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Making Way for Trees? Changes in Land-Use, Habitats and Protected Areas in Great Britain under "Global Tree Restoration Potential"

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Abstract: Numerous tree planting initiatives have been launched worldwide, based on the idea that carbon capture by trees can help to limit global warming. A recent study estimated the additional tree canopy cover that could be established given the growing conditions in every square kilometre of land on earth that is not already forested, urbanised, or used for crop production. It reported a total "tree restoration potential" of >900 million ha worldwide and identified hotspots where opportunities for tree planting initiatives may be the greatest. With the potential for an estimated 4.2 million ha of additional canopy cover, one such hotspot is Great Britain. We quantify the extent of habitats, land uses, and protected areas that would be impacted by tree planting on this scale in Great Britain and discuss the potential social–ecological trade-offs involved. Our findings show that realising the "tree restoration potential" would mean a considerable upheaval for the British landscape with 30–50% of ecologically valuable habitats lost and a reduction of 44% in the area of improved grassland. Up to 21% of land protected by law for its ecological, scientific, scenic, or cultural value would be impacted. Importantly, we demonstrate that an alternative approach based on increasing tree canopy cover by up to 20% in urban areas and on cropland could make a substantial contribution to tree planting targets, potentially offsetting losses elsewhere. Such shifts in the structure and function of the British landscape will depend on deep changes in the food system, evidence-based decisions about which existing habitats to protect, and a long-term commitment to tree planting and maintenance.

Keywords: tree restoration; habitats; land use; protected areas; conservation; agroforestry; urban planning

1. Introduction

Photosynthetic carbon capture by trees is increasingly seen as an effective strategy to address the rise of global atmospheric CO_2 concentrations [1–3]. The idea that trees can help to limit global warming has inspired a number of initiatives aimed at promoting forest conservation and tree planting, often under the auspices of "tree restoration". These include the international Bonn Challenge, which aimed to bring 150 million ha of land under tree restoration by 2020 and a further 350 million ha by 2030 [4]. A recent global analysis of "tree restoration potential" by Bastin et al. [5] identified the additional tree canopy cover that could be achieved given the growing conditions in every square kilometre of land on earth, leading to an estimated total storage potential of 205 gigatonnes of carbon.

In their model, Bastin et al. estimated tree restoration potential by first measuring existing tree canopy cover in 78,774 0.5 ha plots using satellite imagery from a representative sample of global protected areas. A machine learning model was then fitted to these estimates using 10 predictor variables reflecting growing conditions (climate, geology, and soils) in the sample locations. The model was used as the basis for predicting potential canopy cover (i.e., tree restoration potential) in every square kilometre of land on earth, excluding urban areas, cropland, and existing forests. Biome-specific coefficients based on a review of empirical studies were used to estimate the carbon storage given the model predictions.

The resulting global maps highlight several hotspots where tree planting efforts could be intensified (e.g., Colombia, Alaska). One such hotspot is Great Britain, where the Bastin et al. model identifies potential for 42,289 km^2 (4.2 million ha) of additional tree canopy cover (Figure 1). This equates to an estimated 6.5 million tonnes of carbon storage under the Bastin et al. model, although others have argued that their calculations may overestimate carbon storage potential by up to 500% [6–8]. Other critics of the model have focused on the limited representation of soil carbon stocks, poor integration of climate change risks, and the omission of localised warming effects of trees at high latitudes and elevations [6–9]. Fewer commentaries have focused on the feasibility of planting trees across the >900 million ha identified in the model [10,11]. To date, there have been no quantitative analyses of the social–ecological consequences of tree restoration on such a large scale. This is despite controversial decisions made in the modelling process by Bastin et al. to exclude cropland and urban areas as candidate areas for tree planting whilst including grazing land.

