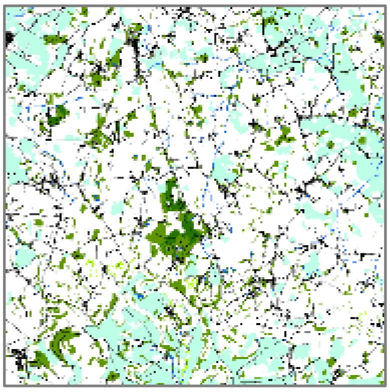
Tree Suitability Modelling – Planting Opportunities for Sessile Oak and Sitka Spruce in Wales in a Changing Climate

Final report



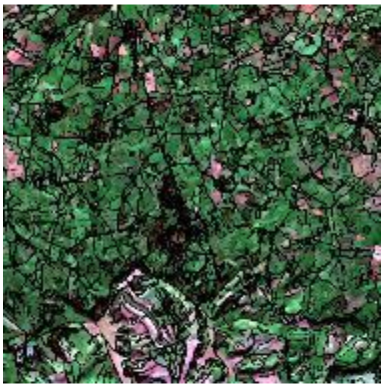


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Table of Contents

Executive Summary

The UK government has legislated a target to reduce UK GHG emissions to net zero by 2050, based on the advice of the Committee on Climate Change.[1] The net zero target requires contribution from all sectors of the economy, including the agriculture and land use, land use change and forestry (LULUCF) sectors. In their net zero advice,[2] the Committee estimated that afforestation in Wales could reach 152,000 hectares (1520 km^2) between now and 2050 through a mix of conifer and broadleaf planting. Their work did not consider a spatial mapping of where these trees could be planted now and in the future under different climate scenarios.

This study was commissioned by the Committee on Climate Change (CCC) to demonstrate the applicability of spatial modelling to species and site selection, in order to reach the tree planting target.

This project utilised preliminary work from the Welsh Government Capability, Suitability and Climate Programme, which is producing updated soil and Agricultural Land Classification (ALC) maps for Wales, and combining these with other biophysical datasets to model land capability and suitability for growing 118 crops. These suitability models are being developed for the present day, and also for a range of climate change scenarios by incorporation of UKCP18 data.

This project focussed on two tree species; sessile oak and Sitka spruce (with exploratory work undertaken for beech), and selected time periods / climate change scenarios: the present day; and medium and high emissions scenarios for 2050 and 2080. It includes identifying current policy and legislative constraints that effectively prevent or restrict tree planting, and for which spatial datasets are readily available. The project considered constraints including areas of deep peat, Priority habitats, and Best and Most Versatile land (ALC); and sensitivities such as historic and open access land.

The constraint and sensitivity datasets were applied to the pure biophysical models, to allow a comparison of areas that are biophysically suitable for tree planting i.e. areas where the environmental conditions are favourable, with areas that are feasible overall for planting, given current policy. Statistical analysis was then undertaken to summarise the land areas predicted to be either Suitable, of Limited suitability, or Unsuitable for sessile oak and Sitka spruce, in the present day and under climate change.

Sitka spruce and sessile oak are both tolerant of a wide range of biophysical conditions found in Wales, but there are differences between these species, largely driven by their different rooting depth strategies. Sitka spruce is a shallow-rooted species that extends long, lateral roots, while oak is a deeper-rooted species. As a result, oak requires areas with deeper soils, and grows best in areas where the soils are

[1] CCC (2019) *Net zero – the UK's contribution to stopping global warming.*

[2] CCC (2019) *Net Zero Technical Report*.

not stony at depth. The shallow-rooting strategy of Sitka renders the most drought-susceptible soils unsuitable for this species, whereas oak is more tolerant. Both species are tolerant of climatic factors leading to all but the strongest frost events. Climatic conditions leading to high soil wetness (defined by the ALC wetness category) currently restricts the suitable area for oak in the uplands of Wales, but this is less limiting for Sitka spruce.

The results demonstrate the high value of spatially mapping the areas of land capability and suitability, by highlighting the changing distribution and extent of key limiting factors that affect overall land suitability for the species. The area summaries show that the amount of land predicted to remain suitable for sessile oak and Sitka spruce by 2080 is set to decline significantly, and therefore in order for the planting ambition to be met, it is likely that planting will need to be carried out in areas subject to certain biophysical limitations, where growth may not be optimal in all years.

The key results from the study are:

Sessile oak

- The suitability model estimates that there is currently 2561.4 km^2 suitable land when both biophysical suitability and manmade constraints (such as deep peat areas) are considered. The suitable areas are concentrated in the lowland, western areas of Ceredigion, Carmarthenshire and Pembrokeshire, with other notable areas on Anglesey, northeast Powys, Flintshire, and lowland areas of Glamorganshire and Monmouthshire.

- By 2050 there is estimated to be 1940.8 km^2 suitable land under the medium emissions scenario, or 1925.9 km^2 under high emissions (values do not include manmade constraints). The suitable area declines, particularly in eastern parts of the country in Flintshire, Monmouthshire, northeast Powys, and south Glamorganshire, because of changing temperature and rainfall patterns, and their effect on the more drought-susceptible soils in these areas.

- It is important to consider manmade constraints in addition to purely biophysical factors, in order to gain a realistic estimate of land available for tree planting. This study considered a number of such constraints, including prime agricultural land, areas of deep peat, sites of importance for biodiversity and ecological resilience, and cultural factors (particularly land ownership) that may limit planting schemes in some way.

- Some areas that are currently suitable may not be suitable in 2050. Conversely, some areas that are currently of limited suitability may become more suitable by 2050.

- Although the current tree planting ambition relates to 2050, planting schemes should take a longer-term view, in order to consider the acceleration of geographic shifts in land suitability, combined with accelerated contraction of suitable areas, which is predicted to occur between 2050 and 2080; these trends could affect the viability of woodlands planted between now and 2050.

- It is estimated that only 1072.9 km^2 land that is currently suitable for sessile oak will remain suitable by 2080 under medium emissions, or 599.7 km^2 under high emissions (including manmade constraints).
- The areas of highest resilience to climate change in terms of continued suitability for sessile oak, are located in Ceredigion and Carmarthenshire, with smaller pockets of land occurring elsewhere.

- Overall, the CCC's planting ambition for Wales (1520 km^2) by 2050 can be met using land deemed suitable. However, the planting targets should take a long-term (2080) view in order to ensure long-term sustainability of this area of woodland; a longer-term view shows that this ambition is unlikely to be met using suitable land alone, and areas of more limited land will likely need to be considered. This highlights the importance of spatial trend mapping and careful site selection.

Sitka spruce

- The suitability model estimates that there is currently 3306.2 km^2 suitable land when both biophysical suitability and manmade constraints (such as deep peat areas) are considered. The suitable areas are concentrated in the lowland areas throughout Wales, while the upland areas are of limited suitability; very little of the country is unsuitable from a purely biophysical perspective.

- By 2050 there is estimated to be 2184.9 km^2 suitable land under the medium emissions scenario, or 1919.1 km^2 under high emissions (values do not include manmade constraints). The suitable area declines, particularly in eastern parts of the country in Flintshire, Monmouthshire and northeast Powys, but also in Anglesey, south Pembrokeshire and south Glamorganshire. This is due to changing temperature and rainfall patterns, and their effect on the more drought-susceptible soils in these areas.

- As with sessile oak, it is important to consider manmade constraints in addition to purely biophysical factors, in order to gain a realistic estimate of land available for tree planting.

- Some areas that are currently suitable may not be suitable in 2050. Conversely, some areas that are currently of limited suitability may become more suitable by 2050.

- A dramatic geographic shift in areas suitable occurs between 2050 and 2080; in the present day and 2050 climate, the most suitable areas are in the Welsh lowlands. However, by 2080 the lowland areas are of limited suitability, and the upland areas of Wales become suitable. This means that the majority of areas currently suitable for Sitka spruce will not be suitable by 2080. Furthermore, many of the upland areas becoming suitable by 2080 will in all likelihood not be available for planting, due to the concentration of deep peat and high value habitats in these areas.

- It is estimated that only 819.7 km^2 land that is currently suitable for Sitka spruce will remain suitable by 2080 under medium emissions, or 273.8 km^2 under high emissions (including manmade constraints).

- Although the current tree planting ambition relates to 2050, planting schemes should take a longer-term view, in order to consider the large geographic shift in land suitability, switching from lowland to upland areas, which is predicted to occur between 2050 and 2080; these trends could affect the viability of woodlands planted between now and 2050.

- There are larger areas of land suitable for Sitka spruce than for sessile oak at every standalone time point analysed in the study (present day, 2050, 2080). However, when looking at the stability of suitable land over time, there is predicted to be less land consistently suitable for Sitka than for oak. This means that Sitka spruce is more likely to become limited by biophysical factors.
- The areas of highest resilience to climate change in terms of continued suitability for Sitka spruce, are predominantly located in west Wales; the Lleyn peninsular, Ceredigion, Pembrokeshire and Carmarthenshire, with smaller pockets of land occurring elsewhere.

- Overall, the CCC's planting ambition for Wales (1520 km^2) by 2050 can be met using land deemed suitable for Sitka spruce. However, the planting targets should take a long-term (2080) view in order to ensure long-term sustainability of newly planted woodlands.

Considering land that is currently suitable and remains suitable in 2050 and 2080, there is a large overlap between areas suitable for sessile oak and areas suitable for Sitka spruce. Sitka spruce is predicted to become more vulnerable to changes over time than sessile oak, while the areas suitable for oak are more geographically stable over time.

In summary, the CCC ambition to plant 1520 km^2 of woodland by 2050 is achievable purely in terms of available suitable land (and limited suitability land), but would require significant changes in the agricultural sector. The CCC scenarios take account of the need to maintain food production at current per capita levels by 2050 without increasing imports, based on future agricultural productivity growth. These changes will require careful planning across the UK to ensure a fair transition to alternative land uses.

In areas prioritised for tree-planting, further decisions must be made as to the balance of species planted, given that the two different species studied compete for much of the same space. Additionally, decisions must be taken regarding how much suitable versus limited suitability land can be utilised in the face of other competing land uses, such as agriculture and renewable energy generation.

The biggest emerging limitation to tree growth in Wales is soil droughtiness, which could significantly impact forest biomass and the effectiveness of climate change mitigation through tree planting. The impact of increasing droughtiness on timber biomass should be considered when selecting sites for tree planting, and when estimating the expected gain in terms of climate mitigation.

Where tree planting is to be carried out on areas of limited suitability, or areas predicted to become limited within the lifetime of the woodland, the impact of these limitations on biomass should be considered, and the planting ambition increased accordingly in order to derive the required mitigation benefits.

