



Research Note

The management and creation of woodland for biodiversity and wider environmental benefits

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Woodland creation and management deliver a wide range of environmental benefits. The extent of those benefits is determined by a range of factors, including the type of woodland, the way it is managed, and its position in the landscape. Here we draw on the evidence base to summarise the importance of these factors in the delivery of biodiversity value and environmental benefits. We begin by discussing how existing woodlands can be managed to improve their condition, such as by increasing their structural complexity and species diversity, and by reducing external pressures, such as herbivore grazing and invasive species. Next, we review the evidence for the creation of new woodland, either as spatially discrete woodlands or through the expansion of existing woodlands. We conclude by discussing the potential synergies and trade-offs between different environmental benefits, and their interaction with social and economic outputs.

Introduction

The UK is committed to the protection, expansion, and sustainable management of woodlands to secure a wide range of environmental and social benefits. Well-managed woodlands of any type can enhance biodiversity and support many protected species. Additionally, woodlands provide important benefits to people through regulating and provisioning ecosystem services such as timber and wood products, climate change mitigation, water quality improvements, and recreation. However, many woodlands have fallen into unfavourable or intermediate ecological condition due to a lack of suitable management, or to external pressures such as herbivore damage, invasive species, and pests and diseases (National Forest Inventory, 2020).

The type, location, and management of woodland elements within a landscape, and the potential network they form, determine the extent to which they support native biodiversity and contribute to the delivery of ecosystem services. Lawton *et al.* (2010) identified four key attributes for managing, restoring, and creating habitats across a landscape to benefit biodiversity: **better**, **bigger**, **more**, and **joined**. For woodland networks, these are implemented through the management of existing woodlands to improve their condition (**better**), and through woodland creation (**more**). New woodlands can be created as spatially discrete woodlands, which could provide stepping stones between nearby woodland fragments (**joined**), or adjacent to existing woodlands to expand them (**bigger**). The location of new woodland and its proximity to other wooded features, including trees outside woodlands, hedgerows, or wood pasture, may also influence connectivity across a landscape.

This Research Note summarises current evidence on how the management, creation, and spatial configuration of woodlands within a landscape affect biodiversity, ecosystem resilience, and key environmental benefits including climate change mitigation and adaptation, flood mitigation, and improved water quality. We primarily focus on the benefits to woodland-associated biodiversity, while also highlighting where actions can deliver benefits to other species. The roles of trees outside woodlands and other wooded habitats, such as wood pasture, are not specifically covered in this review. The evidence has been gathered from technical reports, guidance documents, and the scientific literature, including review articles and meta-analyses. We present the findings in two sections: 'Managing existing woodland' and 'Creating new woodland', each with a table of summary statements that describes the strength and agreement of the evidence (IPBES, 2018). In the final section, we consider trade-offs between biodiversity and productive forestry, as well as between different environmental outcomes. We also highlight some of the potential synergies in woodland management and

creation to achieve multiple environmental benefits, including those beyond the scope of this Research Note.

Managing existing woodland

Woodland management is the maintenance, improvement, and utilisation of existing woodlands through forestry operations and land management activities. Common management objectives include biodiversity enhancement, carbon sequestration, and the production of timber and wood products. There are likely to be synergies and trade-offs between different management objectives depending on factors such as woodland type and operational approach (Sing *et al.*, 2018). These are discussed in more detail in 'Synergies and trade-offs'. Managing existing woodlands to improve their ecological condition has been demonstrated to be a highly effective method of enhancing woodland-associated biodiversity and ecosystem service delivery across a landscape, particularly when ancient woodlands and neighbouring habitats are targeted (Crick *et al.*, 2020).

Here we review the evidence supporting the improvement of woodland ecological condition by increasing structural complexity, increasing tree and shrub species diversity, and reducing external pressures.

