/y	14,467	7,172	3,885	3,287
Carbon gain 2025-55, tC	755,751	371,765	188,599	183,162
Average sequestration rate 2025-2055, tC/y	25,192	12,392	6,287	6,105

Hedgerow carbon code

As reported in Thomas et al. (2025), a Hedgerow Carbon Code is being developed by the Allerton Trust and GWCT but is not yet available. According to the website (November 2025), they have developed a calculator which estimates carbon stored and sequestered for a given hedgerow height, width, composition and management regime, and they are working on including soil carbon beneath the hedge as well. They aim to make this calculator 'commercially available', so it is not clear whether the underlying assumptions and factors will be made public.

To estimate potential marketable carbon units from hedgerows, which may become available once the Hedgerow Carbon Code is released, we have used the Farm Carbon Toolkit calculator. This is a free online calculator that returns values for different widths and lengths of hedge, choosing from the following hedge types: managed under 15 years old, managed over 15 years old, or large hedgerows with trees. It is based on average literature values: managed hedges from Biffi et al (2022 and 2023) and Drexler et al (2023), and large hedges with trees from Crossland (2015) and Falloon et al (2004). Checking the values for sample hedge types, all converted into tC/ha/y, they appear broadly consistent with the literature (Table 13).

Table 13. Estimates for average hedgerow carbon sequestration rates from the Farm Carbon Calculator and literature sources (total sequestration in soil and vegetation unless specified)

Source	Hedge type	tC/ha/y
Falloon et al, 2004	Vegetation only (assumed average of grassland & woodland)	1.00
Farm Carbon Calculator	Managed generic	1.00
Farm Carbon Calculator	Managed over 15 years old	3.08
Farm Carbon Calculator	Managed under 15 years old	4.24
Farm Carbon Calculator	Large hedge with trees	6.67
Biffi et al 2023	Managed, 3 to 6 years old, vegetation only	2.09
Biffi et al 2023	Managed, 7 to 12 years old, vegetation only	1.83
Biffi et al 2023	Managed, 13 to 40 years old, vegetation only	0.86
Biffi et al 2022	Managed, top 50 cm of soil only	1.48
Warner et al 2011	Adding 2 trees per 100m to a hedge	0.44
Agile maps	Hedgerow, WCC low yield wide spacing Sycamore-Ash-Birch	1.1
Agile maps	Hedgerow with trees (average of scrub and woodland)	2.6

Falloon et al (2004) report that 68% of hedges sampled in the Countryside Survey of 2000 were between 1 and 2m wide, and 56% were between 0.5 and 1m high. They therefore assume an average hedge width of 1.5m for their study. This implies that there is considerable potential to enhance carbon sequestration by creating larger, wider hedgerows.

In line with the objectives of the LNRS, we could assume that the hedgerows created are in the 'large hedgerow with trees' category of the FCC, sequestering 6.67 tC/ha/y. However, this is larger than the highest sequestration rates for planted woodland, both from Wilder Carbon (maximum rate 4.7 tC/ha/y) and from the Woodland Carbon Code (maximum rate 3.6 tC/ha/y), which seems unrealistic. Therefore, we used the rates for 'managed hedgerows' instead, i.e. 4.24 tC/ha/y for the first 10 years, then 3.08 tC/ha/y for the next ten years, and zero after that. This equates to an average rate of 2.44 tC/ha/y over the first 30 years, and a total sequestration over 30 years of around **10,000 tC within the LNRS network** only, or **42,000 tC in the whole of Oxfordshire**, for a 40% increase in hedgerow length and an average width of 2 metres.

Soil Carbon Code

There is potential to increase carbon in agricultural soils, through practices such as reduced tillage, cover cropping, catch crops, organic fertilisers, crop diversification, and reduced use of synthetic fertilisers, which also improve soil structure and boost microbial activity (Vikas and Ranjan, 2024).

While there is no single Soil Carbon Code in the UK, a range of proprietary tools are in operation. Thomas (2025) considers several of these: Trinity AgTech, Agreena, FFSL, UKCCC, Soil Capital and BX Carbon. Some of these also assess co-benefits for biodiversity, soil health, soil nutrients, water quality, erosion control, drought resilience, climate resilience and input efficiency. Most include a risk buffer of 5% to 50%, which may be repayable on verification, and consider time periods of 5 to 40 years. However, specific soil carbon sequestration factors for these practices are not reported, as most of them rely on in-field measurements to determine soil carbon gain.

To estimate potential marketable soil carbon units, we therefore use emission factors from the Farm Carbon Toolkit calculator (as for hedgerows). These indicate that a typical soil carbon gain of around 0.4 tC/ha/y could result from either addition of organic matter (e.g. manure) or use of reduced tillage practices on arable soils; this is a conservative estimate as there could be higher gains through combined practices or the use of legume fallow. There could also be potential to improve carbon in pasture, e.g. through shifting to a diverse legume-rich sward, but due to lack of data we only assess the potential for arable soil carbon enhancement.

Table 14. Sequestration factors for enhancing soil carbon in arable fields, from the Farm Carbon Toolkit Calculator

Soil carbon enhancement practice	tC/ha/y
Arable + broiler manure + straw	-0.37
Arable + straw + reduced tillage	-0.40
Arable to 2-year sown legume fallow	-0.98
Arable winter cover crops	-0.01

The maximum carbon and nature scenario identifies most of the 34,494 ha of arable land within the LNRS as having the potential for restoration to semi-natural habitats, with the exception of 4,331 ha of Grade 1 and 2 land, which is retained but with the potential to convert to silvoarable agroforestry, and 70 ha of high grade unidentified 'Agricultural land' which is retained unchanged. The main opportunity for soil carbon enhancement within the LNRS network is therefore the strips of cultivated land in between rows of silvoarable trees on the remaining small area of high-grade arable land. In line with modelling by the Climate Change Committee (CCC) for the UK's 7th Carbon Budget, we assume 2m wide tree strips at 30m spacing for silvoarable, equivalent to 6.67% of each silvoarable field being occupied by trees, leaving 93.3% of the field where soil carbon enhancement can be deployed, or 4,042 ha. At the assumed rate of 0.4 tC/ha/y this would result in sequestration of 1,617 tC/y, or **48,508 tC** over 30 years, adding 12 tC/ha to total carbon stock in arable fields to bring the average stock from 66 to 78 tC/ha, which seems reasonable.

However, there are also opportunities for soil carbon enhancement in the rest of the county, beyond the LNRS zone. The whole area of arable land, including that remaining in the LNRS zone, covers almost

114,000 ha, assuming that silvoarable agroforestry has also been implemented, so this is the space between rows of trees. That could store an estimated **938,793 tC** over 30 years, or 31,293 tC/y.

Agroforestry carbon code

The potential for an agroforestry carbon code was investigated in 2022-23 as a Natural Environment Investment Readiness Fun (NEIRF) project. The project team decided that the WCC was unsuitable for agroforestry because i) commercial fruit and nut trees were not included, and ii) the WCC could underestimate growth in open-grown trees. A tailored approach was developed using allometric modelling, i.e. based on the size and shape of trees. However, it was concluded that this required too much data collection and was not viable, given that little carbon was sequestered due to the low density of tree planting in UK agroforestry (Scottish Forestry, n.d.). Instead, the team recommended integrating agroforestry into the WCC, but this has not been formally implemented. For this study, we have estimated carbon sequestration from agroforestry (silvoarable, silvopasture and traditional orchards) using the WCC, but entering only the actual tree canopy cover area, because the WCC has maximum spacings of 5m which are not large enough for agroforestry. This approach would need to be agreed by the WCC team before it could be used to generate carbon credits.

The assumptions used were as follows:

- Silvoarable trees occupy 6.67% of the total silvoarable area, in line with the CCC approach. This equates to tree strips 2m wide planted at 2m spacing, separated by 30m to allow the passage of farm machinery for cultivating the intervening area, equivalent to 167 trees/ha. Trees are assumed to be hazel, representing a typical fruit or nut tree, as the WCC does not include commercial fruit or nut trees.
- Silvopasture trees occupy 14% of the total silvoarable area, in line with the CCC approach. They are assumed to be large open-grown oak and beech trees with a canopy diameter of 4.2m.
- Traditional orchards are also modelled as hazel, and are planted at 3m spacing throughout the whole area.
- Yield classes are 8 for all types of agroforestry. This relatively high class reflects the fact that i) all agroforestry is on high grade farmland (as lower grade land in the LNRS zone is targeted for habitat restoration), ii) the trees are open-grown, with little competition for light or resources, and iii) agroforestry trees are highly visible to the farmer and may thus receive more attention than woodland trees.
- All trees are planted with tree guards. Silvopasture trees also have individual fences, 2m x 2m i.e. 8m per tree, and traditional orchards are assumed to be in fenced 10ha fields.
- Silvoarable trees are assumed to be clear-felled after 50 years. This is a slightly optimistic estimate given the typical life of commercial fruit trees is 30-45 years; however it reflects the fact that i) the agroforestry trees may not be planted only for their yield of produce, but also for other co-benefits, ii) as part of a nature-focused strategy, older trees bring higher biodiversity value, and iii) some agroforestry trees may be harvested for timber, after a longer rotation. Traditional orchard trees are not clear-felled as they are assumed to be mainly managed for nature rather than as a commercial venture.

The results indicate that the agroforestry area in the maximum carbon-nature scenario could sequester almost 80,000 tonnes of carbon in the first 30 years, or approximately 2,660 tonnes per year (Table 15).