1 Introduction

1.1 Project background

In September 2019, the Welsh Government, in partnership with Environment Systems (EnvSys), ADAS and Cranfield University, undertook a trial crop suitability modelling exercise as part of the project 'Capability, Suitability and Climate Programme'; the ultimate aim of this project is to produce updated soil and crop suitability maps for Wales under a range of climate change scenarios and to facilitate visualisation of changes in soil capability and suitability for 118 crops. The initial trial comprised suitability modelling for six crops.

The CCC is tasked with advising the UK government on building a low-carbon economy and preparing for climate change. Tree planting is a multi-faceted climate mitigation strategy, providing benefits such as carbon capture, flood mitigation, temperature regulation, timber crop, and habitat supporting biodiversity and ecological resilience. Forests may also be highly valued for their aesthetic and recreational qualities.

The UK government aims to achieve net zero carbon emissions by 2050, and extensive tree planting has the potential to contribute significantly to this target through carbon capture. To meet the net zero target, CCC assumed a tree planting target of 950,000 hectares of woodland across the UK between now and 2050, with a planting target of 152,000 hectares (1520 km^2) for Wales.

To date no spatial modelling has been undertaken to evaluate the feasibility of this planting ambition given current biophysical and management constraints, and the likely changes in biophysical suitability under climate change. Therefore, Environment Systems was commissioned by CCC to adapt the spatial modelling approach from the draft 'Capability, Suitability and Climate' project for two tree species for Wales, and provide a statistical analysis of changes in suitable cultivation areas under two climate change pathways. In practice, three species were evaluated as one of the first-choice species (beech) was found to be relatively ill-suited to the Welsh environment, and so a replacement species was chosen (sessile oak).

1.2 Aims and objectives

The draft 'Capability, Suitability and Climate' crop modelling outputs evaluate land suitability for crops based on biophysical properties alone; they do not consider the spatial effects of land use policies, which effectively further restrict areas available for tree-planting. Therefore, this work amends the draft biophysical suitability models generated from the 'Capability, Suitability and Climate' project to include a range of management constraints and sensitivities, and to provide a statistical analysis of the outputs.

The project was tasked with analysing suitability for one coniferous and one broadleaved tree species. The initial species selection - which was based on the CCC's work for their net zero advice - was Sitka spruce, *Picea stichensis*, and beech, *Fagus sylvatica*; Sitka spruce was used to represent all coniferous forestry, and beech for broadleaf forestry across the UK. The latter has characteristics intermediate between fast growing species, e.g. birch, and very slow growing species, e.g. oak. However, beech is not a naturally widespread tree species in Wales, and initial analysis via the crop suitability model yielded relatively low areas of suitable land for the species. Therefore, for the full statistical analysis beech was substituted with sessile oak, *Quercus petraea*.

Land suitability for Sitka spruce and oak was evaluated for five date and climate scenarios:

- the present-day, using baseline data
- 2050 - following the medium[3] climate change scenario
- 2080 - following the medium climate change scenario
- 2050 - following the high[4] climate change scenario
- 2080 - following the high climate change scenario

A time-series analysis was also undertaken for the medium and high emissions scenarios, tracking changes in suitability between the present day and 2080.

2 Biophysical suitability modelling

2.1 Rationale

The Agricultural Land Classification dataset has been previously used for agricultural suitability modelling (Keay *et al.*,2016). The dataset is relevant for modelling tree suitability as it is a seamless national dataset that considers the fundamental biophysical factors that regulate tree growth; soil and climate. The dataset considers different aspects of climate and soil properties, and assigns a summary grade for each soil series, for each factor, according to ALC land grading guidelines (Ministry of Agriculture, Fisheries and Food, 1988). Each soil series is assigned a grade for:

- soil wetness (considering field capacity days, waterlogging and soil texture characteristics);
- droughtiness (considering soil texture and structure effects on water-holding capacity, plus moisture deficit);
- overall climate (guided by annual average rainfall and accumulated temperature as well as local factors);
- soil depth;
- gradient;
- rock;
- stone content

[3] Defined as the UKCP18 RCP6.0 emissions scenario (Moss *et al*., 2010)
[4] Defined as the UKCP18 RCP8.5 emissions scenario (Moss *et al*., 2010)

However, the dataset excludes a number of additional factors of significance to crop growth, such as wind exposure, frost risk, salt spray, and frequency and duration of flooding.

Naumann and Medcalf (2018) combined the ALC data with additional datasets for wind exposure, frost risk and salt spray to create a proof-of-concept model for potato suitability under different climate scenarios. This work is currently being further developed in the Welsh Government project ‘Capability, Suitability and Climate Programme’, which utilises updated ALC, frost, wind, salt spray and flood risk data, and climate change scenarios based on UKCP18 datasets (Lowe *et al.,* 2018). These new datasets were used to create models of biophysical suitability for a range of crops in Wales, including Sitka spruce, beech and sessile oak.

2.2 Data used

The project utilised draft biophysical datasets prepared as part of the Capability, Suitability and Climate Programme project. Certain UKCP18 climate scenario datasets had not been fully interpolated at the time of analysis, leading to a blocky appearance in some locations, and small gaps along the coastline. Datasets used to produce the tree biophysical suitability models are listed in Table 1. Detailed information on the individual datasets will be published under the Capability, Suitability and Climate Programme project.

Table 1: Datasets used in the production of the tree biophysical suitability models

Biophysical factor	Dataset used	Classes
ALC Climate	Present day models utilised the Agricultural Land Classification (ALC) for Wales (2019). Climate change scenarios utilised modelled ALC datasets derived from interpolation of the 2019 ALC and UKCP19 gridded climate data.	ALC Grades 1 – 5[5]
ALC Depth		
ALC Drought		
ALC Wetness		
ALC Stones		
ALC Rock		ALC grade 5 (rock present) or N/A (no rock present

[5] Grade 1 = Land with no or very minor limitations to agricultural use.
Grade 2 = Land with minor limitations which affect crop yield, cultivations or harvesting.
Grade 3 (subgrades 3a, 3b) = Land with moderate limitations which affect the choice of crops, timing and type of cultivation, harvesting or the level of yield.
Grade 4 = Land with severe limitations which significantly restrict the range of crops and/or level of yields.
Grade 5 = Land with very severe limitations which restrict use to permanent pasture or rough grazing, except for occasional pioneer forage crops.

<table>
<tr><td>Aspect</td><td>5m Digital Terrain Model</td><td>S & SW

Other aspects (not S or SW)

Flat</td></tr>
<tr><td>Late Spring Frost Risk</td><td rowspan="2">Present day models generated using Phase 1 habitat data, elevation (Nextmap), soil type (Soils of Wales), annual average wind exposure (see seasonal wind exposure models), and modelled daily solar irradiance. Climate change scenarios substituted elevation for UKCP18 minimum temperature data.</td><td rowspan="2">Hardly any frost

Weak, short-term frosts

Moderate severity and duration frosts

Moderate to strong severity and duration of frosts

Strong frosts

Frequent strong frosts lasting many days</td></tr>
<tr><td>Winter Frost Risk</td></tr>
<tr><td>Salt Spray Risk</td><td>Seasonal average wind exposure model, clipped to a maximum distance from the coast of 500m</td><td>Area within salt spray zone

Area outside of salt spray zone</td></tr>
<tr><td>Wind Exposure - Spring</td><td rowspan="4">All-Wales seasonal average wind exposure models were generated by interpolating weighted wind directions and speeds from six Met Office weather stations in combination with a 5m Digital Surface Model.</td><td rowspan="2">Strong winds (likely to affect crops)

Moderate winds (might affect crops)

Weak winds (unlikely to affect crops)</td></tr>
<tr><td>Wind Exposure - Summer</td></tr>
<tr><td>Wind Exposure - Autumn</td><td rowspan="2">Strong winds (likely to affect crops)

Weak winds (unlikely to affect crops)</td></tr>
<tr><td>Wind Exposure - Winter</td></tr>
<tr><td>Frequency of fluvial/pluvial flooding</td><td>Natural Resources Wales Flood Risk Assessment for Wales (FRAW 2019) layers for present day and climate change scenarios were collated into one flooding frequency layer</td><td>Area flooded during 1/10 or more severe event

Area flooded during 1/30 or more severe event

Area flooded during 1/100 or more severe event

Area flooded during 1/1000 or more severe event

Outside flood risk zone for 1/1000 events</td></tr>
</table>

Frequency of tidal flooding	Natural Resources Wales Flood Risk Assessment for Wales (FRAW 2019) layers for present day and climate change scenarios were collated into one flooding frequency layer	Area flooded during 1/10 or more severe event Area flooded during 1/30 or more severe event Outside flood risk zone for 1/30 events
Defended areas	Natural Resources Wales Flood Risk Assessment for Wales (FRAW 2019) areas defended against flooding	Area is defended against 1/10 flood event Area is defended against 1/30 flood event Area is defended against 1/100 flood event Area is defended against 1/1000 flood event Area is not defended
Duration of fluvial/pluvial flooding	Natural Resources Wales Flood Risk Assessment for Wales (FRAW 2019) used for present day and climate change scenarios	Flooding duration 0 to 2 days Flooding duration 2 to 4 days Flooding duration >4 days Areas without flooding
Urban areas	Built Up Areas Wales 2011 (urban mask used for the ALC mapping)	Area is urban / not urban
Lakes	Water Framework Directive lake waterbodies	Area is a lake / not a lake

2.3 Method

For each crop (including sessile oak and Sitka spruce), all classes of the input biophysical factors were reviewed by ADAS crop specialists and Environment Systems ecological experts, so that each factor was scored as:

- **"Suitable"** (growing conditions are optimal for the species in question),
- **"Limited suitability"** (the species can be supported, but yields are expected to be lower; or adverse weather conditions might destroy the crop in some years; or the crop needs to be managed more intensively), or
- **"Unsuitable"** (the biophysical condition does not allow for significant establishment of the crop).

The suitability scores were based on the scores used for the Capability, Suitability and Climate project, but slightly amended for in order to widen the biophysical space considered Suitable/Limited. This was done because the focus of the Capability, Suitability and Climate Programme was to assess land capability and suitability for supporting commercial crop production. However, functional woodlands can be established in a wider range of environments than would be considered for commercial forestry, therefore the suitability scores for oak were amended based on the established ecological tolerance thresholds of the species (Grime *et al.,* 1988).

In addition to the suitability scoring, each class was assigned a certainty score, expressing how comprehensive knowledge is with regards to the crop and the biophysical conditions under consideration; here, a value of 1 expressed "least certainty", a value of 3 "most certainty".

For the crop suitability modelling, all inputs were used in raster format (50m pixel size, British National Grid). Datasets were combined using raster math to derive the output value for a pixel based on the values of all pixels in the stack of input layers in the same location.

