Using Geographical Information Systems to plan for an extra 1,000,000 trees by 2030: A case study of woodland creation in Lancaster, UK

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Abstract

Woodland creation provides a solution to solving a catalogue of environmental and social problems. This has encouraged Lancaster City Council to plant 1,000,000 trees by 2030. However, careful consideration and spatial planning are necessary to avoid repeating the past mistakes of large-scale afforestation initiatives. As a result, a Geographical Information Systems framework has been identified as vital for ensuring trees are not planted in inappropriate places so that valuable habitats are not lost, and key land uses are not undermined. Constraints mapping was required to identify land across the district of Lancaster that was unsuitable for tree planting, considering environmental, physical and policy constraints to successful woodland creation. Opportunity maps were devised to spatially target where these 1,000,000 trees could be viably planted in order to satisfy multiple ecosystem service benefits. Based on our assumptions, the study concluded that there was ample land across the district to plant 1,000,000 trees, since 106km² was identified as potentially suitable for woodland creation and only 6.25km² of land was required. Results also indicated that it is possible to integrate multiple ecosystem benefits at sites of potential woodland creation, despite its challenges. Nevertheless, there is room for Lancaster City Council to be more ambitious with their tree planting targets.

Keywords – GIS, woodland creation, ecosystem services, constraint and opportunity mapping

Word count – 9092
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1. Introduction

1.1 Context

In October 2018 the United Nations Intergovernmental Panel on Climate Change (IPCC) issued an unsettling warning: take urgent action to limit global warming to a maximum of 1.5°C within the next twelve years or encounter catastrophic climate change and environmental disaster (IPCC, 2018). Temperatures have already increased 1°C above pre-industrial levels (Met Office, 2015) and the evidence is clear: weather patterns are changing, sea levels are rising, species are threatened with extinction, crop yields are declining, and people are being displaced. These consequences will only intensify as global temperatures continue to rise.

The IPCC recommends that greenhouse gas emissions are reduced to net-zero by 2050, requiring "rapid, far-reaching and unprecedented change" (IPCC, 2018). To achieve this, anthropogenic emissions of greenhouse gases will have to be seriously reduced (Meinshausen et al., 2009). However, reducing greenhouse gas emissions may not be sufficient alone, meaning that carbon dioxide removal from the atmosphere will also be necessary (Kreidenweis et al., 2016). Nature-based solutions, such as afforestation, could make essential contributions for achieving global climate targets (Smith et al., 2014).

Not only is afforestation an economically attractive natural mitigation option (Calvin et al., 2014; Smith et al., 2016), but its high carbon sequestration potential has led academics to consider it the most effective climate change solution available today, having the potential to reduce atmospheric carbon by 25% (Bastin et al., 2019). Consequently, world leaders on a global scale are demonstrating unparalleled political will for achieving ambitious afforestation initiatives to increase carbon uptake, such as the World Economic Forum's One Trillion Trees campaign, the Bonn Challenge, the African Forest Landscape Restoration Initiative, and the New York Declaration on Forests. Accordingly, the IPCC has suggested that an increase of one billion hectares of forest will be necessary to limit global warming to 1.5°C by 2050 (IPCC, 2018).

On a national scale, woodland creation is a central part of the UK government’s 25 Year Environment Plan, which aims to plant a Northern Forest to expand the total area of woodland in England to 12% by 2060 (HM Government, 2018). This still remains well below the EU
average of 37% (Quine et al., 2011). As part of a "green industrial revolution", Prime Minister Boris Johnson announced in November 2020 that 30,000 hectares of trees are to be planted every year to protect and restore our natural environment (HM Government, 2020). Between April 2017 and March 2020, 4,273 hectares of land have been newly planted, equating to 6,920,000 trees (Forestry Commission, 2020).

Following its declaration of a Climate Emergency in January 2019, Lancaster City Council has pledged to plant one million trees and hedgerows across North Lancashire by 2030 as part of this Northern Forest project. With support and funding from the Woodland Trust and the Department for Environment, Food and Rural Affairs, the Council hopes that its ambitious target will deliver multiple benefits: ranging from climate mitigation and adaptation, biodiversity conservation, flood risk mitigation and other social benefits.

However, by no means is tree planting a panacea for complex global environmental challenges (Brancalion and Holl, 2020). Integrating multiple ecosystem benefits and navigating around physical, environmental and policy constraints makes achieving ambitious afforestation targets difficult. Nevertheless, Geographical Information Systems (GIS) have been increasingly used by planners to locate where this tree cover can be viably increased. GIS integrates the best available spatial information to target areas where the most ecologically and socially feasible outcomes intersect (Brancalion et al., 2019). A spatial approach to decision making in this area is critical for ensuring that this urgency to achieve arbitrary targets does not justify short-term fixes that fail to produce environmentally and socially beneficial long-term outcomes (Chazdon and Brancalion, 2019).

1.2 Study Area

Lancaster is located in the county of Lancashire in the north-west of England, covering an area of 576.2km² (Figure 1). Lancashire is one of the least wooded areas in the UK, having less than 6% tree cover which is less than half the national average and one of the lowest of any counties in the UK (Hill, 2020). The Lancaster district boasts a wide but distinctive variety of landscapes, including Morecambe Bay, the Lune Estuary, the Bowland Fells and the Yorkshire Dales. The district's predominant landscape types are coastal drumlins, drumlin fields, rolling upland farmland, and the floodplain valley of the River Lune (Lancashire County Council, 2000). Two
Areas of Outstanding Natural Beauty (AONB) span the district: The Forest of Bowland AONB and Arnside & Silverdale AONB.

Figure 1. Location of the study area, Lancaster, Lancashire, United Kingdom, featuring the county’s existing woodland distribution. Contains Ordnance Survey and Forestry Commission data © Crown Copyright and database rights (2020, 2018).
1.3 Research Aims and Objectives

Aim

This investigation aims to use GIS to assess the feasibility of Lancaster City Council’s pledge to plant one million trees by 2030, by identifying land that is most suitable for tree planting within the Lancaster district, using an ecosystems services framework.

Objectives

1. To assemble the most up-to-date and highest resolution layers of constraints and opportunities of woodland creation

2. To use GIS to identify constraints to woodland creation, creating a suitability map identifying areas of the district where there is potential to plant one million trees

3. To use GIS to identify opportunities for woodland creation, creating opportunity maps identifying where woodland creation would benefit flood risk mitigation, biodiversity conservation and public benefit

4. To illustrate woodland creation in practice by plotting one million trees across the district of Lancaster
2. Literature Review: Where should we plant trees?

This literature review seeks to provide an overview of the ongoing debates surrounding large-scale tree planting initiatives. Firstly, the importance of using spatial analysis techniques to assess land suitability is covered, then moving onto a discussion of the considerations around selecting sites for woodland creation, particularly looking at which locations provide the greatest potential in terms of natural capital benefits.

2.1 Land suitability

Alongside the growing support for tree planting initiatives on global and national scales, there has been the increasing concern that large-scale, and potentially inappropriate, tree planting commitments launched by national governments and international bodies may be ignorant to the true complexities of tree planting (Holl and Brancalion, 2020). The obsession with setting targets with the metrics of 'numbers of trees' or 'total area planted' instead of 'survival rates after one year' has been criticised for resulting in large scale plantings in unsuitable places with little attention paid to aftercare (Huxham, 2019). Tree planting is not as simple as filling every available space with trees: the right tree needs to be in the right place for the right reason.

