Ecosystem Services 68 (2024) 101644

Contents lists available at ScienceDirect

Ecosystem Services

journal homepage: www.elsevier.com/locate/ecoser

Using the Ecosystem Services assessment tool TESSA to balance the multiple landscape demands of increasing woodlands in a UK national park

Sara V. Iversen[a,*], Michael A. MacDonald[c], Naomi van der Velden[b], Arnout van Soesbergen[d], Ian Convery[b], Lois Mansfield[b], Claire D.S. Holt[b]

[a] Department of Agroecology, Aarhus University, Blichers Allé, 8830 Tjele, Denmark
[b] Department of Science, Natural Resources & Outdoor Studies, University of Cumbria, Rydal Rd, Ambleside, UK
[c] RSPB Centre for Conservation Science, Castlebridge 3, 5-19 Cowbridge Road East, Cardiff CF11 9AB, UK
[d] Department of Geography, King's College London, Bush House North-East Wing 30, Aldwych WC2B 4BG, UK

ARTICLE INFO

Keywords:
Ecosystem services
Woodland creation
Landscape
Uplands
Afforestation

ABSTRACT

Upland regions in the UK are increasingly under consideration as potential areas for the creation of woodlands. This is driven by a combination of factors, including the aims of UK forestry policy to increase woodland cover, changes in current upland land-use and management, agri-environment schemes in national and international policy and an increasing public awareness of the ecosystem service benefits landscapes can deliver for society. Creating new woodlands in upland areas is challenging, partly due to concerns of potential impacts from a change in land use and stakeholder interests. This study considers a 250 km^2 Cumbrian (England) upland landscape dominated by sheep grazing and, using an established ecosystem service assessment tool (TESSA), estimates the provision of ecosystem services under plausible alternative woodland creation scenarios. The assessment focuses on key ecosystem goods and services, which are identified by stakeholders to be of high importance to the study area, and the potential changes to those under the scenarios. The results indicate that, under lower woodland percentage scenarios (10 %), minor benefits are expected. However, a more complex outcome would be expected from the higher percentage woodland scenarios (75 %) with the woodland cover of 50 % identified as providing the highest overall benefit to society.

1. Introduction

In recent years there has been an increased focus on the role landscapes have in nature conservation and providing ecosystem services to society. The world is increasingly mitigating the outcomes of extreme weather events driven by climate change (IPCC, 2021) and the biodiversity crises challenge. Rethinking and evaluating how we manage large-scale land areas has never been as topical and urgent as now. Creating new woodlands and increasing woodland cover in upland areas has been suggested as one way of mitigating climate change, as well as providing other important ecosystem services to society, such as improving flood protection (Holden et al., 2017; Stratford et al., 2017: Gunnell et al., 2019), nature-recreational tourism (Iversen et al., 2023) and water quality (Broadmeadow & Nisbet 2010a), as well as having rural economic benefits (Hardaker et al., 2021). Woodland cover in the UK stands today at 13 %, which is well below the European average of 37 % (Forest Research 2021), and UK government policy acknowledges the benefits woodlands can provide to the economy, environment and society (DEFRA, 2021).

Management of the uplands in the UK is a highly discussed topic with debates surrounding land-use, cultural heritage, management, entitlement and nature conservation (Reed et al., 2009; Huq & Stubbings, 2015; FitzGerald et al., 2021). The uplands are multifunctional landscapes that provide society with vital services, such as agricultural production, climate change mitigation, water provision, recreation and biodiversity (de Groot et al., 2012; Hardaker et al., 2021), and less

* Corresponding author.
E-mail addresses: sara.iversen@agro.au.dk (S.V. Iversen), Michael.MacDonald@rspb.org.uk (M.A. MacDonald), naomikv@gmail.com (N. van der Velden), arnout.van_soesbergen@kcl.ac.uk (A. van Soesbergen), ian.convery@cumbria.ac.uk (I. Convery), lois.mansfield@cumbria.ac.uk (L. Mansfield), claire.holt@cumbria.ac.uk (C.D.S. Holt).

https://doi.org/10.1016/j.ecoser.2024.101644
Received 22 September 2023; Received in revised form 25 April 2024; Accepted 14 June 2024
Available online 13 July 2024

tangible benefits such as a sense of place or wellbeing. Changing the land use in these areas, by increasing woodland cover, will impact the services provided.

Previous research has highlighted the social and ecological impacts associated with upland tree planting (Reed et al., 2009; Broadmeadow & Nisbet 2010b; Bunce et al., 2014; Hardaker et al., 2020; FitzGerald et al., 2021). The impact of woodlands and management approaches on ecosystem services may have been investigated in detail (Clarke et al., 2015; Baral et al., 2016; Brockerhoff et al., 2017; Sing et al., 2017) but are often very generalised (Peh et al., 2013), without much appreciation of regional differences, site-specific circumstances and impacts on local communities in a landscape with a strong cultural heritage. Some studies have tried to address the need for upland regional assessments, making attempts to untangle social conflict (FitzGerald et al., 2021: Iversen et al., 2022) or understand the economic connections between ecosystem services and tree planting (Hardaker et al., 2021); however, these studies rely on modelling approaches using broad scale transfer values.

Ecosystem service (ES) assessment is a field which is developing rapidly, and many assessment toolkits and approaches are available (Thapa et al., 2014; Guerry et al., 2015; Zank et al., 2016). It is, however, challenging to assess ES at the site-scale, due to the requirement of substantial resources and specialist knowledge on a local level and therefore such assessments are often not carried out or they are extrapolated from larger studies (Baral *et al.* 2014; Bradbury et al., 2021). This is a disadvantage for land managers and decision makers, as the results obtained from finer-scaled site-scale assessments can inform and provide evidence for involved stakeholders on what impacts can be expected. Global environmental challenges, such as the decline in global biodiversity and climate change, require local solutions. TESSA (Toolkit for Ecosystem Service Site-based Assessment) aims to bridge this gap between the need for knowledge and the high resource and specialist cost of obtaining it (Peh et al., 2013) – Fig. 1.

In this study, we present insights and suggestions of how TESSA as a method and the associated site-specific data can be used to specify/ quantify ecosystem services changes in upland landscapes, caused by woodland creation. Previous research (Hardarker *et al.* 2021) has been carried out on a broader scale in the Wales uplands under scenarios of predominantly agricultural or forested land, or combined, which gave insights to valuation of both the services and dis-services delivered under each scenario and main stakeholder beneficiaries. The TESSA finer-scaled toolkit has previously been applied in a UK setting (Blaen et al., 2016; MacDonald et al., 2020), but never in an UK upland landscape. The aim has been to make the assessment as site-specific as possible and thereby more valid and informative to local stakeholders, whilst keeping within the objective of being 'rapid' and resource efficient.

2. Methods and material

2.1. Study site

The Howgill Fells Natural Character Area (NCA) is situated in Cumbria, in the north-west of England and covers an area of 105 km2 or 10,360 ha – (Fig. 2). It lies within the boundaries of the Yorkshire Dales National Park and is representative of the rest of the upland regions of Cumbria by being rural, remote, strongly influenced by hill farming and having a strong cultural identity and similar socio-demographics. The topography is of open exposed rounded hills, which reach a height of 676 m, and are separated from the surrounding regions by steep-sided valleys. There is little variation in vegetation cover, which is mostly upland heath and acid grassland and bracken. The area is grazed by domestic stock, mainly sheep and to a smaller extent cattle and fell ponies. Much of the area (77 %) is common land, where several farmers hold traditional and statutory rights to graze livestock. There are currently 36 farms within the NCA, but these have been declining in numbers over the years, partly due to farms being combined and expanded, a lack of a next generation to carry on from a retired generation, and changes in farming traditions.

The catchment surrounding the NCA provides an important regulating ecosystem service within its capacity to reduce flood risk and thereby reduce risk to local communities, safety of people and infrastructure (Stratford et al., 2017). There are several settlements in the catchment and one large urban area. All of the settlements are in the downstream reaches of the catchment and are therefore impacted by the level of water stored in the catchment and management approaches. Flood risk occurs due to prolonged and heavy precipitation, combined with a steep topology of the surrounding area. This means that there is little opportunity for infiltration into the soil which, combined with a lack of storage (natural or constructed) to reduce the run-off, can lead to high surface run-offs that stress the carrying capacity of streams, rivers, lakes, and reservoirs. This can either be partly prevented or mitigated by the landscape and increasing woodland cover is increasingly used as a nature-based solution that has potential to increase infiltration (Marshall et al. 2009), absorb precipitation (Mulligan 2010) and create flow resistance, and thereby reducing surface run-off (Marshall *et al.* 2014; Chandler et al., 2018).

The Howgill Fells NCA is likely to experience changes to weather and local conditions in the future due to climate change (Orr et al., 2008; Garner et al., 2017). Temperature and precipitation are expected to increase on average, with warmer and wetter winters, and warmer and drier summers. Evidence from the UK Climate Impact Programme (IPCC, 2021) shows that more frequent and extreme weather events are expected to increase rates of erosion to the wider catchment and, subsequently, impact the fells and in-bye land.

Woodland cover within the NCA is, at 0.7 %, one of the lowest levels found in any NCAs in England (Natural England 2010). In recent years, extensive tree planting has been carried out under agri-environment schemes, such as the Environmental Stewardship scheme (Natural England 2020). Tourism is an important source of income to the area (300,000 visitors a year), supporting the many local farms in the area that have in recent years diversified their income stream by offering accommodation via campsites, B&Bs and self-catering options. The top four reasons for visiting are according to Tourism (2015): 'Because of the physical scenery and landscape' (61 %), 'Because of the atmospheric characteristics of the area – peaceful, relaxing, beautiful etc.' (40 %) and 'Been before' (37 %), followed by 'Undertaking a specific activity' (19 %). Hereunder, most participants stated that 'walking' was the specified activity. Overall, 96 % stated that, 'It is a good place for outdoor activities and the majority of visitors stated that they, 'Very much so' or 'quite a lot' felt physically (85 %) and mentally (90 %) better after their visit. The natural environment and landscape are therefore very important in terms of sustaining the tourism industry.

2.2. Defining alternative scenarios

The NCA is currently undergoing extensive landscape changes. At the time of study, approximately 700 ha of new woodland had been planted over a time of two years. More planting has subsequently been carried out and there are discussions and consultations being undertaken, to consider even more. TESSA recommends strong stakeholder engagement within the process (Fig. 1), and by doing so allows the users to develop an understanding of the ecosystem service benefits an area/site provides and how to assess their value on a site-specific level (Birch et al., 2014). It does so by comparing empirical data derived from a 'current' site to estimates for an 'alternative' site.