Based on all input layers, crop suitability (including sessile oak and Sitka spruce), was determined based on the following rules, summarised in Figure 1:

- If the biophysical condition in all input layers (as set out in Table 1) takes the value "suitable", the overall crop suitability is "suitable"
- If at least one biophysical condition in any of the input layers takes the value "limited suitability" and none of the input layers takes the value "unsuitable", the overall crop suitability is "limited suitability"
- If at least one biophysical condition in any of the input layers takes the value "unsuitable", the overall crop suitability is "unsuitable".

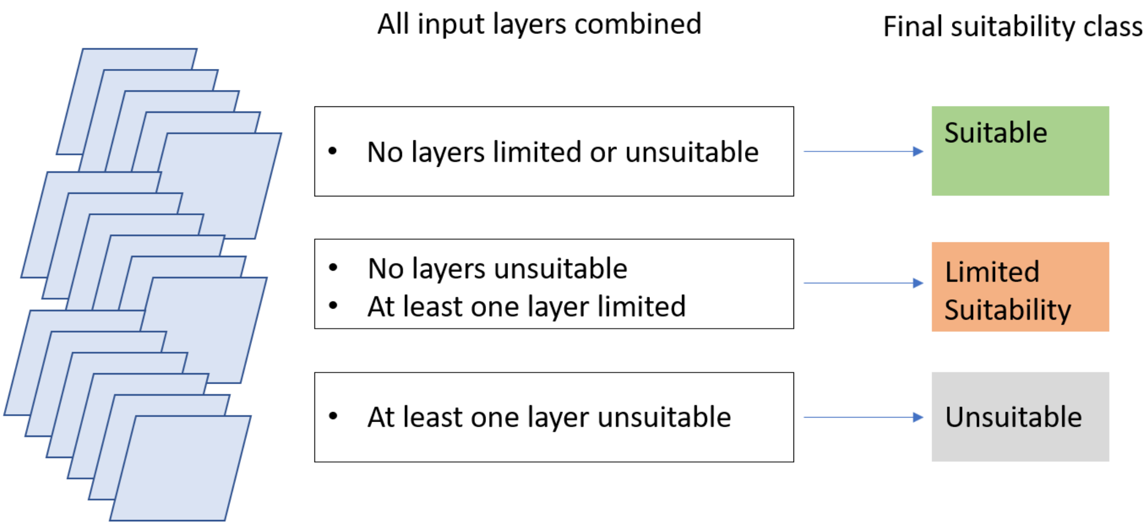


Figure 1: Method of combining multiple environmental factor datasets to produce an overall biophysical suitability class

3 Constraints and sensitivities

3.1 Rationale

The datasets used in Section 2 provide the basis for a comprehensive analysis of the locations where it would be biophysically possible for the selected tree species to grow. However, these factors do not consider aspects of existing land use policy that may restrict the area effectively available for tree planting, and as such the purely biophysical models are likely to over-estimate the total available area. For this reason, a number of masks were applied to the biophysical suitability models in order to consider non-biophysical constraints and sensitivities.

In this analysis, factors that are:

- **Constraints** serve to completely prevent tree planting under current policy/legislation; therefore, areas covered by constraints are classed as 'Unsuitable' in the final maps.
- **Sensitivities** are areas where planting may still be possible, but where there are additional considerations that may affect the type and scale of a woodland planting scheme. Areas covered by sensitivities are classed as 'Limited suitability' in the final maps.

A list of constraints and sensitivities considered by the project is provided in Table 2.

Table 2: List of constraints and sensitivities considered by the project

Constraint factor	**Notes**	**Sensitivity factor**	**Notes**
Existing peat	All areas are a constraint.	Common land	All areas are a sensitivity.
Priority habitats and existing land use	Priority habitats and urban areas are constraints.	Priority habitats and existing land use	Coniferous plantations are a sensitivity.
Best and most versatile land (BMV); overall ALC grades 1, 2 and 3a	Present day: all BMV areas are a constraint. 2050 and 2080: areas of current BMV that remain BMV are a constraint. 2080: areas becoming BMV are a constraint	Best and most versatile land (BMV); overall ALC grades 1, 2 and 3a	2050 and 2080: areas of current BMV that are no longer BMV: sensitivity. 2050: new areas of BMV, that are then lost by 2080: sensitivity.
Designated sites	All designated sites are a constraint.	Stone walls	All areas are a sensitivity.
Historic sites	Scheduled Ancient Monuments (SAMs) are a constraint.	Historic sites	Other historic sites (non-SAMs) are a sensitivity.
		Acid sensitive catchments	All areas are a sensitivity.
		Open spaces	All areas are a sensitivity.

3.2 Effects of constraints/sensitivities

Each individual constraint and sensitivity is significant in affecting the distribution of areas suitable for tree planting. However, some factors are more significant than others, in that they affect a wider geographic area than others, and some factors are more prone to change under climate change (e.g. soil drought changes whereas gradient does not). Some factors are more significant for one species than another.

The different constraints and sensitivities operate in different locations, therefore the maps which display a combination of factors become increasingly complex, with the amount of suitable area for planting decreasing. Appendix A shows a series of maps which outline the impact of individual constraints and sensitives on the planting areas available for the crops.

Appendix B contains bar graphs summarising the total land that is Suitable/Limited Suitability/Unsuitable underneath each constraint/sensitivity, for sessile oak and Sitka spruce, under each scenario.

Appendix C contains bar graphs summarising the area that would become Suitable if one individual constraint/sensitivity were removed (geographic locations where there is only one constraint / sensitivity in operation i.e. not areas where there are multiple overlapping constraints / sensitivities).

For the purpose of this study the constraint and sensitivities datasets were scored identically for all tree species.

3.3 Data used

For the constraints and sensitivities, the datasets used to produce the tree management suitability models are listed in Table 3

The unique attributes of the input datasets listed in Table 3 were scored according to whether they rendered an area Suitable/Limited suitability/Unsuitable for growing trees (constraint and sensitivity datasets were scored the same way for both sessile oak and Sitka spruce meaning that the same areas were mapped as constraint/sensitivity for both species).

Combining all layers into one overall crop suitability layer followed the same method described in section 2.3, to create a map which considered both biophysical and non-biophysical suitability for each species.

Table 3: Datasets used as constraints and sensitivities to modify the tree biophysical suitability models

Constraint or sensitivity factor	**Reason**	**Dataset used**	**Classes/Scores**
Existing peat	Peat soils have high carbon storage value; planting trees in these areas would degrade the peat and release the stored carbon.	Soils of Wales dataset	Area is a peaty soil – Unsuitable Area is not a peaty soil - Suitable
Priority habitats and existing land use	Priority habitats are important sites for biodiversity and are protected by legislation. Coniferous plantations offer opportunities for re-planting once the existing timber has been harvested.	Phase 1 habitats	Area is a priority habitat, arable or urban area – Unsuitable Area is not a priority habitat - Suitable Area is existing coniferous plantation - Limited
Best and most versatile land (BMV); overall ALC grades 1, 2 and 3a	Best and most versatile land is land classified as the highest agricultural capability grades, and is protected from urban development and woodland planting by Planning Policy Wales (PPW)	Predictive ALC (2019 and climate change scenario models).	Present day: Area is currently BMV – Unsuitable Area is not currently BMV – Suitable Climate change scenarios: Area is currently BMV and will stay BMV under climate change – Unsuitable Area is currently BMV but is forecast to not remain BMV under climate change – Limited suitability Area is not currently BMV but is forecast to become BMV under climate change – Unsuitable

			Area is not currently BMV and will not become BMV under climate change– Suitable
Designated sites	Designated sites are important for biodiversity and are protected by legislation	SACs, SPAs, SSSIs, NNRs, LNRs	Area is a designated site – Unsuitable Area is not a designated site - Suitable
Historic sites	Scheduled Ancient Monuments are protected by legislation. Other historic sites have high cultural value, which means that any planting in these areas should consider the impact on the features of historic interest.	SAMs Historic Landscapes (Welsh Government)	Area is a Scheduled Ancient Monument – Unsuitable Area is a non-SAM historic site – Limited suitability Area is not a historic site - Suitable
Acid sensitive catchments	Particular care should be taken during species selection and planting location within acid sensitive catchments in order to protect water quality	NRW Acid Sensitive Catchments	Area is ‘At Risk’ or ‘Failing’ status – Limited suitability Area is not acid sensitive - Suitable
Common land	Planting schemes should consider open access and grazing rights, and engage in wider consultation	CRoW Access Land	Area is CRoW accessible land – Limited suitability Area is not CRoW accessible land - Suitable

Stone walls	Stone walls are a distinctive and valued part of the landscape in several parts of Wales, and should be considered within planting schemes.	NRW LANDMAP Visual and Sensory assessment	Area is characterised by its stone walls – Limited suitability Area is not characterised by stone walls - Suitable
Open spaces	Planting may detract from the aesthetic qualities of areas that are highly valued for their openness	NRW LANDMAP Visual and Sensory assessment	Area is rated 'Open Land - Outstanding' or 'Open Land -High' – Limited Area is not rated 'Open Land - Outstanding' or 'Open Land -High' - Suitable

4 Results

4.1 Biophysical suitability for beech

The initial analysis of land suitability for beech revealed very little area of suitable land in the present day or in the future scenarios, with high areas of land either unsuitable or subject to limitations (Figure 2). A review of the scoring for individual biophysical factors revealed that the limitations for beech were largely driven by soil wetness class in the present day, with most areas being limited by high wetness. Small decreases in wetness are predicted under the 2050 and 2080 scenarios, but this did not lead to an increase in suitable areas due to the emergence of limitations in the drought factor. As a result, beech was excluded from further analysis and replaced with a species more adapted to the present-day Welsh climate; sessile oak.