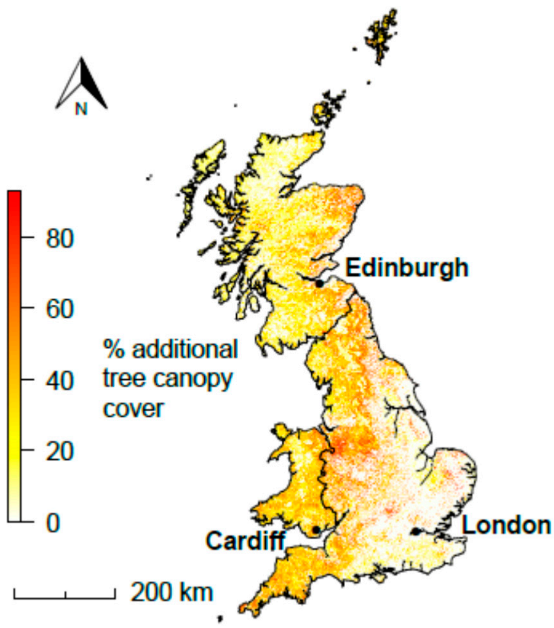

Figure 1. Tree restoration potential in Great Britain. Redrawn from data in [5].

We set out to quantify the habitats, land uses, and protected areas that would be impacted by planting trees in Great Britain according to the predictions of Bastin et al. [5] as a basis for examining social–ecological trade-offs between carbon storage, biodiversity, and food security involved in tree restoration at a landscape scale. We also explored the potential of cropland and urban areas to contribute to tree restoration potential. Whilst our findings are local in extent, our approach represents an efficient framework for evaluating the impact of tree restoration initiatives anywhere in the world.

2. Methods

2.1. Study Area

We limited our analyses to Great Britain (GB), i.e., the mainland of England, Scotland, and Wales, including coastal islands but excluding Northern Ireland, which is also part of the United Kingdom (UK). This was due to the availability of standardised spatial data on habitats and land use, as well as the need to limit the social–ecological scope of the results for interpretation and comparison with previous studies (e.g., [12]). Covering > 228,000 km^2, GB is characterised by a diverse geology, a temperate climate, and predominantly agricultural landscapes. Its population of approximately 65 million is largely urbanised (~80% [13]). The wider UK is among the least forested countries in Europe with 13% forest cover compared to 42% on average across EU Member States [14]. In 2019, the UK government pledged to plant 30 million trees by 2024, a rate of 6 million per year over a 5-year period. Third sector tree planting initiatives are ongoing, including the Woodland Trust target to expand UK woodlands by 35,000 ha per year until 2025 [15]. State-led initiatives include the Forestry Commission's Urban Tree Challenge Fund, which aims to plant at least 130,000 trees in urban areas in England [16].

2.2. Data Analysis

We obtained the global 1 km resolution raster layer of tree restoration potential from [5] and cropped the data to the study area extent. Each pixel value in the raster layer corresponds to the potential additional tree canopy cover (% aerial cover) that could be supported in that grid cell. To represent habitats and land use, we used the 1 km resolution percentage target class version of the Land Cover Map 2015 (LCM2015) for Great Britain [17]. The raster data contain 21 bands, with each band corresponding to a land cover class. Pixel values in each band quantify the percentage cover of the corresponding land cover class in that grid cell. We split the bands into two sets (Table 1). Set 1 incorporated land cover classes considered suitable for tree restoration under the approach of Bastin et al. [5], including grassland, heathland, and sediments. Land cover classes for supra-littoral and littoral sediment were combined. Set 2 included only urban/suburban areas and cropland, which Bastin et al. excluded from their predictions, but which nevertheless could be considered for tree restoration. Other land cover classes (woodland, bare rock, and aquatic habitats) were not considered in the analyses. We downloaded further spatial data on the location of protected sites in Great Britain (Table 1), including Special Areas of Conservation (SACs; designated under the EU Habitats Directive), Sites of Special Scientific Interest (SSSI; a conservation designation to protect rare biological, physiological, or geological features), Areas of Outstanding Natural Beauty (AONBs) or National Scenic Areas (NSAs) in Scotland (protected for their scenic value), and National Parks (NPs; a designation that recognises both the natural and cultural values of the landscape). Thus, we had information on the cover of habitats, land use, and protected areas in every 1 km grid cell across the study area (Figure 2).