The Howgill Fells NCA was identified as the 'current state', an appropriate study site with the current 0.7 % woodland cover. An 'alternative state' had to be defined in order to carry out the assessment. The development of alternative state scenarios and choice of ecosystem service indicators was first and foremost guided and informed in initial meetings and collaboration with key local stakeholders in the early

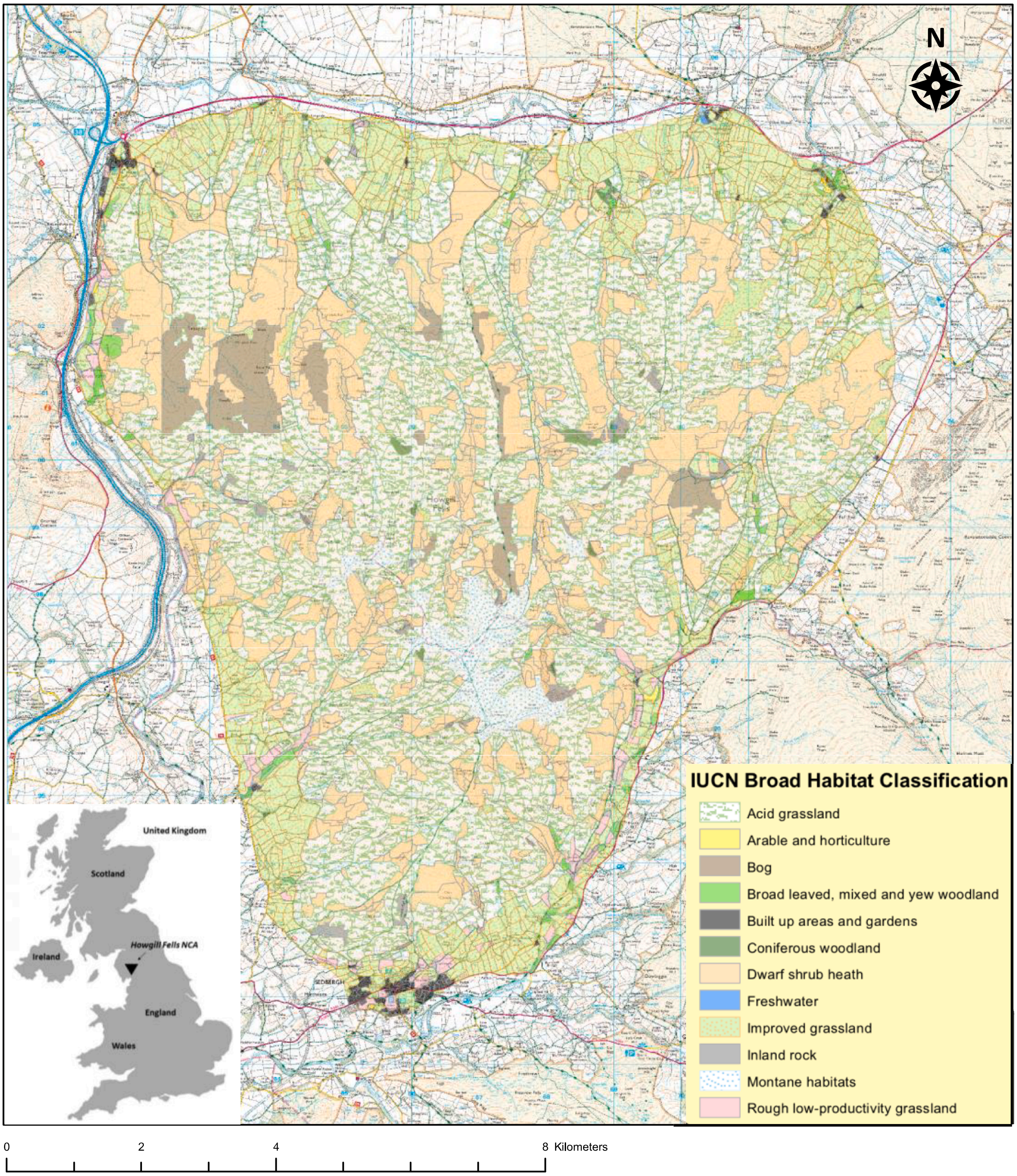

Fig. 1. The conceptual and process-design of using TESSA throughout the study. Designed with inspiration from Peh et al. (2013).

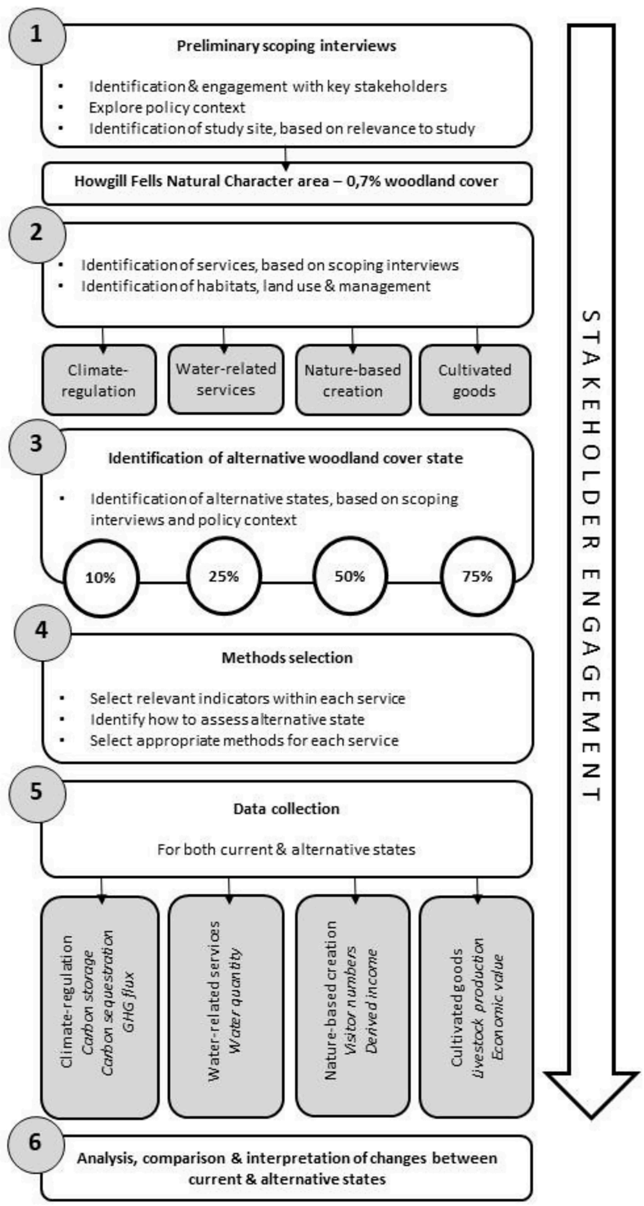

Fig. 2. The outline of study area of the Howgill Fells Natural Character Area and its location within the United Kingdom of Great Britain (small map) (Landcover map 2007).

scoping stage of the study and further supported by review of the literature and environmental policy strategies. Thirteen preliminary semi-structured interviews were held with key stakeholders within the landscape and natural resource managemet sector in Cumbria – see appendix I for details. The interviews were conducted in an inductive, explorative manner, as the aim of gaining the information was discovery in order to get an initial understanding of the subject and not to test an already established hypotheses. There was also a need to further to develop the research questions in conjunction with the literature review and policy context. Participants were chosen based on them being deemed as key stakeholders locally and being influential within the subject of woodland creation. All were invited in writing, with an attached brief introducing the project and purpose of the interview. A snowballing sampling approach (Newing, 2011) was used to verify the choice of participants. The interviews were all, except one, conducted face to face at locations convenient to the participant and generally lasted for approximately 1–1.5 h. The one exception was conducted over the phone due to the participant being overseas. All interviews were recorded and a very simple thematic and constant comparison analysis (Glaser, 1965; Boeije, 2002) was carried out, by review of the material and simple memo writing in order to identify theoretical categories and identify the broad themes as described above.

The results from the interview showed, that there was consensus regarding the topic of woodland creation in Cumbria and their focus was often surrounding questions such as: How much woodland there should be on a landscape scale and what changes from mainly grazed grassland to woodland would entail. Especially on ecosystem goods and services such as: climate regulation, water-related services, nature-based recreation and cultivated goods (agricultural production). These indicators were there chosen for analysis. Stakeholder's perspectives and opinions were also identified as being fundamental to the topic and was perceived as being highly conflicted (this has been studied and published in Iversen et al., 2022).

In terms of how much woodland there should be on a landscape scale, then the extent of the planting has raised local discussions and concerns in terms of what impacts such severe changes on the landscape may have on the local area. Therefore, the level of tree planting thought to be appropriate was highly variable, depending on the specific views, values and interests of the stakeholder. This was taken into consideration in the methodological decision and design, and with further consideration to the unknown future extend of the planting, it was decided to explore different levels of tree planting of expansion of woodland cover to 10 %, 25 %, 50 % and 75 % of land cover in the NCA.

2.3. Climate regulation

The NCA contributes to climate regulation by carbon storage in the vegetation and soil and emissions of greenhouse gas (GHG). Carbon storage is also provided by the peaty soils of the area (40 % of the area), although only 10 % of the 40 % are deemed to be storing a large amount of carbon in blanket bog, due to the challenging steep terrain and shallow soils (NE 2014). Emissions of GHG are likely to occur over the organic soils due to drainage (Alonso et al., 2012). The pastoral grazing of primarily sheep, cattle and horses, contributes to GHG emissions in the form of Methane (CH_4) (Le Mer & Roger, 2001; Richmond et al., 2015). Although most of the grazed fields are not improved, the lower slopes are being fertilised and, as a result, Nitrous oxide (N_2O) emissions will occur (Richmond et al., 2015).

The climate change regulation within the NCA were assessed following TESSA guidance focusing on the three factors that influence climate regulation: 1) changes in above and below-ground carbon storage in plant biomass, dead organic matter, and soil; 2) changes in carbon sequestration; and 3) annual greenhouse gas fluxes. A comparison was then made between the current state and the four alternative scenarios. Carbon storage and GHG fluxes were based on broad habitat categories: broadleaved woodland, coniferous woodland, grassland, bog and "other" (inland rock, fresh water and built-up areas) (Table 1). All

Table 1
Habitat area size in hectare by IUCN broad habitat classification in each of the proposed scenarios. 'Other' signifies: Inland rock, fresh water and built up areas. Due to tree planting only occurring on grassland and being a 'native type consisting mainly of broadleaved tree species, only the habitat categories of broadleaved woodland and grassland will change under each scenario. Coniferous woodland and bog is expected not to change in area size.

IUCN Habitat (ha)	Broadleaved Woodland	Coniferous woodland	Grassland	Bog	Other	Total
Current state	68	12	10,436	332	153	11,000
10 %	1,088	12	9,416	332	153	11,000
25 %	2,738	12	7,766	332	153	11,000
50 %	5,488	12	5,016	332	153	11,000
75 %	8,238	12	2,266	322	153	11,000

grassland types (acid grassland, dwarf shrub heath, improved grassland, montane habitats and rough low-productivity grassland) were combined due to similar qualities in carbon storage, sequestration and GHG flux (Hagon et al., 2013). All calculations were based on data that was obtained by a combination of sampling within the site and processed by the research team and value transfer from previous studies and IPCC conversion factors. Full details of methods used can be found in appendix I.

2.4. Nature-based recreation

The impacts of woodland creation on nature-based recreation (NBR) were surveyed in the NCA from the 1st of June to the 1st of September 2016. The survey combined an in-situ intercept convenience survey (Newing, 2011) with a photo visualisation approach (Kim & Weiler 2013). NBR visitors were invited to participate in a survey and a total of 493 questionnaires were collected. Participant sample size was determined based on data provided by Cumbria Tourism (2015), and Sedbergh Tourist Information Centre (STIC), which showed that there are 317,160 visits each year. By setting the confidence level at 95 % and confidence interval at 5, a questionnaire sample size was determined to be of a minimum of 384 participants to be statistically robust (Newing, 2011).