Large scale afforestation projects in the wrong places have the potential to modify the surrounding landscape and wider environment adversely, notably through increasing greenhouse gas emissions, biodiversity loss and changes in soil and water quality (Helm et al., 2020), causing ecosystem disservices (Shackleton et al., 2016). This means that it is critical that woodland creation only occurs on land suitable for afforestation. For this reason, GIS methodologies have been increasingly used by organisations with ambitious tree planting programmes to ensure decision making is spatially aware (Burke et al., 2020; Farrelly and Gallagher, 2015; Gkaraveli et al., 2004; Lee et al., 2002; Sing et al., 2013). This is said to eliminate the risk of missing opportunities to deliver multiple benefits or unintended environmentally-damaging consequences from short-sighted thinking (Chartered Institution of Water and Environmental Management, 2020).

Without careful planning and spatial consideration, valuable habitats could be lost. The UK landscape remains scarred by historic environmentally-insensitive tree planting programmes, such as the drainage of peatlands for commercial forestry in the Flow Country of northern
Scotland in the 1980s, that has led to modern-day planners steering clear of planting in deep peatland areas (Crane, 2020; Shrubsole and Gordon-Smith, 2019). However, these mistakes are not confined to our pasts, as trees are planted on peatland to this day (BBC News, 2020a). As globally important carbon stores, peatland ecosystems degrade when converted to forestry, changing the ecosystems' morphology, hydrology, and ecology (Lindsay et al., 2010). When trees establish themselves in boggy environments, they can lose their capacity for active carbon sequestration (Lindsay et al., 2010), converting from a carbon sink in natural conditions to a carbon source in drained conditions (Sloan et al., 2018). This means that afforested peat releases more carbon in the atmosphere upon drainage than is captured by the trees, resulting in increased net greenhouse gas emissions (Sloan et al., 2018). Moreover, peatland afforestation directly promotes habitat loss, edge effects, and alien species (Lindsay et al., 2018). These factors have been linked to the biodiversity loss of migratory birds of national importance which use these bogs as critical breeding habitats (Avery and Leslie, 1990, 299).

Likewise, afforestation is discouraged from species-rich grassland habitats for similar reasons (Shrubsole and Gordon-Smith, 2019). As a result of agricultural intensification, in less than a century 97% have been lost, meaning they now only cover a mere 1% of the UK's land area, and they are increasingly becoming under threat from misguided but well-meaning afforestation projects (Plantlife, 2018). Afforestation can severely compromise these fragile ecosystems by disturbing their hydrology, soil nutrient cycles and species richness (Veldman et al., 2015). They tend to be undervalued and targeted as sites for woodland creation, despite being important habitats for invertebrates and vital pollinators, and critical feeding grounds for bird species (Vickery et al., 1999). A Cumbrian farm recently hit the headlines when insufficient spatial analysis and a poor understanding of the local geography led to saplings being ripped up after it was found that the trees would have destroyed a rare flower habitat, significantly threatening the existence of Rare Greater Butterfly Orchids that grow in the meadow (BBC News, 2020b).

Peatland ecosystems and species-rich grasslands are just two examples of habitats that could be adversely impacted by afforestation. These examples reinforce the importance of decision-makers using methods of spatial analysis to assess land suitability, utilising a variety of constraints to ensure decisions are made using an ecological framework and not just made
based on meeting arbitrary targets (Farrelly and Gallagher, 2015; Gkaraveli et al., 2004; Lee et al., 2002; Sing et al., 2013).

Similarly, other landscapes and land uses must be avoided in afforestation decision-making to ensure success. Firstly, there is an upper limit of altitude at which trees can grow naturally – the climatic tree line. This altitude varies greatly depending on a series of factors, but in the United Kingdom, tree growth is generally considered to be constrained at 600m above sea level (Ratcliffe and Thompson, 1988). Secondly, protected areas with any environmental, geological or archaeological designation must be excluded from consideration because of trees' ability to alter the distinctive character of these areas (Forestry Commission, 2017). Moreover, there is also a lot of controversy around tree planting on high-quality agricultural land that is more valuable for growing food crops for direct human consumption. Planting on this land could reduce food production in the UK, increasing food imports and driving deforestation overseas – which would be extremely counter-productive, especially if climate change mitigation is a core aim of an afforestation initiative (Shrubsole and Gordon-Smith, 2019). Agricultural Land Classification (ALC) is a system used across England and Wales to grade land quality for agricultural use. Consequently, this system is often used to inform planning decisions. ALC grades 1-3 are generally considered high-quality agricultural land capable of consistently producing high crop yields (Natural England, 2018). ALC grade 5 is regarded as a good proxy for upland peat bogs (Shrubsole and Gordon-Smith, 2019). As a result, ALC grade 4 is considered the most suitable land for tree planting as it is not suited for crop growing, but sufficient for tree growth.

2.2 Opportunities for maximising ecosystem services

Woodlands provide a wide range of benefits to society, known as ecosystem services (ES) (Quine et al., 2011). These can be categorised as provisioning (timber, fibre and fuel), supporting (soil formation, nutrient cycling, biodiversity), regulating (carbon sequestration, flood protection, pollination) and cultural (health, recreation and tourism) services (Quine et al., 2011). However, trees can also provide ecosystem disservices when planted in inappropriate places (Rouquette and Holt, 2017).
It is viewed that placing tangible values upon ecosystem services, which are believed to be undervalued, will reduce ecosystem degradation (Sukhdev, 2008). As a result, ES tools have become increasingly popular amongst woodland planners for assessing and valuing the benefits provided by woodland creation (Rouquette and Holt, 2017). There are more than 80 fast-evolving ES tools available (Bullock and Ding, 2018), and many are intended for spatial planning, including InVEST which is an example of a tool that integrates GIS to provide a spatial perspective on the variation in ecosystem service supply and demand (Natural England, 2013). Similarly, EcoServ-GIS overlays spatial datasets describing aspects of the landscape, such as habitat type, grey infrastructure and socio-economic factors, to estimate the likelihood of ecosystem service provision (Nayak and Smith, 2019). Maps are produced to draw attention to hotspots and cold spots of ecosystem service delivery and highlight spatial patterns that provide much additional detail, as well as being more user-friendly than non-spatial approaches (Rouquette and Holt, 2017). Each tool has its different strengths, and they are certainly not without their criticisms – mainly over their complexity and varying capabilities – but ultimately ES tools can be incorporated into spatial planning to maximise ecosystem service delivery by ensuring the right tree is in the right place (Nayak and Smith, 2019).

In essence, there is compelling evidence which supports that, in appropriate locations, woodland creation can achieve a wide variety of social and environmental objectives. However, woodland creation initiatives tend to be limited by land availability and financial constraints (RFS, 2020). Opportunity mapping is a GIS-based approach that seeks to overcome these barriers, especially when ES tools are integrated. As a result, environmental planners have utilised opportunity mapping, not least for woodland creation, to identify where efforts should be concentrated to best benefit society, restore and optimise environmental system function, and promote more integrated catchment management (Forest Research, 2017). A typical opportunity mapping methodology uses spatial data to identify locations sensitive to land use change (constraints mapping) and then overlays factors that would make woodland creation beneficial to these locations (opportunity mapping).