For each land cover class in Set 1 (Table 1), we calculated the total area under that class (weighted by % cover). Next, for each grid cell we subtracted the tree restoration potential from the % cover of the corresponding land cover class and calculated the total remaining % cover-weighted area under that class. The same procedure was performed on each class of protected area (SAC, SSSI, AONB/NSA, NP; Table 1) after first merging the separate classes for England, Scotland, and Wales, then converting these polygons to raster layers, in which each cell falling within the protected area was given a value of 100%, whilst any cells falling outside were given a value of 0%. Any cells falling partially within a protected area were given a value corresponding to the proportion of the cell within the polygon. Finally, to provide an estimate of the sensitivity of results to the exclusion of urban areas and cropland (Set 2), we quantified the absolute area of additional canopy cover that could be achieved by planting trees in these areas and compared this with the results obtained from earlier calculations. We modelled two scenarios reflecting mean tree restoration potential of 5% and 20% across all urban and cropland areas. We took these values as they represent realistic minimum and maximum levels of additional tree cover. However, it should be noted that these are mean values across GB; we do not specify any particular cropland or urban areas as more or less suitable for tree restoration.

All analyses were performed in R 3.6.2 [18].

Table 1. Descriptions and sources of spatial data included in the study. * We combined the supra-littoral sediment and littoral sediment classes (see [17]).

Layer (Format)	Source
Tree restoration potential (raster, 1 km resolution)	Bastin et al. [5]
Protected areas (shapefiles): *Special Area of Conservation (SAC)* *Sites of Special Scientific Interest (SSSI)* *Area of Outstanding Natural Beauty (AONB)/ National Scenic Area (NSA)* *National Park (NP)*	hub.jncc.gov.uk England—data.gov.uk/dataset Wales—naturalresourceswales.sharefile.eu Scotland—gateway.snh.gov.uk England—naturalengland-defra.opendata.arcgis.com Wales—lle.gov.wales/catalogue Scotland—spatialdata.gov.scot geoportal.statistics.gov.uk/
Land cover classes (rasters, 1 km resolution): <u>Set 1</u> *Improved grassland* *Neutral grassland* *Acid grassland* *Heather* *Heather grassland* *Sediments* * <u>Set 2</u> *Urban (including suburban)* *Cropland (arable, horticultural)*	Rowland et al. [17]

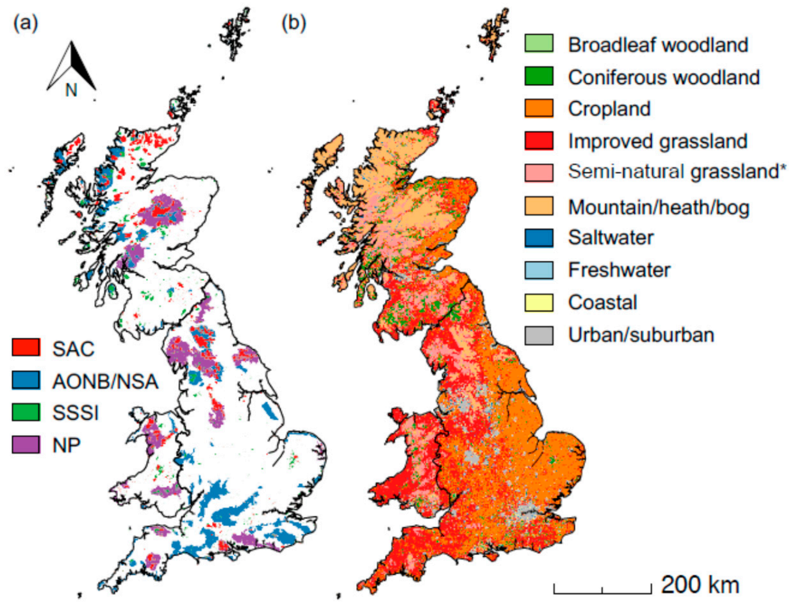

Figure 2. Protected areas (**a**) and land cover classes (**b**) in Great Britain. Dominant land cover of aggregated classes is shown in (**b**). * Semi-natural grassland incorporates neutral, calcareous, and acid grassland classes. See Table 1 for data sources and abbreviations.