Table 15. Estimated marketable carbon units from agroforestry in the LNRS network under the maximum carbon-nature scenario, from the Woodland Carbon Code

	Silvoarable	Silvopasture	Traditional orchards	All agroforestry
Total area	4,331	2,605	355	7,291
Area of trees	289	365	355	1,009
Total carbon gain at 100y, tC	20,082	70,525	58,802	149,409
Average sequestration rate over 100y, tC/y	201	705	588	1,494
Carbon gain 2025-55, tC	**18,233**	**28,797**	**32,651**	**79,681**
Average sequestration rate 2025-2055, tC/y	608	960	1,088	2,656

6.3 Summary of carbon results

Results from all the estimated marketable carbon units are shown in Table 16. We have assumed that planted woodland is marketed under the WCC, and naturally regenerated woodland under Wilder Carbon (with a 50:50 split between the two).

The results indicate that the maximum carbon-nature scenario, including agroforestry, hedgerows and soil carbon in the LNRS network, could generate just over **1.1 million** tonnes of carbon credits in a 30-year period, equivalent to an average of **38,000** tonnes of carbon per year, or 139,000 tonnes of CO_2e per year. The minimum carbon scenario, if all landowners chose to opt for grassland restoration (but also including agroforestry, hedgerows and soil carbon), would be just over 300,000 tonnes of carbon in 30 years, or 10,000 tonnes of carbon per year. If the hedgerow and soil carbon measures were extended throughout Oxfordshire, this would increase to 2.1 million tonnes of carbon (69,000 tC/y) for the maximum scenario, and 1.2 million tonnes for the minimum scenario (41,000 tC/y), mainly due to the soil carbon sequestration.

Table 16. Estimated marketable carbon units for the maximum carbon-nature scenario from different land-use transitions

Land-use transition	ha	tC over 30 years	tC/y over 30 years	$tCO_2e/ha/y$ over 30 years
Maximum carbon-nature scenario				
Woodland Carbon Code				
Planted broadleaved dry woodland	3,740	188,599	6,287	23,051
Planted broadleaved wet woodland	2,002	183,162	6,105	22,386
Total WCC planted woodland	**5,742**	**371,761**	**12,392**	**45,437**
Wilder Carbon				**-**
Arable to semi-natural grassland	13,074	60,942	2,031	7,448
Arable to dry woodland, natural regeneration	1,962	129,182	4,306	15,789
Arable to wet woodland, natural regeneration	767	50,468	1,682	6,168
Modified grassland to dry woodland, natural regeneration	1,778	117,074	3,902	14,309
Modified grassland to wet woodland, natural regeneration	1,235	81,314	2,710	9,938
Arable to tree-grass-scrub mosaic	8,432	110,020	3,667	13,447
Modified grassland to tree-grass-scrub mosaic	7,460	74,053	2,468	9,051
Total Wilder Carbon	**34,708**	**623,053**	**20,768**	**76,151**
Minimum carbon scenario (Wilder Carbon)				0
Arable to semi-natural grassland	**30,101**	**156,633**	**5,221**	**19,144**
Agroforestry (both scenarios)				0
Silvoarable	4,331	18,233	608	2,228
Silvopasture	2,605	28,797	960	3,520
Traditional orchards	355	32,651	1,088	3,991
Total agroforestry	**7,291**	**79,681**	**2,656**	**9,739**
Hedgerows and soil carbon: LNRS network only (both scenarios)				
Hedgerows on arable	184	9,321	311	1,139
Hedgerows on grassland	157	7,663	255	937
Total hedgerows	**341**	**16,984**	**566**	**2,076**
Soil carbon enhancement on arable land	**4,042**	**48,508**	**1,617**	5,929
Hedgerows and soil carbon: Whole of Oxfordshire (both scenarios)				
Hedgerows on arable	619	31,289	1,043	3,824
Hedgerows on grassland	354	17,261	575	2,110
Total hedgerows	**972**	**48,550**	**1,618**	**5,934**
Soil carbon enhancement on arable land	**83,819**	**938,793**	**31,293**	**114,741**
Totals including hedges and soil carbon in LNRS network only				
Maximum carbon-nature scenario	**52,125**	**1,139,987**	**38,000**	**139,332**
Minimum carbon scenario	**41,776**	**301,806**	**10,060**	**36,887**
Totals including hedges and soil carbon in whole county				
Maximum carbon-nature scenario	**132,533**	**2,061,839**	**68,728**	**252,002**
Minimum carbon scenario	**122,183**	**1,223,657**	**40,789**	**149,558**

Total values are summarised in Table 17, which shows how the additional carbon stored and sequestered in the LNRS network would affect carbon storage and sequestration across the whole county. The top table shows values in tonnes of carbon and the lower one shows tonnes of CO_2e.

The table shows that the total carbon stored in ecosystems in the LNRS network could increase from 11 million tonnes of carbon (MtC) to between 12.9 MtC under the minimum scenario and 16.4 MtC under the maximum scenario, a gain of between 1.8 and 5.3 MtC. For the 'whole county' scenario, this would be accompanied by additional sequestration in hedgerows and farmland soil across the whole of Oxfordshire, leading to an increase from 22 MtC to between 24.6 and 28.1 MtC under the minimum and maximum scenarios – a maximum increase of 6 MtC, or 28%.

We also estimated the carbon that could be sequestered over the next 30 years, as this is a typical time period for carbon and nature market agreements. For each habitat transition, this was calculated as the sum of two time periods:

1. **The years taken for the new habitat to reach 'maturity'**, ie. to reach its assumed carbon storage value (YM), OR the time period over which the assessment occurs (T, i.e. 30 years in this case), if shorter.
2. Where the habitat matures within the assessment period, i.e. YM is less than T, **the remainder of the assessment period** (i.e. T – YM), when it is assumed that there can be continued impacts based on the difference in sequestration or emissions between the starting habitat and the new habitat. For example, if the starting habitat was arable land, which is assumed to emit carbon every year during cultivation, there would be ongoing benefits due to the avoidance of these emissions in future. If the new habitat also emits carbon but at a lower rate (e.g. if degraded peatland is partly restored but does not reach its pristine state), there would be an ongoing benefit from the difference in emission factors between the degraded and restored states. See the discussion (Section 8.5, caveats) for further consideration of this assumption.

The equation used for each habitat transition is as follows:

C sequestered = A x ((CF – CS) / MIN (T, YM) + (EF – ES) x MAX (T – YM, 0))

Where:

A = area transitioning from starting habitat S to final habitat F, in hectares (ha)

CF = carbon stored per hectare in final habitat type, in tC/ha

CS = carbon stored per hectare in starting habitat type, in tC/ha

EF = carbon emitted or sequestered per hectare per year by final habitat after reaching maturity, in tC/ha/y

ES = carbon emitted or sequestered per hectare per year by starting habitat, in tC/ha/y

T = years over which the carbon sequestered is being assessed

YM = years for final habitat F to reach maturity (i.e. to reach the estimated final carbon storage)

Using this equation, we estimated that over the next 30 years, the 65,000 ha of changed habitats in the LNRS zone under the maximum carbon-nature scenario could sequester up 101,000 tC/y. We then added on the 84,000 tC/y of ongoing sequestration from the 40,000 ha of unchanged habitats within this zone, i.e. existing woodlands, wetlands, grasslands, to give total estimated sequestration of up to 185,000 tC/y in the LNRS zone, or 205,000 tC/y for the whole county scenario. However, only 38,000 tC/y of these units (or 69,000 tC/y in the whole county scenario) are covered by existing or emerging market mechanisms, as shown in Table 16 and summarised in the last two columns of Table 17.

It may be surprising that the unchanged habitats in the LNRS zone sequester slightly more (84,000 tC/y) than the current sequestration in the whole LNRS zone (83,125 tC/y). This is because the current sequestration includes a negative contribution from emissions from arable land, which is reduced to almost zero in the carbon-nature scenario as most arable is converted to other habitats.

The top table also shows the results for the maximum carbon-nature scenario as a percentage of estimated net emissions from all sources for Oxfordshire in 2023 (1,045,000 tC/y, or 3,833,000 tCO_{2e}/y, DESNZ, 2025) (see also Figure 6). This shows that the maximum carbon-nature scenario could sequester approximately 18% of Oxfordshire's current emissions within the LNRS zone, or 20% including hedgerows and soil carbon measures in the whole county, but only 4% (or 7% including the whole county) would be covered by marketable carbon units.

The table also shows that the minimum carbon scenario (conversion only to grassland habitats) could only sequester a third of the maximum carbon gain in the long term, and a quarter of the marketable units in the next 30 years. The gain in the next 30 years could be a higher proportion of the maximum scenario, estimated as 79%, but this depends on the assumption that grassland habitats could be restored on shorter timescales (30 years) than woodland habitats (110 years). In practice, there is very little evidence on the rate of soil carbon restoration in grasslands, so this assumption is highly uncertain.

Table 17. Estimated carbon storage and sequestration in soils and vegetation in Oxfordshire and in the LNRS network under the nature-based carbon scenarios. Results in tonnes of carbon (top) and tonnes of CO_2 equivalent (bottom).

Note: Carbon storage gain at maturity is only the difference in stored carbon between the initial habitat types and the new habitat types. Carbon sequestered per year over the next 30 years includes annual gains from habitat transitions while habitats mature plus any gains from avoided emissions (from arable land conversion) or assumed higher sequestration rates for the new habitats compared to the initial habitats after they have matured (see equation above). See section 8.5 for important caveats.