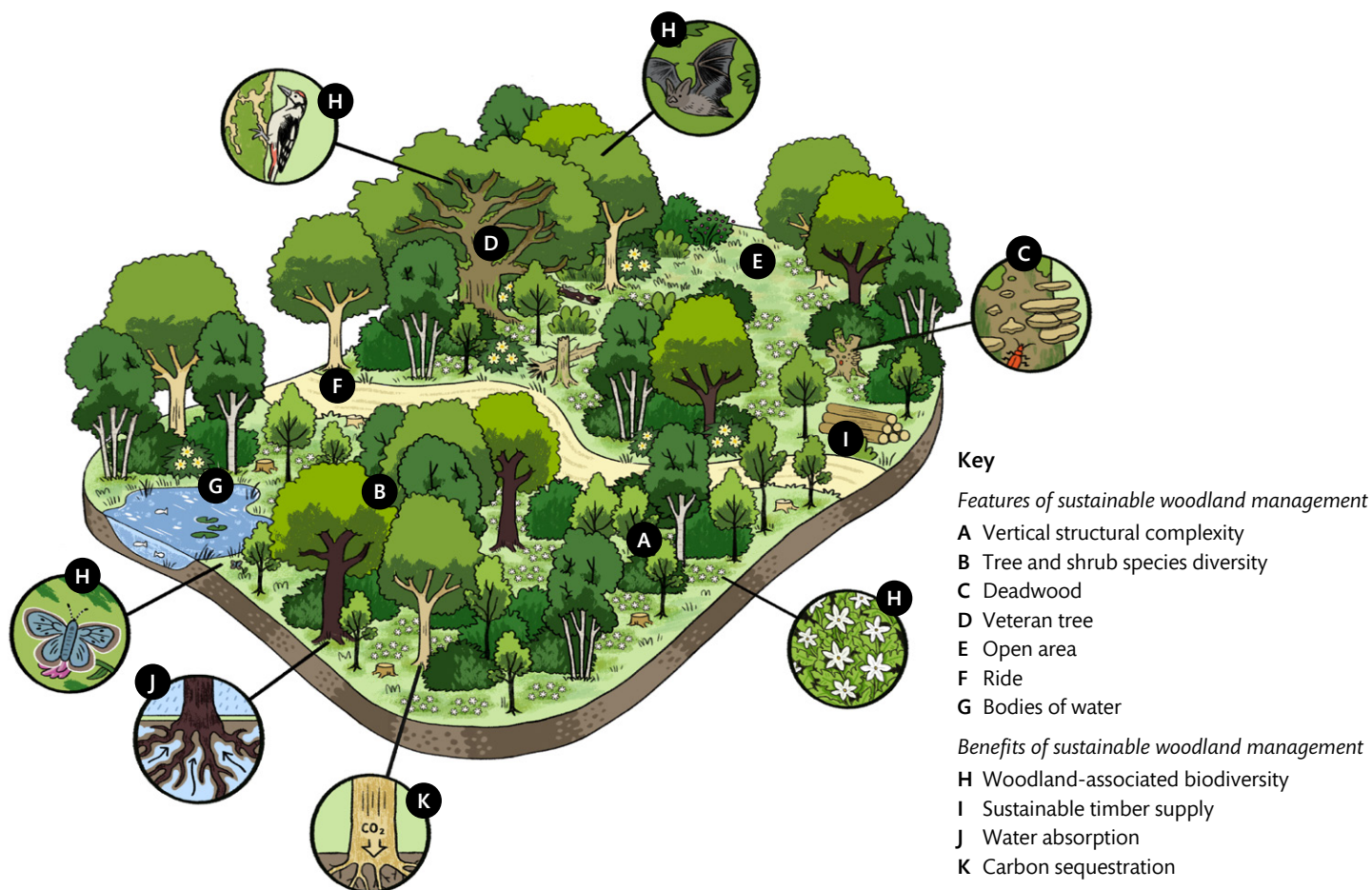
Increasing structural complexity

Structural complexity describes the variation in woodland structure and is influenced by the woodland's underlying topography, hydrology, and geology. Vertical structural complexity (Figure 1A; hereafter referred to in superscript) captures the height and age ranges of tree and understory species and includes features such as deadwood^{1C}, veteran trees^{1D}, and patches of scrub. The variation in stem density and diameter across a woodland, and the distribution of open areas^{1E}, bodies of water^{1G}, and rides^{1F}, is defined as horizontal structural complexity.

Benefits for wildlife

High structural complexity is correlated with a higher diversity of microclimates and ecological niches that benefit a greater number of species^{1H}. Research has demonstrated the positive impact of structural complexity on the abundance and species richness (Box 1) of birds, bats, small mammals, flying insects (Fuller *et al.*, 2018), and vascular plants (Humphrey *et al.*, 2015; Waddell *et al.*, 2024). Certain features have been shown to benefit specific groups, such as areas of lower tree density which are favoured by bats (Fuentes-Montemayor *et al.*, 2013). Early woodland developmental stages are equally important as they support unique species assemblages, particularly among woodland birds (Wilson *et al.*, 2006; Sweeney *et al.*, 2010).

Figure 1 Sustainable woodland management to improve biodiversity value and provide wider environmental benefits.



Note: Broadleaved woodland is represented, but example features and benefits, which are annotated and referenced with superscript letters in the text, also apply to mixed and coniferous woodlands. Variation in the distribution of structural features across a woodland is referred to as horizontal structural complexity.

Box 1 Abundance and species richness

These ecological terms are commonly used to summarise the amount of biodiversity of a given taxonomic or functional group within an area. 'Abundance' refers to the total number of individuals of that group, while 'species richness' describes the total number of species. The two are not always correlated and it is possible to have abundant woodlands with low species richness and habitat that is highly species rich but at a low abundance.

Ancient and veteran trees add further complexity and are important for the abundance and diversity of many forest-associated species (Zeller *et al.*, 2023). Deadwood (fallen, standing, or as part of a living tree) is a component of healthy woodland ecosystems and provides a suite of unique ecological niches. The total volume, species, and decay stage of deadwood determine which associated species are present, and studies have positively correlated the species richness of bryophytes, fungi, lichens, and invertebrates with one or more of these factors (Lassauce *et al.*, 2011; Andringa *et al.*, 2019; Tomao *et al.*, 2020).

Canopy gaps are important features that influence the biodiversity supported by mature woodlands. They allow light to penetrate the woodland interior, potentially to the forest floor, which benefits a range of species, particularly ground vegetation, invertebrates, and lichen (Zeller *et al.*, 2023). Glades, rides, and clearings provide larger patches of open and edge habitats that can also benefit different species assemblages and contribute to overall biodiversity (Iremonger *et al.*, 2006). The decline in traditional management practices, such as coppicing, in favour of uniform and closed-canopy timber plantations has led to a significant decline in forest biodiversity across Europe, particularly affecting species that thrive in more open environments (Kirby, Buckley, and Mills, 2017).

Structural complexity may also bring resilience to a woodland. There is evidence that reduced tree density can increase resilience to pests and pathogens (Roberts *et al.*, 2020), while a greater variety of micro-habitats may mitigate climate change impacts on resident biodiversity (Box 2) (Bellamy *et al.*, 2018).

Box 2 Woodland resilience and adaptation

In the context of woodland ecosystems, 'resilience' and 'adaptation' are interlinked but distinct terms which describe how a woodland may react to external pressures and a changing climate.

'Resilience' describes the capability of a woodland to withstand or recover from an external pressure or shock while maintaining the core species and features that allow it to host biodiversity and deliver ecosystem services (Bellamy *et al.*, 2018). Common pressures include pests, diseases, invasive species, and environmental events such as droughts and storms which bring high winds and heavy rainfall. Many of these threats are becoming more frequent and severe due to climate change.

'Adaptation', on the other hand, is the capacity of the woodland to alter in response to changing environmental conditions such that it can continue to host biodiversity and provision ecosystem services into the future. Adaptive potential can be introduced to a woodland through changes at different levels, such as in species composition by planting non- or near-natives, or in the genetics of the tree species by sourcing seed from southerly provenances (i.e. assisted migration) or including individuals selected for desirable traits (such as higher drought tolerance).

Other environmental benefits

Woodlands with higher structural complexity have been shown to accumulate more above-ground carbon^{1K} than less structurally complex forests due to complementary resource use by trees of different sizes (Ali, 2019). Retaining natural deadwood and brash from forestry operations increases the amount of carbon stored in forest soils (James *et al.*, 2021). Fallen deadwood also adds roughness to the woodland floor which contributes to flood mitigation and better water quality by increasing water infiltration and absorption^{1J}, slowing water run-off, and reducing soil loss (Nisbet *et al.*, 2011).

Increasing tree and shrub species diversity

Closely associated with structural complexity is the variety and spatial distribution of tree and shrub species in the canopy and understory^{1B}. The functional traits of each tree and shrub species (e.g. the level of shade cast, the water-holding capacity of its bark, and the nutritional value of its leaf litter) affect the community of associated species and the delivery of ecosystem services (Mitchell *et al.*, 2021).