3. Results

Our spatial analysis indicated that, under the full tree restoration potential of Bastin et al. [5], 30–50% of habitats would be lost (Figure 3). In absolute terms, the losses are greatest for improved grassland at 28,491 km^2, a large proportion of the total 42,289 km^2 of land identified by [5] as suitable for tree restoration in GB. In relative terms, neutral and calcareous grassland suffer the greatest losses with each habitat reducing in area by 50%. To put these figures into context, if tree cover in urban areas was increased by 5–20% this would represent an additional 836–3343 km^2 of land under tree canopy. For cropland, an increase of 5–20% canopy cover would represent some 2746–10,983 km^2 in absolute terms.

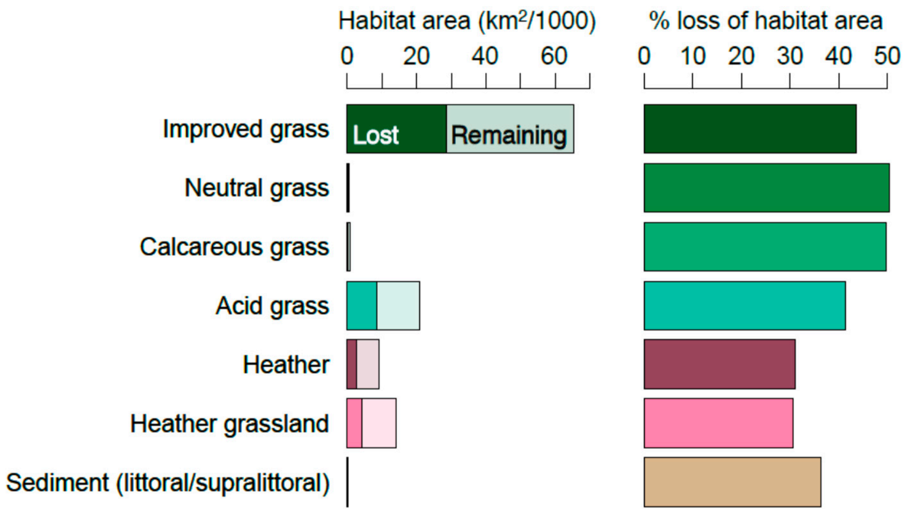

Figure 3. Losses of habitat types in Great Britain under full tree restoration potential [5].

Under full tree restoration potential, 14–21% of protected areas would be covered with additional tree canopy (Figure 4). This equates to a total area of 10,943 km^2 when overlapping designations are accounted for, a figure equal to one quarter of the total potential area of tree restoration in GB according to [5]. AONBs are most affected, with an additional canopy cover of 4950 km^2. A similar area of 4775 km^2 is affected in NPs (21% of the total NP area).

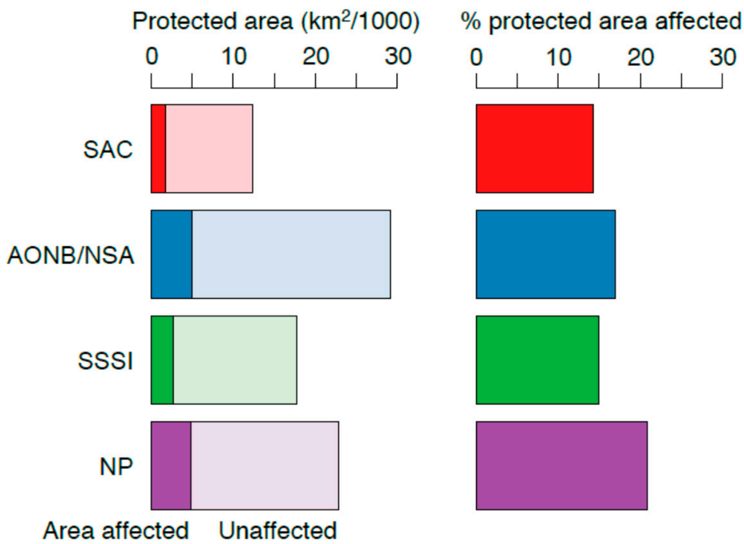

Figure 4. Additional canopy cover in protected areas of Great Britain under full tree restoration potential [5].