Tonnes of carbon	Carbon stored at maturity, tC	Carbon storage gain at maturity, tC	Carbon sequestered, tC/y over next 30 y	Marketable carbon units in next 30 y, tC	Marketable carbon units tC/y over next 30 y
LNRS network					
Current	11,172,705		83,195		
Minimum carbon	12,943,658	1,770,953	146,507	301,806	10,060
Maximum carbon & nature	16,429,571	5,256,866	184,949	1,139,987	38,000
Maximum carbon & nature as % of 2023 Oxfordshire emissions	1572%	503%	18%	109%	**4%**
Minimum as % of maximum		34%	79%	26%	26%
Oxfordshire (LNRS land-use transitions plus hedgerows and soil carbon in rest of county)					
Current	22,023,103		102,904		
Minimum carbon	24,638,787	2,615,685	166,216	1,223,657	40,789
Maximum carbon & nature	28,124,701	6,101,598	204,658	2,061,839	68,728
Maximum carbon & nature as % of 2023 Oxfordshire emissions	2690%	584%	20%	197%	**7%**

Tonnes of CO_2e	Carbon stored at maturity, tCO_2e	Carbon storage gain, tCO_2e after 100 years	Carbon sequestered, tCO_2e/y over next 30 y	Marketable carbon units in next 30 y, tCO_2e	Marketable carbon units tCO_2e/y over next 30 y
LNRS network					
Current	40,966,585	-	305,048	-	-
Minimum carbon	47,460,078	6,493,493	537,192	1,106,623	36,887
Maximum carbon & nature	60,241,762	19,275,177	678,146	4,179,954	139,332
Oxfordshire (LNRS land-use transitions plus hedgerows and soil carbon in rest of county)					
Current	80,751,376	-	377,315	-	-
Minimum carbon	90,342,219	9,590,843	609,458	4,486,744	149,558
Maximum carbon & nature	103,123,903	22,372,527	750,412	7,560,075	252,002

7 Outcomes for biodiversity and ecosystem services

The parallel report (Thomas, 2025) recommends exploring "carbon-plus" models that bundle additional benefits—such as public access, biodiversity gains, flood risk management and water quality improvements—so that buyers invest in multifunctional ecosystem outcomes rather than carbon alone. Not only does this deliver a more effective, integrated strategy, but it can also deliver carbon credits that can be sold at a premium.

7.1 Biodiversity

Biodiversity net gain assessment for changed habitats

To assess the outcomes for biodiversity, the proposed habitat changes for the maximum carbon-nature scenario were input into the Defra Statutory Biodiversity Metric V1.0.4 (Defra, 2025). We assumed that improved grassland and amenity grassland was Moderate condition in the baseline (cropland condition is fixed by the tool), and the condition of all newly restored habitats was Good (the highest option out of the five-point scale). Given that the whole area is in the LNRS network, we marked all habitats as being 'formally identified in local strategy' for the post-intervention assessment, but 'not identified in local strategy' for the baseline, given that none of the existing habitats being changed were in line with the LNRS potential measures.

The Biodiversity Metric does not allow creation of mosaic habitats with scattered trees and scrub, so these habitats were recorded only as grassland. Similarly, agroforestry is excluded, so silvoarable remained as cropland; for silvopasture we increased the condition of the improved grassland from Moderate to Good. It would be possible to do a proxy assessment using a similar approach to Wilder Carbon, where the additional trees and scrub are included separately based on an assumption on the percentage tree and scrub coverage. However this would decrease the score for the mosaic habitats, as scrub and individual trees are only considered to be medium distinctiveness. If the habitat was treated as mosaic rather than separate habitat parcels of scrub and grassland, the score would also decrease because the condition assessment down-grades grassland with high scrub coverage. The resulting change in biodiversity units by broad habitat type is shown in Table 18.

Table 18. Biodiversity net gain results by broad habitat, exported from the Biodiversity Metric

	Baseline		Post-development on-site		On-site change	
Habitat group	On-site existing area	On-site existing value	On-site proposed area	On-site proposed value	On-site area change	On-site unit change
Cropland	34,432	68,882	4,331	9,614	-30,101	-59,268
Grassland	31,222	124,843	44,342	215,212	13,120	90,369
Heathland and shrub	-	-	170	370	170	370
Wetland	-	-	5,344	16,715	5,344	16,715
Woodland and forest	17	309	11,485	34,100	11,467	33,791

Interestingly, only a **42% gain** in biodiversity was achieved for the habitat changes, less than the 50% requirement of the Wilder Carbon tool, even though we were changing 100% of the area from low-distinctiveness to high or very high distinctiveness habitats. This is partly because of the high 'time to reach target condition' for new woodland. However, the Minimum Carbon pathway, which creates only calcareous and neutral grassland, only delivers a slightly higher uplift of 45.9%. In practice, this would offer much less biodiversity value due to the restricted range of habitats and species supported. It is surprising that neither scenario delivers a 50% uplift, but this may reflect limitations in the Defra metric's ability to reflect the benefits of mixed mosaic habitats.

To address this issue, Wilder Carbon implement a modified version of the Defra Biodiversity Metric which partly implements 'Rule 4' of the Biodiversity Metric guidance. This allows habitats to be treated as if they have already been created in advance, in order to effectively ignore the 'time to reach target condition' and thus avoid penalising highly complex, biodiverse habitats in exceptional circumstances where there is strong commitment and expertise for restoring the site to nature. However, although Wilder Carbon set the time to reach target condition to 1, they do not also ignore the delivery risk multiplier, which happens if habitats are created in advance in the Defra metric tool.

Biodiversity net gain assessment for hedgerows

We entered the existing length of hedgerows in the LNRS network (3499 km) in the baseline, marked as 'retained', and the target length to create within the LNRS network (1707 km) in the post-intervention sheet. We marked all habitats as being 'formally identified in local strategy' both in the baseline and post-assessment, given that hedgerows are an ecologically desirable habitat. We assumed that all new hedgerows were 'species-rich hedgerows with trees' of good condition. However, the resulting biodiversity net gain is highly dependent on assumptions about the condition of the existing hedgerows. Under a relatively optimistic assumption, assuming that half of all existing hedgerows are 'species-rich native hedgerows with trees' in good condition and the remainder are 'native hedgerows' in moderate condition, the biodiversity net gain is **39%**. However, a more pessimistic assumption that 20% of existing hedgerows are 'native hedgerow with trees' and the remainder are 'native hedgerow', all in moderate condition {Table 19), gives a biodiversity net gain of **90%**.

Table 19. Biodiversity net gain assessment for the increase in hedgerows in the LNRS network, showing existing retained hedges (assumed 20% with trees) and new species-rich hedges with trees

	Baseline		**Post-development on-site**		**On-site change**	
Habitat group	On-site existing area	On-site existing value	On-site proposed area	On-site proposed value	On-site area change	On-site unit change
Native hedgerow	2,799	12,876	2,799	12,876	-	-
Native hedgerow with trees	700	6,438	700	6,438	-	-
Species-rich native hedgerow with trees	-	-	1,707	17,328	1,707	17,328

7.2 Ecosystem services

We estimated the outcomes of the nature-based carbon pathway for 18 ecosystem services using the Environmental Benefits from Nature Tool developed by Natural England (Figure 11). This indicates the direction and magnitude of change in ecosystem services for the LNRS network only – not the whole county. Changes are shown at three points in time – 1, 10 and 30 years after implementation. This was a very basic assessment based largely on habitat type. Most of the EBNT condition indicators were left as default values, except for Agricultural Land Class, public accessibility and number of designations.

Figure 11. Estimated direction of change in 18 ecosystem services in the LNRS network at 1, 10 and 30 years after implementation for the maximum carbon and nature, from the EBNT

Whole area	1 year	10 year	30 year	Confidence
Food production	↘	↘	↘	2
Wood production	→	→	↗	2
Fish production	→	→	→	2
Water supply	→	→	→	1
Flood regulation	→	↗	↗	1
Erosion protection	↗	↗	↗	1
Water quality regulation	↗	↗	↗	1
Carbon storage	→	→	↗	2
Air quality regulation	→	→	↗	2
Cooling and shading	→	→	↗	1
Noise reduction	→	→	→	2
Pollination	→	↗	↗	1
Pest control	→	↗	↗	1
Recreation	→	→	→	1
Aesthetic value	→	↗	↗	1
Education	→	↗	↗	1
Interaction with nature	→	↗	↗	1
Sense of place	→	↗	↗	1

Change in average score per hectare	
Large decrease (more than -2.5 points out of 10)	↓
Decrease (-0.25 to -2.5 points out of 10)	↘
Minor change (-0.25 to 0.25 points out of 10)	→
Increase (0.25 to 2.5 points out of 10)	↗
Large increase (more than 2.5 points out of 10)	↑

Confidence ratings for each service	
(red) 1	The relationship between the provision of the ecosystem service and habitats is complex. Evidence for scoring/multipliers is partial, although may be stronger for some habitats than others. Evidence gaps have been filled by consulting experts and with a degree of subjectivity, particularly for cultural services.
(amber) 2	We have some suitable evidence to calibrate our range of scores across habitats and multipliers and/ or scoring applied to a limited range of
(green) 3	We have a strong evidence base upon which to base scores across the range of habitats and multipliers used for this ecosystem service.

The EBNT assessment shows that there would be a loss of food production, as expected given that farmland is being converted to woodland or less productive grassland options. We have minimised this through avoiding conversion of Grade 1 and 2 land to non-agricultural use. Most other ecosystem services would increase, yielding significant benefits for climate change adaptation (flood regulation, cooling and shading), mitigation (carbon storage), water quality regulation, resilient food production (pollination, biological pest control, erosion protection), human health and wellbeing (air quality regulation, aesthetic value, interaction with nature) and cultural benefits (educational value and sense of place).

Several ecosystem services showed no significant change. These were:

- **Fish production.** Although the LNRS contains measures to improve fish habitat, they were not included in this study because of their limited and uncertain impact on carbon storage
- **Water supply**. This did not change because improvements in soil infiltration due to creation of more semi-natural habitats were offset by creation of more woodland, which intercepts rainfall and evaporates it back to the atmosphere or uses it in tree growth. Also, the area of sealed surfaces did not change.
- **Noise reduction**. This did not change because we did not identify which habitats were in a good position to contribute to noise reduction, e.g. a strip of woodland between housing and a busy road. This would require fine scale spatial analysis which is beyond the scope of this project. However, an integrated strategy should consider the potential for planting woodland and hedgerows in good locations to provide these extra benefits.
- **Recreation**. We did not assume any changes in public accessibility as a result of the nature-based carbon strategy. However, actions to enhance public accessibility can attract additional grant funding: Thomas et al. (2025) reported the availability of an extra £3,700/ha for planting woodlands with public access and £600/ha for planting woodlands close to settlements). Therefore there would be incentives to improve public access as part of the nature-carbon strategy.