There is a current focus on increasing the proportion and diversity of broadleaved species to support native ecological

communities. This approach is beneficial for various woodland types and frequently takes precedence in restoration efforts of non-native woodlands, such as Plantations on Ancient Woodland Sites (PAWS) (Box 3).

Benefits for wildlife

A high diversity of tree species is well understood to be a key driver of woodland-associated biodiversity, but notably when species with different functional traits are combined, rather than when there is simply a higher number of tree species (Ampoorter *et al.*, 2020).

In many mixed and coniferous woodlands, increasing the proportion of broadleaves is likely to have positive biodiversity outcomes for many different taxa, particularly where native tree species such as oak are incorporated (Broome, Stokes, *et al.*, 2021; Zeller *et al.*, 2023). However, an increased number of broadleaved tree species may not be appropriate in certain situations, such as in native pinewoods or red squirrel strongholds (Forestry Commission, 2012).

Other environmental benefits

Many woodlands of multiple species have been shown to sequester more above-ground carbon than monocultures due to complementarity between species and overyielding (Williams *et al.*, 2017; Warner *et al.*, 2023). Mixed stands can have greater resilience to external pressures and disturbances such as specialist insect pests, fungal pathogens, and weather events predicted to intensify under climate change, including drought and storms (Jactel *et al.*, 2017; Messier *et al.*, 2022). The strength of these effects, however, can depend on both the tree species in the mixture and wider site factors.

The effect on ecosystem service delivery of increasing the proportion of broadleaves in mixed woodlands is likely to be highly context dependent. Certain broadleaved species are better adapted to riparian and floodplain contexts, where they can capture sediment and slow flows while providing additional ecological benefits (Nisbet *et al.*, 2011; Burton *et al.*, 2018). On upland catchment slopes, coniferous species may intercept more rainfall and promote higher infiltration than most broadleaved species, thereby slowing surface run-off (Cooper *et al.*, 2021).

Surface water acidification has negative ecological and environmental consequences. The effect of tree type on water acidification is complex and may be less important than woodland location and maturity (Nisbet and Evans, 2014). In the acid-sensitive uplands, conifers are generally more acidifying than broadleaves as they are more effective at

Box 3 Woodland restoration

Many UK woodlands are in unfavourable ecological condition and require restoration to support biodiversity recovery and establish a resilient ecological network. Restoration approaches primarily focus on increasing native tree cover, safeguarding remnant ecological features, and addressing external pressures. Non-native woodlands, including Plantations on Ancient Woodland Sites (PAWS), are often targeted for these actions. PAWS are areas of ancient semi-natural woodland that have been cleared and replanted with non-native trees. These sites span a continuum ranging from monocultures of non-native conifers to a mix of native and non-native species. They can negatively impact wildlife reliant on native trees (e.g. pied flycatcher and purple emperor butterfly), and can harm native flora through competition from non-native species. The evidence base for restoration is still emerging and environmental benefits will vary depending on site-specific factors and the approach adopted. Removing non-native conifers and reinstating native broadleaves can allow the re-establishment of native ground flora (Kirby, Goldberg, and Orchard, 2017) and create more available niches for wildlife (Quine *et al.*, 2007). A gradual removal strategy has been shown to avoid unintended negative impacts on shade-adapted specialists (Brown, Curtis, and Adams, 2015; Broome, Inchboard, *et al.*, 2021) or species that utilise conifer habitats (Trout *et al.*, 2012).

scavenging atmospheric acid pollutants (Nisbet *et al.*, 2011). On the other hand, alder, a native broadleaved species, can cause local acidification in poorly buffered soils due to nitrate leaching following nitrogen fixation by root nodules (Nisbet and Evans, 2014).

The effect of tree type on carbon sequestration and greenhouse gas mitigation is also highly nuanced and dependent on species, site, management, and the substitution impacts of any harvested wood products (Körner, 2017). Over short timeframes (e.g. up to 50 years), fast-growing productive conifers generally sequester and substitute the greatest amount of carbon (Forster *et al.*, 2021; Matthews *et al.*, 2022). However, after longer periods of time, the carbon sequestration between different woodland types becomes more equal as long-lived broadleaved species accumulate large above- and below-ground carbon stocks (Mayer *et al.*, 2020; Matthews *et al.*, 2022).

Reducing pressures

There is a strong evidence base supporting our understanding of the causes and impacts of woodland degradation by biotic and abiotic pressures. For example, the National Forest Inventory Woodland Ecological Condition demonstrates that pressures such as pests and diseases^{2A}, invasive non-

native plants^{2B}, and damage by wild and domestic animals^{2C} are major factors contributing to unfavourable woodland ecological condition in Great Britain (National Forest Inventory, 2020).

Here we summarise the evidence for local-scale management interventions to reduce pressures in woodlands. Some pressures, such as pollution damage, require broader management or policy actions beyond the woodland area and are not covered here. Evidence for the effectiveness of specific measures is still emerging as there is often a delay between action and biodiversity response (Watts *et al.*, 2020). Removing or reducing negative impacts will likely benefit woodland biodiversity and support the recovery of many threatened or priority species, particularly woodland specialists (Alder, Fuller, and Marsden, 2018).

