Using participatory scenario planning to explore the synergies and trade-offs from upland treescape expansion.

Melissa Minter[1*] (0000-0003-1580-7176), Susan Baker[2] (0000-0002-5616-4157), Euan Bowditch[3] (0000-0003-3340-8160), Sheena Carlisle[2] (0000-0002-0894-6832), Natasha Constant[1] (0000-0002-1910-6791), Alix Syder[1] (0009-0009-7842-5328), Tom Finch[1] (0000-0003-1122-8513)

[1]RSPB Centre for Conservation Science, The Lodge, Sandy, Beds, SG19 2DL, UK

[2]School of Social Sciences, Cardiff University, Glamorgan Building, Cardiff, CF10 3WT, UK

[3]Inverness College UHI, 1 Inverness Campus, Inverness, IV2 5NA, UK

* Corresponding author: melissa.minter@rspb.org.uk

Abstract

1. The future of land-use in the UK uplands is highly debated, with growing interest in increasing tree cover and other land-use changes, alongside a desire to maintain traditional land use patterns and practices. Treescape expansion is likely to result in synergies and trade-offs between different outcomes, so integrating stakeholder preferences into future scenarios will be important for understanding social acceptance or conflicts, and for promoting pathways toward sustainable land use in the future.

2. We used Participatory Scenario Planning to create spatially explicit land use and tree cover scenarios to 2050 in two UK upland landscapes (the North Pennines & Dales in England and the Elenydd in Mid Wales). Stakeholders were asked to list their preferred land use interventions, along with spatial criteria determining their preferred location in the landscape. We then created future scenarios and modelled the impact on greenhouse gas emissions, livestock numbers, timber production, recreation, water run-off and bird populations.

3. Stakeholder-led scenarios resulted in an increase in total tree cover from 2.5% to 3.3 – 9.7% in the North Pennines & Dales, and from 9.7% to 10.1- 26.8% in the Elenydd. With increasing tree cover we found positive impacts on greenhouse emissions and water run-off (both of which declined), and woodland birds and nature-based recreation (both of which increased) and mixed outcomes on timber. On the other hand, increasing tree cover was associated with reduction in livestock numbers and upland birds. The potential decline of upland bird communities was of particular concern to all stakeholder groups which saw a decline in their scenario.

4. Our methodology provides unique insights into stakeholder preferred treescape expansion,

which could be expanded to other landscapes, and additional interests. Further work should disentangle how future land use scenarios could reduce trade-offs whilst still delivering synergies to other ecosystem services.

Key words

Treescape, land-use, participatory scenario planning, upland, ecosystem service

Crynodeb

1. Mae dyfodol defnydd tir yn ucheldiroedd y DU yn bwnc llosg, ac mae diddordeb cynyddol mewn ehangu'r gorchudd coed a newidiadau eraill o ran defnydd tir, ochr yn ochr ag awydd i gynnal arferion a phatrymau defnydd tir traddodiadol. Mae ehangu coedweddau yn debygol o arwain at synergedd a chyfaddawdu rhwng gwahanol ganlyniadau, felly bydd yn bwysig integreiddio'r hyn y mae rhanddeiliaid yn ei ffafrio yn y senarios o'r hyn a allai ddigwydd yn y dyfodol – er mwyn deall derbyniad neu wrthdaro cymdeithasol, a hyrwyddo llwybrau tuag at ddefnyddio tir yn gynaliadwy yn y dyfodol.

2. Aethom ati i ddefnyddio dull cyfranogol o gynllunio senarios er mwyn creu senarios gofodol fanwl o ddefnydd tir a gorchudd coed hyd at 2050, mewn dwy dirwedd ucheldirol yn y DU (Gogledd y Pennines a'r Dales yn Lloegr, ac Elenydd yng Nghanolbarth Cymru). Gofynnwyd i randdeiliaid restru'r ymyriadau defnydd tir y maent yn eu ffafrio, ynghyd â meini prawf gofodol sy'n pennu'r lleoliad y maent yn ei ffafrio yn y dirwedd. Yna, aethom ati i greu senarios o'r hyn a allai ddigwydd yn y dyfodol a modelu'r effaith ar allyriadau nwyon tŷ gwydr, niferoedd da byw, cynhyrchu pren, gweithgarwch hamdden, dŵr ffo a phoblogaethau adar.

3. Roedd senarios dan arweiniad rhanddeiliaid wedi arwain at gynyddu cyfanswm y gorchudd coed o 2.5% i 3.3 – 9.7% yng Ngogledd y Pennines a'r Dales, ac o 9.7% i 10.1 – 26.8% yn Elenydd. Gyda gorchudd coed cynyddol, gwelsom effeithiau cadarnhaol ar allyriadau nwyon tŷ gwydr a dŵr ffo (y ddau'n gostwng), ac ar adar coetir a gweithgareddau hamdden ym myd natur (y ddau'n cynyddu), a chanlyniadau cymysg o ran pren. Ar y llaw arall, roedd cynyddu'r gorchudd coed yn gysylltiedig â gostyngiad yn niferoedd y da byw ac adar yr ucheldir. Roedd dirywiad posibl cymunedau adar yr ucheldir yn enwedig yn destun pryder i'r holl grwpiau o randdeiliaid a welodd ostyngiad yn eu senario nhw.

4. Mae ein methodoleg yn rhoi cipolwg unigryw i ni ar y goedwedd sy'n cael ei ffafrio gan randdeiliaid – y gellid ei ehangu i dirweddau eraill – a'r buddiannau eraill. Dylai gwaith pellach ddatrys sut y gallai senarios defnydd tir yn y dyfodol leihau'r cyfaddawdu, gan barhau i ddarparu synergedd i wasanaethau ecosystemau eraill.

Geiriau allweddol

Coedwedd, defnydd tir, cynllunio senarios cyfranogol, ucheldir, gwasanaeth ecosystemau

• Introduction

The future of land use in the UK uplands is a highly debated public policy issue. Practices such as livestock grazing and grouse shooting are being challenged in the face of the climate and nature crises, and there are calls to increase treescapes (landscapes with trees) and restore degraded peatlands (Crowle et al., 2022; Kirby, 2018; Reed et al., 2009). In particular, the UK's commitment to achieving net zero greenhouse gas emissions by 2050 (HM Government, 2021) is likely to be a major driver of land-use change in the coming decades (Finch et al. 2023). The UK uplands provide multiple ecosystem services (ES), such as food & timber production, climate regulation, recreation and wellbeing (Hardaker et al., 2021; Iversen et al., 2024), as well as habitat for biodiversity which underpins ecosystem service delivery (Reed et al., 2009). Few land uses can simultaneously deliver high levels of all ecosystem services, so any land-use change is likely to incur trade-offs (Hasan et al., 2020). Prioritising land for food production, for example, tends to reduce biodiversity and carbon sequestration (Rigal et al., 2023; Williams et al., 2018). It is important that decision-makers understand these trade-offs, to ensure the efficiency of land-use policy (Bateman & Mace 2020). Understanding the preferences of local stakeholders i.e., people who affect or are affected by land-use change – is also imperative to ensure social acceptance, political legitimacy and long-term sustainability.