8 Discussion

8.1 Overall carbon impact

This study has estimated that fully implementing a nature-based carbon strategy through restoring a mix of native habitats within Oxfordshire's Local Nature Recovery Strategy network could sequester up to 185,000 tonnes of carbon per year on average over the first 30 years (678,000 tCO2e/y) (Table 17). This could offset **18%** of Oxfordshire's 2023 emissions (1,045,000 tC/y), rising to 20% if hedgerows and soil carbon are enhanced in the whole county rather than just within the LNRS network. However, the 'marketable' sequestration that is covered by existing or emerging carbon codes **(38,000 tC/y**, or 130,000 tCO2e/y) would only offset **4%** of emissions (or 7% for the whole county scenario). These estimates are upper limits and are subject to important caveats and uncertainties, discussed in the section below.

If emissions continue to decline as planned, due to ongoing initiatives such as a shift to electric vehicles and improved energy efficiency, the share of residual emissions that could be offset through nature-based solutions could increase further. However, the sequestration rate will reduce as restored habitats mature. This highlights that while sequestration from nature-based solutions can play an important role, especially in the next 100 years, the priority must be to reduce emissions from fossil fuels and land-use as much as possible, while protecting the large amounts of carbon stored and sequestered by existing carbon-rich habitats, especially in the LNRS core APIB areas.

8.2 Co-benefits

Implementing this nature-based carbon strategy would deliver multiple co-benefits for biodiversity and ecosystem services.

Benefits for biodiversity

Benefits for biodiversity are ensured through:

1. Targeting habitat restoration within the LNRS network, to maximise connectivity benefits
2. Delivering the habitat creation measures that have been identified as local priorities by the LNRS
3. Delivering a balanced mix of habitats, not biased towards a single habitat type
4. A strong focus on delivering tree-grass-scrub mosaics and naturally regenerated woodland, which can be better adapted to local conditions and more resilient to change, as well as providing high structural diversity. Anecdotal observations have also indicated that scrub and trees on the floodplain can provide a vital refuge for invertebrates and small mammals during periods of prolonged flooding.

The maximum carbon-nature strategy would increase woodland cover in Oxfordshire from 9% to 14%. When combined with trees in mosaic habitats, urban areas and agroforestry, this could enable Oxfordshire to meet the UK-wide target for 17% tree canopy cover.

Benefits for biodiversity can be maximised through encouraging habitat creation that simultaneously supports the species-focused measures in the LNRS, where the mapped areas overlap. Some examples are listed below, but there are many more (see Appendix 1):

- PM250: Wet woodland could reintroduce black poplar, the UK's most endangered tree species Black poplar could also be fast-growing, in the right conditions, with enhanced benefits for carbon sequestration.
- PM212: Wet woodland could be linked to dense scrub and hedgerows with lots of deadwood and stumps to support Willow Tits.
- PM202: Lowland fen creation could include large reedbeds for Bitterns.
- PM207: New woodlands could include dense scrub for Nightingales
- PM214: Hedgerows and tree-grass-scrub mosaics could include Blackthorn for Black and Brown Hairstreak butterflies.

There are strong synergies between biodiversity, carbon storage and climate resilience. For example, ecosystems with a greater variety of plant species tend to store more carbon, because plants with different heights, root depths and growth patterns can more fully exploit the available resources such as nutrients, light and water (e.g. Anderson, 2024; Fatunsin and Naka, 2025; Lawson et al., 2023; Wu et al., 2025). Natural grasslands and forests tend to have deeper-rooted species, which not only store more soil carbon but are also more resistant to droughts (Bowskill and Tatarenko, 2021; Lawson et al., 2023). Also, a richer diversity of species can improve resistance to climate impacts, as discussed in Section 2.

However, biodiversity benefits will only be delivered if new habitats are protected from damage and sensitively managed to suit the local context. Many of the LNRS measures offer guidance on habitat enhancement and management. This often encourages a minimum intervention approach, such as leaving deadwood in situ (PM60), allowing a certain amount of scrub to grow on grasslands (PM16, PM17) and encouraging natural regeneration (PM39), but some habitats and species require more tailored management, such as adopting specific low-intensity grazing regimes for grasslands.

Benefits for ecosystem services

Implementation of the nature-based carbon strategy would also deliver benefits for other ecosystem services. Crucially, there is the potential to improve climate resilience: woodlands can help to reduce flooding downstream and provide shade and cooling during heatwaves. With climate change already affecting UK food production, adding organic matter to farmland soils can help to retain more water during droughts, silvopasture agroforestry can provide shade to livestock during heatwaves (e.g. Amorim et al., 2023), and restoring grasslands and scrub provides habitat for pollinators and pest predators. There are also benefits for human health from improved air quality and opportunities for interaction with nature, as well as educational value and an enhanced 'sense of place' from restoring distinctive local habitats and species.

We did not assume any changes in public accessibility for the nature-based carbon strategy, but improving public access can attract additional funding. Thomas et al. (2025) reported grants of £3,700/ha for planting woodlands with public access and £600/ha for planting woodlands close to settlements. This could provide additional benefits for human health and well-being (see Smith et al, 2023 for evidence on the socio-economic benefits of access to nature-rich green space).

These benefits can be maximised through targeted actions in priority locations to tackle specific problems. For example, habitat restoration could be targeted at arable land on steep slopes and erodible soils, to maximise the benefits for erosion protection and water quality by reducing runoff of eroded soil into watercourses. Woodland planting can be targeted in upper catchments to maximise flood protection benefits downstream. The LNRS network may not cover all the priority areas for these specific nature-based solutions, but LNRS measures can be applied beyond the network zone. While urban habitats were out of scope for this study, further co-benefits can be delivered through targeting habitat creation in or close to Oxfordshire's greenspace-deprived areas (Crockatt et al., 2024).

8.3 Potential trade-offs for biodiversity

While there are many synergies between carbon sequestration and biodiversity, there can also be trade-offs. Adopting the nature-based carbon strategy presented here will avoid the most common trade-offs, which are associated with the use of fast-growing non-native tree species in commercial plantations. These species offer little or no benefit for native wildlife and may cause harm if planted on open habitats such as grassland or heathland that have existing biodiversity value. In addition, the carbon benefits are transient, as 85% of the wood harvested from UK forests is used for short-lived products such as paper or pallets, or burnt for bioenergy, with the carbon then returning to the atmosphere (Forestry Commission, 2023). While once this had value in displacing fossil fuel emissions, this is diminishing as we shift to low-carbon heat and power systems.

However, there is a major potential trade-off associated with farmland soil carbon sequestration, depending on the method used. While adding organic matter to the soil or using legume fallows will typically bring biodiversity benefits, minimum tillage is more challenging because it is usually accompanied by use of herbicide to kill weeds before replanting the crop. This can have adverse impacts on local soil biodiversity and on the wider environment, due to runoff. Evidence shows that herbicide use can be minimised by adopting a holistic approach to conservation agriculture that combines reduced tillage with the use of cover crops and long and diverse crop rotations (Colbach and Cordeau, 2022). Other weed-suppression options are also possible but may be expensive, such as the use of precision laser or heat treatment equipment.

It is worth noting that the use of biochar for soil carbon sequestration, which is mentioned in local policies but is not part of this nature-based strategy, may also have adverse impacts biodiversity, depending on the source of the biomass used to produce the biochar. If biochar production leads to additional extraction of biomass from local ecosystems, such as over-extraction from local woodlands, over-mowing of grasslands or clearance of scrub, this could have serious adverse effects on biodiversity.

8.4 Trade-offs for food production

Food production will clearly decrease if farmland is converted to non-productive use such as woodland, heathland and wetland. Under the maximum carbon-nature scenario, almost all the arable land in the LNRS recovery zone is converted to semi-natural habitats, with only the small area of Grade 1 and 2 land retained for food production in silvoarable agroforestry systems, accompanied by soil carbon sequestration measures such as minimum tillage. This would lead to a loss of around 34,000 ha of arable land, reducing it from 44% of the county to 31%. In contrast, total grassland area would only decrease by 5,000 ha, from 29% to 27% of the county, due to the creation of large areas of semi-natural grassland and tree-grass-scrub mosaics. Nevertheless, while grazing can continue on this land, stocking density will need to decrease in order to maintain grassland biodiversity and enhance carbon storage.

If nothing else changes, this reduced food production in Oxfordshire will lead to increased production elsewhere for import to the UK, probably in countries with fewer restrictions on farmland expansion where this could cause extensive loss of primary forests and grasslands. To deliver nature recovery and carbon sequestration at a global level, this leakage of impacts overseas will need to be addressed. There are three main approaches for this: reducing food waste; increasing agricultural productivity per hectare on the remaining land; and shifting to a more plant-rich diet (Smith et al., 2022). Of these, dietary change is by far the most effective tool, given that in addition to pasture requirements, half of all arable crops are used for animal feed (Smith et al., 2024).

It is worth noting that the WCC calculator asks users to declare whether their tree-planting project is likely to cause leakage of emissions due to displaced food production, but this is accompanied by a note that leakage is unlikely because ‘legislation prevents intensification of semi-natural areas’. However, this is very misleading as it is only true for strongly protected areas, and most areas both in the UK and overseas are not strongly protected, or this protection is not enforced (Zhao et al., 2024).

8.5 Caveats

The quantities presented in this study should be regarded as broad estimates only, indicating the upper limit of potential carbon sequestration through full implementation of a high-integrity nature-based carbon strategy within the LNRS network. It is very important to be aware of the caveats listed below.