In light of the climate and ecological emergency, woodland planners have adopted opportunity mapping to identify priority landscapes where multiple objectives could be achieved simultaneously (Gimona and van der Horst, 2007). This is associated with the evolving principle
of 'multi-functionality' within forestry that stipulates forest management should guarantee the
delivery of several services, and reserve possibilities to fulfil new services in the future without
endangering or impoverishing the ecosystem (Quine et al., 2011). For woodland creation, this
suggests that afforestation initiatives should seek to solve a catalogue of other environmental
issues beyond carbon sequestration, such as flood management, biodiversity conservation and
public engagement – coined "multiple benefit woodlands" (Forestry Commission, 1998).

**Biodiversity Conservation**

The United Kingdom is not immune to the biodiversity crisis: close to half of species have
declined over the last fifty years and continue to do so while fifteen per cent of species face
extinction (Hayhow et al., 2019). With the potential to support a large variety of plants, animals
and fungi, woodlands provide essential habitats for wildlife. In particular, ancient woodlands
are the UK’s most biodiverse land habitat. In turn, wildlife corridors are an attractive woodland
creation strategy, and so the potential of biodiversity conservation strategies may be more
successful where woodland creation is adjacent to existing ancient woodland networks.
Creating linkages between existing woodlands have been found to increase the size, and
resilience, of existing habitats (Nidderdale AONB, 2020a). Planting adjacent to existing
woodland may also enhance the new woodland’s biodiversity value as the existing woodland
can provide a valuable seed source to facilitate the establishment of woodland flora
(Nidderdale AONB, 2020a). Increasing the connectivity between fragmented woodlands has
been found to reverse population declines and reduce range shifts caused by climate change
for species’ long-term survival (Gilbert-Norton et al., 2010). In recent years, several local
authorities have used GIS to create opportunity maps that extend habitat networks and
spatially target conservation efforts for the greatest impact on biodiversity (Staffordshire
Wildlife Trust, 2013; Nottinghamshire Biodiversity Action Group, 2016; Nidderdale AONB,
2020a).

**Flood risk mitigation**

Impacts of climate change mean that Northern England, particularly the north-west, will
experience flood events at a greater severity than elsewhere in the UK and an eleven per cent
rise in the frequency of flooding (Blöschl et al., 2019). However, in light of climate adaptation,
restricting development on the floodplain and 'softer' and more sustainable flood control methods are becoming increasingly favoured over hard engineering strategies. Woodlands have long been associated with affecting both the quantity and timing of stream flows, and there is a widespread belief that woodlands can help reduce and smooth flood peaks. The restoration of floodplain woodland is thought to offer the greatest potential for flood mitigation by slowing down flood flows and enhancing flood storage (Thomas and Nisbet, 2006). Additionally, the creation of riparian woodlands promotes the natural development of woody debris dams that increases flood storage and delay flood flows (Nisbet and Broadmeadow, 2003). GIS has been used to derive opportunity maps that identify locations for restoring floodplain woodlands, creating riparian woodlands, and locating areas within the wider catchment to promote greater flood control in Northern Ireland (Thomas et al., 2017), Scotland (Broadmeadow et al., 2013a), the Midlands (Broadmeadow et al., 2013b), Yorkshire (Broadmeadow and Nisbet, 2013), and Cumbria (Nisbet and Broadmeadow, 2010).

Public Benefit

Not only are woodlands believed to provide a multitude of social benefits, such as improving an individual's physical health (Powe and Willis, 2004; Pretty et al., 2005; Potchter et al., 2006) and mental health (Maller et al., 2006; Annerstedt et al., 2012; Alcock et al., 2014), woodlands are increasingly being seen as tools for engaging people with the natural environment. This is because they provide opportunities for people to discover the natural environment, wildlife, plants and seasonal change – all of which is magnified when woodlands are close to where people live (Cole and Bussey, 2000; Thompson et al., 2004). This has meant that it is vital for planners to target woodland creation sites close to population centres, especially in the context of a climate and ecological emergency. Ideas such as rewilding the greenbelt and urban forests have been advanced to provide people living in urban centres access to nature (Shrubsole, 2019). Social opportunities remain an area for development in the scope of opportunity mapping. It has been advised that woodlands should be increasingly established in deprived areas. This may expand the opportunities at their disposal, considering that children from deprived backgrounds are considerably less likely – by 20 percentage points – to spend time outside than children from higher socio-economic groups (Juniper, 2020).
Opportunity mapping is a novel approach that encourages positive discussions about "the right tree in the right place for the right purpose". This is because opportunity mapping lends itself to interactive community participation, which tends to be under-valued in the woodland creation sphere. Several organisations have launched their woodland opportunity maps as interactive web maps (Friends of the Earth, 2020; Nidderdale AONB, 2020b; Welsh Government, 2020; Lagas, 2020). In particular, the Glastir Woodland Creation Project encourages community members to engage with spatial data through an online tool that allows them to calculate suitability scores for potential woodland areas near to where they live (Welsh Government, 2020). Participatory mapping aims to increase the acceptability of woodland planting amongst community members, recognising that early engagement in the planning process of woodland creation schemes may support the likelihood of uptake (Forestry Commission, 2004). Forrester and Cinderby (2012) found that participatory mapping with farmers and landowners increased willingness to support schemes and added value to projects.

Ultimately, opportunity mapping provides a practical solution to identifying areas most suitable for woodland creation, especially by producing large-scale assessments that provide strategic contexts for local action. However, they should not be treated as blueprints as they are merely tools that highlight potential areas for woodland creation. The mapping locates areas built upon landscape-scale principles and does not consider local site-based factors that may affect suitability. This means that areas identified as desirable for woodland creation still need to be assessed on a case-by-case basis, whereby site visits and specialist input must be mandatory to provide local refinement and validation to deal with any uncertainties brought about by spatial data (Catchpole, 2006).

In conclusion, location is a critical factor in any decision-making process regarding afforestation, and planting programmes should be tailored accordingly. Spatial analysis is required to ensure that trees are planted in the right places to avoid adversely affecting the surrounding environment and to promote multi-functionality to ensure that afforestation projects serve the most potential in terms of ecosystem services. The remit of suitability and opportunity mapping is without limit. They enable the evaluation of alternative tree planting options in a rigorous and systematic way. As research tools, they can be extremely
sophisticated, as they may be developed to help relate national and international carbon capture targets to local-scale planting initiatives, for instance. Alternatively, they can be simplified for participatory mapping models that seek to engage non-specialist community members with woodland creation schemes.
3. Methodology

In order to determine the scale and extent of woodland creation opportunities available in Lancaster, the first step was to create a suitability map that identified constraints to woodland planting (3.1). Afterwards, opportunity maps were produced. These overlaid the previously identified suitable areas with flood risk, biodiversity conservation and public benefit opportunities to highlight the areas of Lancaster where tree planting could produce multiple ecosystem service benefits (3.2). Planting densities were then calculated to determine how much land is required to plant 1,000,000 trees across the Lancaster district (3.3). Lastly, the area required for 1,000,000 trees was plotted to see woodland creation in practice in Lancaster (3.4).