Data was collected during the hours of 08:00 to 17:00 including weekdays, weekends, and days within and outside school term time. The timings during the day were varied and designed to be able to intercept visitors as they began NBR related activities (primarily hillwalking). All data was collected over 32 days. All visitors who fit the participant profile (visitors for NBR purposes) were asked to participate, with no stratification of age or gender. Residents were excluded from the survey. The four scenarios of different levels of woodland in a single photographic view were presented to participants, who were within the physical site of the landscape in question. The design of the manipulated photographs showing the five different woodland scenarios was created by using a landscape photograph of the Howgill Fells NCA. The photograph editing software PaintShop Pro X9 Ultimate was used to manually edit the photographs and add an increasing level of woodland to each of the pre-designed scenarios (See Iversen et al., 2023 for more detail).

Using Cumbria Tourism (2015) data, a total value of £52,965,803 was calculated (average daily spend £167 x 317,160 visits) as being the current economic value of nature-based recreation in the NCA. Determining the value of the alternative scenarios was calculated with the same approach but using adjusted visitor numbers according to their probability of return visits obtained from the survey. A conservative assumption was made that a 'more likely to visit again' choice under any scenario would entail one extra visit per year, with the added value of an extra £167. Therefore, each participant choosing the 'more likely to visit again' category, would be given the value of £334. Participants choosing the category of 'make no difference to visiting again', applied the value of £167 (one visit/year). For participants choosing the category of 'less likely to visit again', the value of £0 was applied. These figures were then used, in combination with the survey data, to calculate the economic value of nature-based recreation under each of the woodland scenarios (Iversen et al., 2023).

2.5. Cultivated goods

The assessment of cultivated goods (livestock production) applied a baseline account of the livestock numbers within the NCA. This was informed by key stakeholders and the 2013 Defra June Agricultural Statistics (Defra 2013), which shows that within the NCA there are 26,254 sheep and 693 cattle registered. Livestock numbers in any given farmed area are dependent on the carrying capacity of livestock such an area can accommodate in terms of resources. What an area is defined as being able to accommodate is based on the aims and objectives of the specific situation, which may be ecological restoration or, in this case, production. A common and widely used indicator for this is Livestock Units (LU). LU is a reference unit that reflects the energy requirements of different types of livestock (SAC 2016).

The agricultural carrying capacity is defined for the purpose of this study as the level of LU/ha the land area can accommodate for optimal livestock production. The meaning of optimal livestock production is that the animals thrive within the resources available. A maximum stocking density of 0.25 LU/ha is applied as the agricultural carrying capacity to this assessment, informed as a guideline recommendation by the local Natural England advisor, local farmers, an independent advisor and the Rural Payment Agency's Basic Payment Scheme payment stocking density estimates for SDA and Moorland shared grazing. It was furthermore also supported by Harvey & Scott (2016) in their annual Farm Business Survey from 2015 as being the level of stock reported by the farmers themselves. This LU level was applied to each of the predesigned woodland creation scenarios.

Key advisors from the NCA informed that it was most likely that, with an increase in woodland creation, the cattle numbers would remain constant and sheep numbers would decrease. Therefore, cattle are applied as a constant for the assessment. The sheep breeds kept within the NCA are predominantly Swaledale and, to a lesser extent, Rough Fell. An assumption was therefore made of 75 % Swaledale and 25 % Rough Fell, which was deemed appropriate by advisors. Swaledale is a medium sized hill sheep and was therefore categorised according to Natural England's LU definitions as 0.08 LU/ha. Rough Fell is a larger breed and, following Natural England guidelines, an additional 20 % was therefore applied resulting in a definition of 0.10 LU/ha. A further adjustment was made to reach an average between the two LU/ha definitions and a final average of 0.09 was applied to the calculations. The habitat is defined as rough grazing, from information provided by key stakeholders.

Finally, an economic value was applied to the cultivated goods produced by the NCA. The net value of sheep grazing was estimated using the 2015/16 report on Hill Farming (Harvey & Scott, 2016) by applying the average net margin per ewe figure to the number of sheep under each of the predesigned scenarios. These figures exclude agricultural and environmental subsidies, due to subsidies being public money given as support and not generated from the goods. Including the unpaid labour of farmer and spouse, the average loss per ewe for hill sheep in 2015/16 was £66.

2.6. Water-related services

Water-related ecosystem services, with a specific focus on flood risk, were deemed by key local stakeholders to be a significant indicator to assess, due to the large impacts flood events have on the study area. Flood risk as an indicator, was therefore applied to each of the proposed scenarios and assessed using a spatially explicit hydrological modelling tool. Following TESSA guidelines, the Policy Support System (PSS) WaterWorld (Mulligan 2013) was chosen to carry out the assessment, as it can carry out a detailed analysis of hydrological services within a specified area of interest, as well as carrying out a comparison of scenarios of land-use change.

WaterWorld is a web-based hydrological model capable of analysing hydrological ES at scales from global to local at various resolutions (10 km, 1 km and 1 ha). Due to the small size of the study area a 1 ha resolution scale was attainable, providing more accurate modelling results (Mulligan 2013). WaterWorld is a fully distributed, process-based hydrological model that utilises remotely sensed and globally available datasets and simulates four diurnal time-steps for one day each month, totalling 48 time-steps based on a long-term (1950–2000) climatology (WorldClim; Hijmans et al., 2005). The model includes modules for rainfall distribution based on wind interaction, fog inputs based on cloud cover and potential and actual evapo-transpiration based on climate and vegetation cover. Runoff is calculated as the downstream accumulation of water balance along a drainage network.

The WaterWorld modelling was carried out as a comparison of a baseline (current state) to the four previously described scenarios of woodland creation of 10 %, 25 %, 50 % and 75 %. To do this, a Zone Of Interest (ZOI) file, which depicts the Howgill Fells NCA, was first prepared by the use of ArcGIS and a map download from the Natural England Open Source ArcGIS Online (Natural England 2023) and uploaded to WaterWorld. Under each scenario, the relevant percentage was set and applied per pixel within the ZOI. Thereafter, an additional rule was applied of afforestation only in areas within the ZOI no higher than 450 m altitude to remain within the policy context of the planting, which only allows planting under this altitude.

In this analysis we use the WaterWorld green storage metrics and annual flow capacity ratio (Mulligan, 2016) to assess flood risk. The total storage ratio (blue and green) is an annual flow ratio that provides an estimate of use of the available storage capacity by long-term mean annual flows. Values > 1 means that, on an annual basis, there is more water in a pixel than the storage capacity to store it and thus a greater flood risk. The storage ratios for green storage (wetlands, canopy and soils) excludes the blue storage (water bodies and floodplains) and therefore the storage ratios are higher. If the green storage ratios are > 1 it means, there is not enough green storage to store all water on an annual basis. These metrics are described fully in the WaterWorld V2 documentation (Mulligan, 2016).

3. Results

3.1. Climate regulation

A total carbon storage value (t/C) (above and below-ground) was estimated and converted into tonnes of carbon per hectare (t/C/ha^{-1}). A similar amount of carbon is stored in broadleaved and coniferous woodland: 169.4 t/C/ha^{-1} (broadleaved) and 159.2 t/C/ha^{-1} (conifer). Grassland stores 70.2 t/C/ha^{-1} and bog stores a comparatively large amount at 259 t/C/ha^{-1}. This data was used as the foundation for calculating the total carbon storage value within the study area and the four scenarios. By applying the t/C/ha^{-1} values to changes in area between grassland and broadleaved woodland according to the four woodland expansion scenarios, changes in carbon storage values were derived (Table 2). With each woodland expansion scenario there is an increase in total carbon storage, which would be expected considering the higher amount of carbon stored in woodland compared to grassland (Hagon et al., 2013). The coniferous woodland and bogs remained unchanged in each woodland expansion scenario, due to there being no planting on these categories.

Coniferous woodland habitat has the highest rate of sequestration at -9.29 t/CO_2/ha^{-1}/y^{-1}, followed by broadleaved woodland at -4.54 t/CO_2/ha^{-1}/y^{-1}. Grassland sequesters CO_2 at a much lower rate of -2.2 t/CO_2/ha^{-1}/y^{-1} and bogs at a rate of -1.42 t/CO_2/ha^{-1}/y^{-1}. As woodland cover increases, the sequestration values increase substantially, (Fig. 3). The total GHG flux indicates that the NCA would sequestrate an increasing amount of total GHG with each woodland creation scenario and, as a result, have a positive impact on climate regulation and mitigation by reducing GHG emissions and increasing carbon storage (Fig. 4).

Table 2
Total t/C in each IUCN category in the current state and alternative scenarios of the Howgills Fells NCA.

IUCN Habitat	Broadleaved woodland	Coniferous woodland	Grassland	Bog	Total Carbon stocks
Current state	11,519	1,910	734,684	85,988	834,112
10 %	184,307	1,910	662,886	85,988	935,092
25 %	463,817	1,910	546,726	85,988	1,098,442
50 %	929,667	1,910	353,126	85,988	1,379,692
75 %	1,395,517	1,910	159,526	85,988	1,642,942

3.2. Nature-Based recreation

Of the 493 completed questionnaires, 426 were from visitors who stated that they were primarily visiting for nature-based recreational reasons, by choosing either or both categories of: a) 'Appreciating/viewing/landscape' or b) 'Exercise/sports/hobbies'. Anyone primarily visiting for the reason of: c) 'Visiting town', d) 'Visiting family or friends' or e) 'Other' and not choosing any of the reasons in category a or b, were disregarded in the analysis.

The majority of participants felt that changing amounts of woodland, even up to 75 % coverage would not influence their likeliness of return visits, there was a clear decline in the proportion of participants as the amount of woodland shown increased, from 74 % of participants in the 10 % woodland scenario to only 56 % of participants in the 100 % woodland scenario (Fig. 5). As woodland cover increased, so did the proportion of visitors that felt they would be unlikely to visit again, from 3 % at 10 % cover to 28 % at the 100 % cover. There are particularly pronounced increases in the number unlikely to visit in the 75 % and 100 % scenarios. The number of visitors more likely to visit again remains much higher (23—–24 %) than those not likely to return (3—–8 %) in all scenarios with less than 75 % woodland cover. This suggests that significant increases in woodland cover, up to 50 % cover, would result in a net increase in visitors to the area. This does not consider visitors that currently do not visit, might do so in the alternative scenarios.

The result from this study shows that an increase in woodland levels could economically benefit revenue derived from nature-based recreation in the Howgill Fells NCA. The economic value increases with approximately 16–20 % each under the lower woodland scenarios of 10 %, 25 % and 50 % (Fig. 6). The highest revenue to be expected is under the 10 % scenario. However, the increase in economic benefit peaks by 50 % scenario and the difference in monetary value between the current state and 75 % woodland scenario is minimal by £250 (0 %).

3.3. Cultivated goods

The ecosystem service of cultivated goods (livestock production) was assessed by a combination of data obtained from key stakeholders on grazing levels and livestock units (LU) and area-specific agricultural economic values (DEFRA 2015; Harvey & Scott 2015). The results indicate that the Howgill Fells NCA is currently stocking livestock at approx. 0.25LU/ha. This amounts to a total of 2,416LU in the whole of the grazing area of the NCA or 26,000 sheep. Given this stocking rate, the NCA could potentially sustain a further 220LU (2,600 sheep). The current stocking rate was applied to the decrease in grazing available under each of the woodland creation scenarios. Consequently, the results indicates that under the 10 % woodland creation scenario, the NCA would be able to sustain an approximately very similar level of stock amounting to a decrease of 198 sheep. Under each of the higher woodland creation scenarios, a much higher decrease in livestock production would occur.