While national-scale land use scenario modelling (Alliance, 2023; Finch et al., 2023; Smith et al., 2023) has revealed high-level trade-offs arising from future land-use changes at the UK level, these exercises may poorly reflect landscape-scale outcomes and cannot account for the preferences of local stakeholders. Local stakeholders may have different preferences for the ecosystem services provided by the landscape, and for the forms/functions in which they are delivered (land use preferences) (Hölting et al., 2020; Schmidt et al., 2017). Involving local stakeholders in land management planning has key benefits, such as greater public acceptance (Richards et al., 2004), higher likelihood of intervention success (Dougill et al., 2006) and the utilisation of local knowledge (Reed et al., 2008; Sterling et al., 2017). Participatory scenario planning (PSP) is a planning tool in which researchers, policy actors and stakeholders collaboratively develop alternative interpretations of the future (Oteros-Rozas et al., 2015). PSP can empower stakeholders (Reed et al., 2013b), reduce conflict (Kahane, 2012), encourage social learning (Volkery & Ribeiro, 2009) and integrate different types of knowledge (Oteros-Rozas et al., 2015). It has been used to create future scenarios of land use by applying quantitative modelling techniques to qualitative information from stakeholders (Penny et al., 2022; Volkery et al., 2008). These scenarios can be used to predict the impact on ecosystem services (Rodríguez et al., 2023) and biodiversity, and to understand stakeholders' perceptions (Kiatkoski Kim et al., 2021), and it is important to use these methods in contested landscapes, such as the uplands (Thorn et al., 2020)

In this study, we combined PSP with spatially explicit scenario modelling to create landscape-scale scenarios of land use change and treescape expansion in two upland landscapes, to explore the implications for biodiversity and ecosystem services (**Figure 1**). Scenarios were co-developed through participatory workshops in the North Pennines and Dales (NP) in northern England, and the Elenydd (ED) in mid Wales, two upland landscapes with comparatively low current tree cover. We then compared scenarios according to their predicted impact on biodiversity and ecosystem services to understand the synergies and trade-offs associated with future changes in land use and tree cover, and asked to what extent the modelled scenarios fulfil stakeholders' desired outcomes. Whilst PSP has been combined with modelling in the past (e.g. (Penny et al., 2022; Rodríguez et al., 2023), and in other upland landscapes in the UK (Reed et al., 2013a), to our knowledge, these methods have not been used to identify the consequences of treescape expansion in the UK uplands. The failure to meet tree planting targets in the UK (Westaway et al., 2023) suggests that there is still a need to better understand the preferences of local stakeholders to identify opportunities for treescape expansion in contested upland landscapes, and to explore the likely consequences of future changes.

- **Methods**

2.1 Participatory workshops

We hosted two workshops in each case study landscape, in July 2023 and June 2024 in NP and in September 2023 and May 2024 in ED.

2.1.1 Stakeholder selection

We identified potential participants through a stakeholder mapping exercise detailed in Syder et al. (*in prep.*). Workshop participants were local stakeholders, that is, individuals who operate at a local level and have a personal interest and/or connection to the landscape by either living or working within it. We then assigned participants to one of four break-out groups based on our knowledge of major interest categories associated with upland landscapes, which were consistent between both landscapes (**Table 1**). We used a pre-survey of confirmed attendees (Syder et al., *in prep.*) capturing their job role, relationship to the landscape, and broad land use interests to determine break-out groupings. The number of attendees totalled 19 and 13 in NP, and 12 and 12 in ED for the first and second workshop, respectively. In ED, we conducted a separate meeting with farming stakeholders who could not attend the day-long first workshop.

At the start of the 2023 workshops, we presented each participant with a written information sheet that explained the objectives of the research, and asked all participants to sign the consent forms, which were approved by the RSPB Ethics Committee (reference HEC_39_STAND). Each break-out group had a facilitator supported by note-taker to track and audio-record each activity. All audio recordings were transcribed verbatim and uploaded to the qualitative software package N-Vivo (Lumivero, 2023). Transcripts were openly coded to identify preferences, trade-offs and responses to each of the predicted outcomes.

Table 1: *Definitions of local stakeholder interest group categories (Syder et al.* in prep*)*

Conservation	Main interests are in nature recovery and conservation. May or may not own or manage land such as nature reserves. Typically represented by NGOs, not for profits or public bodies.
Land	Involved in the management or ownership of large estates, or industry-based professions (water, forestry, grouse etc). An economic or industry-based interest in land-use, private or public estates.
Access	Members of the community who access the land, but do not own or manage land. May include non-landowning residents, community groups and recreational users.
Farming	Main interest is in farming. May directly own land or manage as tenant farmers.

2.1.2 Land use visions (workshop 1)

Workshops were designed according to guidance on PSP (Metzger et al., 2017; Oteros-Rozas et al., 2015). Firstly, we asked stakeholders to list ecosystem services (ES) provided by the current landscape, and coded ES themes within each group from audio recorded discussions (see **Supplementary Materials SM1** for further information; note that, whilst biodiversity is not strictly a service, we treat it as an ES for simplicity). Then, each break-out group worked together to create their future land use vision (**Supplementary Materials SM2**). Using the created ES list, we first asked participants to select the top 5 ES which they wanted the landscape to provide in 2050. Groups then discussed their preferences for achieving these desired outcomes. Next, we asked ‘What type of land use changes / treescape expansion interventions do you want to deliver these ecosystem services’. Finally, to determine the spatial criteria for intervention placement we asked ‘Where and where not within the landscape would you like these changes to be delivered?’.

2.1.3 Scenario evaluation (workshop 2)

The second workshops provided an opportunity for participants to view the modelled land use scenarios and predicted outcomes (see methods below). We presented maps of new tree cover and land use alongside predicted changes in modelled outcomes in a poster format. In addition, artistic illustrations (some of which are presented in Figure 2) were created for all intervention types and presented to stakeholder groups to aid visualisation of scenarios. Facilitators prompted discussion with questions such as ‘Is this what you expected?’, ‘Do these outcomes surprise you at all?’, and ‘Does this scenario produce a positive change in the impacts you identified as important to you in Workshop 1?’.

Figure 1: Overview of the participatory scenario approach. During workshop 1, groups of participants identified their desired future ecosystem services (‘ecosystem service valuation’) and described their 2050 vision for land use in their landscape. Using participants’ interventions and spatial criteria, we mapped opportunity areas for each intervention and made changes to the land and tree cover maps. We then predicted outcomes for ecosystem services and biodiversity. During workshop 2, the scenarios and predicted outcomes were presented back to the stakeholder groups.

- Spatially explicit land use scenarios

Scenarios involved changes to both land use/cover and tree canopy cover at 10-m resolution (see **Supplementary Materials SM1**). The baseline land cover raster was derived from the UK CEH Land Cover Map 2020 (Morton et al., 2021) which maps 21 land cover categories at 10-m resolution. We edited this map to add additional categories including ‘scrub’, ‘mixed woodland’, ‘bracken’ (ED only) and ‘degraded bog’ (NP only) (see **Supplementary Materials SM1**). The baseline tree canopy cover layer was created using 1-m resolution LiDAR data (Environment Agency, 2023; Welsh Government, 2023) to create a Canopy Height Model, from which we calculated percentage canopy cover at 10-m resolution (see **Supplementary Materials SM1**).

To generate spatially explicit land use scenarios, we first mapped the ‘opportunity area’ for all land use interventions identified by each participant group, according to the spatial criteria provided by participants. For each scenario we then modified the land cover and tree cover of individual 10-m pixels to reflect specific interventions, restricting changes to pixels within each interventions’ opportunity area. We filled the entire opportunity area of each intervention where possible, but whenever a pixel presented an opportunity for multiple interventions, we gave precedence to higher-ranked interventions (see **Supplementary Materials SM1**).

- Predicted outcomes

We estimated the value of each outcome for the current landscape, and for the landscape in 2050 for each group's scenario. We reported the percentage change in each outcome in 2050 compared to the current (2020) value, giving a central, lower and upper estimate (see **Supplementary Materials SM1**).

2.3.1 Livestock production

With arable land covering less than 1% of both landscapes, we made the simplifying assumption that livestock is the only form of food production. To estimate changes to livestock production under future scenarios, we calculated the livestock carrying capacity of each landscape as a proxy for livestock production. Changes were estimated according to relative differences between land covers in the recommended stocking density (Chapman, 2007). We calculated the total (recommended) livestock units each landscape could support based on current land cover (see habitat specific stocking densities in **Supplementary Materials SM1**), then calculated the percentage change in this value under future land cover for each scenario.

2.3.2 Greenhouse gas emissions

To estimate total net greenhouse gas emissions (i.e. sources minus sinks), we predicted changes in carbon sequestration from woodlands and trees, emissions/sequestration from soils, and emissions from agriculture under each scenario.

We first estimated the age of all trees (both inside and outside woodlands) in 2020 using LiDAR-derived mean tree height, then estimated annual flux in 2020 and 2050 using age-specific annual sequestration estimates from the Woodland Carbon Code Calculator (WWC, 2021) (see **Supplementary Materials SM1**). New tree cover was introduced at an annually constant rate between 2025 and 2040, and we calculated the annual flux of new trees in 2050 according to tree type, assumed management and age (see **Supplementary Materials SM1**).

For soil emissions, we estimated the annual net flux of different land cover classes on peat soils (Evans et al., 2022), as well as for future land use transitions from grassland to woodland on mineral and organo-mineral soils (see **Supplementary Materials SM1**).