3.1 Constraints mapping

Primarily, core constraints and sensitivities to woodland planting were identified. These are negative factors that represent locations where its land uses, landforms or land classifications are incompatible with creating sizeable areas of woodland. Taking into account the planting conditions that favour growth, outlined in section 2.1, a list of suitability criteria was devised. The most up-to-date and highest resolution datasets available on these were then sought, predominantly from open data sources produced by national government departments and established research agencies (Table 1). These national data sources were selected above more localised data sources because they provided complete, consistent and easily assembled data for the district, albeit lacking local nuance. ArcGIS Pro was later used to both integrate, and clip down to size, this data (Figure 2). While urban and riparian areas are listed amongst constraints, they should not be seen as an absolute barrier to planting, seeing that some will provide local opportunities.

Burke et al. (2020) and Farrelly and Gallagher (2015) categorised constraints to woodland planting into multiple groups: physical, environmental and policy constraints. This framework defines physical constraints as land that is biophysically unsuitable for woodland creation (water, urban areas and roads), land biologically unsuitable for woodland creation (rock, bog and coastal sediment), or land that is already wooded. Environmental constraints are defined as land that would be negatively affected by tree planting, such as peat bogs and species-rich
grasslands. Policy constraints are defined as land that is affected by local and national policy designations, including areas of environmental, geological and archaeological importance.

**Table 1.** Data sources for constraints data.

<table>
<thead>
<tr>
<th>Category of Constraint</th>
<th>Constraint</th>
<th>Product (Source, Year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physical</td>
<td>Climatic Treeline (600m)</td>
<td>OS Terrain 50 DTM (Ordnance Survey, 2020)</td>
</tr>
<tr>
<td></td>
<td>Water, Rock and Coastal Sediment – including fen, marsh, swamp, bog, saltwater, saltmarsh</td>
<td>Land Cover Map (UK Centre for Ecology &amp; Hydrology, 2015)</td>
</tr>
<tr>
<td></td>
<td>Existing Woodland</td>
<td>National Forest Inventory (Forestry Commission, 2018)</td>
</tr>
<tr>
<td></td>
<td>Rivers</td>
<td>OS Open Rivers (Ordnance Survey, 2020)</td>
</tr>
<tr>
<td></td>
<td>Roads</td>
<td>OS Open Map Local (Ordnance Survey, 2020)</td>
</tr>
<tr>
<td></td>
<td>Buildings</td>
<td>OS Open Map Local (Ordnance Survey, 2020)</td>
</tr>
<tr>
<td></td>
<td>Urban Area</td>
<td>OS Open Map Local (Ordnance Survey, 2020)</td>
</tr>
<tr>
<td></td>
<td>Surface Water</td>
<td>OS Open Map Local (Ordnance Survey, 2020)</td>
</tr>
<tr>
<td>Environmental</td>
<td>Peat</td>
<td>625k Superficial Geology (British Geological Survey, 2010)</td>
</tr>
<tr>
<td></td>
<td>Species-Rich Grassland</td>
<td>Provisional Agricultural Land Classification (Natural England, 2019)</td>
</tr>
<tr>
<td></td>
<td>Agricultural Land Grade 5 – Peat Bog</td>
<td>Provisional Agricultural Land Classification (Natural England, 2019)</td>
</tr>
<tr>
<td>Policy</td>
<td>High-Quality Agricultural Land (Grades 1-3)</td>
<td>Provisional Agricultural Land Classification (Natural England, 2019)</td>
</tr>
<tr>
<td></td>
<td>Sites of Special Scientific Interest</td>
<td>Sites of Special Scientific Interest England (Natural England, 2020)</td>
</tr>
<tr>
<td></td>
<td>Registered Parks and Gardens</td>
<td>Registered Parks and Gardens (Historic England, 2020)</td>
</tr>
<tr>
<td></td>
<td>Scheduled Monuments</td>
<td>Scheduled Monuments (Historic England, 2020)</td>
</tr>
<tr>
<td></td>
<td>RAMSAR sites</td>
<td>Ramsar England (Natural England, 2020)</td>
</tr>
<tr>
<td></td>
<td>Special Areas of Conservation</td>
<td>Special Conservation Areas England (Natural England, 2020)</td>
</tr>
</tbody>
</table>

The base map was then converted to a 10-metre resolution raster grid. For specific datasets, including roads and buildings, a buffering tool was applied to allow for setback distances of 20 metres to minimise disturbance – the height of an average UK tree (Keating, 2019).

To determine suitable sites for woodland creation, simple map overlay was used. This defines fixed thresholds to suitability, ensuring that all unsuitable areas are excluded from the analysis.
In the reclassification of rasters, each layer was treated as a binary constraint. Based on the outlined criteria, the primary raster datasets were assigned a value of 1 if they were considered suitable; and a value of NODATA was assigned to all values considered unsuitable. The reclassified layers were then combined to identify which areas met all of the specified criteria. Land that was covered by one or more constraint was considered unavailable for planting and removed accordingly. The land that was not covered by a constraint was deemed available for tree planting.

**Figure 2.** The spatial extent of the identified constraints to woodland creation. a) Existing Woodland. b) Local Nature Reserves. c) Sites of Special Scientific Interest. d) National Nature Reserves. e) Species-rich Grassland. f) National Parks. g) Conservation Areas. h) Ramsar Sites. i) Special Areas of Conservation. j) ALC Grades – 1, 2, 3, 5. k) Surface Water. l) Buildings. m) Peat. n) Scheduled Monuments. o) Registered Parks and Gardens. p) Water, Rock and Coastal Sediments. q) Roads. r) Rivers. The key inputs for the simple map overlay.
3.2 Opportunity mapping

Considering the objectives of Lancaster City Council’s 1,000,000 trees project, three main categories of opportunities of woodland creation were identified: flood risk mitigation, biodiversity conservation and public benefit. A second set of criteria was then devised from these opportunities, outlined in section 2.2, to ensure multiple ecosystem services could be achieved through woodland creation in Lancaster. The most up-to-date spatial datasets available were then sought (Table 2).

Table 2. Data sources for opportunities data.