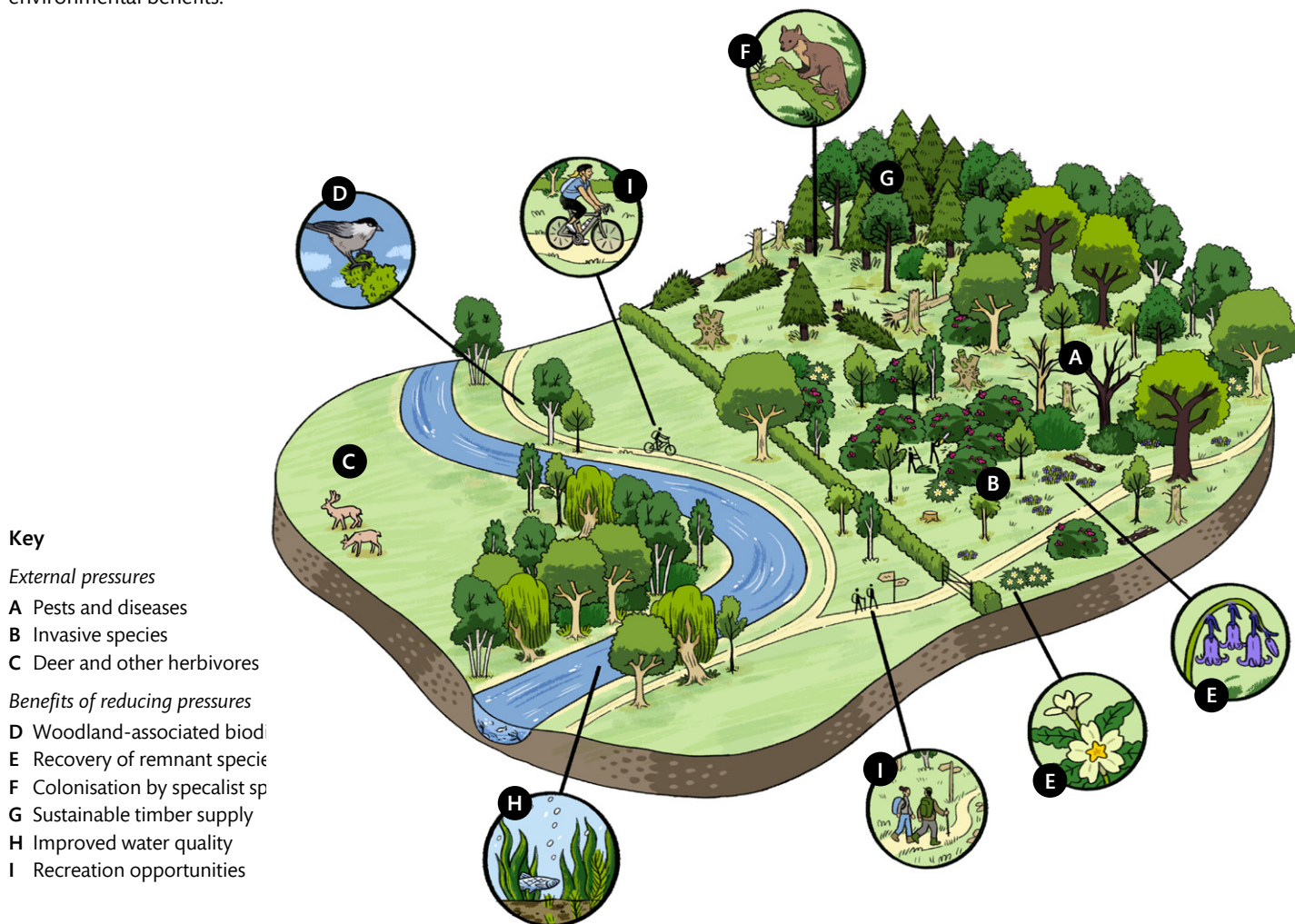
Benefits for wildlife

The negative impacts of over-browsing by herbivores, such as deer, on understory vegetation are well documented (Kirby, 2001; Ramirez, Jansen, and Poorter, 2018), and these changes have been reported to adversely affect woodland birds (Fuller *et al.*, 2007), small mammals (Flowerdew and Ellwood, 2001), and invertebrates (Stewart, 2001). One study found that enclosure of deer from coppiced woodlands resulted in higher density and cover of understory vegetation, as well as a higher abundance of songbirds^{2D}, after three years of coppice growth (Gill and Fuller, 2007).

Similarly, invasive plants (e.g. rhododendron) alter the structure and composition of woodlands, which will in turn alter the availability and distribution of resources, influence animal behaviour, and affect animal-plant interactions (Manchester and Bullock, 2000; Vilà *et al.*, 2011; Stewart *et al.*, 2021). Tree diseases, such as ash dieback, can cause rapid mortality in the affected species with potentially severe negative impacts on populations of associated species and the provision of ecosystem services (Mitchell *et al.*, 2014).

Climate change will present substantial challenges to woodlands due to shifts in temperature, altered rainfall patterns, and extreme weather events (Ray, Morison, and Broadmeadow, 2010; Patacca *et al.*, 2023). Rising average temperatures may also increase the spread of pathogens and diseases (Frederickson-Matika and Riddell, 2021; Inward, 2023). Addressing other external pressures and maintaining functionally varied tree stands within well-connected woodlands can improve woodland resilience and facilitate species adaptation to climate change (Ray, Morison, and Broadmeadow, 2010). However, empirical evidence supporting effective wildlife adaptation measures in woodlands remains limited.

Figure 2 Example external pressures on woodlands which, when reduced, can enhance the woodlands' wildlife value and the delivery of environmental benefits.



Note: Example pressures and potential benefits of effective management are annotated and referenced with superscript letters in the text. Climate change represents an additional pressure to woodlands that will likely exacerbate the threats from pests and diseases (A) and invasive species (B).

Other environmental benefits

Removing or reducing pressures on woodlands will protect biodiversity and enhance ecosystem functions and processes that deliver wider environmental benefits^{2G-I}. For example, enabling understory regeneration through deer control can increase the above-ground carbon stored in woodlands (Tanentzap and Coomes, 2012). Allowing regeneration of ground flora may also improve water regulation and flood mitigation services provided by woodlands, although this has not been tested directly.

Creating new woodland

Woodland creation is the establishment of new woodland on land not previously wooded. New areas of woodland provide habitat, deliver important environmental benefits, and complement existing mature woodland, hedgerows, wood pasture, and lone trees to create diverse wooded landscapes.

Increasing woodland cover in a landscape is well known to benefit many taxa, including birds, mammals, fungi, vascular plants, and certain invertebrate groups (Humphrey *et al.*, 2013; Bowler *et al.*, 2023). While it may take years before these benefits are fully realised (Fuentes-Montemayor *et al.*, 2022), the developmental stages following creation will benefit different species assemblages before a mature woodland is achieved.

Woodland can be established as new spatially discrete woodlands, which can act as stepping stones to improve landscape connectivity, or as an expansion of an existing woodland, which can be colonised more rapidly. Here we review the benefits of woodland creation by these two approaches.

Spatially discrete woodlands

The composition and structure of new spatially discrete woodlands^{3A}, and their proximity to other wooded sites^{3B} and features^{3C}, will strongly influence their success as habitats^{3D} and their capacity to deliver ecosystem services^{3E-H}.

Table 1 Summary of the evidence base (quantity and agreement of evidence) on the biodiversity outcomes and environmental benefits of woodland management actions aimed at improving woodland condition.