Carbon sequestration and storage estimates are highly variable and uncertain

Carbon sequestration and storage estimates for each habitat type are highly uncertain, as there is considerable variation between the same habitat in different locations depending on factors such as soil type, tree and plant species, habitat age and condition, local climate and hydrology, and management history. Estimates also vary depending on the soil depth considered, and the timescale over which sequestration is summed.

Soil depth is particularly relevant on floodplains, which may accumulate carbon to depths of at least 3 metres, whereas most estimates only consider the top 30 cm of soil (D'Elia et al., 2017). The estimates for grassland sequestration used in the Agile maps may therefore underestimate sequestration by floodplain grasslands. For example, Thomas et al. (2025) highlight evidence that floodplain wetlands and grasslands could sequester carbon 30 to 50 times faster than forests (Reed et al., 2022).

Ongoing sequestration is assumed in existing habitats

We assume that there can be ongoing sequestration in some existing semi-natural habitats; this assumption is reflected in the sequestration factors in Appendix 2, which are used to estimate current sequestration in Table 3 and potential future sequestration over the next 30 years in Table 17. This appears to contradict the prevailing view that once habitats have 'matured', equilibrium is reached and ongoing sequestration is balanced by loss of carbon due to decay of dead organic matter. If this was not the case, the argument is that there would be a resulting continuous decrease in atmospheric CO_2 concentrations over time. Emissions or sequestration can therefore only continue if habitats are being disturbed or are recovering from previous disturbance.

However, in an intensively managed and continually disturbed landscape such as the UK, it is questionable whether any habitats have reached a state of equilibrium. Our estimates of current emissions therefore assume ongoing sequestration from semi-natural woodlands on the basis that most woodlands in England are in a state of long-term recovery following widespread deforestation during the first and second World Wars. We assume that typical Oxfordshire woodlands are around 100 years old, and hence not fully mature. According to the Woodland Carbon Code Calculator they will continue to sequester carbon for the next 30 years at least, albeit at a lower rate than before. This contradicts the approach taken by some other analyses, which assume zero sequestration from existing semi-natural woodlands.

In our estimate of future sequestration over the next 30 years in Table 17, the assumption of ongoing sequestration makes little difference because sequestration is dominated by woodlands, which have not reached maturity in 30 years; hence the second part of the equation (post-maturity sequestration) is only used for habitats (mainly grassland) that are assumed to mature in less than 30 years, which have low ongoing sequestration rates. For the estimate of marketable carbon emissions, we use the Wilder Carbon and WCC approach which does not include benefits from ongoing sequestration post-maturity, only from avoided emissions due to conversion of arable land to other habitats.

There is also a prevailing viewpoint that disturbing ecosystems by extracting biomass (e.g. thinning, understory removal, or felling and replanting woodlands) will stimulate further sequestration and hence yield carbon benefits. However, this fails to consider what happens to the carbon in the extracted biomass, most of which is soon released back to the atmosphere (see Section 8.3, and Forestry Commission 2023). In addition, the extraction process can cause extensive damage to soil and vegetation which can cause further carbon loss. The Woodland Carbon Code Calculator makes it clear that thinning woodlands has a negative impact overall on carbon sequestration.

Taking a global perspective, it is clear that soil depths continue to increase over time in many undisturbed ecosystems, due to the accumulated input of organic matter such as fallen leaves and wood, dead roots, dead organisms, or sediment trapped on floodplains. This does not noticeably reduce global CO_2 emissions is because it is counterbalanced by loss of carbon due to erosion of soil, vegetation and carbonate rocks in other locations, such as in intensively cultivated soil, deforested areas or actively eroding regions such as coasts and mountains. Recent evidence indicates that this balancing mechanism emits much more 'geological' carbon than previously thought (60% of the carbon released into the atmosphere by rivers comes from erosion of long-term carbon stores in soils and rocks, not from the biosphere), and hence the carbon being sequestered by mature ecosystems may have been underestimated (Dean et al., 2025). This is an area where more research is needed.

Not all 'marketable carbon units' are currently available

For our estimates of 'marketable carbon units', only those from the WCC and Wilder Carbon are currently available; those for hedgerows, agroforestry, orchards and soil carbon are estimated in anticipation that the emerging codes for these options will be released in the near future. However, proprietary tools for soil carbon units are operational, based on in-field measurement and verification. It is also possible that additional options (such as wetland or heathland restoration) could be funded via Wilder Carbon through post-implementation verification. For options based on post-implementation verification, it is critical to obtain baseline soil carbon measurements before the habitat restoration begins.

Risk buffers were not applied for hedgerows and soil carbon

The established market mechanisms used for the assessment of 'marketable carbon units' – the WCC and Wilder Carbon – apply delivery risk buffers of 20-40% to account for this uncertainty. We did not apply buffers for our estimates of hedgerow and soil carbon sequestration, as formal carbon codes have not yet been released; hence the actual marketable carbon units from hedgerows and soil could be at least 20% lower than our estimates.

These estimates assume the maximum possible area of land in the LNRS zone is restored for nature

The LNRS network covers 41% of the county, of which 6% is existing areas of importance for biodiversity and 34% is the target zone for nature recovery. This was set to be larger than the Global Biodiversity Framework target of 30% of land restored for nature, to allow for landowners choosing which areas to restore. When constraints are removed (buildings, sealed surfaces, road, rail, gardens, water, existing woodland and other semi-natural habitats), 73% of the LNRS recovery zone (25% of the county) is suitable for restoration, and our nature-based carbon scenarios estimate the outcomes if all this area (around 65,000 ha) is restored for nature. However, it is more likely that landowners will choose to convert small portions of their land that are unprofitable to farm, such as areas that are poorly drained or on steep slopes, so the maximum carbon sequestration within the LNRS network is unlikely to be delivered in practice.

Further sequestration is possible through nature-based options beyond the LNRS zone

However, the LNRS also includes 48 'unmapped measures' which can add value in many areas beyond the target network. The 'whole county' scenario already includes ambitious assumptions for two of these measures: a 40% increase in hedgerow length (PM62) and enhancement of soil carbon on all arable fields (PM71), but other measures could also be taken up beyond the LNRS network if the right incentives and support are in place. These could include agroforestry (PM72), which is currently only modelled within the LNRS network, other in-field trees (PM73), habitat restoration to create wildlife corridors on farms (PM70), and planting urban trees (PM81).

Higher or lower-carbon habitat restoration options could be chosen

The LNRS provides landowners with a choice of options at each location, and these will have different carbon outcomes. To illustrate the range of potential outcomes, we used two scenarios. The upper limit comes from the 'maximum carbon-nature' scenario, which focuses on implementing options with high carbon sequestration factors, while the lower limit comes from the 'minimum carbon' scenario and assumes 100% conversion to semi-natural grassland (acid, calcareous or neutral depending on soil type). Both scenarios also includes the same agroforestry, soil carbon and hedgerow options. The minimum scenario only results in a third of the maximum carbon gain in the long term, and a quarter of the marketable units in the next 30 years (10,000 tonnes of carbon per year). This is significant because ongoing unpublished research at the Leverhulme Centre for Nature Recovery indicates that grassland restoration is currently the preferred habitat transition for farmers undertaking BNG projects, probably because it allows continued grazing, can be more easily reversed and does not attract a 'time to reach target condition' penalty in the Biodiversity Metric.

Conversely, it is also possible that a higher proportion of woodland planting could be chosen, delivering more carbon sequestration. As our maximum carbon-nature scenario aims to deliver a balanced mix of habitats in line with the LNRS, woodland is restricted to the highest priority zones, just 17% of the restored habitat area, although a further 25% becomes tree-grass-scrub mosaic and 11% becomes agroforestry. Scenarios dominated by either grassland or woodland would deliver worse outcomes for nature as they would not support the recovery of species needing other habitat types.

Supporting policies are essential

Delivery of any part of this strategy depends on adequate supporting policies. Currently, the payments under the WCC typically do not cover the full cost of woodland planting, although stacking carbon payments with wider co-benefits can help (Thomas, 2025). Wilder Carbon offers a higher price but has more conservative estimation of potential units; however, the number of units delivered could increase post-verification.

In addition, it is vital to protect both existing and restored habitats in order to secure the benefits for carbon, biodiversity and ecosystem services in the long term. This will become more challenging with the ongoing changes to environmental and habitats regulations. Thomas et al (2025) suggested the use of secure covenants as one method of ensuring longevity and permanence of carbon storage.

9 Conclusions

We have developed a high-integrity nature-based carbon strategy for Oxfordshire, based on restoring a balanced mix of locally important habitats in line with the Local Nature Recovery Strategy. This could increase overall carbon storage in the county by up to 28% (6 million tonnes of carbon) once habitats are mature. Over the first 30 years, up to 185,000 tonnes of carbon per year could be sequestered, offsetting **18%** of Oxfordshire's 2023 emissions. However, only 38,000 tonnes of this are covered by existing or emerging market mechanisms, offsetting **4%** of emissions. Extending hedgerow and soil carbon restoration to the whole county rather than just within the LNRS network could increase sequestration to cover 20% of emissions, of which 7% are marketable. These are broad estimates subject to high levels of uncertainty, and represent upper limits as they assume almost complete conversion of low-grade farmland within the LNRS network, which is unlikely to occur in practice.

If emissions continue to decline as planned, the share of residual emissions that could be offset through nature-based solutions could increase significantly, although the sequestration rate will decline as restored habitats mature. Sequestration from nature-based solutions can therefore play an important role, especially in the next 100 years, but only if emissions from fossil fuels and land-use are reduced as much as possible.

As well as playing a key role in delivering both nature recovery and net zero objectives, this strategy can also deliver multiple benefits for climate change adaptation, helping to reduce the impacts of floods, droughts and heatwaves, and can help to support human health and well-being through improving air quality and providing nature-rich green spaces for recreation and relaxation. In contrast, other carbon sequestration options such as fast-growing non-native plantations generally deliver little or no benefit for biodiversity, while the impacts of biochar are highly dependent on the biomass source.