Further to this, an economic net value (without agricultural and environmental subsidies) was applied to the livestock following the aforementioned methodology. Livestock production from hill farms in England are a loss-making activity without subsidies and, currently, each ewe on a hill farm has a net profit margin of −£66. The results show that, by applying the per ewe value to the stock levels (LU units) that the NCA would be able to sustain under each woodland creation scenario, an economic value decrease would be expected from this cultivated good in the Howgill Fells NCA (Fig. 7).

3.4. Water-related services

The results from the hydrological modelling (Table 3) show that as woodland creation increases, the total water storage in the catchment increases as the additional tree cover provides more canopy and soil

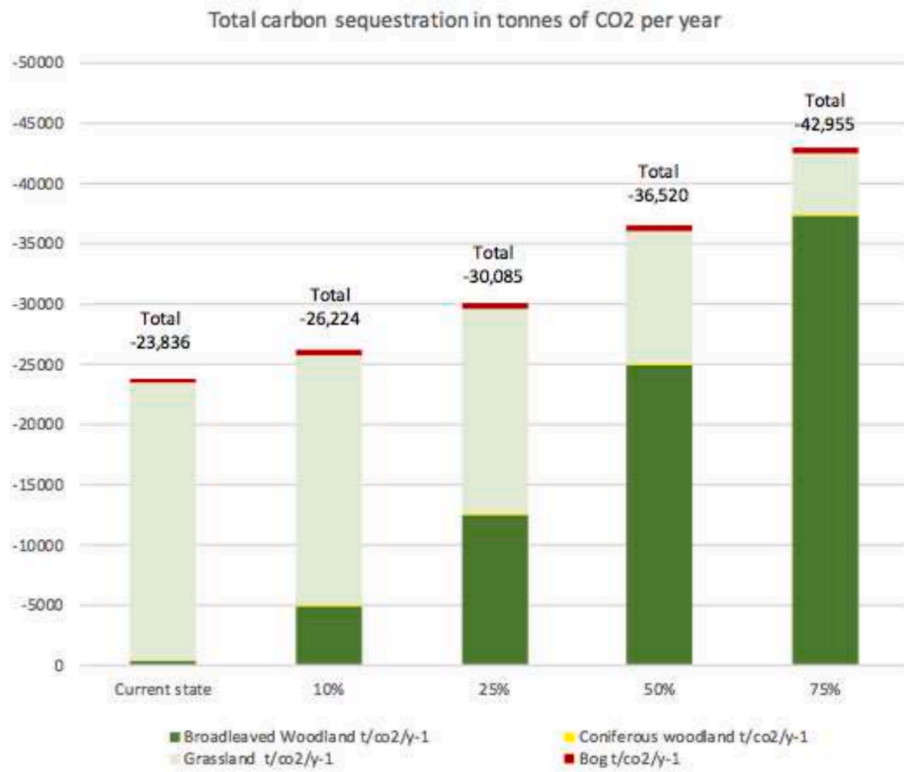

Fig. 3. Total carbon sequestration in tonnes of CO_2 per year under current state and each of the scenarios, in each of the IUCN Broad habitat groups.

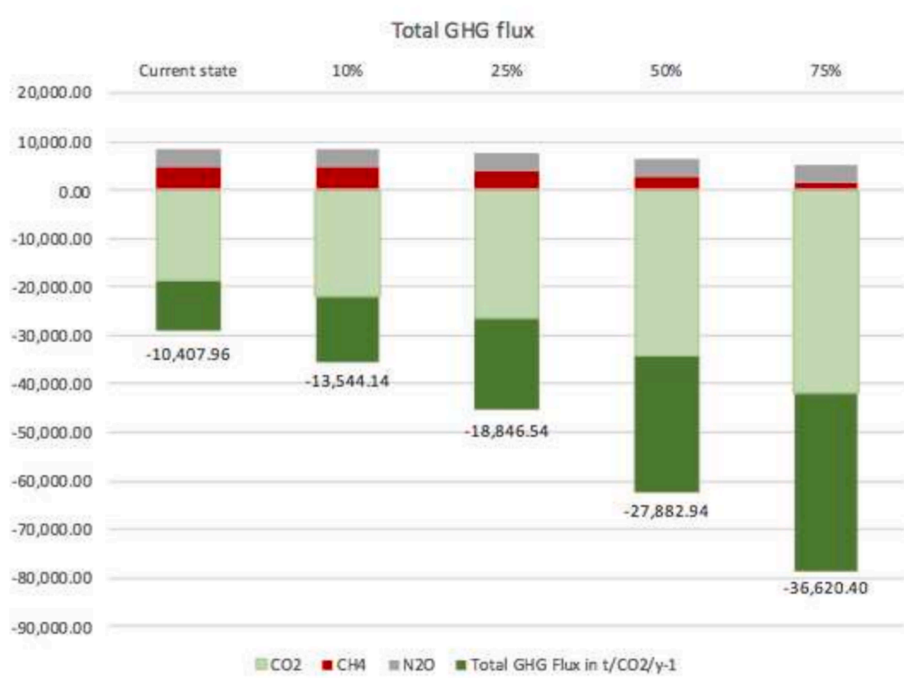

Fig. 4. Current state and alternative state total GHG flux final summary, incorporating CO_2, CH^4 and N^2O into the total flux assessment. The positive values indicate emissions and the negative values sequestration. Total sequestration in $t/CO_2/y^{-1}$ increases under each alternative scenario.

storage. At the same time, the increased tree cover leads to higher evapotranspiration and thus reduced flows. The combination of increased storage with lower run-off results in a significant reduction in flood risk, expressed as capacity storage ratios. The high-capacity storage ratios under the baseline indicate the high flood risk of the catchment but under a scenario of 75 % increase in tree cover this flood risk can be reduced by more than 24 % although under a scenario of 50 % woodland creation a reduction of nearly 23 % can already be achieved. The values for the green capacity storage ratio only show that nearly all storage in the catchment consists of green storage as there are only small

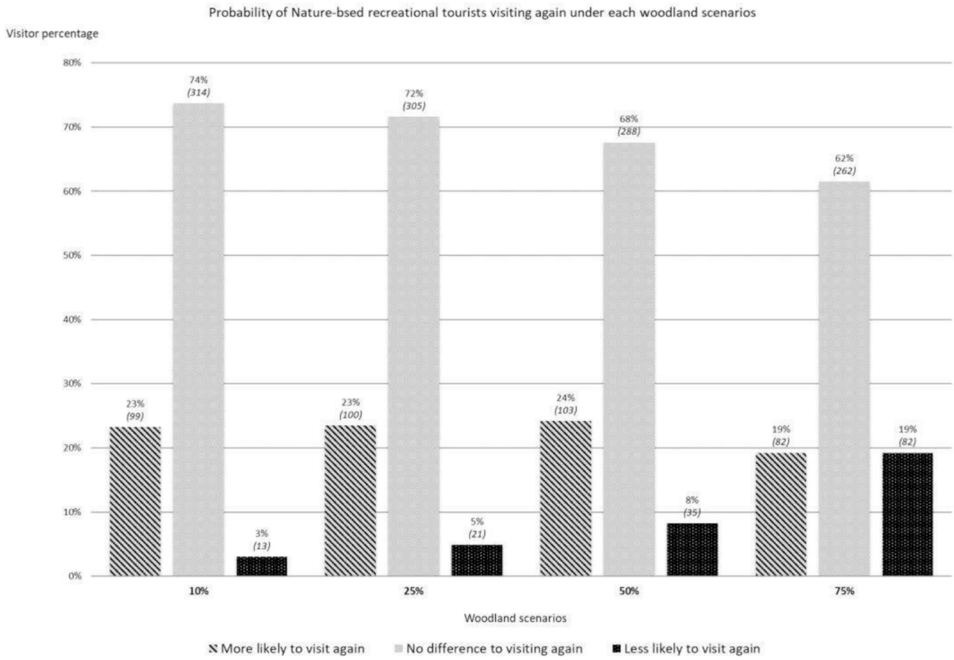

Fig. 5. Percentage of visitors and number of participants (brackets, italics) under each of the woodland scenarios and probability choice for return visits.

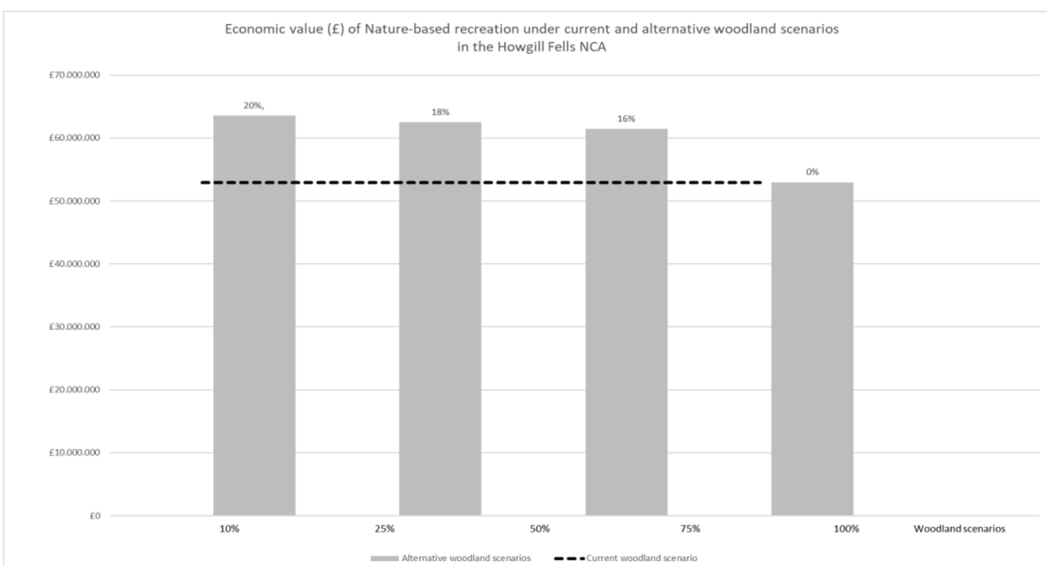

Fig. 6. Economic value of nature-based recreation in the Howgill Fells NCA under each of the woodland scenarios (grey columns) and current state with the green line. The percentage labels above columns indicate percentage change from current state.

differences with the total capacity ratio values (which also include water bodies and floodplains).

3.5. Summary

An assessment of ecosystem services for the Howgill Fells NCA was carried out under the guidelines of the TESSA ecosystem service assessment toolkit. This assessment focused on the pertinent ecosystem services provided by the NCA to society, as informed by key stakeholders and literature and impacts on these ecosystem services under four pre-designed woodland creation scenarios of 10 %, 25 %, 50 % and 75 % woodland cover. Fig. 8 illustrates the societal consequences that can be expected to occur under each of the woodland creation scenarios. By using the above four indicators, the greatest changes in ecosystem services provided by the NCA are found with the higher woodland creation scenario, due to cultivated goods showing the largest decrease (76 %) in cultivated goods (livestock production). Furthermore, at the 75 % scenario level there are no benefits to nature-based recreational tourism, as this experiences no increase from the current state. Large benefits in terms of an increase (carbon storage = 97 %, GHG flux = 251 %) would be expected from climate regulating services, as a result of the substantial increase in woodland cover and therefore a larger capacity for carbon storage and the reduction of GHG emissions. Additionally, water-related services for flood risk prevention would be improved by the higher scenarios.