4. Discussion

Our findings show that achieving the full restoration potential identified by Bastin et al. [5] would mean a considerable change in the structure and function of the landscape of Great Britain. Up to 50% of ecologically valuable habitat, such as semi-natural grassland and heathland, would be lost. Large parts of protected areas, including AONBs and NSAs protected for their scenic value, would be transformed. Of SACs and SSSIs, the most valued of ecological and scientific areas in GB, 14% would need to be covered with tree canopy. However, these predicted losses of ecologically valuable and protected areas might be avoided if greater emphasis was placed on a land sharing approach to tree planting. For example, if trees were selectively planted in urban areas and on cropland up to an additional average canopy cover of 20%, these losses could be minimised whilst still delivering the estimated 6.5 million tonnes of additional carbon storage calculated for GB by [5]. However, there would still need to be a substantial reduction (28,491 km^2 or 44%) in the area of improved grassland. Clearly, when considering options for tree planting on a national scale there is a need to examine the trade-offs between carbon sequestration and other factors such as agricultural production, biodiversity, food waste, diet changes, and public health, as well as social–political constraints to land use change imposed by issues such as land tenure.

4.1. Agriculture

One option for increasing tree cover in agricultural landscapes is land sharing through agroforestry practices in arable, livestock, and mixed farming landscapes. This could include permitting more hedgerow trees to mature, as well as planting new hedgerows and boundary trees. The total length of existing hedgerows in GB has been estimated at 402,000 km [12], suggesting substantial potential for hedgerow management to contribute towards carbon sequestration. However, the predominant management of this resource is presently based on annual mechanical flailing by tractor, itself dependent on fossil fuels, which prevents potentially millions of existing hedgerow trees from maturing. Mature trees in agricultural landscapes provide multiple benefits such as natural flood management and pesticide spray capture. They can also mitigate soil erosion and improve soil structure, compensating to some extent for any reductions in productivity. In pastoral landscapes, reduced grass productivity due to shading by trees can be outweighed by the positive effects of trees on animal health [19]. An open tree canopy may be particularly beneficial to livestock under climate change, providing shade during more frequent heatwaves and shelter during more intense storms [19,20].

Agricultural land sparing may also form part of an effective strategy to increase tree cover in GB. This would involve establishing larger patches of woodland in a farmed landscape, for example through opportunistic buying up of low value agricultural land or by providing incentives to farmers to increase tree canopy cover. But whether through land sparing, land sharing, or a combination of the two approaches, it is clear that realising tree restoration potential will depend on deep changes in the British food system and food consumption patterns in a way that is replicated worldwide. These changes are essential to sustain a growing global population, as outlined in the recent 'EAT-Lancet' study, which recommended a shift towards more plant-based diets, greater consumption of nuts, and vastly reduced or zero red meat consumption [21]. One important narrative in the tree planting debate is that such shifts in consumption patterns would free up land used for livestock production to make way for trees. Our finding that 44% of improved grassland is suitable for tree restoration supports this narrative in the context of Great Britain.

4.2. Biodiversity

The potential negative outcomes of large-scale tree planting initiatives for biodiversity and ecosystem functioning, such as those we report here, have recently been highlighted in diverse ecosystems worldwide [22,23]. The replacement of native habitats with monocultures, particularly of exotic species, can lead to severe consequences. Observed effects include rapid declines in invertebrate and bird diversity, soil carbon losses, and changes in river flow regimes (e.g., [24,25]. Yet whilst the protection of priority habitats and species within their native ranges remains the key challenge for conservation managers, the spatial distributions of tree species are shifting rapidly under climate change [26]. Thus, species considered native may not persist within their historical ranges, requiring well-informed decisions to be made about species choice in any given location.

In addition to sensitive selection of tree species, tree restoration planning should also consider the ecological, cultural, and economic value and rarity of diverse plant and animal species and the landscapes they inhabit. In Great Britain, any reductions in unimproved grassland area, particularly in neutral and calcareous grasslands, may be seen as unacceptable because of the severe losses already incurred due to agricultural intensification in the last century (97% loss of unimproved grassland between 1932 and 1984 [27]). Unlike improved grassland, species-rich grasslands cannot persist in a woodland context, being susceptible to shading, smothering by leaf litter, and nutrient elevation. Whilst some degraded acid grasslands may be seen as suitable for tree planting, particularly those dominated by bracken (*Pteridium aquilinum*), any further losses in unimproved grasslands should be unnecessary, because the remaining areas in question are relatively small and would therefore have a negligible impact on tree planting targets.