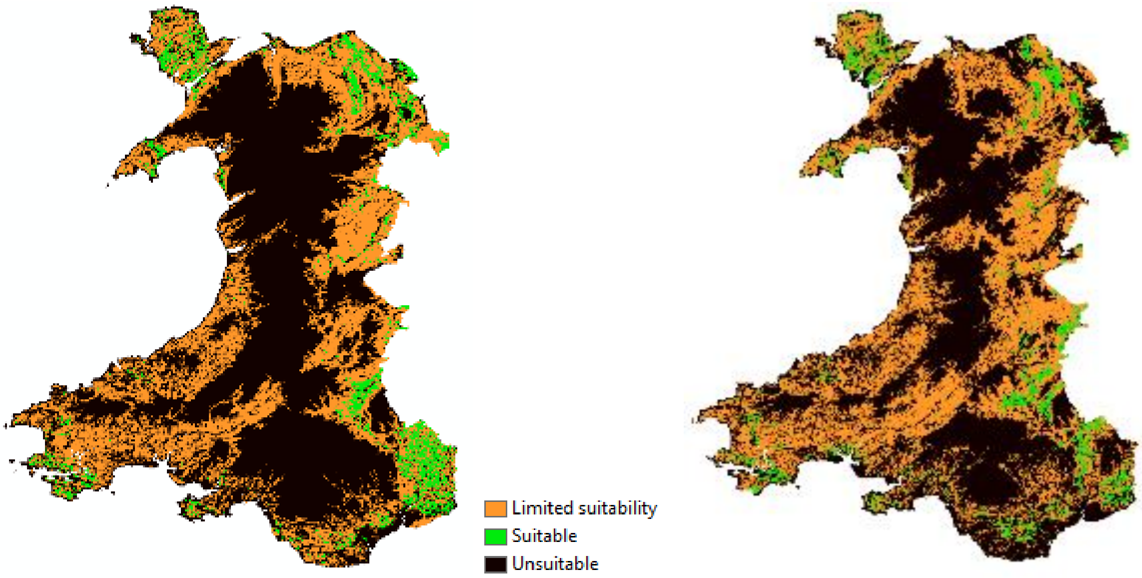


Figure 2. Biophysical suitability for beech in the present day (left) and in 2050 under the medium emissions scenario (right)

4.2 Suitability for sessile oak at discrete time periods

Sessile oak is tolerant of a wide range of biophysical conditions found in Wales, but does not tolerate permanently waterlogged soils (which cover a large proportion of upland Wales, with smaller pockets distributed throughout the lowlands). It is a deep-rooted species, and therefore sustains stronger growth on deeper soils. Soils with a high stone content within the rooting zone are less favourable for oak than soils of lower stone content, as a high stone content reduces the available water capacity within the soil. Some winter chilling is required for germination, but once established, oak is a relatively frost-tolerant species, although strong spring frosts can damage new growth. Sessile oak which can grow on steep slopes as well as flat land. The main bio-physical change over time that is expected to reduce the suitability of land for this species is soil droughtiness.

Figure 3 shows the land suitability for sessile oak under present day conditions, allowing a comparison between pure biophysical suitability and overall suitability (biophysical suitability plus man-made constraints and sensitivities). It can be seen that many of the areas biophysically Unsuitable are driven by ALC wetness (Appendix A), with the soils of the wettest grades, largely found in upland Wales, classified as Unsuitable. Figure 4 and Figure 5 show the changing suitability for sessile oak in 2050 and 2080 respectively, under the medium emissions scenario. Figure 6 and Figure 7 show the suitability for sessile oak in 2050 and 2080 under the high emissions scenario.

Area summaries for each suitability class, time period and emission scenario are shown in Table 4, and this information is represented graphically in Figure 8 and Figure 9. It can be seen that the area biophysically Limited remains broadly similar across all time periods and scenarios. However, viewing this information in map format reveals that the geographic location of the Limited areas changes significantly. For example, the present day Limited area of 6133.0 km^2 is less than the area Limited under the 2080 High scenario (5924.3 km^2), but comparing the respective maps (Figure 3 and Figure 7) reveals the emergence of new Limited areas appearing in Anglesey and south west Wales, which were previously Suitable.

Table 4. Summary areas of Suitable/Limited suitability/Unsuitable land for sessile oak from the present day to 2080, under medium and high emissions scenarios.

Time/emissions scenario	**Biophysical only (km^2)**			**Biophysical + manmade constraints (km^2)**		
	Suitable	**Limited**	**Unsuitable**	**Suitable**	**Limited**	**Unsuitable**
Present day	8614.8	6133.0	5998.7	2561.4	3972.9	14212.2
2050 medium	8105.6	6434.0	6118.7	1940.8	4712.7	14004.9
2080 medium	6312.6	6613.4	7731.6	1645.9	4187.4	14824.3
2050 high	7838.9	6243.6	6575.8	1925.9	5268.6	13463.8
2080 high	4005.2	5924.3	10728.9	976.2	3934.9	15747.2

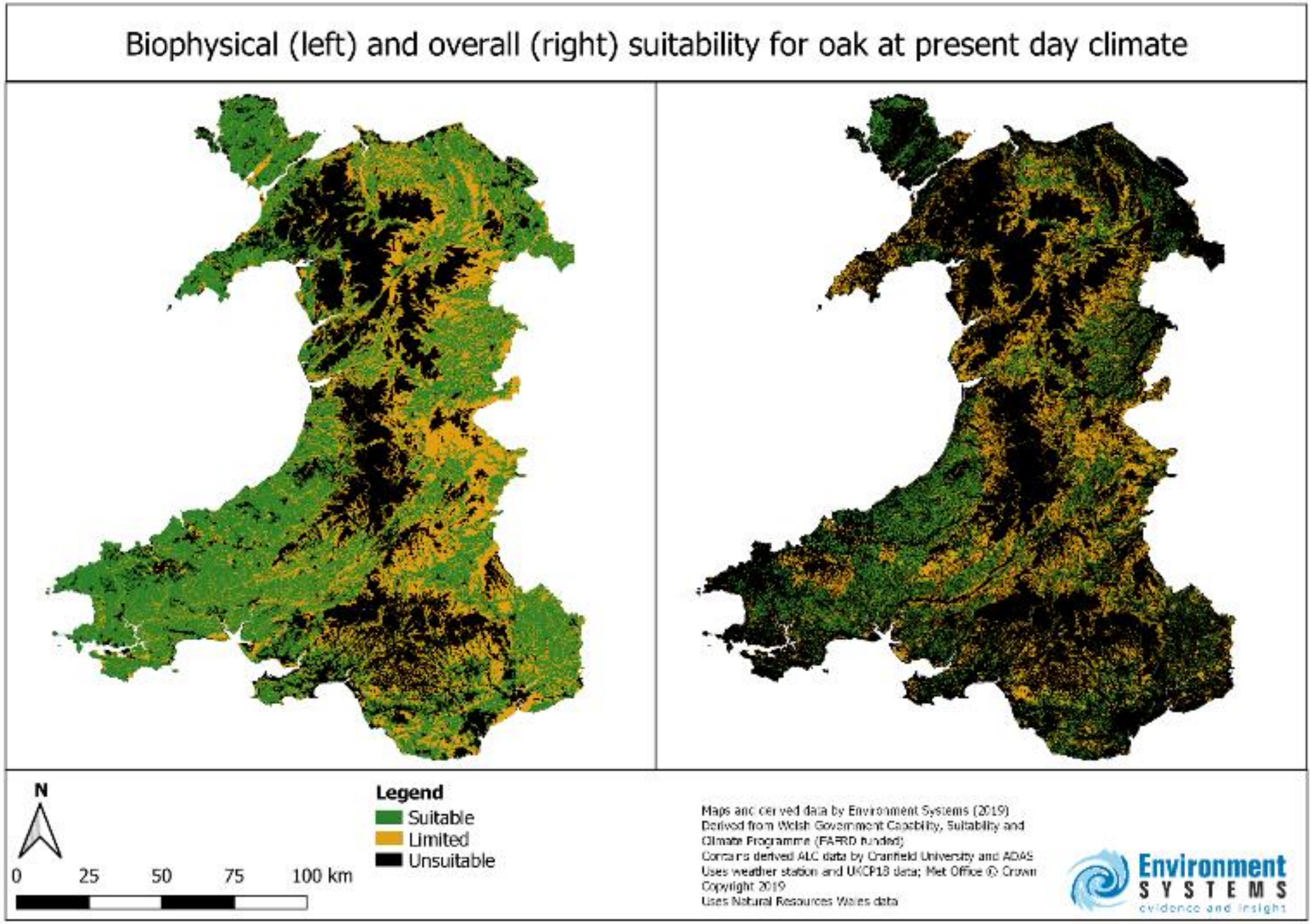


Figure 3. Present-day suitability for sessile oak; biophysical suitability versus overall suitability (biophysical suitability plus man-made constraints and sensitivities)

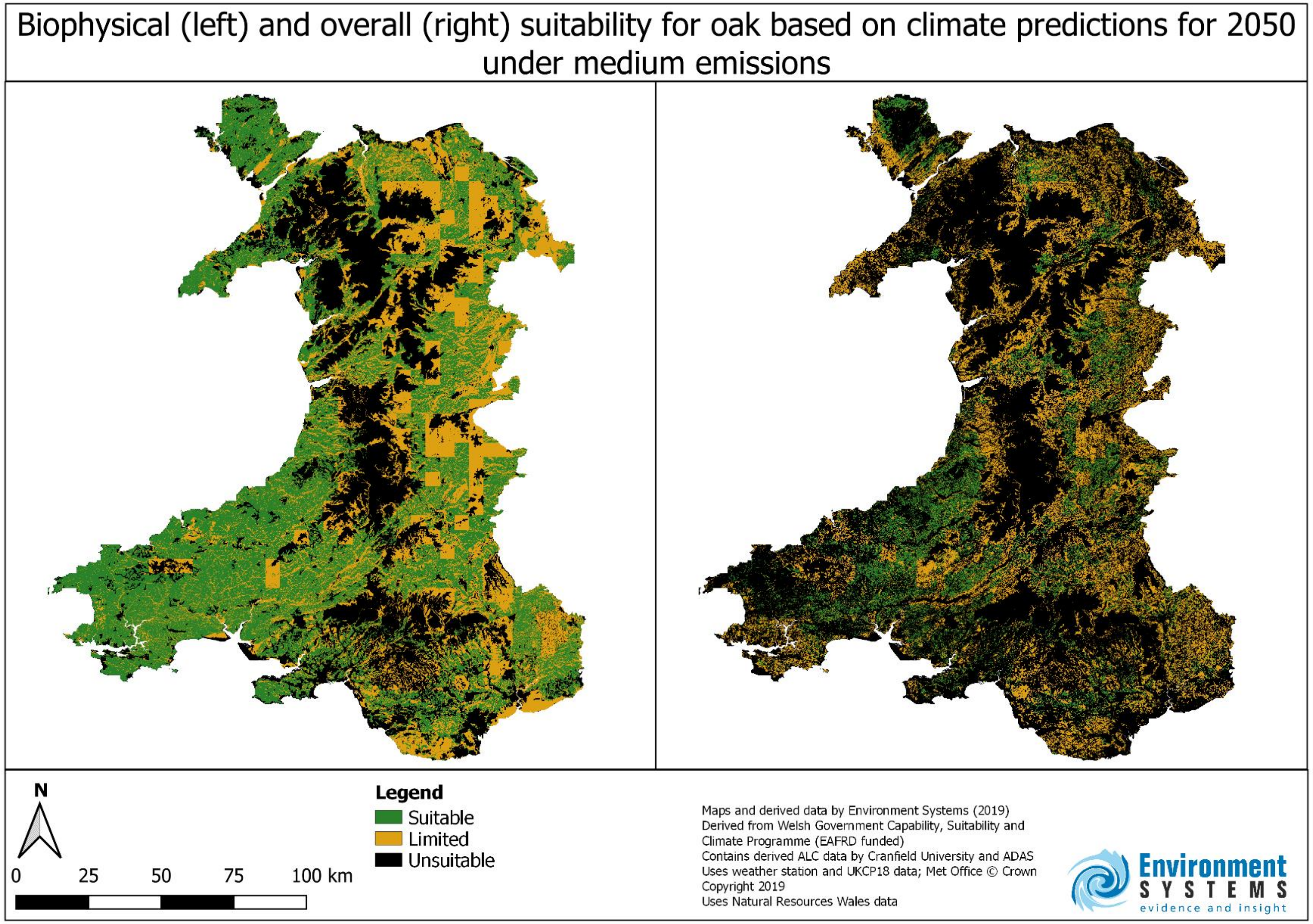


Figure 4. Suitability for sessile oak in 2050 under the medium emissions scenario; biophysical suitability versus overall suitability (biophysical suitability plus man-made constraints and sensitivities)