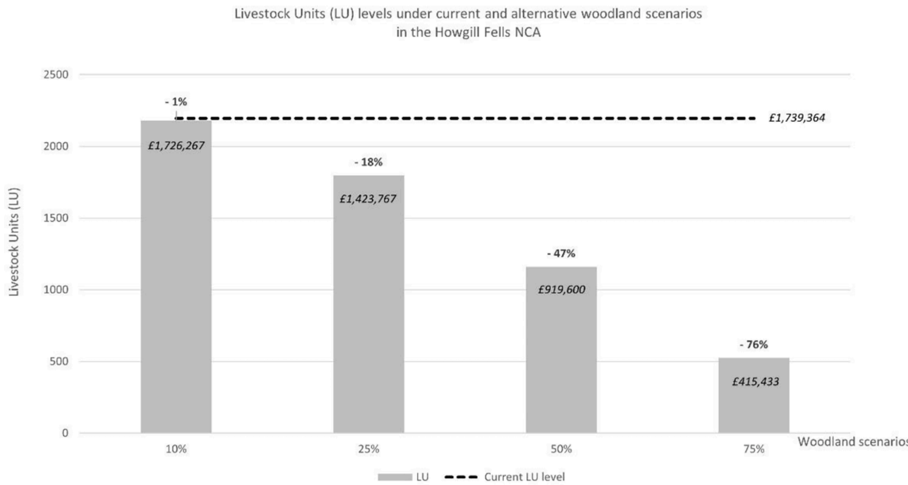

Fig. 7. Livestock units and economic value of cultivated goods in study site as livestock units (LU) under the current state and alternative woodland creation scenarios. The dotted line illustrates the current level of stocking rates the NCA could sustain as a maximum. The economic net profit margin value of the cultivated goods is displayed in italic.

Table 3
Mean total water storage increase and total and green capacity storage ratios for baseline and scenarios over the Howgill Fells Natural Character Area.

	Total water storage increase (km^3)	Total capacity storage ratio (km^3/km^3)	% change from baseline	Total green capacity storage ratio (km^3/km^3)
Baseline		12.010		12.0494
10 %	0.009460	10.308	−14.2	10.333
25 %	0.023650	9.659	−19.6	9.675
50 %	0.04724	9.258	−22.9	9.268
75 %	0.091223	9.0539	−24.6	9.0622

4. Discussion

Assessing changes to ES caused by changes in land use is complicated when assessment is required on a site-specific level. Our study does have its limitations, mainly due to the rapid assessment approach of TESSA. A site-specific assessment was carried out in the Howgill Fells NCA, by the use of a rapid ES assessment toolkit, TESSA. It is important to note that TESSA is a method that aims to assess ES site-specifically and 'rapidly', i.e., allowing users to carry out an assessment with limited resources. Finding a balance between obtaining and analysing dependable and good site-specific quality data, whilst keeping the assessment 'rapid' is, however, very challenging. For this study, this meant that more time was used on developing methods, gathering data and analysing than the TESSA guidelines suggest. The combination of using field-specific primary data, value-transfer secondary data from previous studies and expert opinion allowed the assessment to become site-specific and the results are therefore pertinent to the NCA. Due to the representative nature of the study site, the results can be used to a large extent to aid understanding of similar circumstances across upland Cumbria. They also provide a model which, with small adjustments of site-specific data, can be applied on a larger scale to upland areas and be used to aid assessments of the impacts of woodland creation schemes nationally.

TESSA recommends a collaborative approach of engaging with stakeholders for site-specific advice and information throughout the process, which has been very beneficial from start to finish in this study. Stakeholders, such as farmers, land managers and local representatives from governmental departments have taken part in providing information and advice on local conditions and approaches. This addresses the need for site-specific ES assessment and makes the results relevant and informative to local stakeholders. In addition, it should be noted that attitudes and opinions on the subject of woodland creation, as well as the willingness to engage with the research, changed within the group of stakeholders as time and the research progressed. Collaboration between scientists and a wide range of stakeholders are documented as being beneficial (de Vente et al., 2016; Pocock et al., 2017) and may influence long-term thinking on the topic of changes in land use.

The climate regulation assessment in this study quantifies how a change in land-use in the Howgill Fells NCA from grazed grassland to woodland would aid climate regulation by increasing carbon storage and GHG sequestration rates. On a local scale, these results address the need for climate mitigation evidence, which was raised by stakeholders and has been highlighted by IPCC. Moreover, the results are useful for informing local stakeholders participating in woodland creation carbon off-setting schemes and local commitments for reducing carbon emissions in line with UK climate change act targets.

The climate regulation results suggest that both carbon storage and sequestration would gradually increase in correspondence with the escalation of woodland creation scenarios. Our results fall within the range of estimation identified by Morison *et al.* (2012) but are slightly higher than the UK average estimated by Broadmeadow & Mathews (2003). The higher values from our study may be explained by the large amount of old mature trees within the NCA, which store a substantial amount of carbon. Within the grassland category our study provides similar values to the Hagon et al. (2013) study. A slightly higher value was derived from our study and may be explained by the large volume of grass found in the predominantly rough, low-productivity and acid grassland in the Howgill Fells NCA.

The total estimation of the Greenhouse gas (GHG) flux in the current state of the NCA and the four woodland creation scenarios indicates that the NCA would have an increasingly positive impact on climate change mitigation with increasing woodland cover. The values derived for our study are from a combination of primary and secondary data and the carbon storage and GHG sequestration values therefore offer a useful model for further research and estimates in woodland and grassland habitats in upland areas of England. These values are, however, area and woodland/grass-type specific, which is the strength and benefit from a site-specific assessment. These values will only be accurate for similar sites in this area, as soil, climate, species and growing conditions will differ elsewhere (Pearson et al., 2013; Morrison et al., 2012; Hagon et al., 2013; Vanquelova *et al.* 2013). Our results are, however, further validated by similar results being found well with results from woodlands in the nearby Lake District National Park Greig (2012). Our results also indicated a larger amount of CO_2 being sequestered in the coniferous woodland compared to broadleaved. This can be explained by the

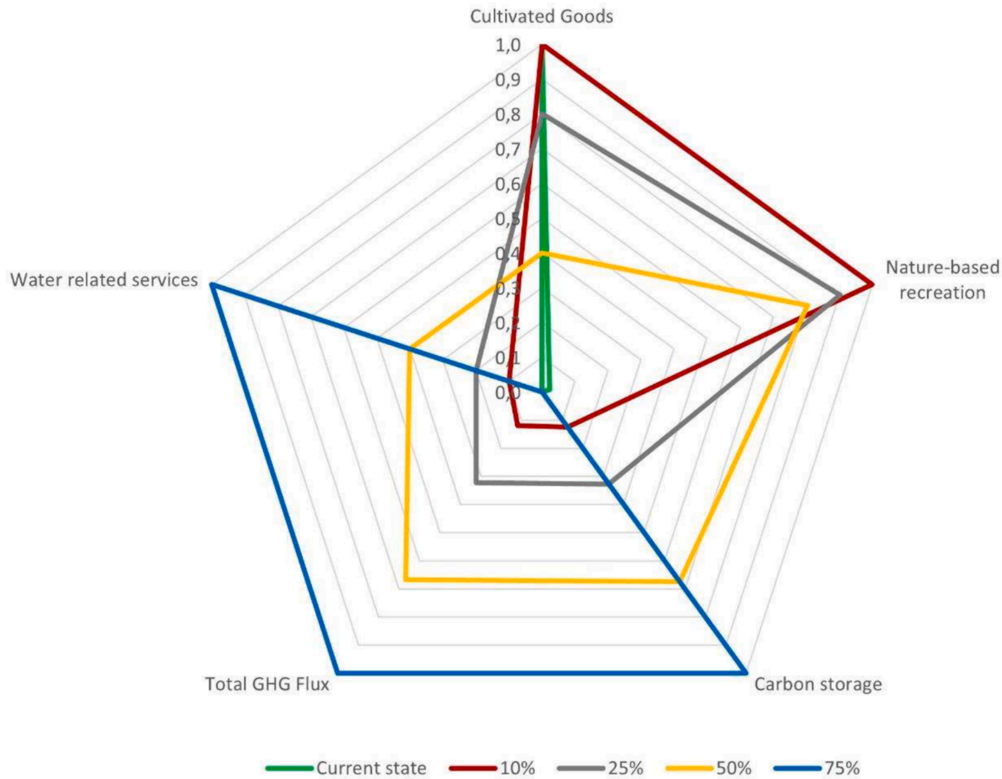

Fig. 8. Societal consequences expected under the alternative woodland scenarios using a normalised scale (0–1), based on the summary of the four ecosystem service indicators; climate (total GHG flux), water-related services regulation (total capacity storage ratio (km3/km3), nature-based recreation (£) and cultivated goods (LU). This normalised scale provides an understanding for the expected overall impacts from change in land use.

age of the tree. Most of the coniferous woodlands within the NCA are of a similar age (40–80 years), which is the stage in a tree's lifespan where they sequester at the highest rate.

Our method of assessing Nature-based recreation (NBR) within the NCA using a survey with a convenience intercept sampling approach was beneficial. It allowed us to focus on NBR participants who were visiting this area specifically. By using site-specific data obtained from the local tourist centre and combining it with Cumbria Tourism data, we were able to make an economic assessment that is meaningful to the local area directly, but it does have its limitations. Firstly, the calculations carried out used a value of £167 per person per trip, which was informed by Cumbria Tourism data. This is under the assumption of only 1 visit per year from that person. The information derived from the data collection suggested that most visitors visit the Howgill Fells NCA 1–2 times a year (45 %), but that 18 % visit 3–5 times a year and 15 % >5 times a year. Additionally, 23 % indicated that they had visited in the past, but not on a regular yearly visiting pattern. Therefore, the derived value can be observed as being conservative. The reason behind using the value as it stands is that it was unclear from the information collected on return visits as to whether the visits are day visits and/or include accommodation. Therefore, the data from Cumbria Tourism (2015) was deemed more accurate, but nonetheless a conservative estimate.

Previous research by Hardaker et al., 2020 showed that broadleaved and mixed woodland in the Wales uplands delivers the highest level of public ES, compared to agricultural land use. Our results support these findings and furthermore add insights to the value of NBS as a cultural ecosystem service, which was not included in the Hardaker et al., 2020 study. The assessment has shown that NBR visitors to the Howgill Fells NCA offer a substantial economic value to the area, in its current state. It furthermore suggests that increasing woodland areas within the study area, would, up to a point of 75 % woodland coverage, be beneficial to the local economy. If local planning authorities and tourist boards are concerned about loss of tourism revenue caused by changes in land-management in the landscape (Iversen 2020), then it is important to address such concerns by using data obtained from the visitors in question and not a large broad data set, which includes the general public, residents or even tourists visiting for alternative reasons than NBR. Such evidence has now been provided by our study.