However, deliver of this strategy depends on the right support mechanisms – both adequate carbon prices, and payments or incentives for wider benefits, such as through agri-environment schemes. Restored habitats must be protected from development and managed sensitively to deliver benefits in the long term. Alongside restoring habitats, it is also vital to protect existing habitats for their stored carbon as well as biodiversity and ecosystem services, especially in the LNRS core APIB zones. With good support from both national and local policy mechanisms, this high-integrity policy can play a key role in delivering multiple benefits for carbon, nature and people in Oxfordshire.

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Appendix 1: LNRS Potential measures

Key measures used for this analysis are highlighted in green

ID	Description
PM_1	Enhance and maintain existing areas that are particularly important for biodiversity in Oxfordshire
PM_3	Create, maintain, or enhance wildlife passages to reduce habitat fragmentation by roads, rail, and other infrastructure
PM_5	Create areas of calcareous species-rich grasslands in suitable locations, particularly slopes
PM_6	Create areas of neutral species-rich grasslands in suitable locations
PM_7	Create areas of species-rich acid grasslands in suitable locations
PM_8	Create varied physical ground structure when creating new grassland habitats
PM_9	Create new areas of lowland meadow by creating and restoring meadows in suitable locations (particularly on floodplains)
PM_10	Enhance (or maintain a good condition of) existing calcareous grassland
PM_11	Enhance (or maintain a good condition of) existing neutral species-rich grasslands
PM_12	Enhance (or maintain a good condition of) existing acid grasslands
PM_14	Enhance existing lowland meadows through grazing, cutting, or a combination to increase and support species diversity (particularly for floodplain and MG4 habitats)
PM_17	Manage existing areas of scrub to create a varied age and physical structure including glades and scalloped edges
PM_18	Enhance (or maintain a good condition of) existing grassland around roads and infrastructure including road verge nature reserves (RVNR) to increase biodiversity
PM_21	Enhance (or maintain a good condition of) existing heathland
PM_22	Create new areas of heathland on suitable soil types
PM_23	Enhance (or maintain a good condition of) existing wood pasture and parkland to support local species and future climates
PM_26	Improve (or maintain a good condition of) existing orchards for biodiversity
PM_29	Create (and manage) areas of new parkland and wood pasture, planning to produce future ancient and veteran trees
PM_30	Create new areas of habitat that contain a matrix of habitat types including small woodland patches, scattered trees, scrub, and grassland
PM_33	Enhance existing woodlands to achieve a diverse structure and good ecological condition, suitable for the woodland type, age, and nearby species
PM_35	Enhance existing ancient woodland to improve structural diversity, woodland condition, and benefit local species
PM_36	Enhance the biodiversity value of existing ancient woodlands that are 'plantations on ancient woodland sites' (PAWS).
PM_38	Create new woodland by planting trees (or enabling their natural regeneration) using species that are suited to the soil type and site conditions
PM_40	Create new areas of wet woodland along rivers, river corridors, and riparian land as appropriate
PM_42	Restore river diversity and manage rivers and their riparian (riverside) habitats to achieve good ecological condition that supports species
PM_45	Enhance the condition (or maintain a good condition) of lakes in Oxfordshire
PM_46	Enhance existing ponds by undertaking sensitive management and restoration of ponds and pond complexes to improve biodiversity and water quality
PM_48	Enhance, restore, or manage chalk rivers and streams to achieve (or maintain a good condition of) physical habitat and water quality
PM_50	Enhance existing fens through appropriate management and restoration to achieve good ecological condition
PM_51	Manage fen buffer areas to create and enhance areas of rough vegetation that help to enhance the condition of the fen habitat
PM_54	Create wetland habitats that contain a matrix of various habitat types suitable for the site (e.g. wet grassland, ponds, ditches, hedgerows, trees, or wet woodland)
PM_55	Create new, varied ponds in suitable locations across all habitat types to increase biodiversity and create more clean water habitats

ID	Description
PM_58	Create areas of new good quality grazing marsh and enhance (or maintain a good condition) of existing floodplain grazing marsh
PM_75	Restore biodiversity around heritage assets and scheduled monuments in a complementary manner
PM_76	Create and/or manage greenspaces and habitats in urban areas to enhance their condition to benefit wildlife, improve connectivity, and provide wider benefits
PM_78	Create or enhance a mosaic of habitats in a manner and size that complements the current use of the land by the local community. This action is suitable to take in and around community-use areas like playing fields, play spaces, cemeteries, golf courses, allotments, public parks, religious grounds and other community spaces or gardens.
PM_83	Create and/or enhance community and local growing spaces, community farms, and allotments to improve soil health and benefit biodiversity
Species-focused measures	
PM_202	Create or manage large reedbeds in wetland habitats to recover Bittern populations
PM_207	Manage woodlands and scrub for Nightingales. Coppice on rotation and encourage dense layers of shrub in woodlands with scrub at the edges
PM_208	Create and manage protected, undisturbed plots to encourage Stone Curlews to nest. Create and manage areas of open, sparsely vegetated grassland with stony ground, grazed short (typically by rabbits or sheep)
PM_212	Support Willow Tits by linking up wet woodland, dense scrub, and hedgerow habitats along river corridors with lots of deadwood and stumps
PM_213	Plant new Barberry plants in suitable locations to support the Barberry Carpet Moth. Aim to connect up existing areas of Common Barberry and increase the spread of this plant.
PM_214	Retain, manage, plant, and connect up Blackthorn hedgerows, trees, and scrub for Black and Brown Hairstreak butterflies
PM_215	Create or enhance suitable flower-rich grassland habitats with plentiful populations of violets and light patches of scrub for the Dark Green Fritillary
PM_216	Create (or maintain existing areas of) scrubby calcareous grassland slopes which face East, North, or West and have strongly growing populations of cowslip and primrose to encourage Duke of Burgundy butterflies
PM_217	Maintain and increase Wild Liquorice plants and their seed pods on suitable rough, unimproved calcareous grassland, lanes and scrub margins for the Liquorice Piercer Moth and introduce suitable grazing regimes.
PM_219	Create and manage south facing calcareous grassland, grazed to extremely short turf with Sheep's Fescue growing, to benefit the Silver Spotted Skipper
PM_220	Create and manage wide field margins and sheltered grasslands to contain Kidney Vetch (Anthyllis vulneraria) on low nutrient soils which get disturbed, to support Small Blue butterflies
PM_221	Plant (and manage) Dark Mullein on grassland in and around the Chilterns to support the Striped Lychnis Moth
PM_222	Manage woodlands for White Admiral butterflies achieving partial shade with honeysuckle, brambles, and areas of bare ground
PM_223	Retain Elm trees for White Letter Hairstreak butterflies and plant or grow new disease resistant Elms especially within 2km of existing Elm woodlands
PM_224	Manage woodlands for the Wood White butterfly and then consider reintroductions of the butterfly to suitable woodlands
PM_225	Manage sites that have, or could have, Desmoulin's Whorl Snail to maintain an appropriate vegetation structure
PM_226	Create and maintain fish passes or remove structures within rivers to enable fish to migrate and reproduce
PM_227	Develop a dense, undisturbed litter layer in woodlands, particularly ancient beech woods, and manage them to achieve partial shade for the Mountain Bulin Snail
PM_229	Ensure the long-term continuity of suitable tree species with careful management to support rare woodland fungi and plants
PM_230	Retain veteran trees which host rare lichens and manage woodlands and trees to increase future lichen populations
PM_231	Manage existing populations of Autumn gentian and where suitable, create new areas of Autumn Gentian, allowing the range and population of the Autumn Gentian beetle to expand
PM_232	Manage and cut reedbed on long rotation and prevent scrub and trees from invading to support the Cigarello Gall-fly

ID	Description
PM_233	Ensure that alkaline tufa spring-fed fens in Oxfordshire have a flow of clean calcareous spring flow into the fen and graze, or cut and rake vegetation to keep open, short, sunny pools to support Clubbed General Soldierflies
PM_234	Graze pastures with unmedicated animals to supply unmedicated dung to support rare dung specialist species and dung beetles
PM_236	Conserve, manage and enhance suitable areas to increase populations of Marsh Lousewort for the Lousewort Flea Beetle
PM_237	Manage grasslands that are good quality, warm, sunny, and open to encourage and retain yellow meadow anthills (mounds). Graze to a short sward using suitable species like sheep to support the Meadow Ant Hoverfly
PM_238	Manage and create orchards that retain deadwood to support Noble Chafer beetles
PM_239	Continue extensive grazing management (or cutting and raking) over suitable large areas to keep wetlands short and open throughout the year. Retain or create pools in open wetlands to host snails
PM_240	Create unpolluted, shallow streams to support Southern Damselflies
PM_241	Create new areas of connected coppice with standard trees including oaks (Quercus robur) especially in and around Brasenose Wood, Oxfordshire to support the spider (Tuberta maerens)
PM_243	Manage woodlands for bats. Typically, retain deadwood and mature trees with dark, humid conditions with well connected foraging/commuting corridors nearby.
PM_245	Create, manage, and enhance connected corridors of coppice, woodland, and hedgerows to support Hazel Dormice
PM_249	Manage (or enhance) riverside banks, ditches, and watercourses for Water Voles
PM_250	Plant or enable Black Poplars to grow in Oxfordshire and retain dead and dying poplars where they have been growing. Retain deadwood where possible
PM_251	Within appropriate floodplain habitats, recover Creeping Marshwort by maintaining and creating damp, grassland on the margins of floodplain ponds that flood in winter. Maintain consistently short, sparse vegetation through regular, extensive grazing
PM_252	Enhance existing areas of Devil's bit scabious and create new large areas in suitable, large habitat areas. In suitable sites, reintroduce Marsh Fritillary butterflies
PM_253	Undertake management to increase the presence of Downy Woundwort
PM_254	Maintain populations of, or (re)introduce, Fen Violets at suitable sites
PM_256	Regenerate Juniper and manage sites to recover Juniper populations
PM_257	Create new areas of bare limestone in woodlands, along rivers, in walls, built structures, and gardens to encourage Limestone Ferns.
PM_259	Maintain low soil nutrient levels, prevent scrub encroachment, and graze at key times to reduce coarse, dominant grasses in suitable sites where Meadow Clary is present or has been present
PM_260	Manage woodlands for Military Orchids and create open conditions in glades. Exclude and control deer and rabbits and clear moss cover as necessary around the orchids
PM_261	Manage chalk grassland to retain moisture and increase populations of the Monkey Orchid. Identify suitable sites (without Lady Orchids) to reintroduce and manage Monkey Orchids to expand their range and prevent extinction
Unmapped measures	
PM_2	Prioritise connectivity when creating and maintaining habitats to join up areas of nature and habitats more effectively
PM_4	Create or improve boundaries using natural products that support biodiversity.
PM_13	Maintain or introduce grazing or cutting techniques that enhance the structural diversity of grasslands and support local species.
PM_15	Implement conservation grazing techniques that minimise or reduce the need for permanent physical fencing
PM_16	Create and maintain pockets of diverse scrub on grasslands as appropriate.
PM_19	Create new road verge nature reserves (RVNR) to allow wildflowers to grow, flower, and set seed by changing their management.
PM_20	Where new roads are created assess the opportunity for new road verge nature reserves
PM_24	Enhance (or maintain a good condition of) existing ancient and veteran trees and the species that they support.
PM_25	Selectively create more veteran features in mature non-veteran trees where appropriate
PM_27	Enhance, create, or maintain a good condition of existing 'open mosaic habitat on previously developed land' (OMHPDL) to conserve and enhance biodiversity on these open, dynamic areas.