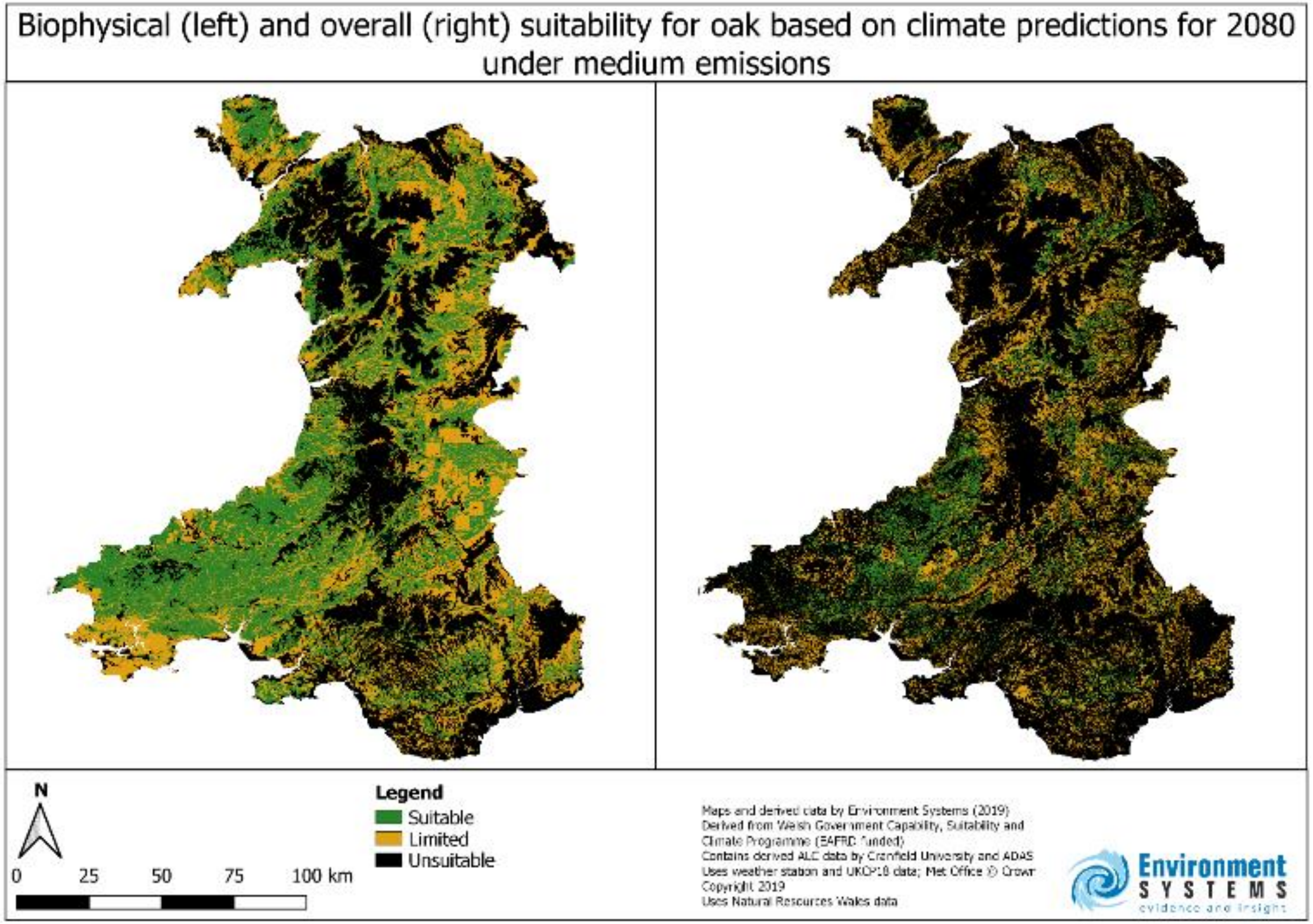


Figure 5. Suitability for sessile oak in 2080 under the medium emissions scenario; biophysical suitability versus overall suitability (biophysical suitability plus man-made constraints and sensitivities)

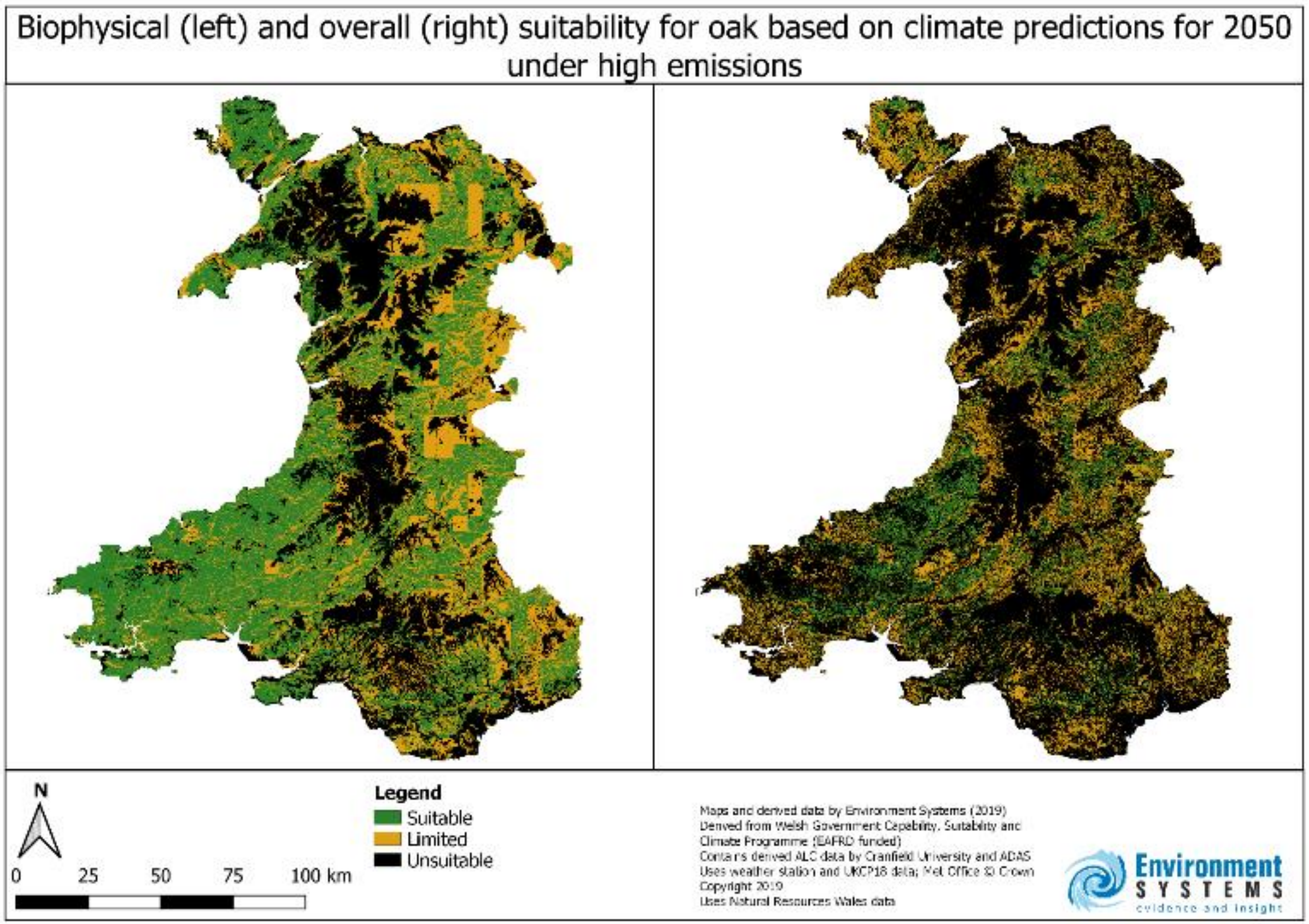


Figure 6. Suitability for sessile oak in 2050 under the high emissions scenario; biophysical suitability versus overall suitability (biophysical suitability plus man-made constraints and sensitivities)