Biodiversity	Carbon sequestration	Water quality	Flood mitigation	Resilience
Increasing structural complexity				
<ul style="list-style-type: none"> ● Higher structural complexity is associated with greater abundance and species richness of many taxa (Humphrey <i>et al.</i>, 2015). ● Certain structural features, such as deadwood and open space, benefit specific wildlife including many rare and threatened species (Zeller <i>et al.</i>, 2023). 	<ul style="list-style-type: none"> ● Higher structural complexity often increases above-ground carbon sequestration due to complementary resource use (Ali, 2019). ● Retaining deadwood on-site increases soil carbon stocks (James <i>et al.</i>, 2021). 	<ul style="list-style-type: none"> ● A dense understory and fallen deadwood both increase surface roughness, reducing sediment losses into watercourses (Nisbet <i>et al.</i>, 2011). ● Partial harvesting methods reduce sediment, nutrient, and pollution losses into watercourses compared to clearfell approaches (Nisbet <i>et al.</i>, 2011; del Campo <i>et al.</i>, 2022). 	<ul style="list-style-type: none"> ● A dense understory and fallen deadwood both increase surface roughness and water retention, slowing surface run-off (Calder <i>et al.</i>, 2008). ● A more intense thinning regime will increase surface run-off (del Campo <i>et al.</i>, 2022). 	<ul style="list-style-type: none"> ● Reduced tree density can increase resilience to pests and pathogens (Roberts <i>et al.</i>, 2020). ● Higher structural complexity can provide resident biodiversity with resilience to the effects of climate change through enhanced provision of microclimates (Mina <i>et al.</i>, 2022).
Increasing tree and shrub species diversity				
<ul style="list-style-type: none"> ● Higher tree species diversity (especially of species with contrasting functional traits) drives greater abundance and species richness for many taxa (Ampoorter <i>et al.</i>, 2020). ● A higher proportion of native broadleaves will benefit biodiversity in the majority of situations (Zeller <i>et al.</i>, 2023). 	<ul style="list-style-type: none"> ● Higher tree species diversity (especially of species with contrasting functional traits) is linked to greater carbon sequestration (Warner <i>et al.</i>, 2023). ● Effect of species type (broadleaved or coniferous) is highly dependent on other factors such as site type and management (Mayer <i>et al.</i>, 2020). 	<ul style="list-style-type: none"> ○ Lack of direct evidence on the effect of higher species diversity on water quality. ● Conifers are generally more acidifying in upland regions, but species type (broadleaved or coniferous) has a small impact on water acidification compared to woodland location and maturity (Nisbet and Evans, 2014). 	<ul style="list-style-type: none"> ○ Lack of direct evidence on the effect of higher species diversity on flood mitigation. ● Impact of species type is location-dependent with certain broadleaved species more suitable in riparian areas and conifers more effective on catchment slopes (Cooper <i>et al.</i>, 2021). 	<ul style="list-style-type: none"> ● Higher species diversity can provide resilience to external pressures such as specialist pests and pathogens and storms (Jactel <i>et al.</i>, 2017; Field <i>et al.</i>, 2025) ● Higher species diversity can provide resident biodiversity with resilience to the effects of climate change (Messier <i>et al.</i>, 2022).
Reducing external pressures				
<ul style="list-style-type: none"> ● Reducing intense browsing pressure increases structural complexity, with associated benefits to biodiversity (Ramirez, Jansen and Poorter, 2018). ● Phytosanitary felling can increase the loss of highly associated species (Mitchell <i>et al.</i>, 2014). 	<ul style="list-style-type: none"> ● Reducing browsing pressure promotes natural regeneration and can increase carbon sequestration (Tanentzap and Coomes, 2012; Mayer <i>et al.</i>, 2020). 	<ul style="list-style-type: none"> ○ Lack of direct evidence on the effect of reducing invasive species pressure on water quality. ● Large-scale phytosanitary felling may lead to reduced water quality through soil nutrient leaching (Nisbet <i>et al.</i>, 2011). 	<ul style="list-style-type: none"> ● Reducing browsing pressure increases understory density, with associated benefits to flood mitigation (Nisbet <i>et al.</i>, 2011). ● Phytosanitary clear-felling likely to increase run-off and flood risk (Cooper <i>et al.</i>, 2021). 	<ul style="list-style-type: none"> ● Reducing pressures from invasive plant and mammal species benefits woodland biodiversity and supports climate change resilience (Vilà <i>et al.</i>, 2011).

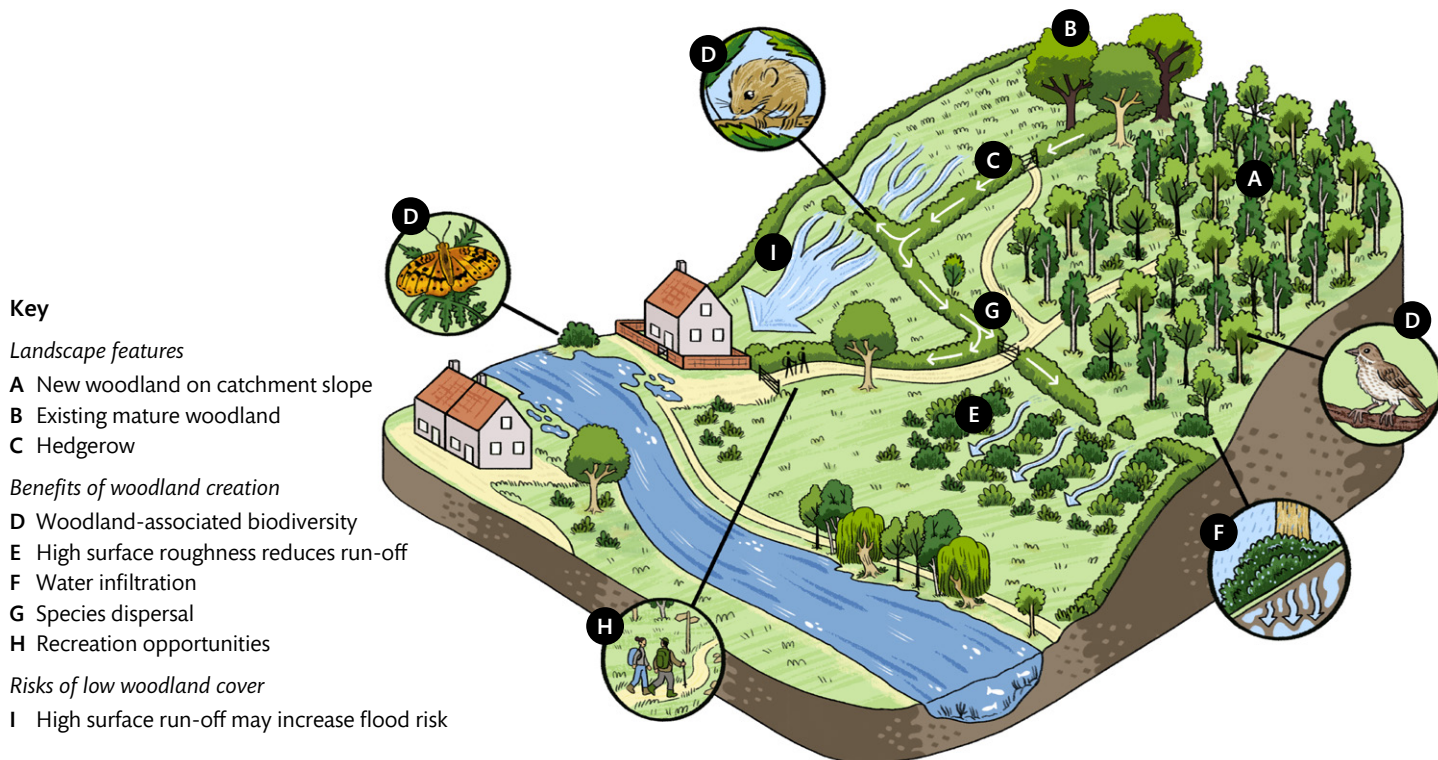
● **Well established:** high agreement, high quantity ● **Established but incomplete:** high agreement, low quantity
 ● **Unresolved:** low agreement, high quantity ○ **Inconclusive:** low agreement, low quantity