To calculate emissions from agriculture, we first used gridded census data to estimate the total (absolute) population size of cattle, lambs, ewes and other sheep in each landscape, then scaled these numbers according to relative changes in recommended livestock carrying capacity (see livestock production, above) under each scenario. We then used published emissions factors (either per head of livestock or per hectare of agricultural grassland) to calculate the total net flux of emissions from enteric methane, manure management, fuel use and fertiliser use (see **Supplementary Materials SM1**). Net emissions from woodlands, soils and agriculture were then combined to give a total annual flux under each scenario (2050) and for the current landscape (2020).

2.3.3 Biodiversity (birds)

To estimate the impact of our scenarios on bird populations, we used Generalised Additive Models (GAM) models to predict abundance of each species as a function of land cover and tree cover. Count data came from the Breeding Bird Survey (BBS) (Heywood et al., 2023) for a sample of 200 m transects nested within 1-km grid squares within our study landscapes and surrounding upland landscapes similar in character. We calculated the proportional coverage of each land cover class in each 200m square, and tree cover within the square and within a 1-km buffer. We also extracted topographic variables (slope, elevation) and other variables (muirburn, hedgerows) for each square. We fitted GAM models with species count as the predictor variable, with latitude and longitude as smoothed terms, and effective area (accounting for number of visits and species- and habitat-specific detection probability) as an offset, alongside land cover and topographic covariates (**see Supplementary Materials SM1**). We created models for upland (NP = 10, ED = 3) and woodland indicator species (NP

= 9, ED = 6), and predicted counts across the landscapes at 200-m resolution, for the current landscape and across the 8 stakeholder scenarios (**see Supplementary Materials SM1**). For each species, we then summed abundance across each landscape under each scenario, calculated the change between current (2020) and future (2050), and averaged this across upland and woodland indicator groups using geometric mean.

2.3.4 Water run-off

To predict the total volume of water run-off in the current landscape and under future scenarios, we used the Curve Number method (Natural Capital Project, 2024). We first mapped hydrologic soil groups (Ross et al., 2018) across each landscape and cross-tabulated the area of each land cover and soil type. We used run-off curve numbers specific to each soil type / land cover combination, and accounting for slope, to estimate run-off for each 10-m pixel for a design storm of 20 mm (see **Supplementary Materials SM1**). Total run-off was summed across each landscape under each scenario and expressed relative to the predicted value in 2020.

2.3.5 Nature-based recreation

To predict changes to nature-based recreation, we followed (Vallecillo et al., 2019) attributing a nature-based recreation value to each land cover class (based on the nature recreation of each land cover value, from urban areas (low score) to semi-natural habitats (high score)), modified according to protected area status and distance to roads and urban areas. We combined recreation values from (Vallecillo et al., 2019) and (Burkhard et al., 2009) to create mid, upper and lower estimates (see **Supplementary Materials SM1**), which we summed across each landscape under each scenario, and expressed relative to the predicted value in 2020.

2.3.6 Timber production

We predicted the impact of our scenarios on long-term, cumulative timber production by summing over a 200-year window the total biomass removed through clearfell and/or thinning for broadleaved, mixed and coniferous woodland of different yield classes (see **Supplementary Materials SM1**). Annual biomass estimates were taken from the Woodland Carbon Code Calculator (WCC, 2021).

Results

3.1 Ecosystem service preferences

In total participants from both landscapes included 2 provisioning, 4 regulating and 8 cultural ES in their future land use visions (**Supplementary Materials SM3, Figure 4i**). Uniquely, biodiversity was included in all eight land use visions. Carbon and water-related regulating services were also important, especially in NP where Land and Conservation stakeholders felt carbon storage was crucial to the delivery of all ES: *"without that [carbon] we're not going to have many of the other ones"*. Cultural services such as access, recreation, community and wellbeing were mentioned by all groups and were represented in the final visions of all ED groups but not of the Land or Farming groups in NP. Food production was mentioned by all groups in NP but was only retained in the final visions of the Land and Farming groups, who referred to the farming identity of these landscapes: *"food production would mean a working landscape"*. The ED Farming group felt strongly about food production in their final vision, whilst the Land group instead emphasised water supply as a priority service. Timber and wood products were mentioned infrequently and did not form part of any final vision.

- Stakeholder preferences and scenarios

Stakeholder groups included a variety of land use interventions within their 2050 land use visions (**Figure 2**). Peatland restoration was selected by all groups except the NP Farming group. While only four groups selected semi-natural grassland creation, all recognised the value of existing grassland for biodiversity. Several different treescape expansion interventions were selected, including individual boundary trees, low density wood pasture, and the expansion of higher density woodlands (**Figure 2**, **Supplementary Materials SM4**). Some interventions were only selected in one landscape, such as ffridd (an upland fringe habitat dominated by bracken, heather and grass with scattered trees/scrub) which was selected by all groups in ED.

All groups agreed that tree planting should not be allowed on peat soils, however some stakeholders, mostly in ED, were comfortable with natural colonisation of species such as willow (*Salix spp*) on peat as part of a wider desire to promote natural processes. In NP, all groups favoured woodland/scrub establishment in upland gills (i.e. steep-sided streams), and most groups across both landscapes included spatial criteria intended to avoid negative impacts of trees on breeding waders. Most groups also wished to avoid negative impacts of trees on priority habitats such as semi-natural grasslands.

Figure 2: The 10 most commonly selected interventions (covering treescape expansion and other land-use changes) by stakeholders in Elenydd (ED, green) and North Pennines & Dales (NP, orange). Ticks identify interventions represented in the final land use vision of each stakeholder group (Land, Access, Farming & Conservation) in each landscape. See **Supplementary Materials SM4** for a complete list of interventions and associated spatial rules. Illustrations by Jonathan Halls.

Between-group differences in 2050 tree cover were driven by different choices about which interventions to deploy and where. In both landscapes, Land and Conservation groups selected several treescape interventions, such that tree cover increased by 55-177% (**Figure 2 & 3**). In contrast, both Farming groups typically selected low density treescapes including wood pasture and boundary trees (for livestock shading), and natural colonisation (ED only), resulting in smaller increases in tree cover of 4-35% (**Figure 2 & 3**). The ED Access group selected open habitats including semi-natural grassland creation and peatland restoration with some lower density treescape expansion (boundary trees, natural colonisation, scrub), resulting in a lower increase in tree cover of 7%. In contrast, the NP Access group selected multiple treescape interventions (including deciduous woodland on gills, slopes and expansion from current woodlands, wood pasture and scrub) resulting in an increase in tree cover of 289% (**Figure 2 & 3**, **Supplementary Materials SM4**).

Figure 3: Total tree cover (0-100% canopy cover per 10m cell), areas of peatland restoration (highlighted in purple), and areas of semi-natural grassland creation (highlighted in orange) under the 100% 2050 scenario of each group in each landscape (ED = Elenydd, NP = North Pennines & Dales). Inset tables show total tree cover (TC), total semi-natural grassland coverage (SG) and total (restored) bog coverage (BG) in 2050. For new areas of all interventions see **Supplementary Materials SM5** and to explore scenarios further please see this Shiny app https://stand-treescapes.shinyapps.io/stand_wp2_app/.

- Predicted outcomes

All modelled scenarios resulted in an increase in tree cover, with typically positive outcomes for woodland birds, recreation, greenhouse gas emissions and water-run off, but negative outcomes for livestock and upland birds (**Figure 4**). Encouragingly, most scenarios achieved a positive predicted outcome for the ecosystem services that stakeholders prioritised in their final visions, the main exception being biodiversity, with a mixture of winners (typically woodland birds) and losers (typically upland birds) (**Figure 4i**).

Figure 4: Predicted outcomes on ecosystem services and biodiversity from participatory land use scenarios, by stakeholder group and landscape. In a-h, all values are expressed as a

percentage change between 2020 and 2050, with error bars showing upper and lower estimates and vertical dashed lines showing no change from present. a) abundance of upland birds, b) abundance of woodland birds, c) greenhouse gas emissions, d) total water run-off, f) nature-based recreation, g) lifetime timber production, and h) total tree canopy cover. i) Predicted outcomes and their corresponding ecosystem services, with mid-estimates of percentage change in each outcome highlighted by down arrows (percentage decrease), dash (no change, between -2 and +2%) or up arrows (percentage increase). Green colouring represents a positive outcome, and red represents a negative outcome. Grey boxes indicate ecosystem services included in each groups' final vision.