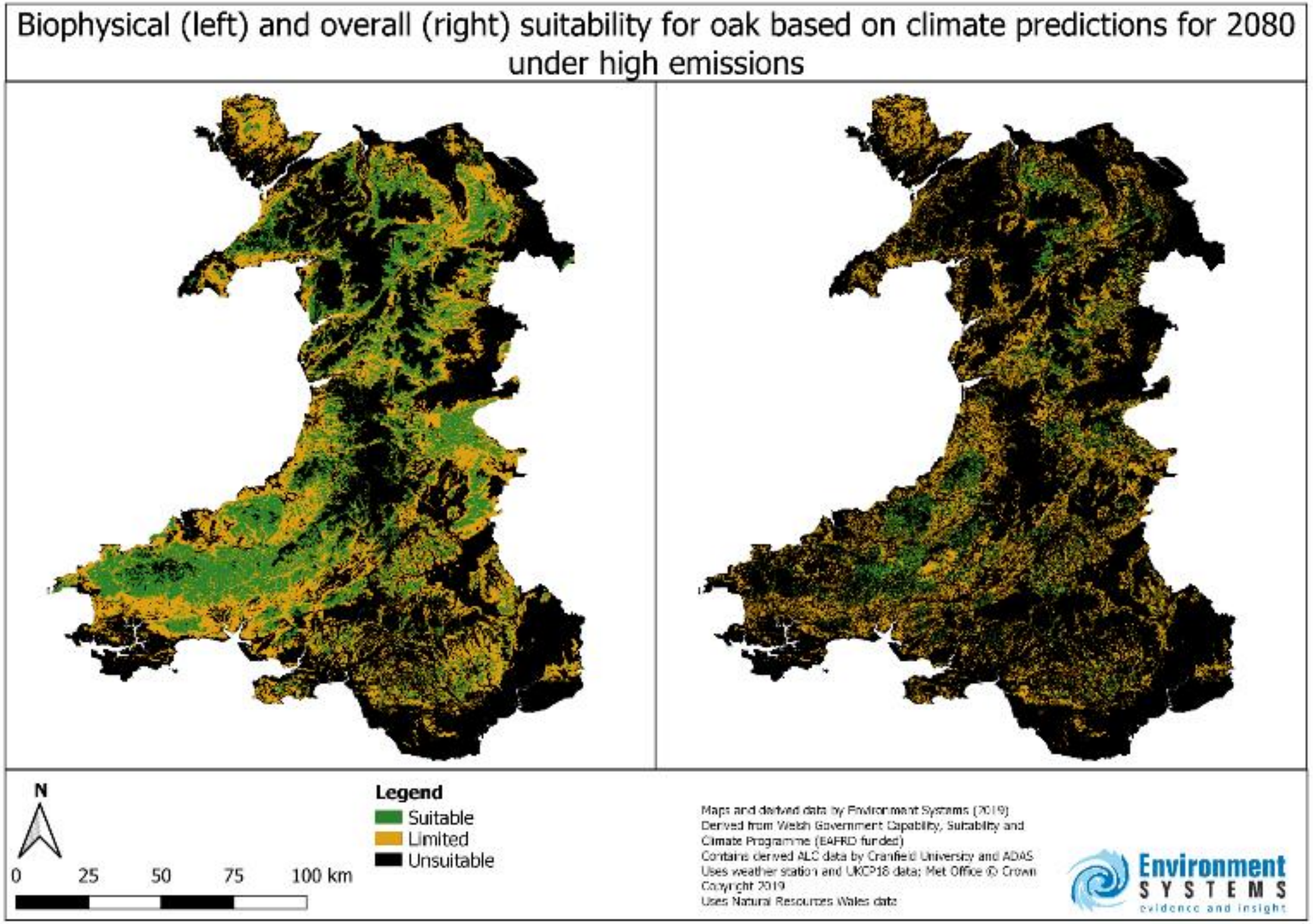


Figure 7. Suitability for sessile oak in 2080 under the high emissions scenario; biophysical suitability versus overall suitability (biophysical suitability plus man-made constraints and sensitivities)

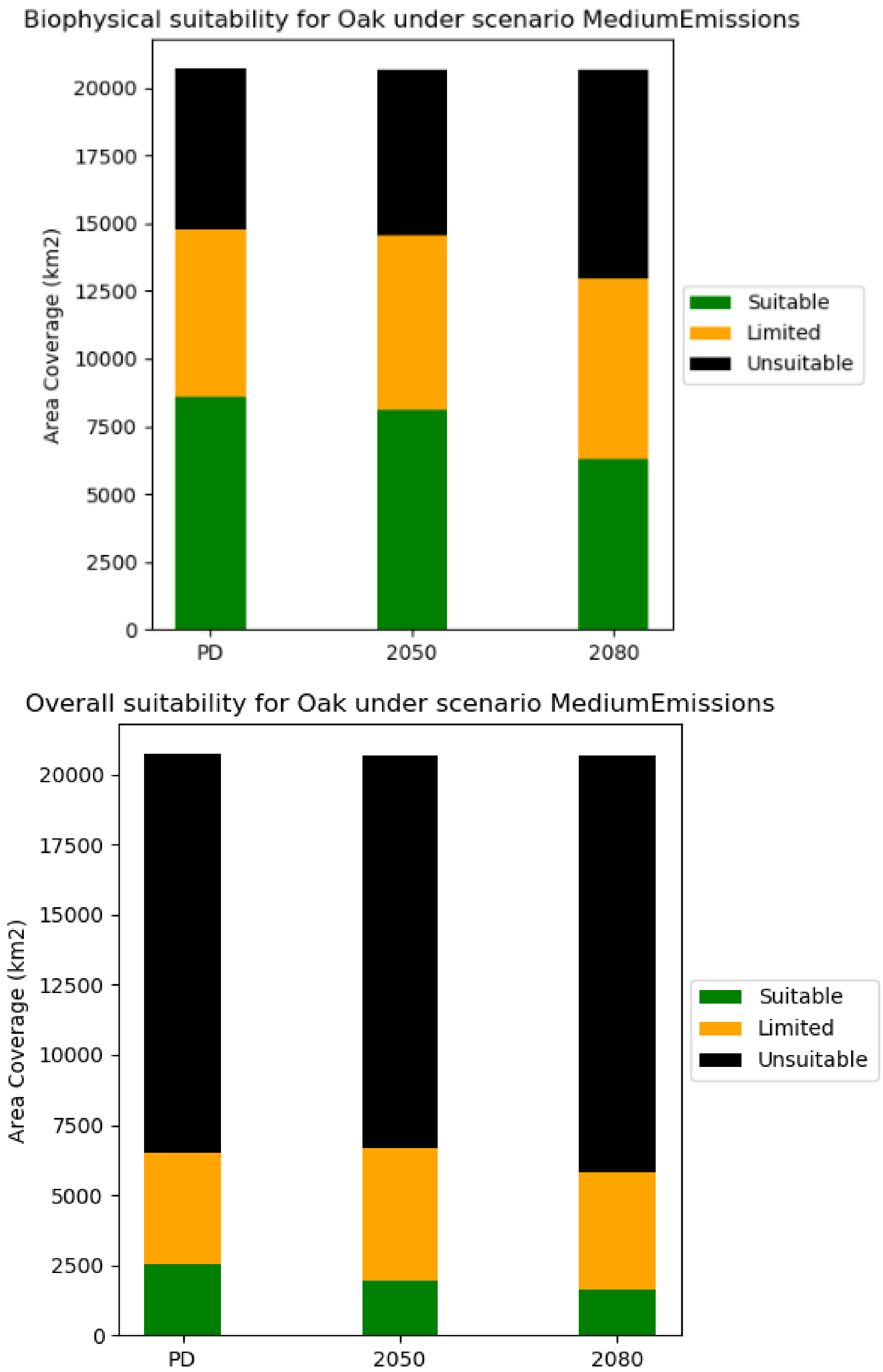
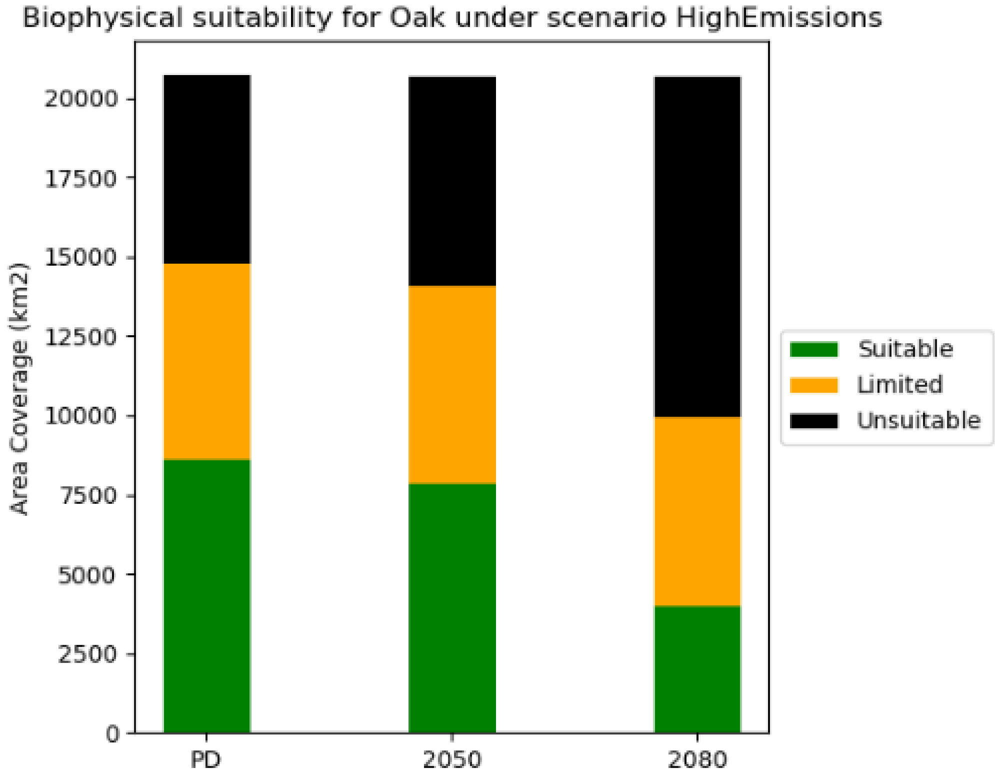


Figure 8. Bar graphs showing changes in the proportion of Suitable/Limited suitability/Unsuitable land for sessile oak between the present day and 2080 under the medium emissions scenario. Top; biophysical constraints only. Bottom; overall suitability (biophysical plus manmade constraints)



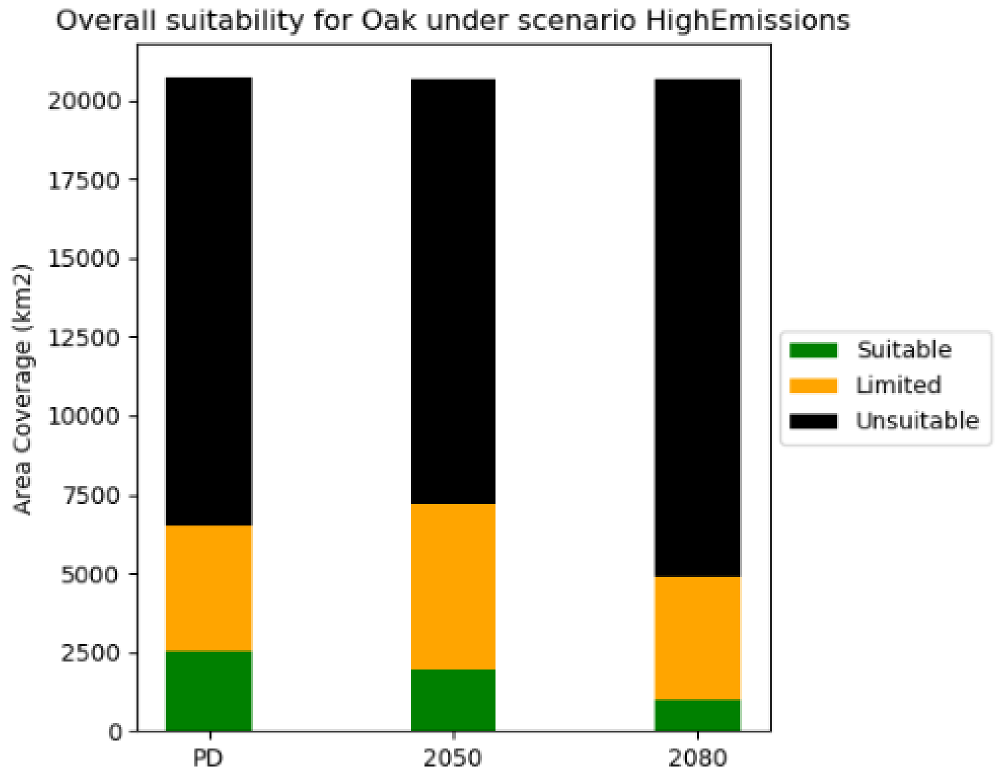


Figure 9. Bar graphs showing changes in the proportion of Suitable/Limited suitability/Unsuitable land for sessile oak between the present day and 2080 under the high emissions scenario. Top; biophysical constraints only. Bottom; overall suitability (biophysical plus manmade constraints)