Benefits for wildlife

The size of a new woodland is an important spatial consideration. Bigger woodlands tend to support both a higher number of species and larger population sizes of individual species. This is due to both the larger area of continuous woodland and the increased likelihood of a greater abundance

and diversity of micro-habitats to provide shelter and resources. Larger population sizes in bigger woodlands are typically reflected by higher levels of genetic diversity, which can allow populations to adapt more readily to changing conditions (Bellamy *et al.*, 2018). Many taxa, including birds (Whytock *et al.*, 2018), vascular plants (Waddell *et al.*, 2024), and certain bryophyte and invertebrate species are more abundant and

Figure 3 Landscape features and benefits of spatially discrete woodland creation.



Note: Example landscape features, potential benefits of woodland creation, and risks associated with low woodland cover are annotated and referenced with superscript letters in the text. The positioning of new woodland creation (A) within the topography of a catchment will affect the delivery of environmental benefits such as flood mitigation (E and F). Isolation of a new woodland, relative to other wooded features, will impact the rate of colonisation by local biodiversity (G).

have higher species richness in larger woodlands (Humphrey *et al.*, 2015). For other taxa, such as many small mammal species and some invertebrates, the significance of woodland area is conditional on other factors, such as habitat quality or isolation (Humphrey *et al.*, 2015; Fuentes-Montemayor *et al.*, 2020).

Woodland isolation is a product of its geographic position, its proximity to other trees and woodlands, and how easily species can move through the surrounding landscape. The degree of isolation of a newly established woodland, and the age of the nearby existing forests, will influence the species that a new woodland can host and the rate at which those species colonise, with different taxa and functional groups responding differently (Humphrey *et al.*, 2015). For slow-dispersing taxa, such as many woodland specialist vascular plants and fungi, proximity to established woodland is a major factor determining colonisation success (Scheidegger and Werth, 2009). Proximity to other wooded habitats, such as wood pasture, parkland, and areas of scrub, may also increase connectivity from existing woodland habitat to sites of afforestation (Prevedello and Vieira, 2010).

Other environmental benefits

Woodland soils are typically undisturbed and well-structured compared with those of other open land uses³¹. This leads to

greater water infiltration^{3F} which improves water storage and reduces surface run-off^{3E}, soil nutrient leaching, and topsoil erosion during heavy rainfall (Nisbet, 2020; Cheng *et al.*, 2022). The total amount of new woodland cover, its development through time, and its distribution within a catchment will impact the effectiveness of these new wooded areas for both flood mitigation and water quality improvement. When established on the slopes of catchments, particularly in a cross-slope configuration, woodland soils can absorb surface water flowing neighbouring agricultural land, slowing run-off and preventing topsoil erosion (Cooper *et al.*, 2021). However, afforestation in drought-prone areas may have negative effects on water yield during dry weather (Buechel, Slater, and Dadson, 2022).

Establishing new woodlands in a river floodplain can lessen peak flood magnitude, particularly for smaller flood events, and modelling studies suggest floodplain afforestation could decrease the flow rate, raise the water level, and delay peak discharges (Dixon *et al.*, 2016; Cooper *et al.*, 2021). Riparian woodlands may also contribute to reducing peak flood flows and have been shown to improve water quality by intercepting pesticide drift and reducing sediment run-off (Binner *et al.*, 2017). By shading watercourses, they also lessen thermal stress to fish and subdue weed growth (Nisbet *et al.*, 2011). While it is recognised that higher woodland cover can provide greater mitigation benefits for small-scale floods, woodlands do not

appear to provide any significant mitigation for extreme flooding events (Nisbet *et al.*, 2011).

Generally, woodlands sequester more atmospheric carbon than agricultural land uses and are significant long-term carbon sinks (Morison *et al.*, 2012). Creating new woodlands is therefore likely to greatly increase landscape-scale carbon sequestration (despite potential initial carbon losses from soil disturbance) if undertaken sensitively, and avoids carbon-rich habitats that do not habitually support tree cover (Mayer *et al.*, 2020; Seddon *et al.*, 2021). Peat-forming wet woodlands have the potential to make disproportionately high contributions to carbon sequestration despite generally small woodland areas (Milner *et al.*, 2024).

Larger woodlands will sequester greater amounts of carbon, as more land area will become wooded. Forest edges may accumulate more above-ground biomass than woodland interiors due to adjacent nitrogen deposition, suggesting that woodland area spread across multiple smaller sites may store more above-ground carbon (Meeussen *et al.*, 2021; Morreale *et al.*, 2021). The location of afforestation activities may also impact net carbon sequestration through both the land cover type it replaces and the growth rate of the trees established at that site.

Woodland expansion

Woodland expansion is the enlargement of an existing site^{4A} by adjacent woodland creation. Compared to spatially discrete woodland creation, woodland expansion affords a range of advantages to both the mature and newly established woodlands. Even greater benefits can be achieved if expansion is used to link multiple mature woodlands.