Global studies have contributed to the understanding of the relationship between woodlands and water-related services (Marion et al., 2014; Wehr et al., 2016; Nóbrega et al., 2018; Solek & Resh, 2018; Gunnell et al., 2019), but implementing this knowledge and contextualizing to a specific case or area of interest is difficult, as demonstrated by Stratford et al. (2017) and Chandler *et al.* (2017).The latter study compared the impacts of land use and tree species on surface runoff and concluded that different tree species can create large differences in soil hydraulic properties, but also that, *"the influence of land use can mask the influence of trees. The choice of tree species may therefore be less important than forest land use for mitigating the effects of surface runoff"*. Gunnell et al., 2019 investigated the use of the WaterWorld flood risk assessment method to better understand the dynamics of natural infrastructure and their role in alleviating flood risk by storage capacity and surface run-off, in the context of climate change and its flood risk impacts on urban areas. They concluded that natural storage (canopy cover and soil storage) on a catchment level has an important role in preventing floods. Increasing our knowledge of methods and tools to assess the impacts of water-related services using nature-based solutions such as woodland creation on a landscape scale, would be of substantial value to stakeholders, beneficiaries, and policy decision makers, when identifying priority areas for creating new woodlands.

The water-regulation assessment showed us that the NCA is an area which is highly sensitive to flooding. The area will always be at risk of flooding due to its topography and climate. However, the results shows, that increasing of trees on the hills would lower this risk which, in addition to other natural flood management measures, would be expected to have beneficial impacts. In terms of assessing flood mitigation, WaterWorld being a water resource model is unable to assess the characteristics of peak/low flows and the resulting data should therefore be viewed with caution. Further to this, this assessment was carried out on an area of increasing forest cover over previously grazed grassland which has an impact on water quantity. There are other important factors to consider for such an assessment that are not covered in the WaterWorld Policy Support System, such as hydrological roughness. Hydrological roughness techniques, such as leaky woody debris (LWD), are increasingly being installed and trialled in upland catchments. Whilst they are not currently in use at the Howgill Fells NCA study site used here, evidence from such trials suggests that forests would help increase water storage and slow peak flows at the lower ends of catchments. Therefore, it would be reasonable to assume that such measurements would highlight areas of afforestation that will aid in mitigating floods in other areas. However, how the current planting would impact water balance on a much more localised scale within each planting compartment and the nearby stream is not within the capabilities of WaterWorld and not possible to do without long-term monitoring and data collection from the field (Stratford et al., 2017).

The assessment for the Howgill Fells NCA included grazed land on mainly common land areas, which is typical of grazing in upland Cumbria (Haley & Scott 2015). This assessment provides insight into the value of livestock production in upland areas of Cumbria without the public support from agricultural and environmental subsidies and grants. Our results demonstrate how livestock numbers within the area would decrease under each scenario. This is useful information for the farmers within the area, as discussions are currently taking place between stakeholders regarding the extent of common land areas to be planted with trees.

We have not considered the impact of forest expansion on biodiversity in the landscape, which is a topical and important question in landscape management. Woodland creation in upland open landscapes would likely change the biodiversity dynamics it would support. For example, some woodland bird species are likely to benefit (Douglas et al., 2020), while species that nest on open ground may be negatively affected (Amar et al., 2011). Considerations of the impact on biodiversity may introduce constraints on where trees may be planted (e.g. Defra guidance), while changes to biodiversity could plausibly affect the number of visitors to an area. However, both of these considerations were outside the scope of this rapid assessment to indicate potential changes to ecosystem services.

4.1. *Which scenario is "best"?*

At the lowest woodland creation scenario of 10 % there is little detrimental impact to changes from the current state. The results suggest that the least divisive compromise may be reached in this scenario, and the highest levels of services would be expected to be delivered by 1. nature-based tourism would be at its highest positive outcome. This may, in addition to providing a service to society, be of interest to hill farmers seeking to diversify and offer an opportunity for extra income. And 2. Cultivated goods (livestock production) would remain unaffected. Climate-regulation and water-related services would in this scenario deliver modest beneficial inputs, but still positively, compared to the current state of the NCA. The 25 % scenario delivers a similar outcome to the 10 % scenario, albeit with slight increases/decrease on all indicators.

The levels of ES delivery changes noticeably by the 50 % woodland scenario. A substantially large amount of carbon could potentially be stored and GHG sequestrated, with benefits mitigating climate change. In addition, flood risk would be lowered at a more moderate level and nature-based tourism would at this level deliver a similar level of service, as it currently does under the current state of the NCA. However, cultivated goods as an ES would decrease with 47 %. This may be interpreted as equally a benefit and adverse output, as there would potentially be less livestock production, which leads to less reliance on public payments for agricultural subsidies. However, less livestock could have an impact socially and economically on locals who farm in this area and on the area's cultural identity. The many and large ES benefits delivered at this 50 % scenario, would mean that the livestock levels currently within the study area would be nearly halved.

At the highest scenario of woodland creation (75 %), the ES benefits on most of the indicators stops. This scenario delivers the highest level of benefits to climate and flood risk mitigation. But it would be at the cost of very low levels of cultivated goods production and nature-based recreation would revert back to similar levels in the current state.

The result of this study gives an objective insight into the societal consequences that would be expected to occur under each scenario and based on the four ES indicators. Stakeholders have been involved throughout the process of the study and results have been disseminated to involved parties. The study has not, however, included a formal assessment of their viewpoint on the results, which may have added interesting insights on what scenario may have been perceived as "best" according to them, but this was not within the remit of the study. It is recommended for future research to do so.

5. Conclusion

This study, using the TESSA rapid ecosystem service assessment has shown, with consideration to the caveats described above, to be a useful tool in the site-specific assessment of ecosystem services in the uplands of Cumbria. Concerns regarding uncertain impacts caused by changes in land use can act as a barrier for woodland creation in Cumbria and the results obtained from our study therefore help overcome this barrier, by providing quantifiable evidence for what could be expected.

The results suggest that the woodland creation scenario of 10 % would be the least divisive scenario, as minor benefits would be experienced at the climate and flood risk mitigation indicators and high benefits experienced regarding cultivated goods and nature-based recreation. Nevertheless, the 50 % scenario provides substantial overall benefits to society due to delivering high levels of both climate and flood risk mitigation and nature-based recreational activities. It does, however, come at the cost of decreasing livestock levels on the hills with 47 %. Nonetheless, based on our result, we put forward that the 50 % scenario provides the best overall ES benefits to society.

In a time where every parcel of land is evaluated for its usage, relevance, and resources, being able to assess the impact of changes in land use and management decisions is important. Society is increasingly exposed to the realities of climate change and the increasing demands on natural resources. This is driven by societal needs. We have added to the knowledgebase on site-specific methods that can be used to estimate and quantify ecosystem services in relation to woodland creation in upland areas. The data used has been obtained locally and is therefore useful for future upland ecosystem service assessments. Changes must be initiated locally, to be able to facilitate global change, which can only happen if the outcomes and impacts of changes are understood.

Funding source information

This work was supported by the Forestry Commission, UK (Grant number CFS 7/16) and the University of Cumbria, UK. Further funding and support was provided by SustainScapes – Center for Sustainable Landscapes under Global Change (grant NNF20OC0059595).The funders had no role in the study design, data collection and analysis, decision to publish, or preparation of the manuscript.

Data.

The data that support the findings of this study are available from the corresponding author, [author initials], upon reasonable request.

CRediT authorship contribution statement

Sara V. Iversen: . **Michael A. MacDonald:** Conceptualization, Formal analysis, Methodology, Supervision, Validation, Writing –

original draft, Writing – review & editing. **Naomi van der Velden:** Writing – original draft, Writing – review & editing, Supervision. **Arnout van Soesbergen:** Data curation, Formal analysis, Investigation, Methodology, Software, Validation, Writing – original draft, Writing – review & editing. **Ian Convery:** Conceptualization, Funding acquisition, Project administration, Supervision, Writing – original draft, Writing – review & editing. **Lois Mansfield:** Supervision. **Claire D.S. Holt:** .

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Sara V. Iversen reports financial support was provided by Forestry Commission.Further funding and support was provided by SustainScapes – Center for Sustainable Landscapes under Global Change at Aarhus University, Denmark

Data availability

Data will be made available on request.

Acknowledgments

This study was only possible due to the many people involved in this study, aside from the author's team, the many participants and collaborators. We thank all the farmers from the Howgill Fells NCA farming community for their time, knowledge sharing and conversations. A special thank you also goes to Pete Leeson, from the Woodland Trust, for all his dedication and knowledge on all things related to trees in upland environments, as well as facilitating contacts and patiently answering questions. Many others have offered guidance, reflections and help, but a special thank you goes to especially Keith Jones from Forestry Commission England, Timothy Nicholsen from Natural England, James Steele from Newcastle University and Tim Pearson from Winrock International. We are very grateful for your help.

Appendix

Scoping study participant list.

Details of scoping study participants (key stakeholders) and advisors, which took part in developing current and alternative scenarios.

Participant ID	Profession	Interview details
P1	Director – Cumbria Woodlands	15/12/14 – Meeting
P2	Senior Conservation Officer	15/12/14 – Meeting
P3	Managing Director –Cumbria Farmers Network	15/01/15 – Meeting
P4	Woodland officer – Forestry Commission	11/01/15 – Meeting
P5	Woodland officer – United Utilities	11/2/15 – Meeting
P6	National Park Lead strategy advisor	18/02/15 – Meeting
P7	Area Director – Forestry Commission	31/03/15 – Meeting
P8	Senior Conservation Officer – RSPB	12/02/15 – Meeting
P9	Partnership Manager – Woodland Trust	31/03/15 – Meeting
P10	Lead advisor – Natural England	04/04/15 – Meeting
P11	Lune Rivers Trust	20/03/15 – Meeting
P12	Woodland inspirations ltd. – Woodland consultant	17/12/15 – Meeting
P13	Director – Forest Carbon	26/03/15 – Phone meeting
P14	Director – Cumbria Farm Environment Partnership	31/02/15 – Meeting
P15	Academic	03/03/15 – Meeting

Detailed methods.

Climate regulated services

The NCA contributes to climate regulation by carbon storage in the vegetation and soil and emissions of greenhouse gas (GHG). Carbon storage is also provided by the peaty soils of the area (40 % of the area), although only 10 % of the 40 % are deemed to be storing a large amount of carbon in blanket bog, due to the challenging steep terrain and shallow soils (NE 2014). Emissions of GHG are likely to occur over the organic soils due to drainage (Alonso et al., 2012). The pastoral grazing of primarily sheep, cattle and horses, contribute to GHG emissions in the form of Methane (CH_4) (Le Mer & Roger, 2001; Richmond et al., 2015). Although most of the grazed fields are not improved, the lower slopes are being fertilised and, as a result, Nitrous oxide (N_2O) emissions will occur (Richmond et al., 2015).

The climate change regulation within the NCA were assessed following TESSA guidance focusing on the three factors that influence climate regulation: 1) changes in above and below-ground carbon storage in plant biomass, dead organic matter and soil; 2) changes in carbon sequestration; and 3) annual greenhouse gas fluxes. A comparison was then made between the current state and the four alternative scenarios. Carbon storage and GHG fluxes were analysed within broad habitat categories: broadleaved woodland, coniferous woodland, grassland, bog and "other" (inland rock, fresh water and buildt up areas) (Table 1). All grassland types (acid grassland, dwarf shrub heath, improved grassland, montane habitats and rough low-productivity grassland) were combined due to similar qualities in carbon storage, sequestration and GHG flux (Hagon et al., 2013).

Carbon storage.

For each category, carbon stocks in above-ground biomass (AGB), below-ground biomass (BGB), and soil were calculated following protocols recommended in TESSA. Total carbon stocks were then calculated by multiplying ($t/C/ha^{-1}$) by habitat area.