4.3 Areas consistently suitable for sessile oak – time-series

The main bio-physical change over time that is expected to significantly change and reduce the suitability of land for sessile oak is soil droughtiness. **Error! Reference source not found.** shows the proportions of Suitable/Limited suitability/Unsuitable areas for sessile oak over time, for both the medium and high emissions scenarios; the corresponding area totals are shown in Table 5. The colour scheme is interpreted as follows:

- Areas which are suitable in the present day and remain suitable up to and including 2080 are shown in green.
- Areas in yellow represent areas which fluctuate between Suitable and Limited over time; some areas are Suitable in the present day but become Limited by 2080, and some areas are currently Limited but become Suitable either in 2050 or 2080 (and are never Unsuitable).
- Areas which are Limited for the entire period (present day to 2080) are shown in orange. It must be remembered that the reasons for an area becoming Limited may change. For example, an area may be Limited due to wetness in the present day, but in 2080 the wetness may be Suitable and the area is instead limited by another biophysical factor, such as drought. In these cases the overall suitability class remains Limited.
- Areas shown in grey are either Suitable or Limited suitability for part of the period present day-2080, but at some stage conditions are classed Unsuitable.
- Areas shown in black remain Unsuitable for the entire period present day-2080.

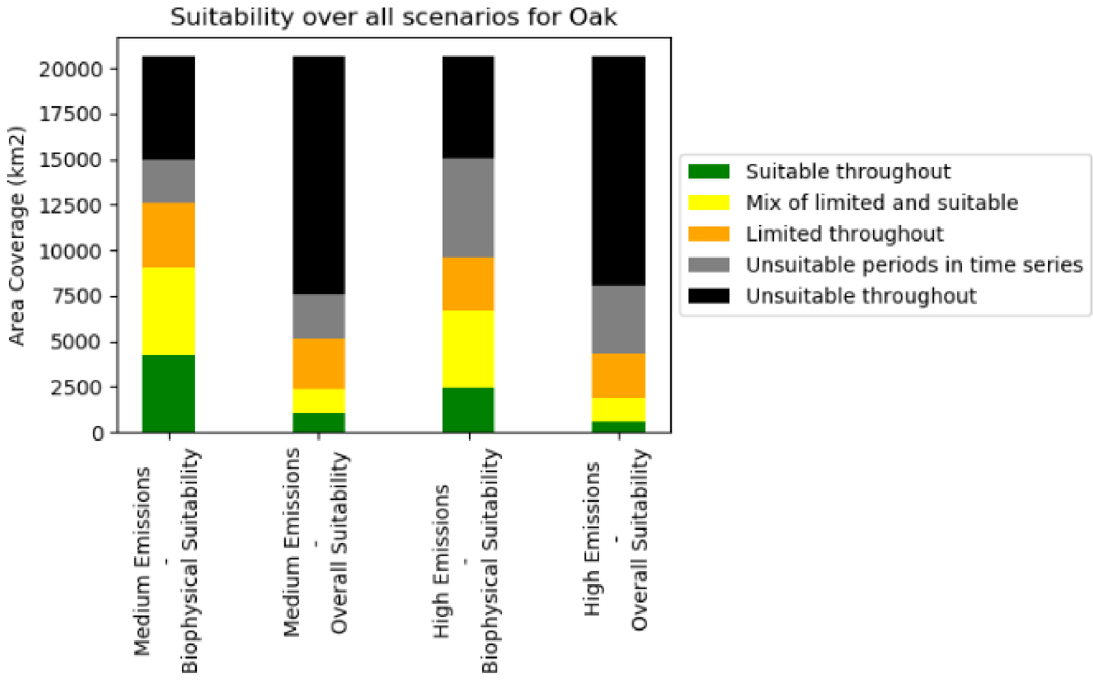


Figure 10. Changes in suitability for sessile oak between the present day and 2080 (medium and high emissions scenarios), showing areas that are Suitable at all time-periods (green); areas which fluctuate between Suitable and Limited (yellow); areas that are Limited at all time-periods (orange); areas which are at some point Unsuitable (grey) and areas which are at all times Unsuitable (black).

Table 5. Land area totals for time-series suitability classes for sessile oak, representing changes in land suitability between the present day and 2080 under medium and high emissions scenarios

Changes in suitability over time (present day-2080)	**Area under medium emissions (km^2)**	**Area under high emissions (km^2)**
Stays suitable (biophysical only)	4252.1	2414.1
Stays suitable (biophysical + manmade constraints)	1072.9	599.7
Mix of limited and suitable (biophysical only)	4819.2	4269.8
Mix of limited and suitable (biophysical + manmade constraints)	1279.1	1284.3
Stays limited (biophysical only)	3577.5	2921.1
Stays limited (biophysical + manmade constraints)	2793.2	2418.0
Unsuitable periods in time series (biophysical only)	2322.2	5467.5
Unsuitable periods in time series (biophysical + manmade constraints)	2405.6	3719.3
Stays unsuitable (biophysical only)	5686.3	5585.8
Stays unsuitable (biophysical + manmade constraints)	13106.6	12636.9

The bar graphs in Figure 10 show less consistently suitable area for oak under the high emissions scenario than under the medium emissions scenario, but similar areas classed as Limited. The high emission scenario shows a higher proportion of areas that are intermittently unsuitable than expected under the medium emissions scenario. These differences can be visualised in the map versions of the data, to identify the geographical locations associated with these trends.

The time-series information is presented in map format for the medium emissions scenario in Figure 11 and for the high emissions scenario in Figure 12. In these maps, comparison of the biophysical suitability under the medium and high emissions scenarios shows that under medium emissions the areas that are consistently suitable for oak occur in west Wales. While the amount of Limited area is similar between the two emissions scenarios it can be seen that under medium emissions the Limited areas are concentrated along eastern Wales, whereas under the high emissions scenario large parts of eastern Wales are unsuitable at certain periods, rather than Limited; under the high emissions scenario more Limited land appears in west Wales, at the expense of land that is forecast to be consistently suitable under the medium emissions scenario.

The CCC's planting ambition for Wales (152,000 hectares) by 2050 can be met using land currently deemed suitable. However, a longer-term (2080) view shows that some of this land is likely to become limited by drought, therefore planting will require careful site selection, and potentially a reassessment of the planting target in order to accommodate the impact of site limitations on tree growth.

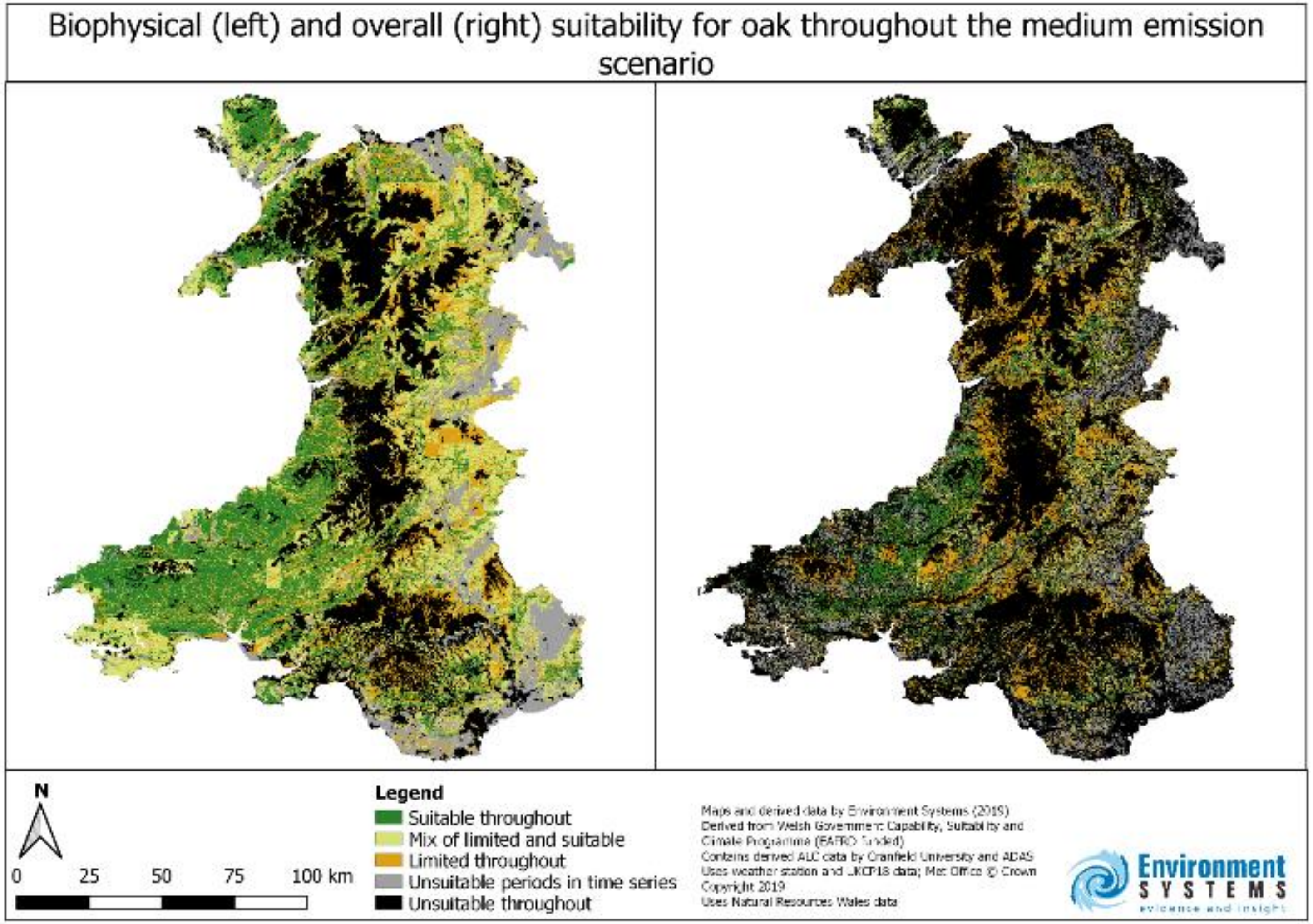


Figure 11. Spatial representation of changes in suitability for sessile oak between the present day and 2080 (medium emissions scenario), showing areas that are Suitable at all time-periods (green); areas which fluctuate between Suitable and Limited (yellow); areas that are Limited at all time-periods (orange); areas which are at some point Unsuitable (grey) and areas which are at all times Unsuitable (black). Biophysical suitability is shown on the left and overall suitability (biophysical plus manmade constraints) is shown on the right.