Our results suggest that the integrity of areas protected for biodiversity value, particularly SACs and SSSIs, may be compromised by tree restoration. The threats posed by tree planting in species-rich open systems such as grasslands, mire, and blanket bog could be seen as unacceptable due to the cultural meanings, perceived benefits, and environmental legislation (e.g., EU Habitats Directive) associated with these habitats. Previous work in GB has shown that afforestation of open habitats such as grasslands and fens may only deliver marginal contributions to carbon storage at best, and at worst lead to net carbon emissions [28,29]. Furthermore, tree restoration should not be pursued at the expense of restoration of other priority habitats identified under the UK Biodiversity Action Plan. Such restoration efforts deliver multiple benefits and can also be important for carbon storage. For example, there is evidence that peatland degradation is a significant contributor to GB carbon emissions [29]. Thus, it would be counterproductive to sacrifice peatland restoration in favour of tree planting.

4.3. Urban Areas

Our analysis shows that realising an additional 20% canopy cover in urban areas would make only a small contribution to the overall area of land covered by trees. However, urban trees deliver multiple benefits, helping to prevent heart disease, hypertension, diabetes, and respiratory illness [30,31], although careful planning is required to avoid exacerbating symptoms for those suffering with pollen allergies and asthma [32–34]. Careful species choice is also necessary, because some species are less effective at trapping pollutants and others may emit volatile organic compounds (VOCs), which contribute to tropospheric ozone production [35]. Churkina et al. [36] even suggested prohibiting the planting of certain species due to their high VOC emissions.

The advantages of carefully selected urban trees extend to effective flood management, biodiversity, noise reduction, pedestrian safety, and cooling during heatwaves, among others [37]. Yet the perceived destruction of urban trees has resulted in recent social conflicts in GB, most notably in Sheffield where the city council's decision to fell over 6000 street trees was met with opposition by local environmental activists [38,39]. Where urban trees are retained, their growth is often constrained by impermeable surfaces or box planters. These constraining features can result in water stress, reducing the growth rates and health of urban trees [40]. Heavy pollarding is also common practice, which further reduces the potential for urban trees to store carbon.

Our lower value of a 5% tree cover increase in urban areas is approximately in line with minimum urban tree cover recommendations in England, where a study of 265 towns and cities found an average of 15.8% canopy tree cover and recommended an increase to a minimum of 20% [41]. Our scenario of a 20% increase from the current baseline would take urban tree coverage to average values of 35.8%, which is close to the upper limit for some northern and western European cities [42] and could be more challenging to implement widely. However, it is clear that tree planting in British cities holds substantial potential for delivering multiple benefits, including carbon sequestration. To realise this potential, there must be shifts towards a greater awareness of the benefits of urban trees, a willingness to share urban spaces with mature trees, and a long-term commitment to tree maintenance.

5. Conclusions

Efforts to plant trees over vast swathes of land are gaining pace worldwide, based on the idea that photosynthetic carbon capture by trees can help to limit global warming. We have shown how tree planting at a sufficient scale to address rising global atmospheric CO_2 concentrations would be associated with pronounced shifts in the structure and function of the British landscape. It may be possible to achieve such shifts through a combination of approaches, including land sharing and land sparing in both urban and agricultural landscapes; deep changes in the British food system and food consumption patterns, particularly towards more plant-based diets; sound, evidence-based decisions about which existing habitats to protect; and a commitment to preserving and maintaining urban trees. However, such approaches must work within the practical constraints imposed by current land tenure arrangements. Thus, in addition to rethinking the uses of public land, policies must focus on incentivising land use change among private land owners. They must also give careful consideration to the biodiversity value of land, avoiding priority habitats and mitigating environmental impacts by adopting judicious planting and management practices. This will require clear policy guidance and close coordination between public, third sector, and private organisations involved in tree planting initiatives.

Author Contributions: Conceptualisation: M.A.W.; data curation: M.A.W.; formal analysis: M.A.W.; methodology: M.A.W.; visualisation: M.A.W.; writing—original draft: M.A.W.; writing—review and editing: J.B., S.B., S.C., K.D.-S., F.R., U.S., B.S., M.T., L.T., and M.V.D.W. All authors have read and agreed to the published version of the manuscript.

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