AGB carbon storage estimates for grassland were calculated by sampling protocol of Den Holland (2008) and Peh *et al.* (2014) using ten randomly located 1 m^2 sampling plots. All vegetation within each sampling plot was clipped as close to the ground as possible, but without cutting stem base, corms or roots (Den Holland (2008). Samples were oven-dried and converted from 'fresh weight' to dry biomass per hectare (t/ha) using conversion factors established by den Hollander (2008). Above-ground carbon was assumed to be 47 % of the total dry biomass (Eggleston et al., 2006).

AGB carbon stocks in woodland habitats were estimated by sampling 100 x 5 m transects (n = 9 (conifors) and n = 15 (broadleaved). The sample size was guided by Verplanke and Zahabu (2009). Measurements of tree diameter at breast height and species were used to determine AGB, which was converted into carbon for each transect using regression equations. Litter carbon stocks were calculated using IPCC Tier 1 values (Peh et al., 2013) and added to the total carbon stored in AGB.

Below-ground estimates of carbon storage in grassland were based on estimates by Anderson-Teixerira & DeLucia (2010) of 14 t dry matter/ha. This was then multiplied by the carbon value of 0.47 (Peh et al., 2013). In woodland habitats, BGB carbon stocks were similarly calculated using IPCC conversion factors of 0.23 using the category "other broadleaf above-ground biomass" 75–150 t/ha-^{1} and conversion factor 0.29 using the category of "conifers above-ground biomass" 50–150 t/ha-^{1} (Mokany *et al.* 2013). Soil carbon storage estimates were guided by Hagon *et al.*(2012), who carried out a review of current literature on carbon stored in the soil of various habitats specific to the Cumbrian uplands and concluded a mean value for each habitat. The tree planting in the NCA is not being carried out on the bog habitats and thus the carbon stock and sequestration values remain a constant value and will not be affected by the planting. The bog habitats do, however, add to the total carbon stock and sequestration value of the study area and therefore remain relevant.

Greenhouse gas fluxes.

Carbon sequestration in bog habitat was estimated following TESSA protocol (Peh et al., 2013) and (Nieveen et al., 2005), whereby carbon sequestration rates in woodland habitats was calculated by using the Forestry Commission Woodland Carbon Code (WCC) (West & Mathews 2012). Species and spacing variables were collected in the field and management technique estimates were obtained by questioning landowners and forestry officers. Yield data were obtained using the Forest Research Ecological Site Classification (ESC), as recommended by WCC (West & Matthews, 2012). In grassland habitats, carbon sequestration was estimated using a UK specific average grassland estimate derived by De Deyn *et al.* (2010) of −2.20 t/C/ha^{-1} and a further total area carbon sequestration value was calculated. For both woodland and grassland habitats, the total amount of annual sequestration was calculated for each alternative scenario by using the mean t/CO_2/ha^{-1}/y^{-1} derived from each habitat category and applied to the change in area size for each category. For the woodland habitats, mean sequestration rate for broadleaves only were used, as only broadleaved woodlands are planted as part of the alternative scenarios.

Annual CO_2 emissions were calculated using IPCC (2006) tier 1 annual emission factors (0.25) for drained organic soil in temperate grassland dominated habitats, and with consideration to locations of planting on grassland and future woodland management techniques. CO_2 emissions from mineral soil and soil without disturbance was deemed insignificant (Peh et al., 2013). Drained organic soil within the study site was identified using Soilscape (Institute 2016) and by interviewing Natural England representatives.

IPCC tier 1 emission factors (IPCC, 2021) and the 2013 Defra Agricultural Statistics for Howgills NCA were used to estimate Methane (CH_4) emissions. Livestock levels taken from the 2013 Defra agricultural statistics of the current and alternative states of the Howgills NCA indicates grazing stock levels of: Cattle − 693, Sheep − 26,354. Very ponies and few wild grazers have been observed in the areas and have therefore been omitted.

Nitrous oxide (N_2O) emissions were estimated using National Atmospheric Emissions Inventory (NAEI) data. The NAEI data is substantial and provide an online mapping tool for UK emission data from the agricultural sector, which is derived and modelled from the 2014 Agricultural Census for the UK and combined with emission factors for livestock, fertilizer use and CEH Land Cover Map 2007 (Dore et al., 2016). By selecting the area of interest (Howgills NCA), total emissions per year is obtained in tonnes of N_2O. N_2O emissions remain constant between the current and alternative scenarios, as no trees will be planted on the improved grassland on the lower slopes. CO_2, CH_4 and N_2O were converted to Global Warming Potential (GWP) in CO_2eq. and the annual flux of GHG was calculated by combining the GHG emissions with the carbon sequestration.

Equations used.

Equation ID & reference	Purpose	Equation	Scaling coefficients
1 (Verplanke & Zahabu, 2009**)**	Above-ground carbon stock – woodland habitats.Determining number of sampling plots needed in woodland habitats	$n = \frac{(Nxs)^2}{\frac{N^2xE^2}{t^2} + Nxs^2}$	n = number of plots requiredN = total area in ha, divided by 0.05 ha (area of the plot)S = standard of deviation of the mean carbon stockE = mean carbon stock (from preliminary 9 plots), multiplied by the desired precision at 0.1 (10 %)t = sample statistics, t-distribution 95 % confidence levels, set at 2
2 (Muukkonen, 2007**)**	Above-ground biomass estimates for Sitka spruce (*Picea sitchensis*), Norway spruce (*Picea abies*), Scots pine (*Pinus sylvestris*), Beech (*Fugus sylvatica*) and Oak (Both Quercus robur and *petraea*)	$Biomass = Exp(\beta_0 + \beta_1)x\frac{dbh}{dbh + \beta_2}$	Species: $\beta_0 \beta_0$ $\beta_1 \beta_2$ *Picea abies* −1.694 10.825 11.816*Pinus sylvestris* −2.688 10.745 8.062*Quercus* spp. −0.604 10.677 15.900*Fagus spp.* 0.006 10.933 21.216
3 (Jenkins et al., 2011**)**	Above-ground biomass estimates for Larch (*Latrix decidua*)	$Biomass = Exp(-2.0336 + 2.2592xLndbh)$	
4 (Brown et al., 1997**)**	Above-ground biomass estimates for general hardwood – used for any hardwood species where species specific equations were not obtainable	$Biomass = 0.5 + \frac{(25,000xdbh^{2.5})}{(dbh^{2.5}x246,872)}$	
5 (Anderson-Teixeira and DeLucia, 2011**)**	**Below-ground carbon stock − Grassland**	$Bg_{carbon} = (area(ha)x14)x0.47$	**Where:**Bg_{carbon} Bg_{carbon} is Below-ground carbon
6 (Mokany et al., 2006**)**	Below-ground carbon stock − Woodland	$Bg_{carbon}(t) = (totalabovegroundbiomass(t)xconversionfactorx0.5$	Where:Bg_{carbon} Bg_{carbon} is Below-ground carbonIPCC conversion factors:Other broadleaf above-ground biomass 75–150 t/ha-$^{1.}$ = 0.23conifers above-ground biomass 50–150 t/ha-^{1} = 0.29
7 (Nieveen et al., 2005**)**	Carbon sequestration in bog habitat estimates	$C_{seg} = ((latitudex0.0436) - 2.7302)xsitearea(ha)$	Where:C_{seg} C_{seg} is carbon tonnes per year sequestered in the bog

(*continued on next page*)

(*continued*)

Equation ID & reference	Purpose	Equation	Scaling coefficients
8 IPCC, 2021	CO_2 emisions in organic soil	$tC/ha/y^{-1} = areainhaxemissionfactor$	IPCC emission factor:Drained organic soil in grassland dominated habitats in cold temperate regions −0.25
9 IPCC, 2021	CH^4 emissions for cattle and sheep	$CH^4 emissions = EF_{(t)} x \frac{(N(_t)}{1000}$	Where:$EF_{(t)}$ is emissions factor for that specific species population (cattle = 57, Sheep = 8), kg $CH^4 head^{-1} y^{-y} N_{(t)}$ is number of animals of specific species on site

References

Alonso, I., Weston, K., Gregg, R., Morecroft. 2012. Carbon storage by habitat - Review of the evidence of the impacts of management decisions and condition on carbon stores and sources., Natural England Research Reports - Number NERR043.

Amar, A., Grant, M., Buchanan, G., Sim, I., Wilson, J., Pearce-Higgins, J.W., Redpath, S., 2011. Exploring the relationships between wader declines and current land-use in the British uplands. Bird Study 58, 13–26.

Anderson-Teixeira, K.J., DeLucia, E.H., 2011. The greenhouse gas value of ecosystems. Glob. Chang. Biol. 17, 425–438.

Baral, H., Guariguata, M.R., Keenan, R.J., 2016. A proposed framework for assessing ecosystem goods and services from planted forests. Ecosyst. Serv. 22, 260–268.

Birch, J.C., Thapa, I., Balmford, A., Bradbury, R.B., Brown, C., Butchart, S.H.M., Gurung, H., Hughes, F.M.R., Mulligan, M., Pandeya, B., Peh, K.S.H., Stattersfield, A. J., Walpole, M., Thomas, D.H.L., 2014. What benefits do community forests provide, and to whom? A rapid assessment of ecosystem services from a Himalayan forest, Nepal. Ecosystem Services 8, 118–127.

Blaen, P.J., MacDonald, M.A., Bradbury, R.B., 2016. Ecosystem services provided by a former gravel extraction site in the UK under two contrasting restoration states. Conserv. Soc. 14 (1), 48–56.

Boeije, H., 2002. A purposeful approach to the constant comparative method in the analysis of qualitative interviews. Qual. Quant. 36, 391–409.

Bradbury, R.B., Butchart, S.H., Fisher, B., Hughes, F.M., Ingwall-King, L., MacDonald, M. A., Merriman, J.C., Peh, K.S.H., Pellier, A.S., Thomas, D.H., Trevelyan, R., 2021. The economic consequences of conserving or restoring sites for nature. Nat. Sustainability 4 (7), 602–608.

Broadmeadow, M., 2003. Forests, carbon and climate change: the UK contribution. Forestry Commission Information Note 48, 1–12.

Broadmeadow, S., Nisbet, T., 2010a. Opportunity Mapping for Woodland Creation to Reduce Diffuse Sediment and Phosphate Pollution in the Lake District. Farnham, Surrey, UK.

Broadmeadow, S., Nisbet, T., 2010b. Opportunity Mapping for Woodland to Reduce Flooding in the River Derwent, Cumbria. Forest Research, Farnham, Surrey, UK.

Brockerhoff, E.G., Barbaro, L., Castagneyrol, B., Forrester, D.I., Gardiner, B., González-Olabarria, J.R., Lyver, P.O.B., Meurisse, N., Oxbrough, A., Taki, H., 2017. Forest biodiversity, ecosystem functioning and the provision of ecosystem services. Springer.

Brown, S., Schroeder, P., Birdsey, R., 1997. Aboveground biomass distribution of US eastern hardwood forests and the use of large trees as an indicator of forest development. For. Ecol. Manage. 96 (1–2), 37–47.

Bunce, R.G., Wood, C.M., Smart, S.M., Oakley, R., Browning, G., Daniels, M.J., Ashmole, P., Cresswell, J., Holl, K., 2014. The landscape ecological impact of afforestation on the British uplands and some initiatives to restore native woodland cover. Journal of Landscape Ecology 7, 5–24.