3.3.1 Biodiversity

All groups indicated that they wanted the future landscape to provide for biodiversity (**Figure 4i**), and many groups included spatial rules to avoid adverse impacts of treescape expansion on existing habitats and species (**Supplementary Materials SM4**). All scenarios resulted in an overall increase in woodland bird abundance (**Figure 4b, i**) with the largest increases in the NP Access (+84%) and ED Land (+214%) groups, consistent with large increases in tree cover. In contrast, most scenarios resulted in a decrease in upland bird populations (**Figure 4a, i**), except for both Farming groups (ED +0.7%, NP -3.1%) whose prime concern was the protection of open habitats for their cultural, aesthetic and food production values.

In both landscapes, there was a trade-off between the upland and woodland bird indicators: scenarios which minimised impacts on upland birds tended to see smaller gains for woodland birds, and vice versa **(Figure 5**). Disaggregating the impacts of future scenarios on individual bird species is beyond the scope of this paper, but the species making up the upland bird indicator do not respond uniformly to a given scenario. Notably, Curlew *Numenius arquata* tended to respond less negatively than the upland indicator on average in NP, even increasing under the Access and Land groups' scenarios, whereas Red Grouse *Lagopus lagopus scotica* declined across all scenarios. In ED, where data availability restricted the upland indicator to just 3 species, Wheatear *Oenanthe oenanthe* declined under all scenarios whereas Meadow Pipit *Anthus pratensis* and Stonechat *Saxicola torquate* increased under the Access and Farming groups' scenarios (**Supplementary Materials SM8**).

Most groups expressed concern about the impact of their scenarios on already-declining species of upland birds. NP Access noted that certain upland habitats were unsuitable for tree planting; emphasising the cultural significance of the commons: "*Culturally and from the heritage point of view…there's a whole lifestyle and tradition of the commons, but you know commons are big areas, but most of them are peat and not appropriate for planting anyway because of upland birds*". Similarly, NP Land expressed concerns about the adverse effects of treescape expansion on wader habitats, advocating for low-density tree planting over large-scale woodland creation: "*Any trees in a landscape where there's waders we know is likely to have a negative impact…but I do think there is an argument to say lower density trees doesn't have the same impact as a true woodland; you know you're not going to be bringing those land-based predators like…foxes…weasels and stoats*." ED Farming acknowledged the trade-offs between tree planting on upland bird populations, but noted potential benefits for other species: "*I see what [trees] bring and I'm very interested in that balance…if you do put trees then your upland birds might go down.*"

Figure 5: Trade-off between woodland and upland birds in a) North Pennines & Dales b) Elenydd landscapes. Points show the percentage change in the geometric mean upland and woodland bird abundance from the present landscape, and error bars represent the upper and lower estimates.

3.3.2 Greenhouse gas emissions

All scenarios which included both peatland restoration and increased tree cover resulted in a reduction in net GHG emissions between 2020 and 2050, and most groups who included carbon sequestration in their vision saw a decrease in GHG emissions under their scenario (except ED Farming) (**Figure 4c, i**). Groups which saw a decrease in emissions were pleased with this outcome: "*Happy to see positive change in GHGs*" (ED Conservation); "*Carbon storage is important to me, which in this landscape means good quality bog/peatland and broadleaf woodland*" (NP Conservation).

Groups with very small increases in tree cover (ED Access & Farming) or no peatland restoration (NP Farming) resulted in a very small reductions (ED Access -3.8%) or even small increases (Farming NP =+1.6%, ED = +2.2%) in net emissions, though two of these groups (ED Access, NP Farming) did not include carbon sequestration as a priority ES in their final vision. These changes in net emissions were partly driven by changes in the age profile of existing woodlands, which are projected to provide a smaller carbon sink in 2050 than at present: this explains how net emissions increase over time even as tree cover increases (**Supplementary Materials SM7**). ED Farming and Access groups were surprised by the small reductions in GHG emissions in their scenarios, with these groups discussing the need for improved land management to enhance carbon capture. ED Farming discussed how woodlands become less efficient for sequestering carbon over time as they age, requiring active investment and management by landowners to improve carbon sequestration (e.g. through coppicing to encourage regrowth of shoots to recapture carbon).

Only one group's scenario achieved net zero emissions (ED Land, -140%). In NP the greatest reduction was -70% (Access). Both ED Land and NP Access had the largest increase in tree cover in their respective landscapes (**Figure 4h**). Despite ED Land being the only group which reached net zero, they were surprised by how little peatland restoration occurred in their scenario, "*I'm shocked at that. I know it's expensive but it's a priority isn't it, and in terms of carbon and run-off and wildlife*."

3.3.3 Water run-off

All groups in NP and the ED Farming group included water storage/flood management in their final vision (**Figure 4i**), and all scenarios delivered a decrease in estimated water run-off (**Figure 4d**). In general, scenarios with bigger increases in tree cover, peatland restoration and semi-natural grassland creation resulted in the largest decreases in water-run off, though this depended on prior land use. In NP, the Land group had the largest decrease (-40%), driven by large areas of improved grassland being converted into silvo-pastoral orchard systems. The Access group had a smaller decrease (-23%) because their scenario saw tree cover increase mainly on semi-natural grassland, which already has a relatively low run-off value (**Supplementary Materials SM6**). In ED, the Land group had the largest decrease in total water run-off (-54%), corresponding to a large increase in tree cover (**Figure 4d**).

Most groups were pleased with the decrease in water-run off, though one participant in ED Land stated that the gains in reduced water-run-off from treescape expansion could be even more ambitious, citing a need for improving investment in peatland restoration in their final vision. Similarly, NP Conservation were surprised by the low levels of water run-off in their scenario believing this to be an underestimate given the high investment in peatland.

3.3.4 Livestock production

Livestock production decreased in most scenarios, with the smallest decreases in both Farming groups (ED -2%, NP -0.4%) and NP Conservation (-2.7%). NP Conservation were content that livestock was only minimally affected by their scenario, "*It's pretty good from the farming perspective because it doesn't sound like we've got to lose loads…of farmers and the whole culture of food production*." Both Farming groups were similarly relieved that their scenarios did not forecast negative impacts on food production.

Nonetheless, discussions within these groups, as well as with ED Access, highlighted concerns regarding the future of livestock farming in upland areas. They cited issues such as the potential loss of government funding, uncertainty surrounding agri-environment schemes, pressure from conservation organisations to reduce livestock on peat, and public safety concerns when recreational users interact with livestock on public walkways. One farmer noted, "*So these are the sort of external pressures that farmers are debating at the moment about whether they're going to carry on keeping cattle and if you drop below a certain number of cattle you'd be better off coming out because of the capital costs*." The three groups which included food production as an ecosystem service in their final vision (both Farming groups and the NP Land group) had relatively small impacts on food production compared to other groups (**Figure 4e**). These groups' scenarios included integrating livestock with trees for shading through boundary trees and wood pasture (Farming) and silvo-pastoral orchards integrated with livestock (NP Land). The largest decreases in livestock were seen in the Land group in ED (-33%) and the Access group in NP (-17%), corresponding to the largest increases in tree cover.

A few groups raised concerns regarding reductions in livestock, highlighting the risk of public misinterpretation of model outcomes that could elicit negative messaging in the form of "*more trees, less food*." (ED Land). This group emphasised the importance of promoting innovative food production opportunities, such as agroforestry and the concept of "*living barns*," where woodlands offer shelter for livestock during winter, a period when animals are typically housed indoors and produce excessive manure. A member of ED Land expressed their surprise at the modelled impact on livestock, stating: *[We have] always been looking at agroforestry as a big part of the future, working with farmers especially towards changing some farming practices, perhaps more towards heavier grazing animals, different types of animals and that the concept of living barns is a big thing for the uplands to be able to have grazing cattle in a water catchment.*" Similarly, ED Conservation suggested sustainable land uses, such as agroforestry and wood pasture offer opportunities where trees, biodiversity, and farming can coexist. In addition, ED Conservation were more interested in the impact on farming income than on total livestock numbers "*livestock numbers not the best measure; farm income impact a big issue*."

3.3.5 Nature-based recreation

All scenarios resulted in an increase in total nature based-recreation value, except the NP Farming group where there was a slight decrease (**Figure 4f**). These increases were associated with conversion of grassland into land covers with a higher nature-based recreation value such as woodland and bog. Increases were greater in ED due to the smaller size of the landscape, and its closeness to roads and urban areas which increased the overall value of sites for recreation value. The Access and Conservation group in NP included this ecosystem service in their final vision and had greater increases in recreation value in their scenario compared with other groups.