<table>
<thead>
<tr>
<th>Category of Opportunity</th>
<th>Opportunity</th>
<th>Product (Source, Year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flood risk management</td>
<td>Flood Risk</td>
<td>Indicative Flood Risk Areas (Environment Agency, 2020)</td>
</tr>
<tr>
<td></td>
<td>Floodplain Woodland</td>
<td>WWNP Floodplain Woodland Potential (Environment Agency, 2020)</td>
</tr>
<tr>
<td></td>
<td>Riparian Woodland</td>
<td>WWNP Riparian Woodland Potential (Environment Agency, 2020)</td>
</tr>
<tr>
<td></td>
<td>Wider Catchment Woodland</td>
<td>WWNP Wider Catchment Potential (Environment Agency, 2020)</td>
</tr>
<tr>
<td></td>
<td>Existing Woodland</td>
<td>National Forest Inventory (Forestry Commission, 2018)</td>
</tr>
<tr>
<td>Public Benefit</td>
<td>Priority Places</td>
<td>Priority Places for England (Forestry Commission, 2016)</td>
</tr>
<tr>
<td></td>
<td>Greenbelt Land</td>
<td>Greenbelt Boundaries (Ministry of Housing, Communities and Local Government, 2014)</td>
</tr>
</tbody>
</table>

The "Floodplain Woodland Potential", "Riparian Woodland Potential" and "Wider Catchment Woodland Potential" datasets were taken from the Environment Agency’s "Working with Natural Processes" (WWNP) maps which were generated to identify land that has the greatest potential to be afforested for natural flood mitigation purposes (Burgess-Gamble, 2018). The "Priority Places" dataset, which considers population, deprivation and existing public access provision, identifies areas where trees and woodlands would be of greatest amenity value to the public, because of their proximity to towns and cities, and especially deprived urban areas (Shrubsole and Gordon-Smith, 2019).
Using an ecosystem services framework, opportunity maps were created to identify the most suitable locations for woodland creation. This integrated the ecosystem services opportunities listed in Table 2 with the suitability maps produced previously. As opposed to the simple map overlay used prior, the weighted map overlay used more flexible thresholds to suitability, making it more inclusive (Heywood et al., 2011).

Euclidian distance was used to target areas in close proximity to the opportunities. Primary grid layers were then standardised to ensure that values of 1 were assigned to the most suitable cells and values of 0 were assigned to the least suitable cells (Figure 3). Inverting the values was necessary to ensure that closest proximities were classified as the most suitable. Next, the raster calculator tool was used to both assign equal weightings to the eight standardised layers (such as 0.125 each), and then to combine the layers. To understand which areas of the district are most suitable for either flood risk mitigation, biodiversity conservation, or public benefit, unequal weightings were then used to favour one particular category (such as 0.25 for each of the four flood risk mitigation opportunity layers). Both methods produced opportunity maps with suitability surfaces scored on a range of 0.0 to 1.0 (0-100%).

**Figure 3.** Standardised euclidian distance layers prior to weighting, showing the key inputs for the weighted map overlay – the opportunity layers. The most suitable cells (value = 1) are illustrated in white. The least suitable cells (value = 0) are illustrated in black.
3.3 Planting density

Calculating planting density, also referred to as stocking density, was necessary to determine how much land is required to plant 1,000,000 trees across the Lancaster district.

Planting densities ultimately depend on the specific objectives of the planting programme. For instance, tree planting for timber production requires a higher planting density at 2,500 trees per hectare (2m spacing) which facilitates rapid vertical growth through encouraging light competition (Natural Resources Wales, 2015). Alternatively, woodlands with biodiversity and landscape amenity objectives tend to be planted at lower planting densities at 1,600 trees per hectare (2.5m spacing), facilitating bushier growth in the young trees and slower canopy closure (Natural Resources Wales, 2015).

A 2.5m spacing is generally considered the standard spacing for new native mixed woodlands (Little et al., 2009). The greater the spacings and the lower the planting density, the less thinning and maintenance required once the trees have established (Natural Resources Wales, 2015). Wider spacings, between 3-5m, are generally not recommended because maintenance becomes increasingly difficult as spacings widen (Little et al., 2009). Nonetheless, once trees become established at around 15 years, it is recommended that they are thinned out at 5m spacings (Natural Resources Wales, 2015).

Number of trees per hectare is calculated using the equation: \[ \frac{10,000}{\text{spacing in metres} \times \text{spacing in metres}} \]
(British Hardwood, 2014).

2.5m spacings were therefore adopted across planting sites. This means that 6.25km² of land would be required to plant 1,000,000 trees (Table 3), making it feasible for Lancaster City Council to plant 1,000,000 trees across the district, excluding physical, environmental and policy constraints, considering this equates to 1.1% of the district's land area.

Table 3. Planting density calculations.

<table>
<thead>
<tr>
<th>Spacing (m)</th>
<th>Situation</th>
<th>Trees per hectare</th>
<th>1,000,000 trees (hectares)</th>
<th>1,000,000 trees (km²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Timber production</td>
<td>2500</td>
<td>400</td>
<td>4</td>
</tr>
<tr>
<td>2.5</td>
<td>Conservation</td>
<td>1600</td>
<td>625</td>
<td>6.25</td>
</tr>
</tbody>
</table>
3.4 Woodland Creation in Practice

The opportunity maps were then analysed, particularly concentrating in on the pattern and distribution of low suitability and high suitability scores across the district. The region group tool was used to dissect the maps into polygons of varying sizes to identify potential woodland creation sites. After, the analysis was centred on particular areas of interest that were thought to provide particular benefits, such as in a close proximity to rivers for flood protection and areas that would extend existing (ancient) woodlands – for this, select by location was an essential tool. This bottom-up approach was favoured over the more top-down approach of adopting a suitability threshold – that typically removes all values below a certain suitability score, such as 40% – because it gave me much greater control over the final outcome, by being able to choose locations that satisfy multiple criteria. For instance, areas adjacent to existing ancient woodland, in flood risk areas, near to "priority places". Selection continued until 6.25km$^2$ (the area required for 1,000,000 trees, planted at 2.5m spacings) was achieved.
4. Results

4.1 Constraints Mapping

The combination of physical, environmental and policy constraints (Figure 4) makes a significant 470km² unavailable for tree planting (Figure 5), 82% of the district of Lancaster’s total land area. This means that only 106km² of land is available for tree planting in Lancaster (Figure 6) – a mere 18% of Lancaster's land area.

Figure 4. A map of all the constraints that make land unavailable for woodland creation in Lancaster (environmental, physical and policy constraints). Contains Ordnance Survey data © Crown copyright and database right [2020].
Figure 5. A constraints map produced using a simple map overlay, featuring all land that is unavailable for woodland creation in Lancaster (red). Unavailable land makes up an area of 470.1 km². This is 82% of the district’s land area.
Figure 6. A suitability map produced using a simple map overlay, featuring all land that is available for woodland creation (green). Land that was covered by one or more constraint, and so unavailable for planting, has been removed accordingly. Available land makes up an area of 106.1 km². This is 18% of the district’s land area.
Environmental constraints are the largest category of constraint in Lancaster, making 426km² (74%) of land unavailable for woodland creation (Table 3). Amongst this, species-rich grassland is the most extensive environmental constraint, removing 215km² (37%) of total land. Second to this, ALC grade 5 (a proxy for peat bog) removes 165km² (29%) of land. Policy constraints are the second largest category of constraint, removing 252km² (44%) from planting. Sites of Special Scientific Interest (SSSIs) remove 114km² (20%) of land, and ALC grades 1-3 remove 54.4km² (9%) from planting. Physical constraints occupy 168km² (29%), whereby urban area takes up 42km² (7%) and existing woodland removes 41km² (7%).

Table 3. The proportion of land considered unavailable for woodland creation by each category of constraint. Area percentages are calculated assuming Lancaster’s total land area is 576.2km². NB. The category totals amount to greater than the total area because they contain areas of overlap (Figure 4).