Chandler, K., Stevens, C., Binley, A., Keith, A., 2018. Influence of tree species and forest land use on soil hydraulic conductivity and implications for surface runoff generation. Geoderma 310, 120–127.

Clarke, S.J., Harlow, J., Scott, A., Phillips, M., 2015. Valuing the ecosystem service changes from catchment restoration: A practical example from upland England. Ecosyst. Serv. 15, 93–102.

de Groot, R., Brander, L., van der Ploeg, S., Costanza, R., Bernard, F., Braat, L., Christie, M., Crossman, N., Ghermandi, A., Hein, L., 2012. Global estimates of the value of ecosystems and their services in monetary units. Ecosyst. Serv. 1, 50–61.

de Vente, J., Reed, M.S., Stringer, L.C., Valente, S., Newig, J., 2016. How does the context and design of participatory decision making processes affect their outcomes? Evidence from sustainable land management in global drylands. Ecology and Society 21.

DEFRA. 2021. Environmental Land Management Schemes. UK.

den Hollander, H., 2008. Precipitation influence on savanna vegetation: Cover, biomass, leaf area index and C3: C4 ratio. Wageningen University, Holland. MS thesis.

Dore, A., Reis, S., Oxley, T., ApSimon, H., Hall, J., Vieno, M., Kryza, M., Green, C., Tsagatakis, I., Tang, S. 2016. Calculation of Source-Receptor Matrices for Use in an Integrated Assessment Model and Assessment of Impacts on Natural Ecosystems. Pages 107-112. Air Pollution Modeling and its Application XXIV. Springer.

Douglas, D.J.T., Groom, J.D., Scridel, D., 2020. Benefits and costs of native reforestation for breeding songbirds in temperate uplands. Biol. Conserv. 244, 108483.

Eggleston, S., Buendia, L., Miwa, K., Ngara, T., Tanabe, K., 2006. 2006 IPCC guidelines for national greenhouse gas inventories. Institute for Global Environmental Strategies Hayama, Japan.

FitzGerald, O., Collins, C.M., Potter, C., 2021. Woodland Expansion in Upland National Parks: An Analysis of Stakeholder Views and Understanding in the Dartmoor National Park. *UK*. Land 10, 270.

Garner, G., Hannah, D.M., Watts, G., 2017. Climate change and water in the UK: Recent scientific evidence for past and future change. Prog. Phys. Geogr. 41, 154–170.

Glaser, B.G., 1965. The constant comparative method of qualitative analysis. Soc. Probl. 12, 436–445.

Greig, S. Woodlands and Carbon in the Lake District National Park. Sandwood Enterprise, UK. https://www.yumpu.com/en/document/read/24767531/forest-carbon-account-presentation-pdf-lake-district-national- *Accessed 18/2/2016*.

Guerry, A.D., Polasky, S., Lubchenco, J., Chaplin-Kramer, R., Daily, G.C., Griffin, R., Ruckelshaus, M., Bateman, I.J., Duraiappah, A., Elmqvist, T., Feldman, M.W., Folke, C., Hoekstra, J., Kareiva, P.M., Keeler, B.L., Li, S., McKenzie, E., Ouyang, Z., Reyers, B., Ricketts, T.H., Rockstrom, J., Tallis, H., Vira, B., 2015. Natural capital and ecosystem services informing decisions: From promise to practice. Proc. Natl. Acad. Sci. u. s. a. 112, 7348–7355.

Gunnell, K., Mulligan, M., Francis, R.A., Hole, D.G., 2019. Evaluating natural infrastructure for flood management within the watersheds of selected global cities. Sci. Total Environ. 670, 411–424.

Hagon, S., Ottitsch, A., Convery, I., Herbert, A., Leafe, R., Robson, D., Weatherall, A., 2013. Managing land for carbon: a guide for farmers, land managers and advisors. Lake District National Park Authority, England.

Hardaker, A., Pagella, T., Rayment, M., 2020. Integrated assessment, valuation and mapping of ecosystem services and dis-services from upland land use in Wales. Ecosyst. Serv. 43, 101098.

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. Ecosyst. Serv. 48, 101253.

Harvey, D., Scott, C. 2016. Farmbusiness Survey, Hill farming in England. Newcastle University, England.

Hijmans, R.J., Cameron, S.E., Parra, J.L., Jones, P.G., Jarvis, A., 2005. Very high resolution interpolated climate surfaces for global land areas. Int. J. Climatol. 25 (15), 1965–1978.

Holden, J., Haygarth, P.M., Dunn, N., Harris, J., Harris, R.C., Humble, A., Jenkins, A., MacDonald, J., McGonigle, D.F., Meacham, T., 2017. Water quality and UK agriculture: challenges and opportunities. Wiley Interdiscip. Rev. Water 4.

Huq, N., Stubbings, A., 2015. How is the role of ecosystem services considered in local level flood management policies: case study in Cumbria, England. JEAPM 17, 155–173.

Ipcc, 2021. Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press U.

Iversen, S.V., van der Velder, N., Convery, I., Holt, C.D.S., Mansfield, L., 2022. Why understanding stakeholder perspectives and emotions is important in upland woodland creation – a case study from Cumbria. UK. Landuse Policy 114, 105929.

Iversen, S.V., Holt, C.D.S., van der Velder, N., Mansfield, L., Convery, I., Kjeldsen, C., Thorsøe, M.H., 2023. Impacts of woodland planting on nature-based recreational tourism in upland England – a case study. Landsc. Urban Plan. 230, 104587.

Jenkins, T.A., Mackie, E.D., Matthews, R.W., Miller, G., Randle, T.J., White, M.E., 2011. FC woodland carbon code: Carbon assessment protocol. Forestry Commission, Edinburgh.

Le Mer, J., Roger, P., 2001. Production, oxidation, emission and consumption of methane by soils: a review. Eur. J. Soil Biol. 37, 25–50.

MacDonald, M.A., de Ruyck, C., Field, R.H., Bedford, A., Bradbury, R.B., 2020. Benefits of coastal managed realignment for society: Evidence from ecosystem service assessments in two UK regions. Estuar. Coast. Shelf Sci. 244, 105609.

Marion, D.A., Sun, G., Caldwell, P.V., Miniat, C.F., Ouyang, Y., Amatya, D.M., Clinton, B. D., Conrads, P.A., Laird, S.G., Dai, Z., 2014. Managing forest water quantity and quality under climate change. Climate Change Adaptation and Mitigation Management Options. ROUTLEDGE. England, pp. 249–305.

Marshall, M.R., Francis, O.J., Frogbrook, Z.L., Jackson, B.M., McIntyre, N., Reynolds, B., Solloway, I., Wheater, H.S., Chell, J., 2009. The impact of upland land management on flooding: results from an improved pasture hillslope. Hydrol. Process. 23, 464–475.

Mokany, K., Raison, R.J., Prokushkin, A.S., 2006. Critical analysis of root: shoot ratios in terrestrial biomes. Glob. Chang. Biol. 12, 84–96.

Morrison, J., Matthews, R., Miller, G., Perks, M., Randle, T., Vanguelova, E., White, M., Yamulki, S., 2012. Understanding the carbon and greenhouse gas balance of forests in Britain. Forestry Commission Research. Report.

Mulligan, M., 2016. Documentation for the WaterWorld Model V2. www.policysupport.org/waterworld.
Muukkonen, P., 2007. Generalized allometric volume and biomass equations for some tree species in Europe. Eur. J. for. Res. 126, 157–166.
Newing, H., 2011. Conducting research in conservation: social science methods and practice. Routledge, England.
Nieveen, J.P., Campbell, D.I., Schipper, L.A., Blair, I.J., 2005. Carbon exchange of grazed pasture on a drained peat soil. Glob. Chang. Biol. 11, 607–618.
Nóbrega RLB, Lamparter G, Hughes H, Guzha AC, Amorim RSS, Gerold G. 2018. *A multi-approach and multi-scale study on water quantity and quality changes in the Tapajós River basin, Amazon*. Proceedings of the International Association of Hydrological Sciences **377**:3.
Orr, H., Wilby, R., Hedger, M.M., Brown, I., 2008. Climate change in the uplands: a UK perspective on safeguarding regulatory ecosystem services. Climate Res. 37, 77–98.
Pearson T, Walker S, Brown S. 2013. Sourcebook for land use, land-use change and forestry projects. Winrock International and the BioCarbon Fund of the World Bank.
Peh, K.S.H., Balmford, A., Bradbury, R.B., Brown, C., Butchart, S.H.M., Hughes, F.M.R., Stattersfield, A., Thomas, D.H.L., Walpole, M., Bayliss, J., Gowing, D., Jones, J.P.G., Lewis, S.L., Mulligan, M., Pandeya, B., Stratford, C., Thompson, J.R., Turner, K., Vira, B., Willcock, S., Birch, J.C., 2013. TESSA: A toolkit for rapid assessment of ecosystem services at sites of biodiversity conservation importance. Ecosyst. Serv. 5, 51–57.
Pocock, M.J., Tweddle, J.C., Savage, J., Robinson, L.D., Roy, H.E., 2017. The diversity and evolution of ecological and environmental citizen science. PLoS One 12, e0172579.
Reed, M., Bonn, A., Slee, W., Beharry-Borg, N., Birch, J., Brown, I., Burt, T., Chapman, D., Chapman, P., Clay, G., 2009. The future of the uplands. Land Use Policy 26, S204–S216.
Richmond, A., Wylie, A., Laidlaw, A., Lively, F., 2015. Methane emissions from beef cattle grazing on semi-natural upland and improved lowland grasslands. Animal 9, 130–137.
Sing, L., Metzger, M.J., Paterson, J.S., Ray, D., 2017. A review of the effects of forest management intensity on ecosystem services for northern European temperate forests with a focus on the UK. Forestry: an International Journal of Forest Research: 1–14.
Solek, C.W., Resh, V.H., 2018. Water Provision in Chaparral Landscapes: Water Quality and Water Quantity. Valuing Chaparral. Springer, pp. 207–244.
Stratford, C., Miller, J., House, A., Old, G., Acreman, M., Duenas-Lopez, M., Nisbet, T., Burgess-Gamble, L., Chappell, N., Clarke, S., 2017. Do trees in UK-relevant river catchments influence fluvial flood peaks?: a systematic review. NERC Centre for Ecology and Hydrology, Wallingford, UK.
Thapa, I., Butchart, S.H.M., Gurung, H., Stattersfield, A.J., Thomas, D.H.L., Birch, J.C., 2014. Using information on ecosystem services in Nepal to inform biodiversity conservation and local to national decision-making. Oryx 50, 147–155.
Tourism, C., 2015. 2015 Cumbria Visitor Survey. Cumbria Tourism, Penrith, England.
Verplanke, J., Zahabu, E., 2009. A field guide for assessing and monitoring reduced forest degradation and carbon sequestration by local communities: research project Kyoto: think global, act local. ITC.
Wehr, R., Munger, J., McManus, J., Nelson, D., Zahniser, M., Davidson, E., Wofsy, S., Saleska, S., 2016. Seasonality of temperate forest photosynthesis and daytime respiration. Nature 534, 680.
West, V., Matthews, R. 2012. Estimating woodland carbon sequestration from the Carbon Lookup Tables Version 1.4. Forest Commission, England.
Zank, B., Bagstad, K.J., Voigt, B., Villa, F., 2016. Modeling the effects of urban expansion on natural capital stocks and ecosystem service flows: A case study in the Puget Sound, Washington, USA. Landsc. Urban Plan. 149, 31–42.