ED Access group shared mixed feedback on the proposed increase in recreation. They raised concerns about tourism activities such as off-road driving harming the environment but acknowledged the importance of recreational opportunities that connect visitors to local communities, promoting environmental awareness and landscape preservation: "*I think there's quite a significant opportunity to get people out into the Elan Valley and to do stuff. Walking, meditations, bird watching, all those things…. I still think one of the most important things has to be buy-in from people to make changes, is to accept all of the changes, and you've got an opportunity with this area to get people to accept changes by understanding why it's a really important area to use*."

NP Access supported their scenario's recreation levels, noting that while future recreation growth might be slow due to the landscape's remoteness and urban residents' preference for the nearby Lake District, they expected tourism to steadily rise with population growth and increasing cultural diversity among visitors. NP Conservation were satisfied with the recreational outcomes predicted under their scenario, while also being cautious about further increases in recreational activities. They emphasised the importance of promoting respectful and sustainable tourism to avoid environmental degradation. ED Farming were less interested in recreational opportunities within their vision, seeing it mainly as a form of income diversification. ED Farming felt recreation in the landscape would naturally increase with improved road access, but were concerned about environmental impacts if activities were not properly managed: "*if they improve it then they have to open it for scramble bikes and stuff ... but it will cut up the peatland*."

3.3.6 Timber production

No stakeholder group included timber production as an ecosystem service in their land vision, and the change in timber production was the most variable of all predicted outcomes, with scenarios resulting in large increases (ED Land, +73%), large decreases (NP Farming, -67%) or no change (**Figure 4g**). Timber production typically increased with increasing tree cover, though this varied according to woodland type, with mixed productive woodland being more productive than new broadleaved woodland (which we assumed was thinned but not otherwise harvested).

Three groups from NP (Access, Farming and Land) included the removal of conifer plantations in their scenarios, with one member from NP Land stating *"I am sceptical as to whether this is suitable area for commercial timber growth."* This resulted in overall decreases in long-term timber production (Access -21%, Farming -67%) or a small increase (Land +15%) due to the additional inclusion of new mixed productive woodland (**Figure 4g**). ED Conservation expressed surprise that timber production remained stable with some advocating for replacing conifer plantations (though not included in their scenario) with broadleaved woodlands to benefit from carbon financing projects. NP Farming believed that timber production outcomes should show a more pronounced decline, and raised concerns about the costs and environmental impact of removing conifers from hard-to-access areas. Similarly, ED Conservation expressed concerns of the negative impacts of removing conifer plantations on the timber industry and suggested that some plantations could be preserved under a continuous cover forestry alongside broadleaved woodlands: "*There's no reason why you can't do both and if you use continuous cover forestry, it's even better. I was thinking it might be easiest to try and advocate no clear felling of anything from now on because that protects soils. It accumulates carbon better…It's just far more stable in the landscape and that's more important than barring certain species*." Finally, ED Access pointed out that unsustainable tree species, affected by disease and climate change, may compromise timber production, emphasising that tourism and recreation could yield greater economic benefits for local communities.

• Discussion

We have used PSP and scenario modelling to generate new empirical insights into the synergies and trade-offs for biodiversity and ecosystem services as a result of treescape expansion in two upland landscapes. The future of land use is a contested and often emotive subject, but our participatory approach identified common ground among diverse stakeholders, including the importance of protecting and restoring open habitats, and a general preference for less intensive forms of treescape expansion. Through modelling fine-scale spatially explicit scenarios we quantified the likely impacts on biodiversity and multiple ecosystem services, allowing stakeholders to understand the potential consequences of their preferences and identify trade-offs which need managing.

In both landscapes, all stakeholder groups identified opportunities to increase tree cover but differed in the overall magnitude of tree cover increase. Changes to predicted outcomes reflected a combination of the number, location and configuration of land-use interventions contained within each scenario. Scenarios tended to result in positive (modelled) outcomes for water run-off, GHG emissions, nature-based recreation and woodland birds, but mixed results for timber, and negative outcomes for livestock production and upland birds. In general, most scenarios improved outcomes that were deemed as important by stakeholders, except for livestock production and biodiversity (upland birds). While stakeholders discussed how livestock production may be a poor proxy for food quality or farm business viability, there was concern among all groups about the impact on upland birds. The following discussion unpacks the synergies and trade-offs which arise with increasing tree cover, drawing on our modelled results, participants' discussions, and the wider literature.

3.1 Increasing tree cover in the uplands

All groups' scenarios resulted in expansion of tree cover, along with other land-use changes, and this acceptance of increasing tree cover has been demonstrated in other upland regions of the UK (FitzGerald et al., 2021). In addition to woodland creation, stakeholders selected non-woodland interventions, such as scrub, scattered trees, and integrating trees with livestock through wood pastures that aligned with stakeholders' values of the landscape (Syder et al., *in prep*).

In England, funding is available to land managers to create woodlands through the England Woodland Creation Offer (EWCO) (UK Gov, 2021). This scheme is in the process of transitioning into the wider Environmental Land Management (ELM) scheme (UK Gov, 2023) which already supports, for example, agroforestry and the establishment of hedgerow trees. In Wales, the Sustainable Farming Scheme (Welsh Government, 2024a) is still under development and is expected to commence in 2026. The Welsh Woodland Creation Grant (Welsh Government, 2024b) is already operative, and supports tree planting and maintenance, including for agroforestry. While these schemes nominally support the kinds of treescapes preferred by our participants, future work is planned to understand the barriers (and any policy changes required) to implement these changes.

3.2 Synergies with increasing tree cover

GHG emissions decreased as a result of increasing tree cover and peatland restoration, consistent with other evaluations and the concept of nature-based climate solutions (Bradfer-Lawrence et al., 2021). However, net emissions remained positive in all but one scenario, due to ongoing agricultural emissions, and a predicted saturation in the size of the sink provided by existing trees and woodlands (Pugh et al., 2019). These scenarios are still potentially compatible with a national net zero target, as other landscapes across England and Wales may be better placed to deliver net negative emissions through more ambitious changes to land use or management. While most stakeholders were pleased with the reduction in emissions, some were disappointed in the size of this reduction, and some ED stakeholders felt that our opportunity mapping under-estimated the potential for peatland restoration. There is no UK-wide spatial data for peat condition, and while we were able to use some data from England to assign areas of 'degraded bog' in England (see **Supplementary Methods SM1**), no such data were available for the Welsh landscape. Without accurate spatial data on both peat extent and condition, it is likely the mapped opportunity areas for peatland restoration may not represent conditions on the ground.

Nature-based recreation increased across all scenarios in line with the expansion of tree cover and semi-natural habitats. More complex economic models of recreation find similar increases following expansion of semi-natural habitats, though results are sensitive to the location of habitat creation (Finch et al., 2020). It has also been found that increasing woodland in the Howgill Fells (part of the NP landscape) could benefit the local economy through nature-based recreation (Iversen et al., 2023), based on visitors scoring how much tree coverage they would accept to still visit the area through a photo elicitation exercise. There were mixed feelings about potential increases in recreational opportunities among stakeholder groups. The benefits and impacts perceived by stakeholders following increases in recreation and tourism have been widely explored (Nguyen et al., 2022), with some recognising the economic benefits and raised awareness of the environment and its cultural heritage, but others expressing concerns over the associated environmental impacts. A study in another upland landscape in Wales found similar support to our results for low impact recreation/tourism through hiking and camping, but with negative views on 4x4 offroad driving (Holmes et al., 2022).

Water run-off decreased in all scenarios, which is supported by evidence that increases in tree cover can reduce peak flows following storm events (Monger et al., 2024). However, future changes in hydrological processes are likely to be more strongly impacted by future climate change through changes in precipitation and temperature than through changes in land use or tree cover (Buechel et al., 2024), and our predictions did not consider future projected climate change. As discussed above, some stakeholders felt that our scenarios under-estimated the potential extent of peatland restoration, which is expected to provide flood-risk adaptation (Goudarzi et al. 2024).