ID	Description
PM_28	Improve habitat condition and biodiversity by introducing or maintaining flexible grazing regimes where appropriate (and/or cutting and collecting).
PM_31	Create new orchards or restore orchards in areas where there used to be traditional orchards, using a diverse range of trees.
PM_32	Create new areas that contain a mix of habitats suitable to the site to benefit wildlife.
PM_34	Manage populations of species that reach unsustainable levels so that existing woodlands can achieve good ecological condition to support a diverse range of species.
PM_37	Enhance and/or create areas of active, worked coppice in Oxfordshire.
PM_39	Use low intervention woodland creation techniques including natural regeneration where appropriate, especially near existing ancient woodland
PM_41	Improve water quality through action(s) that help to reduce or stop pollution of freshwater habitats
PM_43	Restore, create and enhance marginal habitats
PM_44	Manage operational canals to enhance (or maintain good condition of) habitats or wildlife corridors through Oxfordshire
PM_47	Enhance (or maintain a good quality of) existing reedbeds to create a varied vegetation structure that supports reedbed species.
PM_49	Create, improve, and manage the variety of ditches across Oxfordshire to benefit biodiversity in appropriate locations.
PM_52	Where appropriate, retain and/or create ‘fen carr’, a wet woodland fen habitat that tends to be made up from ‘sallow’ willow species and alder.
PM_53	Ensure that fens in Oxfordshire retain continued, appropriate flow rates of clean water into fen habitats to support their ecological condition
PM_56	Create more reedbed habitat at suitable locations to provide habitat for reedbed specialists (often as part of larger wetland mosaics)
PM_57	Enhance any existing fen, marsh and swamp wetland habitat areas.
PM_59	Create and manage biodiverse habitat alongside riverbanks to enhance biodiversity, improve water quality, and offer a corridor to enable wildlife to move along rivers, banks, and watercourses.
PM_60	Across all habitat types that have trees, retain dead, decaying, and/or dying wood in the environment where it is safe to do so (including deadwood in water).
PM_61	Manage existing hedgerows and hedgerow trees to enhance their condition and longevity to benefit biodiversity.
PM_62	Plant, or allow the growth of, new and diverse hedgerows
PM_63	Slow, stop, and/or reverse the spread of invasive species that compromise the health of habitats in Oxfordshire.
PM_64	Create and manage graded margins up to hedgerows and dry-stone walls to support birds and other farmland species.
PM_65	Create and manage wide arable field margins and in-field strips as wildflower grassland.
PM_66	Create and manage field margins to improve and increase biodiversity around fields.
PM_67	Create and improve areas that support rare arable plants on farmland.
PM_68	Support farmland birds over winter
PM_69	Take action to improve farmland bird nesting success
PM_70	Retain, improve, or create habitat to increase the opportunity for wildlife to move through the landscape (e.g. wildlife corridors).
PM_71	Across Oxfordshire’s farmland, increase the biodiversity in soils by choosing cultivation practices that can regenerate species and produce healthy soils
PM_72	Plant (or allow the growth of) diverse trees of various ages and types on farmland
PM_73	Retain and/or plant in-field trees with suitable buffer zones to ensure continuity of open grown trees (live, dead, or dying) that support species across the landscape.
PM_74	Create a tailored integrated pest management plan to reduce the use of artificial fertilisers and pesticides
PM_77	Integrate wildlife-friendly measures into homes, gardens, greenspaces and developments.
PM_79	Create and enhance wildlife-rich corridors of suitable habitat between, through, or near settlements in Oxfordshire.
PM_80	Ensure that actions in urban areas offer wider benefits and meet relevant green space standards.
PM_81	Increase tree canopy cover in Oxfordshire by planting and managing trees and woodlands in built up areas

ID	Description
PM_82	Carry out wildlife-friendly actions that also reduce flood-risk and the impact of heat in built-up areas
PM_83	Create and/or enhance community and local growing spaces, community farms, and allotments to improve soil health and benefit biodiversity
PM_84	Reduce pollution and damage to the environment by changing products, behaviours, and actions

Appendix 2: Carbon storage and sequestration estimates from the Agile opportunity maps

Notes

- WCC = Woodland Carbon Code; NERR043 = Alonso et al (2012).
- See further notes below this table for more detail on how the WCC was used to derive sequestration rates for woodland habitats.
- Carbon scores are scores on a scale of zero to 10. Scores for major habitats are based on actual carbon storage from available literature relevant to the UK. Scores for other habitats are based on expert judgement, informed by understanding of the factors affecting carbon storage and other ecosystem services from a literature review of over 700 papers (Smith et al 2017).
- 'Score ratio' means that the carbon values were based on a major habitat for which specific values were available, adjusted based on the ratio of the carbon scores out of 10 for the habitat in question compared to the reference habitat. For example, the score for carbon storage in broadleaved plantations was 9/10 of the score for semi-natural broadleaved woodland. This approach was used to maintain consistent ranking of different habitats, as deriving values from individual literature sources can result in misleading results if the assumptions, metrics and local contexts are not consistent.

Habitat	**Carbon score out of 10**	**Carbon storage tC/ha**			**Carbon sequestration tC/ha/y**	**Source**	
		Vegetation	Soil	Total		**Carbon storage**	**Carbon sequestration**
Broadleaved and mixed woodland: semi-natural	10	**111.0**	**162.0**	273.0	4.1	Cantarello et al. (2011)	Analysis of WCC: average sequestration rate from 100 to 130 years after planting, weighted by typical mix of species and yield class in Oxfordshire (see notes at end of table)
Broadleaved and mixed woodland: plantation	9	99.9	145.8	245.7	4.4	Score ratio (cf semi-natural woodland)	Analysis of WCC: average sequestration rate over first 60 years, less assumed loss of 50% from HWP, weighted by typical mix of species and yield class in Oxfordshire (see notes at end of table)
Native pine woodlands	7	68.3	122.5	190.8	1.7	Score ratio (cf plantation)	Analysis of WCC: average sequestration rate from 100 to 130 years after planting, weighted by range of yield classes (see notes at end of table)
Coniferous woodland: plantation	8	**78.0**	**140.0**	218.0	3.9	Cantarello et al. (2011)	Analysis of WCC: average sequestration rate over first 60 years, less assumed loss of 50% from HWP, weighted by typical mix of species and yield class in Oxfordshire (see notes at end of table).
Wood pasture and parkland with scattered trees	5	55.5	81.0	136.5	1.5	Score ratio (cf semi-natural woodland)	25% broadleaved woodland, 75% semi-natural grassland
Traditional orchards	5	55.5	81.0	136.5	0.0	Score ratio (cf semi-natural woodland)	NERR trad orchards
Dense scrub	6	**24.0**	**140.0**	164.0	1.1	Cantarello et al. (2011)	WCC low yield wide spacing sycamore-ash-birch average over first 10 years (note: this excludes herbaceous layer).
Hedgerows	5	20.0	116.7	136.7	1.1	Score ratio (cf dense scrub)	Same as dense scrub