<table>
<thead>
<tr>
<th>Category of Constraint</th>
<th>Constraint</th>
<th>Area (km²)</th>
<th>Area (% Lancaster)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physical</td>
<td>Climatic Treeline (600m)</td>
<td>22.8</td>
<td>4.0</td>
</tr>
<tr>
<td></td>
<td>Water, Rock and Coastal Sediment – including fen, marsh, swamp, bog, saltwater, saltmarsh</td>
<td>33.2</td>
<td>5.8</td>
</tr>
<tr>
<td></td>
<td>Existing Woodland</td>
<td>41.0</td>
<td>7.1</td>
</tr>
<tr>
<td></td>
<td>Rivers</td>
<td>4.8</td>
<td>0.8</td>
</tr>
<tr>
<td></td>
<td>Roads (with buffer)</td>
<td>9.0</td>
<td>1.6</td>
</tr>
<tr>
<td></td>
<td>Buildings (with buffer)</td>
<td>7.8</td>
<td>1.4</td>
</tr>
<tr>
<td></td>
<td>Urban Area</td>
<td>42.4</td>
<td>7.4</td>
</tr>
<tr>
<td></td>
<td>Surface Water</td>
<td>6.9</td>
<td>1.2</td>
</tr>
<tr>
<td></td>
<td><strong>TOTAL</strong></td>
<td><strong>168.0</strong></td>
<td><strong>29.1</strong></td>
</tr>
<tr>
<td>Environmental</td>
<td>Peat</td>
<td>46.8</td>
<td>8.1</td>
</tr>
<tr>
<td></td>
<td>Species-Rich Grassland</td>
<td>214.8</td>
<td>37.3</td>
</tr>
<tr>
<td></td>
<td>Agricultural Land Grade 5 – Peat Bog</td>
<td>164.5</td>
<td>28.5</td>
</tr>
<tr>
<td></td>
<td><strong>TOTAL</strong></td>
<td><strong>426.1</strong></td>
<td><strong>73.9</strong></td>
</tr>
<tr>
<td>Policy</td>
<td>High Quality Agricultural Land (1-3)</td>
<td>54.4</td>
<td>9.4</td>
</tr>
<tr>
<td></td>
<td>National Parks</td>
<td>22.8</td>
<td>4.0</td>
</tr>
<tr>
<td></td>
<td>National Nature Reserves</td>
<td>1.2</td>
<td>0.2</td>
</tr>
<tr>
<td></td>
<td>Local Nature Reserves</td>
<td>0.4</td>
<td>0.1</td>
</tr>
<tr>
<td></td>
<td>Sites of Special Scientific Interest</td>
<td>114.2</td>
<td>19.8</td>
</tr>
<tr>
<td></td>
<td>Registered Parks and Gardens</td>
<td>1.1</td>
<td>0.2</td>
</tr>
<tr>
<td></td>
<td>Scheduled Monuments</td>
<td>1.4</td>
<td>0.2</td>
</tr>
<tr>
<td></td>
<td>RAMSAR sites</td>
<td>27.8</td>
<td>4.8</td>
</tr>
<tr>
<td></td>
<td>Special Areas of Conservation</td>
<td>29.1</td>
<td>5.0</td>
</tr>
<tr>
<td></td>
<td><strong>TOTAL</strong></td>
<td><strong>252.4</strong></td>
<td><strong>43.8</strong></td>
</tr>
</tbody>
</table>
Constraint-free land occupies an area of 106.1 km² (18%). This means that it is more than feasible for Lancaster City Council to plant 1,000,000 trees across the district of Lancaster, excluding environmental, physical and policy constraints, which may only occupy 6.25 km² (1.1%) if 2.5 m spacings are adopted. In spite of that, the land available for tree planting is distributed unequally across the district (Figure 6). The Bowland Fells and the Morecambe Coast are entirely absent of land available for tree planting. In contrast, a large quantity of this available land exists between the Bowland Fringe and Pendle Hill region which spans the district’s centre. The challenge now is to look within this available space to find the best locations to achieve the 6.25 km² target whilst satisfying multiple ecosystem services objectives.

4.2 Opportunities Mapping

When all opportunities are considered, suitability scores across the Lancaster district range from 43% to 85% (Figure 7a). The areas most suitable for woodland creation are where multiple opportunities overlap, such as the Bowland Fringe and Pendle Hill region where rivers and woodlands are prominent landscape features. As a result, this area seems to be the most appropriate for the creation of "multiple benefit woodlands" outlined in section 2.2. In contrast, areas on the district’s outskirts are less suitable for woodland creation (such as the Bowland Fells), potentially where there is a lesser population requirement. Nevertheless, suitability for woodland creation in the district is highly influenced by each opportunity group (Figure 7).

When all flood risk mitigation opportunity layers are considered (Figure 7b), suitability scores across the Lancaster district range from 29% to 1% (perfectly suitable). Here, suitability scores take a more equal distribution across the district.

When all public benefit opportunity layers are considered (Figure 7c), suitability scores range from 23% to 1%, favouring the district to the west.

When all biodiversity conservation opportunity layers are considered (Figure 7d), suitability scores range from 31% to 1%, spanning a range of available areas across the district.
Figure 7. Opportunity maps produced using a weighted map overlay, showing the distribution of suitability scores across the district. Land within a close proximity to opportunity layers, and therefore most suitable, represents a greater suitability score (red). Land further away from opportunity layers, and therefore less suitable, represents a lower suitability score (blue). A) All 8 opportunity layers. B) All 4 flood risk mitigation layers. C) All 2 public benefit layers. D) All 2 biodiversity layers.
4.3 Woodland Creation in Practice

Two alternative scenarios were played out to demonstrate how differently 6.25 km² (1,000,000 trees) could look across the district (Figures 8-9).

Figure 8. Scenario 1. An example scenario of woodland creation, plotted to achieve 1,000,000 trees across Lancaster whilst satisfying multiple ecosystem service objectives. Sites have a collective area of 7.1 km², equivalent to 1,136,000 trees.
Figure 9. Scenario 2. An example scenario of woodland creation, plotted to achieve 1,000,000 trees across Lancaster whilst satisfying multiple ecosystem service objectives. Sites have a collective area of 6.3 km², equivalent to 1,008,000 trees.
Scenario 1 illustrates how 1,000,000 trees could be planted with just two large patches of woodland (Figure 8). The patches are located within, or at least in a close proximity to, a "priority place", meaning that these woodlands could benefit more deprived communities. These potential sites are also near the M6 and other road networks, which means they are accessible to members of the local community to facilitate engagement with nature. The patches reconnect fragments of existing woodland, including ancient woodlands, which will serve to boost biodiversity conservation by increasing connectivity. They are also adjacent to River Lune flood risk areas, which means that they may help to attenuate flood flows. As a result, scenario 1 could achieve multiple ecosystem service benefits across the Lancaster district.