Timber production showed a variable response across scenarios, reflecting the competing effects of treescape expansion and removal of conifer plantations. No stakeholder groups included timber as an ecosystem service in their final vision, with some believing that the landscapes were not suitable for timber production, and others expressing a preference for alternative models including continuous cover forestry with native species. There have also been negative perceptions towards productive woodlands in other uplands in the UK (Iversen et al., 2022), and a similar desire for broadleaved over conifer woodlands, but perceptions were less negative in areas of gradual afforestation (Ní Dhubháin et al., 2009). Our focal landscapes do not contain much existing productive forestry, and so commercial forestry-sector interests were poorly represented amongst our stakeholder sample.

4.3 Trade-offs from increasing tree cover

Most scenarios resulted in a reduction in total livestock units, due to woodlands and restored bogs having lower recommended stocking densities than the land covers they replace. The trade-off between food production and environmental outcomes has been demonstrated before (Finch et al., 2023), though our participants were keen to highlight the potential for synergies. For example, integrating livestock with trees through agroforestry does not have to impact food production, and globally it has been suggested that trees could be integrated into agricultural systems without impacting yield (Sprenkle-Hyppolite et al., 2024). Our assumptions treated wood pasture and agroforestry as equivalent (with respect to livestock units) to semi-natural grassland and improved grassland, respectively, reflecting the potential to increase tree cover without impacting livestock production. Participants also reflected that reduced production might be an acceptable price to pay for higher quality products, provided farm livelihoods were protected. A more appropriate outcome (as opposed to total livestock units), may be to understand the impact of land use change on farmer income, which could be supplemented with agri-environment payments (Collas et al., 2022).

All stakeholders included biodiversity in their future vision, and whilst scenarios with higher tree cover benefited woodland species, upland indicator species declined on average. The negative relationship between woodlands and wader species is well established, (Douglas et al., 2014; Pálsdóttir et al., 2022) but this pattern depends on the quantity of semi-natural habitats and the presence of moorland management in a particular landscape (McGrory et al., 2024). Indeed, the stakeholders highlighted that the open habitats in the landscape would not be appropriate for planting, and that lower density planting options may have less effect, though research investigating this is lacking. Due to data availability/suitability, our upland predictions were based on only three species in ED and ten species in NP, and so may not be representative of all upland species in these landscapes. In addition, individual species making up each indicator do not respond uniformly to land-use change. Future research could use our methodology to explore how the placement and amount of treescape intervention types may have the least impact on upland birds, whilst still benefiting woodland species.

3.4 Limitations

We acknowledge that there are limitations to our study. The stakeholder preferences for land-use change in our focal landscapes may not be representative of other upland landscapes, but our study highlights the value of integrating stakeholder preferences into scenario modelling. In addition, the participants may not be representative of all stakeholder interests within the focal landscapes, and future work should focus on interests we did not capture in our study. The modelled impacts on biodiversity and ecosystem services are intended to be illustrative only, and each have their own limitations; but they provide an insight at least into the direction of synergies and trade-offs resulting from upland treescape expansion. While the biodiversity outcomes are based on landscape-specific models, the finding that upland birds may decline is applicable to other upland landscapes in the UK with little tree cover and open habitat specialists. In addition, assumptions had to be made when converting land use visions into spatially explicit scenarios, such as interpreting the spatial rules and interventions, for example participants selected ‘woodland expansion’, and assumptions were made to the exact size extent of this expansion. Thus, modelled scenarios may not represent exactly what the groups visioned, but follow-up workshops to gather feedback on scenarios provide the opportunity to iteratively refine scenarios.

• Conclusion

By understanding stakeholder preferences for future treescape expansion, and the synergies and trade-offs which are likely to arise from these changes, our study reveals the different forms of treescapes preferred by different stakeholder groups, and an overarching concern regarding the negative outcome on upland bird communities. While based only in two landscapes, our approach could be replicated in other upland or lowland landscapes. This method could be expanded to specifically understand how different land use and spatial criteria choices may reduce trade-offs from treescape expansion. This could provide synergies to key ecosystem services and gain further insights into where and what type of treescapes may be placed across a landscape with minimal trade-offs.

Author contributions

All authors conceived the ideas, designed methodology and collected the data; Melissa Minter, Alix Syder, Natasha Constant and Tom Finch analysed the data; Melissa Minter led the writing of the manuscript. All authors contributed critically to the drafts and gave final approval for publication.

Acknowledgements

We thank all participants who took the time to spend two days contributing to this work through participatory workshops. We also thank Elizabeth Charman, Chris Jones, Ben

Bonham & Fiona Walker who assisted with stakeholder selection in our two focal landscapes. We thank our workshop volunteers Paul Jackson, Michael MacDonald, Andrew Weatherall, Martin May, Charlotte Hogg & Jonathan Halls. We additionally thank Jonathan Halls for creating the illustrations featured in Figure 2. We thank our funders, the UK Research and Innovation Research Council through the Future of UK Treescapes Programme (Grant Reference NE/X003841/1). We thank Dario Massimino for preparing and providing the Breeding Bird Survey data, which is a Partnership between the BTO, RSPB, and Joint Nature Conservation Committee (on behalf of Natural Resources Wales, Natural England, Council for Nature Conservation and Countryside, and NatureScot) and relies on volunteer surveyors. We finally thank Richard Bradbury and Will Peach for helpful comments on the draft manuscript.

Data availability

Tree canopy cover data produced for this work have been published in Environmental Information Data Centre (Minter & Finch, 2025a, https://doi.org/10.5285/9e3055a3-a56b-4210-9628-4acd096ed9b7; Minter & Finch 2025b, https://doi.org/10.5285/e358f49d-511c-4136-824b-9edb245d5ac4). In addition, summary data from scenarios and all R scripts can be found in this repository https://doi.org/10.5281/zenodo.14069669. All third-party data used for scenario creation and predicted outcomes can be found in Supplementary Materials Table 1.4.1. All scenario maps and predicted outcomes are presented in a Shiny app https://stand-treescapes.shinyapps.io/stand_wp2_app/.

Conflict of interest

The authors declare no competing interests.

References

Bradfer-Lawrence, T., Finch, T., Bradbury, R. B., Buchanan, G. M., Midgley, A., & Field, R. H. (2021). The potential contribution of terrestrial nature-based solutions to a national ‘net zero’ climate target. *Journal of Applied Ecology*, *58*(11), 2349-2360. https://doi.org/10.1111/1365-2664.14003

Buechel, M., Slater, L., & Dadson, S. (2024). Broadleaf afforestation impacts on terrestrial hydrology insignificant compared to climate change in Great Britain. *Hydrology and Earth System Sciences*, *28*(9), 2081-2105. https://doi.org/10.5194/hess-28-2081-2024

Burkhard, B., Kroll, F., Müller, F., & Windhorst, W. (2009). Landscapes' capacities to provide ecosystem services - A concept for land-cover based assessments. *Landscape Online*, *15*, 1-22. https://doi.org/10.3097/lo.200915

Chapman, P. (2007). Conservation Grazing of Semi-natural Habitats. *SAC Technical Note TN586*.

Collas, L., Crastes dit Sourd, R., Finch, T., Green, R., Hanley, N., & Balmford, A. (2022). The costs of delivering environmental outcomes with land sharing and land sparing. *People and Nature*. https://doi.org/10.1002/pan3.10422

Crowle, A. J. W., Glaves, D. J., Oakley, N., Drewitt, A. L., & Denmark-Melvin, M. E. (2022). Alternative future land use options in the British uplands. *Ibis*, *164*(3), 825-834. https://doi.org/10.1111/ibi.13041

Dougill, A. J., Fraser, E. D. G., Holden, J., Hubacek, K., Prell, C., Reed, M. S., Stagl, S., & Stringer, L. C. (2006). Learning from Doing Participatory Rural Research: Lessons from the Peak District National Park. *Journal of Agricultural Economics*, *57*(2), 259-275. https://doi.org/10.1111/j.1477-9552.2006.00051.x

Douglas, D. J. T., Bellamy, P. E., Stephen, L. S., Pearce-Higgins, J. W., Wilson, J. D., Grant, M. C., & Fuller, R. (2014). Upland land use predicts population decline in a globally near-threatened wader. *Journal of Applied Ecology*, *51*(1), 194-203. https://doi.org/10.1111/1365-2664.12167

EnvironmentAgency. (2023). *National Lidar Programme https://www.data.gov.uk/dataset/f0db0249-f17b-4036-9e65-309148c97ce4/national-lidar-programme*.