Expansion can be achieved through two methods: tree planting^{4B} and natural processes^{4C} (Box 4). Tree planting provides control over species composition and spatial distribution but can lead to greater ground disturbance and may bring pests and diseases onto the site. Employing natural processes removes the biosecurity concern and may be less intensive and costly, but the outcome is unpredictable and species composition and positioning can only be controlled through enrichment planting and silvicultural management. Fencing or deer control may be required to protect self-seeded saplings if herbivore pressure is high.

Benefits for wildlife

Increasing the size of a woodland by tree planting or natural processes is well understood to boost its value for biodiversity^{4E}

Figure 4 Landscape features and benefits of expansion of an existing mature woodland through tree planting and natural processes.

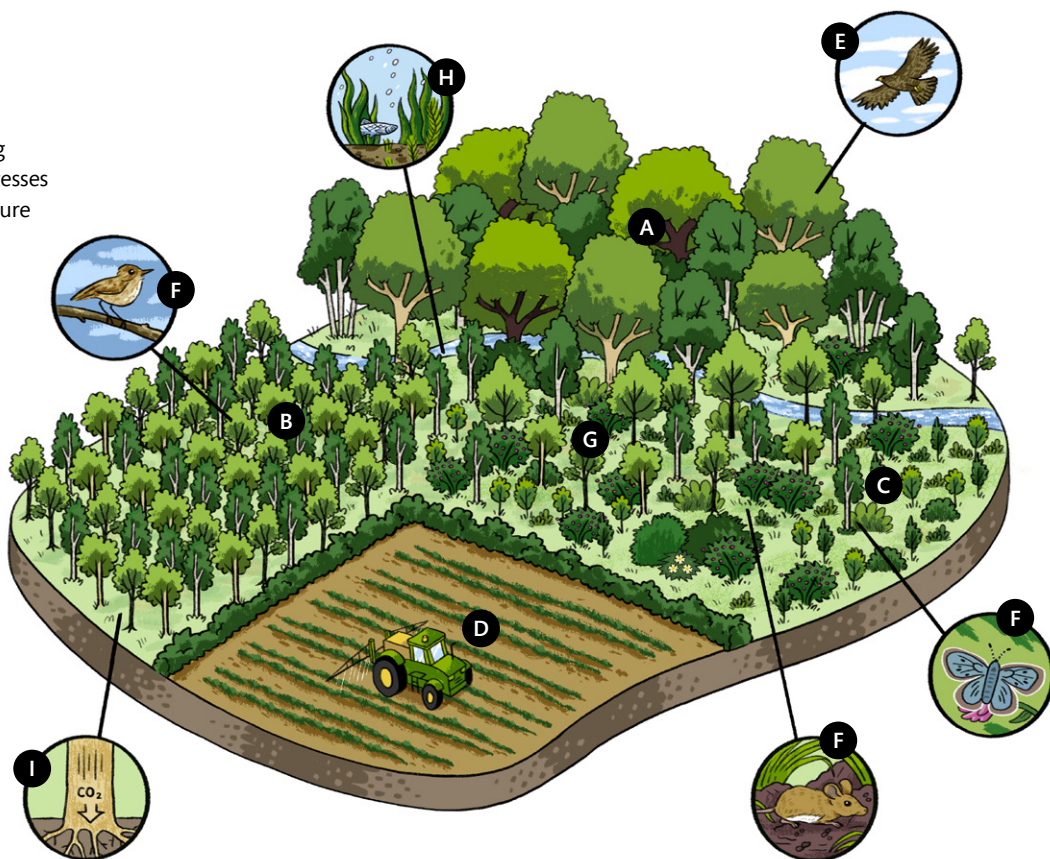
Key

Landscape features

- A Existing mature woodland
- B Woodland expansion by tree planting
- C Woodland expansion by natural processes
- D Environmental pressure from agriculture

Benefits of woodland expansion

- E Woodland-associated biodiversity
- F Early successional assemblages
- G Buffer against external pressures
- H Improved water quality
- I Carbon sequestration



Note: Example landscape features and potential benefits are annotated and referenced with superscript letters in the text. Woodland expansion brings benefits to both the newly afforested areas, such as specialist early successional assemblages (F), and the existing woodland, such as by providing a buffer (G) against external environmental pressures (D).

Box 4 Natural colonisation and natural regeneration

Collectively termed 'natural processes', both 'natural colonisation' and 'natural regeneration' describe the growth of tree saplings from natural seed dispersal or vegetative reproduction. The difference between the terms is that natural regeneration occurs within a woodland or on land that was recently forested (such as following a clearcut or coup felling) whereas natural colonisation occurs on land that has not been woodland in recent history.

in several ways. Firstly, expansion leads to a bigger woodland which, as described above, can support higher species diversity and abundance. Secondly, expansion inherently develops horizontal structural complexity by creating new younger areas of woodland next to mature trees which will be inhabited by different species assemblages^{4f} including, over time, woodland specialist assemblages. Thirdly, compared to isolated woodland creation, afforestation adjacent to existing mature woodland has been shown to grow more quickly and with higher structural complexity, further enhancing biodiversity (Hughes *et al.*, 2023). Finally, the adjacency of expansion also expedites colonisation from the mature woodland into the new habitat when compared to spatially discrete woodland creation, particularly for slow-dispersing species (Humphrey *et al.*, 2015).

The method of expansion influences the species and communities that colonise the afforested area. The early successional scrub that is typically the result of natural colonisation in lowland areas provides a wildlife-rich and structurally diverse habitat that is favoured by small mammals, bird communities (Broughton *et al.*, 2022), and invertebrates such as Lepidoptera^{4f} (Merckx, 2015). Tree planting is often supported by the suppression of such scrub, but generally delivers young woodland more quickly and with greater reliability. While this may benefit woodland-associated taxa, canopy closure limits light penetration and reduces biodiversity value until canopy gaps develop or are introduced through management.

Other environmental benefits

Woodland expansion provides many of the same ecosystem services as spatially discrete woodland creation, but also presents its own opportunities and challenges. The higher growth rate of adjacent woodland creation may lead to greater carbon sequestration, while expanding a woodland through natural processes may avoid the initial carbon losses from the soil disturbance of tree planting. The method of expansion may also affect flood mitigation since young woodland is achieved more quickly through tree planting, but natural colonisation

may result in a denser and more varied root network that enhances water infiltration (Harvey and Henshaw, 2023).

Enlarging a woodland also creates a buffer^{4g} along the extended edge(s) that reduces negative edge effects and protects the mature site, its wildlife, and any internal water bodies^{4h} from external environmental pressures, such as pesticide spray drift^{4d}, pet disturbance, and extreme weather events (Crick *et al.*, 2020).