Scenario 2 serves to show how 1,000,000 trees could be planted with 10 small patches of woodland, ranging from 0.05km² to 1.2km² in size, and distributed across a variety of locations across the district (Figure 9). Here, proposed sites of woodland creation seek to connect patches of existing woodland, including ancient woodlands, to extend biodiversity networks. Sites have been proposed near to the green belt and within "priority places" to make woodland areas more accessible to population centres and more deprived communities. Sites have also been proposed close to flood risk areas to enhance flood storage and reduce flood flows. Similar to scenario 1, scenario 2 could also satisfy multiple ecosystem services across the Lancaster district.
5. Discussion

5.1 Land Availability

Suitability maps have been generated to identify potential areas of land across the district of Lancaster, where woodland creation may occur without undermining other essential land uses (Figure 5). These maps were the product of environmental, physical and policy constraints to tree planting to ensure woodland creation only occurs on appropriate land (Figure 4). Based on the assumptions made in this study, a total of 106 km² was identified as potentially available, which is ample considering only 6.25km² of this is required to plant 1,000,000 trees at 2.5m spacings (Figure 6).

Opportunity maps identified that the planting of 1,000,000 trees could be used to solve a catalogue of other environmental issues beyond carbon sequestration, such as biodiversity conservation, flood risk management and for the public's benefit – simultaneously (Figure 7). It has been made possible to target woodland creation adjacent to existing woodlands or, better yet, ancient woodlands to increase the connectivity between fragmented woodlands to enhance species and structural diversity (Figure 7d), or close to flood risk areas to intercept, slow, store and filter water to reduce flood peaks and slow floodwaters (Figure 7b). Targeting woodland creation in areas accessible to the public, especially deprived communities, has also been made possible (Figure 7c). A Community Forest model may even be adopted to provide residents with much-needed access to nature to support their wellbeing and engagement with the natural world, which may ultimately facilitate economic and social regeneration (The Woodland Trust, 2011).

Nevertheless, whilst "multiple benefit woodlands" have been the integral aim of the study, the concept of multi-functionality has brought its challenges. The suitability maps showed an uneven distribution of areas available for planting, particularly in the more remote regions of Lancaster such as the Bowland Fringe and Pendle Hill region that has a disproportionate amount of land available for planting and thus will see a majority of the woodland creation. Accordingly, large swathes of the district are unavailable for planting such as the Morecambe and Heysham Coast and the Bowland Fells. This imbalance will isolate a large proportion of the community from the public benefits of having a woodland on their doorstep, as well as
potentially exceeding the limits to woodland cover in those areas classified as suitable. Nonetheless, this trade-off is commonplace in woodland creation design. Shrubsole and Gordon-Smith (2019) struggled to increase woodland cover in a close proximity to urban areas because they found that, because towns and cities were initially established near productive soils, these areas were most likely to be classified as high-quality agricultural land (ALC grades 1-3), and therefore unsuitable for tree planting. Whereas, the lowest quality agricultural land (ALC grade 4), which is the most suitable agricultural land grade for tree planting, is more likely to be present in the more remote and isolated parts of the district, making it challenging to target sites for public benefit.

5.2 Community Acceptance

This framework took an objective approach to determining land availability and suitability for woodland creation using clearly identified criteria to aid decision-making for woodland creation elsewhere. However, what it did not consider were the more qualitative factors that may govern actual availability. Examples of these less quantitative factors may include social acceptability to tree planting programmes and land ownership and tenure. This framework does not intend on being a top-down model used to impose land-use change on others, and so it is entirely within the rights of landowners who may possess perfectly suitable land for woodland creation to reject this. Land ownership data is particularly difficult to access and consequently did not fall within this investigation's remit. It is therefore viable that land identified as available is in fact not suitable for woodland creation. The farming industry has had a history of resistance to forestry (Scambler, 1989; Dhubháin and Gardiner, 1994; Bell, 1999). This is because, despite the well-known benefits of agroforestry, some farmers are less receptive to tree planting over the concerns of land devaluation and a loss of productivity when converted from agricultural land to woodland. Another obstacle is the fear that they may be unable to absorb this reduction in value without financial assistance, especially when grants are perceived as being unnecessarily bureaucratic or economically insufficient (Lawrence and Dandy, 2014).

Similarly, local communities may be apprehensive of woodland creation because it may change the local landscape's character or become too intimidating. Studies have shown that with the increasing intensity of afforestation in a landscape, scenic beauty decreases - except for
moderate-level afforestation, which positively affects scenic beauty (Tahvanainen et al., 1996). Consequently, the optimal percentage for the desired amount of forest cover has been defined at between 25% and 50% (van der Horst, 2006), or a 1/3 or 2/3 ratio (Tahvanainen et al., 1996; Bell, 1998). Ultimately, the acceptance of trees by communities and farmers must be secured through stakeholder engagement and education.

Participatory GIS tools (PGIS) have been utilised to incorporate local perceptions into the evidence base to plan and develop scenarios (Brown and Fagerholm, 2015). Natural England produced a PGIS tool in 2015 to record public perceptions of the natural environment in the Morecambe Bay area (Davies et al., 2015). By getting users to place digital pins onto Ordnance Survey and satellite maps, the tool sought to identify locations where people experienced cultural ecosystem services (Ecosystem Knowledge Network, 2015). Similar software could perceive where the public might want to see woodland creation across the district. Accordingly, this dataset could be layered with other spatial data in GIS to identify correlations and, therefore, provide a solution to community resistance.

5.3 Further Study Potential and Limitations

The role of spatial distribution and area of these woodland patches in biodiversity conservation is a critical, albeit contentious, topic – the SLOSS debate (Diamond, 1975) – that requires further research. Scenarios 1 and 2 demonstrate the alternative possibilities of woodland creation in Lancaster (Figures 8-9). On the one hand, larger woodland patches generally have greater species richness and abundance, perhaps because of the direct effect of habitat area on population size and because larger woodlands are more likely to contain a higher microhabitat diversity and be less affected by edge effects (Eycott et al., 2007). From a water quality perspective, fewer and larger woodland areas are said to be more beneficial than numerous smaller woodlands because edge effects are known to promote evapotranspiration and pollutant deposition (Nisbet et al., 2011). In this case, scenario 1 may be better for biodiversity conservation objectives, where there are larger and fewer patches of woodland (Godefroid and Koedam, 2003). However, because even individual trees can provide important steppingstones for biodiversity across the landscape, smaller patches should not be discounted (Lander et al., 2010). Smaller patches can have a greater potential for ecosystem service delivery because they can be more practical and less likely to suffer from disease (Valdés et al.,
Fahrig (2017) even argues that habitat fragmentation can have largely positive effects on biodiversity. For public benefit, fewer and larger woodlands planted across the district will be more concentrated and therefore less accessible to the local community. For this reason, Scenario 2 may be more beneficial for achieving public benefit objectives where there are several small patches of woodland. Ultimately, further research should investigate the spatial distribution and patch sizes of woodland creation in Lancaster to further enhance ecosystem service benefits.

The investigation could be extended further by relaxing certain constraints. For instance, close to half of the land was made unavailable by policy constraints. Albeit necessary to protect local landscapes' character, some of the National Park or SSSI land could be afforested to meet planting targets. Therefore, removing policy constraints would add another 252km² which would add a great deal of flexibility to the programme, especially considering ownership and acceptability are likely to be barriers to woodland creation unaccounted for in the study.