Evans, C., Artz, R., Burden, A., Clilverd, H., Freeman, B., Heinemeyer, A., Lindsay, R., Morrison, R., Potts, J., Reed, M., & Williamson, J. (2022). Aligning the peatland code with the UK peatland inventory. *Report to Defra and the IUCN Peatland Programme*.

Finch, T., Bradbury, R. B., Bradfer-Lawrence, T., Buchanan, G. M., Copping, J. P., Massimino, D., Smith, P., Peach, W. J., & Field, R. H. (2023). Spatially targeted nature-based solutions can mitigate climate change and nature loss but require a systems approach. *One Earth*, *6*(10), 1350-1374. https://doi.org/10.1016/j.oneear.2023.09.005

Finch, T., Day, B. H., Massimino, D., Redhead, J. W., Field, R. H., Balmford, A., Green, R. E., Peach, W. J., & Villard, M. A. (2020). Evaluating spatially explicit sharing-sparing scenarios for multiple environmental outcomes. *Journal of Applied Ecology*, *58*(3), 655-666. https://doi.org/10.1111/1365-2664.13785

FitzGerald, O., Collins, C., & Potter, C. (2021). Woodland Expansion in Upland National Parks: An Analysis of Stakeholder Views and Understanding in the Dartmoor National Park, UK. *Land*, *10*(3). https://doi.org/10.3390/land10030270

Government, H. (2021). Net Zero Strategy: Build Back Greener.

Hardaker, A., Pagella, T., & Rayment, M. (2021). Ecosystem service and dis-service impacts of increasing tree cover on agricultural land by land-sparing and land-sharing in the Welsh uplands. *Ecosystem Services*, *48*. https://doi.org/10.1016/j.ecoser.2021.101253

Hasan, S. S., Zhen, L., Miah, M. G., Ahamed, T., & Samie, A. (2020). Impact of land use change on ecosystem services: A review. *Environmental Development*, *34*. https://doi.org/10.1016/j.envdev.2020.100527

Heywood, J. J. N., Massimino, D., Balmer, D. E., Kelly, L., Noble, D. G., Pearce-Higgins, J. W., Woodcock, P., Wotton, S., Gillings, S., & Harris, S. J. (2023). The Breeding Bird Survey 2022.

Hölting, L., Komossa, F., Filyushkina, A., Gastinger, M.-M., Verburg, P. H., Beckmann, M., Volk, M., & Cord, A. F. (2020). Including stakeholders' perspectives on ecosystem services in multifunctionality assessments. *Ecosystems and People*, *16*(1), 354-368. https://doi.org/10.1080/26395916.2020.1833986

Iversen, S. V., MacDonald, M. A., van der Velden, N., van Soesbergen, A., Convery, I., Mansfield, L., & Holt, C. D. S. (2024). Using the Ecosystem Services assessment tool TESSA to balance the multiple landscape demands of increasing woodlands in a UK national park. *Ecosystem Services*, *68*. https://doi.org/10.1016/j.ecoser.2024.101644

Iversen, S. V., Naomi, v. d. V., Convery, I., Mansfield, L., & Holt, C. D. S. (2022). Why understanding stakeholder perspectives and emotions is important in upland woodland creation – A case study from Cumbria, UK. *Land Use Policy*, *114*. https://doi.org/10.1016/j.landusepol.2021.105929

Iversen, S. V., van der Velden, N., Convery, I., Mansfield, L., Kjeldsen, C., Thorsøe, M. H., & Holt, C. D. S. (2023). Impacts of woodland planting on nature-based recreational tourism in upland England – A case study. *Landscape and Urban Planning*, *230*. https://doi.org/10.1016/j.landurbplan.2022.104587

Kahane, A. (2012). *Transformative scenario planning. Working together to change the future.* Berrett-Koehler, San Francisco, California, USA.

Kiatkoski Kim, M., Álvarez-Romero, J. G., Wallace, K., Pannell, D., Hill, R., Adams, V. M., Douglas, M., & Pressey, R. L. (2021). Participatory multi-stakeholder assessment of alternative development scenarios in contested landscapes. *Sustainability Science*, *17*(1), 221-241. https://doi.org/10.1007/s11625-021-01056-0

Kirby, K. J. (2018). What sort of treescapes do we want in Britain and what can we reasonably expect: a personal reflection. *Arboricultural Journal*, *40*(1), 39-46. https://doi.org/10.1080/03071375.2018.1420294

McGrory, R. E., Briers, R. A., Tomlin, C., Findlay, M. A., Kerslake, L. J., Riddle, N., & White, P. J. C. (2024). Impacts of forest extent, configuration and landscape context on presence of declining breeding Eurasian curlew Numenius arquata and implications for planning new woodland. *Forest Ecology and Management*, *572*. https://doi.org/10.1016/j.foreco.2024.122281

Metzger, J. P., Esler, K., Krug, C., Arias, M., Tambosi, L., Crouzeilles, R., Acosta, A. L., Brancalion, P. H. S., D'Albertas, F., Duarte, G. T., Garcia, L. C., Grytnes, J.-A., Hagen, D., Jardim, A. V. F., Kamiyama, C., Latawiec, A. E., Rodrigues, R. R., Ruggiero, P. G. C., Sparovek, G., . . . Joly, C. (2017). Best practice for the use of scenarios for restoration planning. *Current Opinion in Environmental Sustainability*, *29*, 14-25. https://doi.org/10.1016/j.cosust.2017.10.004

Minter, M. & Finch, T. (2025a). Tree canopy cover and height data at 10m resolution for the North Pennines and Dales landscape, northern England, 2023. NERC EDS Environmental Information Data Centre. https://doi.org/10.5285/9e3055a3-a56b-4210-9628-4acd096ed9b7

Minter, M. & Finch, T. (2025b). Tree canopy cover and height data at 10m resolution for the Elenydd landscape, Wales, 2023. NERC EDS Environmental Information Data Centre. https://doi.org/10.5285/e358f49d-511c-4136-824b-9edb245d5ac4

Monger, F., Spracklen, D. V., Kirkby, M. J., & Willis, T. (2024). Investigating the impact of woodland placement and percentage cover on flood peaks in an upland catchment using spatially distributed TOPMODEL. *Journal of Flood Risk Management*, *17*(2). https://doi.org/10.1111/jfr3.12977

Morton, R. D., Marston, C. G., O'Neil, A. W., & Rowland, C. S. (2021). Land Cover Map 2020 (10m classified pixels, GB) [Data set]. NERC EDS Environmental Information Data Centre. https://doi.org/https://doi.org/10.5285/35c7d0e5-1121-4381-9940-75f7673c98f7

Nguyen, H. V., Lee, D., & Warren, C. (2022). A comparison of stakeholder perspectives of tourism development in Sapa, Vietnam. *Tourism and Hospitality Research*, *23*(1), 17-29. https://doi.org/10.1177/14673584221075179

Ní Dhubháin, Á., Fléchard, M.-C., Moloney, R., & O'Connor, D. (2009). Stakeholders' perceptions of forestry in rural areas—Two case studies in Ireland. *Land Use Policy*, *26*(3), 695-703. https://doi.org/10.1016/j.landusepol.2008.09.003

Oteros-Rozas, E., Martín-López, B., Daw, T. M., Bohensky, E. L., Butler, J. R. A., Hill, R., Martin-Ortega, J., Quinlan, A., Ravera, F., Ruiz-Mallén, I., Thyresson, M., Mistry, J., Palomo, I., Peterson, G. D., Plieninger, T., Waylen, K. A., Beach, D. M., Bohnet, I. C., Hamann, M., . . . Vilardy, S. P. (2015). Participatory scenario planning in place-based social-ecological research: insights and experiences from 23 case studies. *Ecology and Society*, *20*(4). https://doi.org/10.5751/es-07985-200432

Pálsdóttir, A. E., Gill, J. A., Alves, J. A., Pálsson, S., Méndez, V., Ewing, H., & Gunnarsson, T. G. (2022). Subarctic afforestation: Effects of forest plantations on ground-nesting birds in lowland Iceland. *Journal of Applied Ecology*, *59*(10), 2456-2467. https://doi.org/10.1111/1365-2664.14238

Penny, J., Djordjević, S., & Chen, A. S. (2022). Using public participation within land use change scenarios for analysing environmental and socioeconomic drivers. *Environmental Research Letters*, *17*(2). https://doi.org/10.1088/1748-9326/ac4764