Habitat	Carbon score out of 10	Carbon storage tC/ha			Carbon sequestration tC/ha/y	Source	
		Vegetation	Soil	Total		Carbon storage	Carbon sequestration
Hedgerow with trees	7	65.5	139.3	204.8	2.6	Average of broadleaved woodland and hedgerow. Note that hedgerow trees can grow well due to the lack of competition for light (Poulton et al 2003)	As for storage
Felled woodland	2	0.0	140.0	140.0	0.0	Vegetation zero, soil as for plantation	Zero (could be some emissions as debris decays, but could also be regrowth)
Bog woodland	10	55.5	452.8	508.3	2.0	Vegetation half of semi-natural woodland (as trees smaller); soil 80% of bog (as trees may reduce carbon storage)	Half of semi-natural woodland (as trees smaller)
Wet woodland	10	90	243	333.0	4.1	80% broadleaved woodland; 20% bog	Same as semi-natural woodland
Tall herb and fern	4	2.6	107.0	109.6	0.6	Score ratio (cf semi-natural grassland)	Same as semi-natural grassland
Ephemeral / short perennial	2	1.3	53.5	54.8	0.6	Score ratio (cf semi-natural grassland)	Same as semi-natural grassland
Bracken	4	2.6	107.0	109.6	0.6	Score ratio (cf semi-natural grassland)	Same as semi-natural grassland
Semi-natural grassland	4	**2.6**	**107.0**	109.6	0.6	Cantarello et al. (2011)	NERR043 semi-natural grass
Acid grassland	4	2.6	107.0	109.6	0.6	Score ratio (cf semi-natural grassland)	NERR043 semi-natural grass
Calcareous grassland	3	2.0	80.3	82.2	0.6	Score ratio (cf semi-natural grassland)	NERR043 semi-natural grass
Neutral grassland	4	2.6	107.0	109.6	0.6	Score ratio (cf semi-natural grassland)	NERR043 semi-natural grass
Calaminarian grasslands	2	1.3	53.5	54.8	0.6	Score ratio (cf semi-natural grassland)	Same as ephemeral
Improved grassland	3	2.0	80.3	82.2	0.2	Score ratio (cf semi-natural grassland)	NERR043 improved grass
Arable fields, horticulture and temporary grass	2	**2.0**	**64.0**	66.0	-0.3	Cantarello et al. (2011)	NERR043 arable
Arable field margins	3	2.6	70.4	73.0	0.6	Vegetation same as semi-natural grassland; soil 10% more than arable	Same as semi-natural grassland
Woody biofuel crops	4	**4.4**	**105.0**	109.4	0.0	Cantarello et al. (2011)	Zero as will be burnt. Displaced emissions not accounted for (will approach zero as we shift to renewables).
Intensive orchards	5	55.5	81.0	136.5	1.3	Score ratio (cf semi-natural grassland)	NERR043
Bog	10	**7.0**	**566.0**	573.0	0.3	Cantarello et al. (2011)	Mid-point of NERR043 sources ranging from 0.1 to 0.5. But can be source if degraded (as most UK bogs are).
Dwarf shrub heath	4	**6.9**	**102.0**	108.9	0.9	Cantarello et al. (2011)	Field et al 2020 Table A3
Inland rock	0	0.0	0.0	0.0	0.0	Zero	Zero

Habitat	Carbon score out of 10	Carbon storage tC/ha			Carbon sequestration tC/ha/y	Source	
		Vegetation	Soil	Total		Carbon storage	Carbon sequestration
Freshwater (generic)	1	1.5	25.8	27.3	0.0	Score ratio (cf fen, marsh and swamp)	Zero (unknown)
Standing open water	1	1.5	25.8	27.3	0.0	Score ratio (cf fen, marsh and swamp)	Zero (unknown)
Canals	0	0.0	0.0	0.0	0.0	Zero (unknown)	Zero (unknown)
Running water	0	0.0	5.0	5.0	0.0	Zero vegetation, guess for soil	Zero (unknown)
Fen, marsh and swamp (generic)	6	**8.7**	**155.0**	163.7	0.0	Cantarello et al. (2011)	Zero (may be positive or negative; highly dependent on condition)
Lowland fens	6	8.7	155.0	163.7	0.0	Score ratio (cf fen, marsh and swamp)	Zero (may be positive or negative; highly dependent on condition)
Purple moor grass and rush pastures	4	5.8	103.3	109.1	0.6	Score ratio (cf fen, marsh and swamp)	Same as semi-natural grassland
Upland flushes, fens and swamps	6	8.7	155.0	163.7	0.0	Score ratio (cf fen, marsh and swamp)	Zero (may be positive or negative; highly dependent on condition)
Aquatic marginal vegetation	2	2.9	51.7	54.6	0.0	Score ratio (cf fen, marsh and swamp)	Zero (unknown)
Reedbeds	4	5.8	103.3	109.1	0.0	Score ratio (cf fen, marsh and swamp)	Zero (unknown)
Other swamps	4	5.8	103.3	109.1	0.0	Score ratio (cf fen, marsh and swamp)	Zero (may be positive or negative; highly dependent on condition)
Sealed surface and buildings	0	0	0	0.0	0.0	Zero	Zero
Artificial unvegetated, unsealed surface	0	0	0	0.0	0.0	Zero (unknown)	Zero
Bare ground	1	2	17	18.3	0.0	Score ratio (cf amenity grassland)	Zero
Garden	1	2	17	18.3	0.1	Score ratio (cf amenity grassland)	Assume half of vegetated garden
Vegetated garden	2	3	33	36.5	0.2	Score ratio (cf amenity grassland)	Same as improved grassland
Unvegetated garden	0	0	0	0.0	0.0	Zero	Zero
Open mosaic habitats on previously developed land	2	4	17	20.7	0.2	Vegetation one sixth of dense scrub, soil same as bare gound	Assume one sixth of dense scrub, to reflect patchy scrub typical on OMHD sites.
Parks and gardens	4	6	67	73.1	0.6	Score ratio (cf amenity grassland)	Assume 10% woodland and 90% improved grass
Footpath / cycle path - green	2	3	33	36.5	0.2	Score ratio (cf amenity grassland)	Same as amenity grassland
Green bridge	1	2	17	18.3	0.2	Score ratio (cf amenity grassland)	Same as amenity grassland
Amenity grassland	3	**4.8**	**50**	54.8	0.2	Cantarello et al. (2011)	Same as improved grassland
Road island / verge	3	5	50	54.8	0.2	Score ratio (cf amenity grassland)	Same as amenity grassland
Natural sports facility, recreation ground or playground	3	5	50	54.8	0.2	Score ratio (cf amenity grassland)	Same as amenity grassland

Habitat	Carbon score out of 10	Carbon storage tC/ha			Carbon sequestration tC/ha/y	Source	
		Vegetation	Soil	Total		Carbon storage	Carbon sequestration
Cemeteries and churchyards	4	6	67	73.1	0.6	Score ratio (cf amenity grassland)	Same as parks and gardens
Allotments, city farm, community garden	3	5	50	54.8	0.0	Score ratio (cf amenity grassland)	Zero as may be a source or a sink
Intensive green roof	2	3	33	36.5	0.1	Score ratio (cf amenity grassland)	Half of amenity grassland
Green wall	1	2	17	18.3	0.1	Score ratio (cf amenity grassland)	Same as intensive green roof
Brown roof or extensive green roof	1	2	17	18.3	0.1	Score ratio (cf amenity grassland)	Same as intensive green roof
Tree	7	78	113	191.1	4.1	Score ratio (cf semi-natural woodland)	Same as semi-natural woodland
SuDS retention pond	3	4.8	50	54.8	0.0	Same as amenity grassland	Zero as may be a source or a sink
SuDS detention basin	4	6	67	73.1	0.1	Score ratio (cf amenity grassland)	Half of amenity grassland
Bioswale	2	3	33	36.5	0.1	Score ratio (cf amenity grassland)	Same as SuDS detention basin
Rain garden	2	2.9	52	54.6	0.1	Score ratio (cf fen, marsh and swamp)	Same as SuDS detention basin
Introduced shrub	4	**24**	**50**	74.0	0.5	Cantarello et al. (2011)	Half of dense scrub
Flower bed	2	3	33	36.5	0.0	Score ratio (cf amenity grassland)	Zero as may be a source or a sink

Derivation of carbon sequestration estimates for woodland

Estimates of average sequestration rates in different types of Oxfordshire woodland were based on the methodology derived for the PAZCO (Pathways to a Zero Carbon Oxfordshire) study (see Hampton et al., 2021 for the whole study, with the land-use section in Chapter 9, and Smith, 2021 for Annex 1, containing the methodology). Details from the methodology Annex are reproduced below for ease of reference.

The estimates were derived using the Woodland Carbon Code Calculator (WCC 2025): at the time of the PAZCO study the existing version was 2.0. We used Forest Research's Ecological Site Classification tool to work out what types of woodland are suitable for Oxfordshire's soil types and climate (warm dry, or warm moist on higher land), and what the range of yield classes (productivity) would be in different soils:

- On carbonate soils only Beech is suitable, with a yield class of 5 (low).
- On non-carbonate soils, Beech ranges from yield class 4 to 10; Oak 7 to 8; Ash 9, Sycamore 8, Scots pine 9 to 13, Sitka Spruce* 9 on one soil type, otherwise 15 to 19; Larch. 8-10.

We then assumed the following average compositions for different woodland types:

- Semi-natural broadleaved: 50% Beech; 25% Oak; 25% Sycamore, Ash and Birch. Not thinned; planted at 3m spacing.
- Broadleaved plantations: 80% Beech, 20% Oak. Managed with regular thinning and planted at 2.5m spacing.
- Mixed plantations: 25% Beech, 25% Oak, 25% Scot's pine, 25% Larch,

- Conifer plantations, split equally between Scot's pine, Larch and Sitka Spruce*, managed with regular thinning and planted at the closest recommended spacing.

*Note that Sitka Spruce is in fact rarely used in Oxfordshire; it is far more common to see Douglas Fir for example. However, the Forestry Commission's Ecological Site Classification tool predicts that Douglas Fir is not suitable on most woodland soil types in Oxfordshire, so we have assumed Sitka Spruce instead in order to keep the methodology consistent. This could be changed in future but would make little difference to the estimates of carbon storage and sequestration.

For semi-natural woodlands we assume that the woodlands are currently 100 years old, so we take the average sequestration rate from ages 100 to 130 years to estimate sequestration from 2020 to 2050 (for PAZCO; for the present study this would be equivalent to 2025-2055).

For plantations we take average sequestration rates over 60 years (the typical rotation length), and then subtract the amount lost due to decay of harvested wood products, which we assume to be 50% (i.e. we assume that 50% of all harvested wood is currently locked up in timber construction or other long lived products, with the rest used for short-lived products such as paper, cheap furniture or fuel combustion). This is an optimistic assumption, as currently 85% of harvested wood in the UK is used for short-lived products or bioenergy, returning the sequestered carbon to the atmosphere shortly after harvest (Forest Research, 2023).