Additionally, high-quality agricultural land comprises a significant proportion of land made unavailable due to policy constraints - specifically agricultural land grade 3 which constitutes around half of the agricultural land across England and Wales (Ministry of Agriculture, Fisheries and Food, 1988). Whilst England (and therefore the dataset used in this study) follows a broad classification for "good to moderate quality land", Scotland and Wales divide ALC grade 3 into 3.1 and 3.2, and 3a and 3b respectively. Classifications 3.2 and 3b are therefore indicative of lower-yielding land compared to their counterparts and so could be used for tree planting, without encroaching on higher-yielding agricultural land. If there was a way to divide ALC grade 3 in England, more land could be made available for woodland creation, and thus this should be investigated further.

The opportunity layers used to represent public benefit, particularly the "priority places" dataset, were too coarse and generalised. Subsequently, this meant that deprived communities and public access provision could not be accurately represented, especially as it only targeted the Lancaster and Morecambe region of the district - ultimately ignoring deprivation elsewhere. Alternative methods for more accurately targeting where woodland creation would best benefit people could include the Index of Multiple Deprivation dataset, which would provide a more representative picture of the population's socio-economic profile.
Once again, community engagement through public consultation/PGIS could make the site selection process more democratic, by selecting locations where the local community would like to see increased woodland cover.

5.4 Carbon Sequestration

Ultimately, this investigation successfully identified and illustrated where 1,000,000 trees could be planted across the district of Lancaster. However, after plotting the potential sites of woodland creation across the district, the degree of ambition surrounding the 1,000,000 trees target may be questioned. The other ecosystem service benefits, beyond carbon sequestration, have been discussed and there seems to be a high degree of ecosystem service delivery potential across the district for flood risk mitigation, biodiversity conservation and public benefit.

When calculating the annual carbon sequestration rate for 1,000,000 native broadleaved trees in Lancaster, this target’s carbon sequestration potential seems negligible. Carbon sequestration potential is dependent on the trees' age, spacings, yield class and choice of management strategy (Woodland Carbon Code, 2020). Based on the assumptions that the trees are planted at 2.5m spacings with a yield class of 10, over a 100-year period, it was calculated that 1,000,000 trees could sequester 6731 tonnes of carbon per year. These calculations can be found in Appendix 1.

Assuming that the average UK person emits 5.3 tonnes of carbon dioxide annually (Carbon Brief, 2020), 1,000,000 trees may only serve to offset 1,270 people's emissions, which is around 7.7% of the Lancaster University population (Lancaster University, 2020), and 0.9% of the district of Lancaster's population (Lancashire City Council, 2020). In order to offset the university population alone, Lancaster City Council would need to pledge to plant 13,700,000 trees, which would occupy 81.69km². In order to offset the district of Lancaster's population, Lancaster City Council would need to pledge to plant 115,000,000 trees, which would occupy 718.69km² - which is beyond the land mass of the district alone! Therefore, to increase the carbon sequestration potential of woodland creation in order to hold some weight behind national climate targets, woodland creation targets need to be significantly more ambitious, especially as 1,000,000 trees only consumes 1.1% of the district's land area.
6. Conclusion

This analysis has identified three broad areas of land: 168km² of land that is biophysically and biologically unavailable for woodland creation (physical), 252km² of land that is affected by local and national policy designations concerning areas of environmental, geological and archaeological importance (policy) and, most significantly, 426km² of land that would be adversely affected by woodland creation (environmental). Consequently, based on the assumptions made in this study, a total of 470km² of land is unavailable for tree planting in Lancaster, leaving just 106km² for woodland creation. However, this is considered ample land to meet Lancaster City Council's target of planting 1,000,000 trees across the district of Lancaster, which may only require 6.25km² of land.

Amidst a global climate and ecological emergency, a spatially targeted method that seeks to carefully select sites to maximise the multiple ecosystem service benefits that trees provide is crucial to achieving environmental targets. The opportunity maps produced proved that, across the Lancaster district, it is possible to plant multi-benefit woodlands that aim to ensure biodiversity protection, flood risk management and people's engagement with nature. However, it also demonstrated that 1,000,000 trees might not be ambitious enough for carbon sequestration objectives.

This Geographical Information Systems framework was beneficial for several reasons. It used the most up-to-date and highest resolution datasets to ensure that past afforestation mistakes were not repeated. It did this by excluding various land uses and classifications, landforms and land types from the decision-making framework to avoid unintended environmentally-damaging consequences. The framework also integrated multiple ecosystem services, including biodiversity conservation, flood risk mitigation, and public benefit, which would be necessary to maximise the initiative's efficiency and help solve the catalogue of environmental problems that the district faces. For this reason, I believe that the method has wider potential application for woodland creation programmes across the country.

The next challenge is engaging landowners and community members with the results of the study to increase the acceptability of tree planting in areas classified as suitable. This may be done through participatory GIS, orchestrated through workshops, consultation and education.
7. Acknowledgements

I wish to acknowledge and extend my gratitude to:

- Professor Duncan Whyatt for supervising me throughout this project and providing constant guidance to ensure it ran as smoothly as it did.
- Lancaster City Council for inspiring this project, providing me with help and ideas to kickstart this project and for their permission to pursue it.
- Thomas Burke for his insight into carbon calculations.
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9. Appendix

Appendix 1. Carbon calculations and assumptions.

1 million trees are equivalent to 625ha/6.25km² (2.5m spacings).

SAB species refer to sycamore, ash and birch species – including alder, ash, aspen, big leaf maple, downy/silver birch, bird cherry, black poplar, blackthorn, cider gum, common alder, common lime, crab apple, crack willow, field maple, goat willow, green alder, grey willow, hawthorn, hazel, holly, horse chestnut, rowan, sycamore, whitebeam, wild cherry, wild service tree.

Yield class for Lancaster is equivalent to 10 – the average yield class of listed SAB species, including ash, aspen, alder, birch, cherry, lime, maple, poplar species.

Source: http://www.forestdss.org.uk/geoforestdss/

Woodland Carbon Code Carbon Calculation Spreadsheet (Biomass Carbon Lookup Table):

<table>
<thead>
<tr>
<th>Species</th>
<th>Spacing (m)</th>
<th>Yield Class</th>
<th>Management</th>
<th>Period (year)</th>
<th>Total (tCO₂/ha/5yr period)</th>
</tr>
</thead>
<tbody>
<tr>
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<td>48.1</td>
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</tr>
<tr>
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</tr>
<tr>
<td>SAB 2.5</td>
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<td>NO_thin</td>
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<td>88.1</td>
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TOTAL (100 year period) 1076.8
ANNUAL 10.77 (2d.p.)

(Woodland Carbon Code, 2020)

Carbon sequestration per hectare per year is equivalent to 10.77tCO₂.
Carbon sequestration per year for 625 hectares is equivalent to 6371tCO₂.
Average UK person carbon emissions is equivalent to 5.3tCO₂ (Carbon Brief, 2020).
Carbon offset potential is equivalent to 6731/5.3, which equals 1270 people.

Population Statistics
Lancaster University Population: 16,595 (Lancaster University, 2020)
Lancaster District Population: 146,038 (Lancashire County Council, 2020)