Project, N. C. (2024). *InVEST 3.14.2. Urban Flood Risk Mitigation*. Stanford University, University of Minnesota, Chinese Academy of Sciences, The Nature Conservancy, World Wildlife Fund, Stockholm Resilience Centre and the Royal Swedish Academy of Sciences. http://releases.naturalcapitalproject.org/invest-userguide/latest/en/urban_flood_mitigation.html#how-it-works

Pugh, T. A. M., Lindeskog, M., Smith, B., Poulter, B., Arneth, A., Haverd, V., & Calle, L. (2019). Role of forest regrowth in global carbon sink dynamics. *Proc Natl Acad Sci U S A*, *116*(10), 4382-4387. https://doi.org/10.1073/pnas.1810512116

Reed, M. S., Bonn, A., Slee, W., Beharry-Borg, N., Birch, J., Brown, I., Burt, T. P., Chapman, D., Chapman, P. J., Clay, G. D., Cornell, S. J., Fraser, E. D. G., Glass, J. H., Holden, J., Hodgson, J. A., Hubacek, K., Irvine, B., Jin, N., Kirkby, M. J., . . . Worrall, F. (2009). The future of the uplands. *Land Use Policy*, *26*, S204-S216. https://doi.org/10.1016/j.landusepol.2009.09.013

Reed, M. S., Dougill, A. J., & Baker, T. R. (2008). Participatory indicator development: what can ecologists and local communities learn from each other? *Ecol Appl*, *18*(5), 1253-1269. https://doi.org/10.1890/07-0519.1

Reed, M. S., Hubacek, K., Bonn, A., Burt, T. P., Holden, J., Stringer, L. C., Beharry-Borg, N., Buckmaster, S., Chapman, D., Chapman, P. J., Clay, G. D., Cornell, S. J., Dougill, A. J., Evely, A. C., Fraser, E. D. G., Jin, N., Irvine, B. J., Kirkby, M. J., Kunin, W. E., . . . Worrall, F. (2013a). Anticipating and Managing Future Trade-offs and Complementarities between Ecosystem Services. *Ecology and Society*, *18*(1). https://doi.org/10.5751/es-04924-180105

Reed, M. S., Kenter, J., Bonn, A., Broad, K., Burt, T. P., Fazey, I. R., Fraser, E. D. G., Hubacek, K., Nainggolan, D., Quinn, C. H., Stringer, L. C., & Ravera, F. (2013b). Participatory scenario development for environmental management: A methodological framework illustrated with experience from the UK uplands. *Journal of Environmental Management*, *128*, 345-362. https://doi.org/10.1016/j.jenvman.2013.05.016

Richards, C., Carter, C., & Sherlock, K. (2004). *Practical approaches to participation*. Citeseer.

Rigal, S., Dakos, V., Alonso, H., Aunins, A., Benko, Z., Brotons, L., Chodkiewicz, T., Chylarecki, P., de Carli, E., Del Moral, J. C., Domsa, C., Escandell, V., Fontaine, B., Foppen, R., Gregory, R., Harris, S., Herrando, S., Husby, M., Ieronymidou, C., . . . Devictor, V. (2023). Farmland practices are driving bird population decline across Europe. *Proc Natl Acad Sci U S A*, *120*(21), e2216573120. https://doi.org/10.1073/pnas.2216573120

Rodríguez, T., Reu, B., Bolívar-Santamaría, S., Cortés-Aguilar, A., & Buendía, C. (2023). A framework for participatory scenario planning to guide transitions towards sustainability in mountain social-ecological systems: A case study from the Colombian Andes. *Land Use Policy*, *132*. https://doi.org/10.1016/j.landusepol.2023.106817

Ross, C. W., Prihodko, L., Anchang, J. Y., Kumar, S. S., Ji, W., & Hanan, N. P. (2018). Global Hydrologic Soil Groups (HYSOGs250m) for Curve Number-Based Runoff Modeling. . https://doi.org/https://doi.org/10.3334/ORNLDAAC/1566

Schmidt, K., Walz, A., Martin-Lopez, B., & Sachse, R. (2017). Testing socio-cultural valuation methods of ecosystem services to explain land use preferences. *Ecosyst Serv*, *26*(Pt A), 270-288. https://doi.org/10.1016/j.ecoser.2017.07.001

Smith, A. C., Harrison, P. A., Leach, N. J., Godfray, H. C. J., Hall, J. W., Jones, S. M., Gall, S. S., & Obersteiner, M. (2023). Sustainable pathways towards climate and biodiversity goals in the UK: the importance of managing land-use synergies and trade-offs. *Sustain Sci*, *18*(1), 521-538. https://doi.org/10.1007/s11625-022-01242-8

Sprenkle-Hyppolite, S., Griscom, B., Griffey, V., Munshi, E., & Chapman, M. (2024). Maximizing tree carbon in croplands and grazing lands while sustaining yields. *Carbon Balance Manag*, *19*(1), 23. https://doi.org/10.1186/s13021-024-00268-y

Sterling, E. J., Betley, E., Sigouin, A., Gomez, A., Toomey, A., Cullman, G., Malone, C., Pekor, A., Arengo, F., Blair, M., Filardi, C., Landrigan, K., & Porzecanski, A. L. (2017). Assessing the evidence for stakeholder engagement in biodiversity conservation. *Biological Conservation*, *209*, 159-171. https://doi.org/10.1016/j.biocon.2017.02.008

Thorn, J. P. R., Klein, J. A., Steger, C., Hopping, K. A., Capitani, C., Tucker, C. M., Nolin, A. W., Reid, R. S., Seidl, R., Chitale, V. S., & Marchant, R. (2020). A systematic review of participatory scenario planning to envision mountain social-ecological systems futures. *Ecology and Society*, *25*(3). https://doi.org/10.5751/es-11608-250306

UK Gov (2021) Guidance: England Woodland Creation Offer, https://www.gov.uk/guidance/england-woodland-creation-offer

UK Gov (2023) Policy paper: Environmental Land Management (ELM) update: how government will pay for land-based environment and climate goods and services, https://www.gov.uk/government/publications/environmental-land-management-update-how-government-will-pay-for-land-based-environment-and-climate-goods-and-services/environmental-land-management-elm-update-how-government-will-pay-for-land-based-environment-and-climate-goods-and-services

Vallecillo, S., La Notte, A., Zulian, G., Ferrini, S., & Maes, J. (2019). Ecosystem services accounts: Valuing the actual flow of nature-based recreation from ecosystems to people. *Ecol Modell*, *392*, 196-211. https://doi.org/10.1016/j.ecolmodel.2018.09.023

Volkery, A., & Ribeiro, T. (2009). Scenario planning in public policy: Understanding use, impacts and the role of institutional context factors. *Technological Forecasting and Social Change*, *76*(9), 1198-1207. https://doi.org/10.1016/j.techfore.2009.07.009

Volkery, A., Ribeiro, T., Henrichs, T., & Hoogeveen, Y. (2008). Your Vision or My Model? Lessons from Participatory Land Use Scenario Development on a European Scale. *Systemic Practice and Action Research*, *21*(6), 459-477. https://doi.org/10.1007/s11213-008-9104-x

Welsh Government. (2023). *LiDAR Welsh Government,* https://datamap.gov.wales/maps/lidar-viewer/.

Welsh Government. (2024a). *Sustainable Farming Scheme Guide*, https://www.gov.wales/sustainable-farming-scheme-guide

Welsh Government. (2024b). *Woodland Creation Grant: overview,* https://www.gov.wales/woodland-creation-grant-overview

Westaway, S., Grange, I., Smith, J., & Smith, L. G. (2023). Meeting tree planting targets on the UK's path to net-zero: A review of lessons learnt from 100 years of land use policies. *Land Use Policy*, *125*. https://doi.org/10.1016/j.landusepol.2022.106502

Williams, D. R., Phalan, B., Feniuk, C., Green, R. E., & Balmford, A. (2018). Carbon

Storage and Land-Use Strategies in Agricultural Landscapes across Three Continents. *Curr Biol*, *28*(15), 2500-2505 e2504. https://doi.org/10.1016/j.cub.2018.05.087

WWC. (2021). *WWC Woodland Carbon Calculation Spreasheet V2.4*. https://woodlandcarboncode.org.uk/standard-and-guidance/3-carbon-sequestration/3-3-project-carbon-sequestration