Synergies and trade-offs

Woodlands are planted and managed to deliver multiple objectives. Understanding the potential synergies and trade-offs between these objectives will help planners and forest managers make informed decisions about the best approach to woodland management or creation.

Managing existing woodlands

Managing a woodland to maximise its biodiversity value often involves significant trade-offs with timber production and carbon sequestration (Sing *et al.*, 2018). Actions to improve woodland structure, such as establishing a diverse mixture of tree species or employing selective thinning regimes, can increase harvesting costs. The felling of premature plantation trees, such as in PAWS restoration, may be required to establish a native woodland community, but could cause the loss of a productive timber crop. Areas that are not designated as high value for biodiversity or other environmental benefits can be managed under an integrated approach to deliver multiple benefits while maintaining productivity (Sing *et al.*, 2018).

Woodlands with high biodiversity value are known to also provide a range of other environmental benefits. Structurally complex and diverse riparian woodlands stabilise riverbanks and reduce sedimentation, thereby improving water quality and enhancing flood mitigation. The aesthetic, recreational, and cultural value of a woodland is also enhanced by high levels of biodiversity (Sing *et al.*, 2018). Recreation in woodlands is valued at around £907 million annually and provided health benefits to an estimated 3.2 million people in 2022, valued at £1149 million (Office for National Statistics, 2024).

Productive woodlands provide habitats for species and can deliver synergistic environmental benefits. For example, depending on their age, species, and location within the catchment, they can deliver flood mitigation benefits. Highly productive woodlands also sequester large amounts of carbon, although this may be offset by carbon losses from harvesting. Management operations provide access to woodlands (e.g. by

Table 2 Summary of the evidence base (quantity and agreement of evidence) on the biodiversity outcomes and environmental benefits of woodland creation actions.

Biodiversity	Carbon sequestration	Water quality	Flood mitigation	Resilience
Spatially discrete woodlands				
<ul style="list-style-type: none"> ● Increasing woodland cover in a landscape is well known to benefit species of many taxa (Bennett, Radford, and Haslem, 2006). ● The size and isolation of a new woodland will strongly influence the species that colonise the new habitat and the rate of colonisation (Humphrey <i>et al.</i>, 2015). 	<ul style="list-style-type: none"> ● Woodlands sequester greater amounts of carbon than agricultural land (Mayer <i>et al.</i>, 2020). ⦿ Peatland afforestation can lead to net carbon loss (Anderson, 2020). 	<ul style="list-style-type: none"> ⦿ Woodlands can improve water quality by reducing pollutant and sediment content (Cheng <i>et al.</i>, 2022). ⦿ Planting in riparian areas is particularly effective at reducing diffuse pollution and soil erosion into waterways (Binner <i>et al.</i>, 2017). 	<ul style="list-style-type: none"> ⦿ Well-positioned woodlands, particularly on catchment slopes, can help to reduce the volume of surface run-off (Binner <i>et al.</i>, 2017). ⦿ Some evidence that woodlands can mitigate smaller flooding events (Binner <i>et al.</i>, 2017; Cooper <i>et al.</i>, 2021). 	<ul style="list-style-type: none"> ⦿ Well-connected new woodlands have greater resilience to climate change at a landscape scale (Craven <i>et al.</i>, 2016).
Woodland expansion				
<ul style="list-style-type: none"> ● Larger woodlands are generally linked to greater species richness and abundance for many taxa (Humphrey <i>et al.</i>, 2015). 	<ul style="list-style-type: none"> ● As expansion increases woodland cover, it will generally lead to higher rates of carbon sequestration if undertaken sensitively and if carbon-rich habitats, such as peatlands, are avoided (Mayer <i>et al.</i>, 2020). 	<ul style="list-style-type: none"> ⦿ Woodland expansion increases woodland cover, which improves water quality by reducing pollutant and sediment content (Cheng <i>et al.</i>, 2022). ⦿ Expansion of riparian woodlands and shelterbelts is most likely to benefit water quality (Nisbet <i>et al.</i>, 2011). 	<ul style="list-style-type: none"> ⦿ Impact on surface flows and flood mitigation is likely dependent on existing woodland position, location of expansion, and species choice (Cooper <i>et al.</i>, 2021). 	<ul style="list-style-type: none"> ⦿ Larger woodlands support bigger tree- and woodland-associated species populations, leading to increased genetic diversity and resilience to climate change (Oliver <i>et al.</i>, 2015).

● **Well established:** high agreement, high quantity ⦿ **Established but incomplete:** high agreement, low quantity
 ⦿ **Unresolved:** low agreement, high quantity ○ **Inconclusive:** low agreement, low quantity

creating roads and paths), although intensively managed sites may have less recreational value (Sing *et al.*, 2018). The benefits of enhanced access will also need to be balanced against the potential for harmful impacts on biodiversity from increased woodland use (Marzano and Dandy, 2012).

Creating new woodlands

Woodland creation replaces an existing land cover, and the biodiversity value and ecosystem service provision that is lost may represent a significant trade-off. For example, establishing new woodlands on agricultural land could affect food production and security. However, there is limited evidence to fully assess the impact of woodland expansion on provisioning services such as food production in agricultural landscapes (Burton *et al.*, 2018).

Woodland creation on existing non-woodland semi-natural habitats may increase carbon sequestration, but may also result in a net loss of biodiversity (Wilkes *et al.*, 2020). Furthermore, potential environmental benefits may be greater from the creation or restoration of other semi-natural habitats compared

to woodland in some locations. For example, in upland areas, heathland may have greater biodiversity and recreational value, while woodlands may provide greater carbon storage and timber (Cordingley *et al.*, 2016).

The size of woodland creation sites may also present important trade-offs. Large woodlands have been shown to benefit many taxa (Humphrey *et al.*, 2015) and to be buffered against external pressures. However, creating large woodland sites may not always be feasible due to constraints from other land uses. In these cases, focussing creation on expanding and joining existing smaller woodland fragments can be more beneficial than creating larger isolated woodlands (Synes *et al.*, 2020).

Siting new woodlands close to urban areas can provide social, cultural, and health benefits by enhancing access to nature. Additionally, woodland creation near populated areas and close to pollution sources is likely to provide enhanced benefits from air pollution absorption (Powe and Willis, 2004). However, the woodland and biodiversity it hosts may be negatively affected by pollution and high footfall.

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