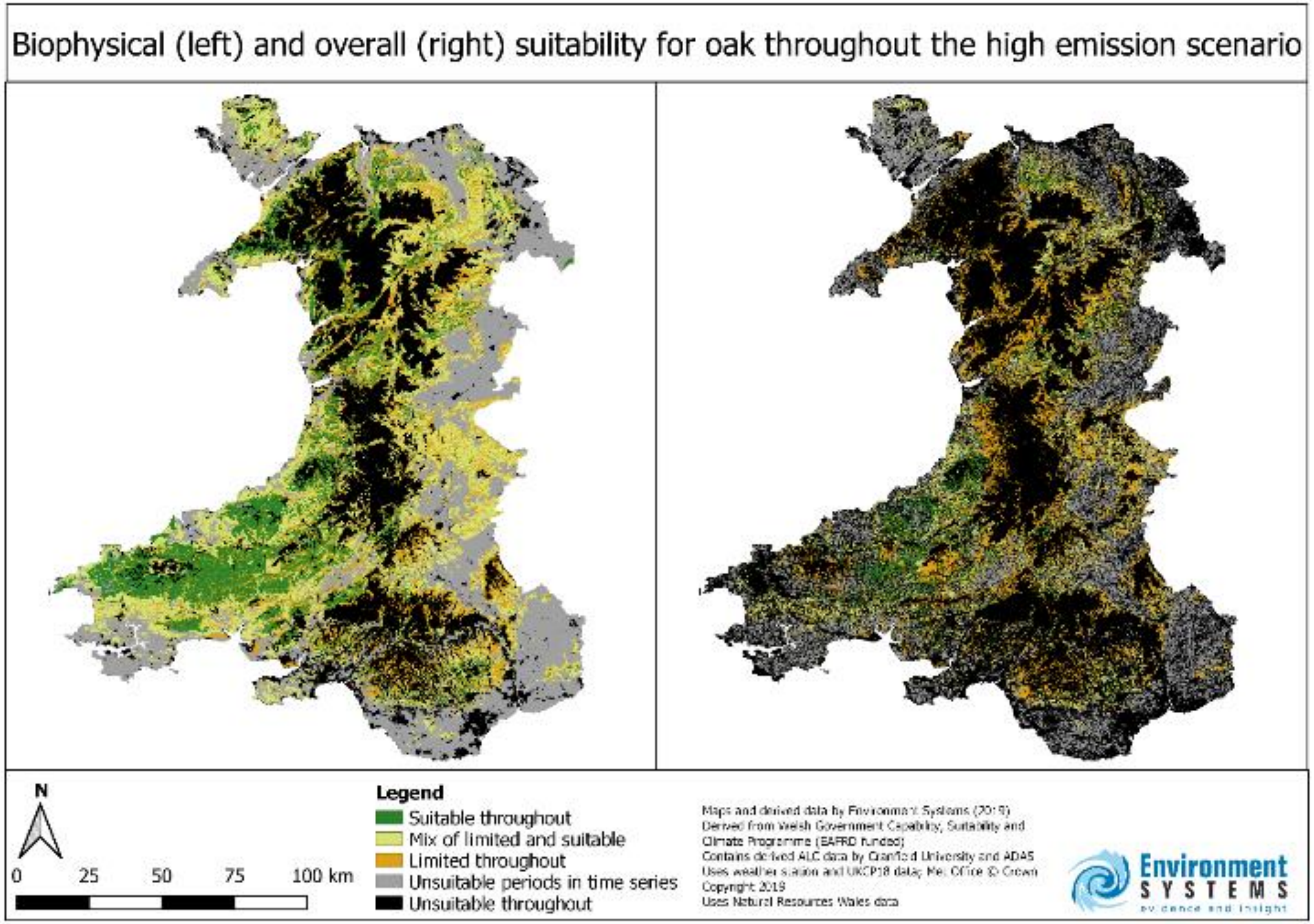


Figure 12. Spatial representation of changes in suitability for sessile oak between the present day and 2080 (high emissions scenario), showing areas that are Suitable at all time-periods (green); areas which fluctuate between Suitable and Limited (yellow); areas that are Limited at all time-periods (orange); areas which are at some point Unsuitable (grey) and areas which are at all times Unsuitable (black). Biophysical suitability is shown on the left and overall suitability (biophysical plus manmade constraints) is shown on the right.

4.4 Suitability for Sitka spruce at discrete time periods

Sitka spruce is tolerant of a wide range of biophysical conditions found in Wales, including very wet soils. It is a shallow-rooted species, and therefore grows on a wide range of soil depths, including shallower soils. Soils with a high stone content within the rooting zone are less favourable than soils of lower stone content, as a high stone content reduces the available water capacity within the soil. Late spring frosts can damage Sitka trees, but it can grow on steep slopes as well as flat land. The main bio-physical change over time that is expected to reduce the suitability of land for this species is soil droughtiness.

Figure 13 shows the land suitability for Sitka spruce under present day conditions, allowing a comparison between pure biophysical suitability and overall suitability (biophysical suitability plus man-made constraints and sensitivities). Figure 14 and Figure 15 show the changing suitability for Sitka spruce in 2050 and 2080 respectively, under the medium emissions scenario. Figure 16 and Figure 17 show the suitability for Sitka spruce in 2050 and 2080 under the high emissions scenario.

Area summaries for each suitability class, time period and emission scenario are shown in Table 6, and this information is represented graphically in Figure 18 (medium emissions) and Figure 19(high emissions). It can be seen that the area biophysically Unsuitable remains broadly similar over time under both scenarios, but that the amount of land classed as Limited increases, at the expense of land classed as Suitable.

Viewing this information in map format reveals a sharp shift in the areas identified as biophysically Suitable between 2050 and 2080; a trend that is forecast under both the medium and high emissions scenario. In the present day, and in 2050 under both emissions scenarios, areas suitable for Sitka are concentrated in the lower altitude areas of Wales, with the highest regions classified as Limited. However, in 2080 under both emissions scenarios the pattern of suitability is reversed; lower lying areas become Limited, and the upland areas become Suitable. This switch is driven by increases in soil droughtiness (Appendix A), with the lowland areas becoming significantly more drought-susceptible over time due to changing rainfall and temperature patterns, while the climate of the upland areas remains sufficient to prevent drought limitations in those elevated areas, within the time-frame and under the scenarios studied.

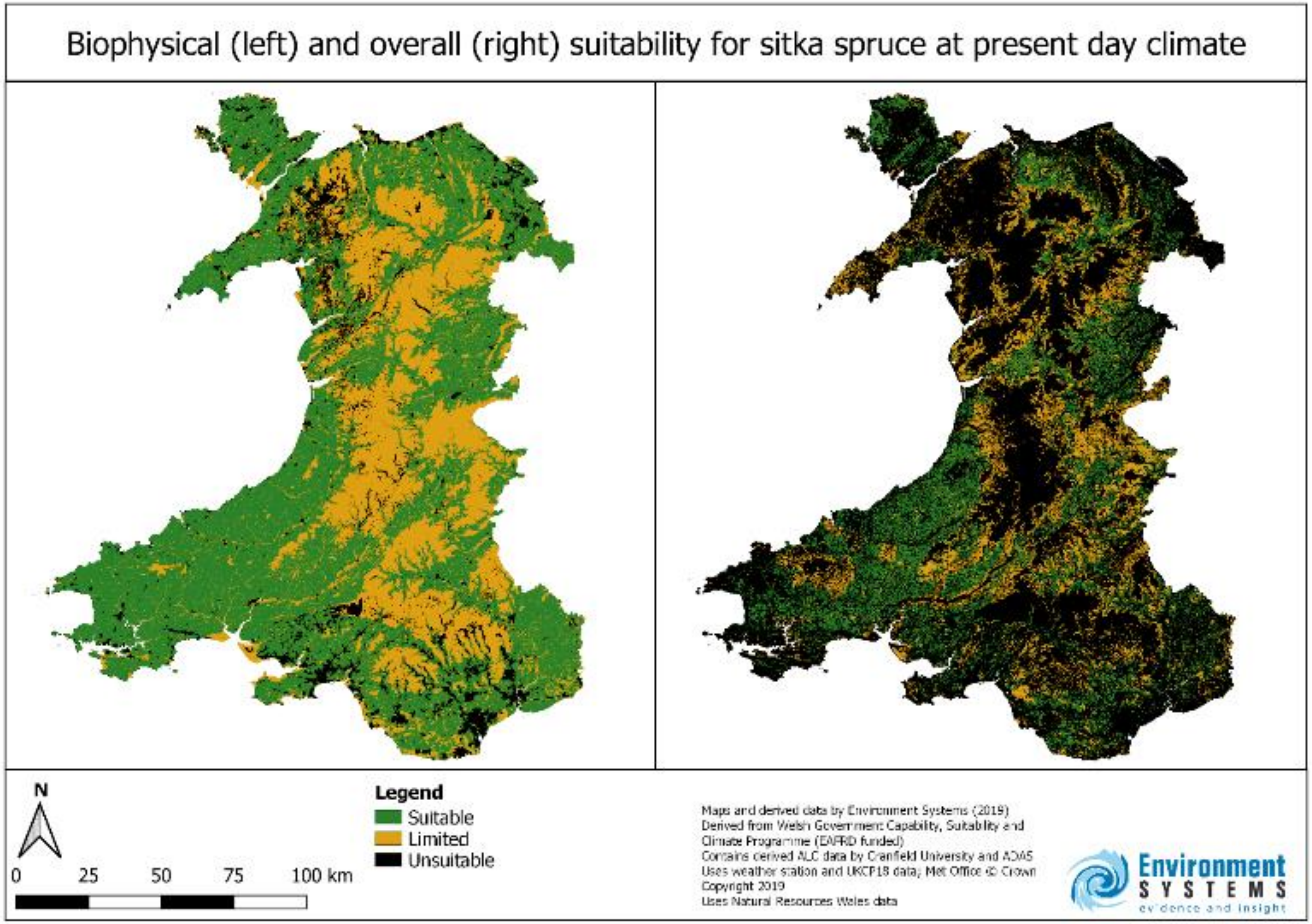


Figure 13. Present-day suitability for Sitka spruce; biophysical suitability versus overall suitability (biophysical suitability plus man-made constraints and sensitivities)

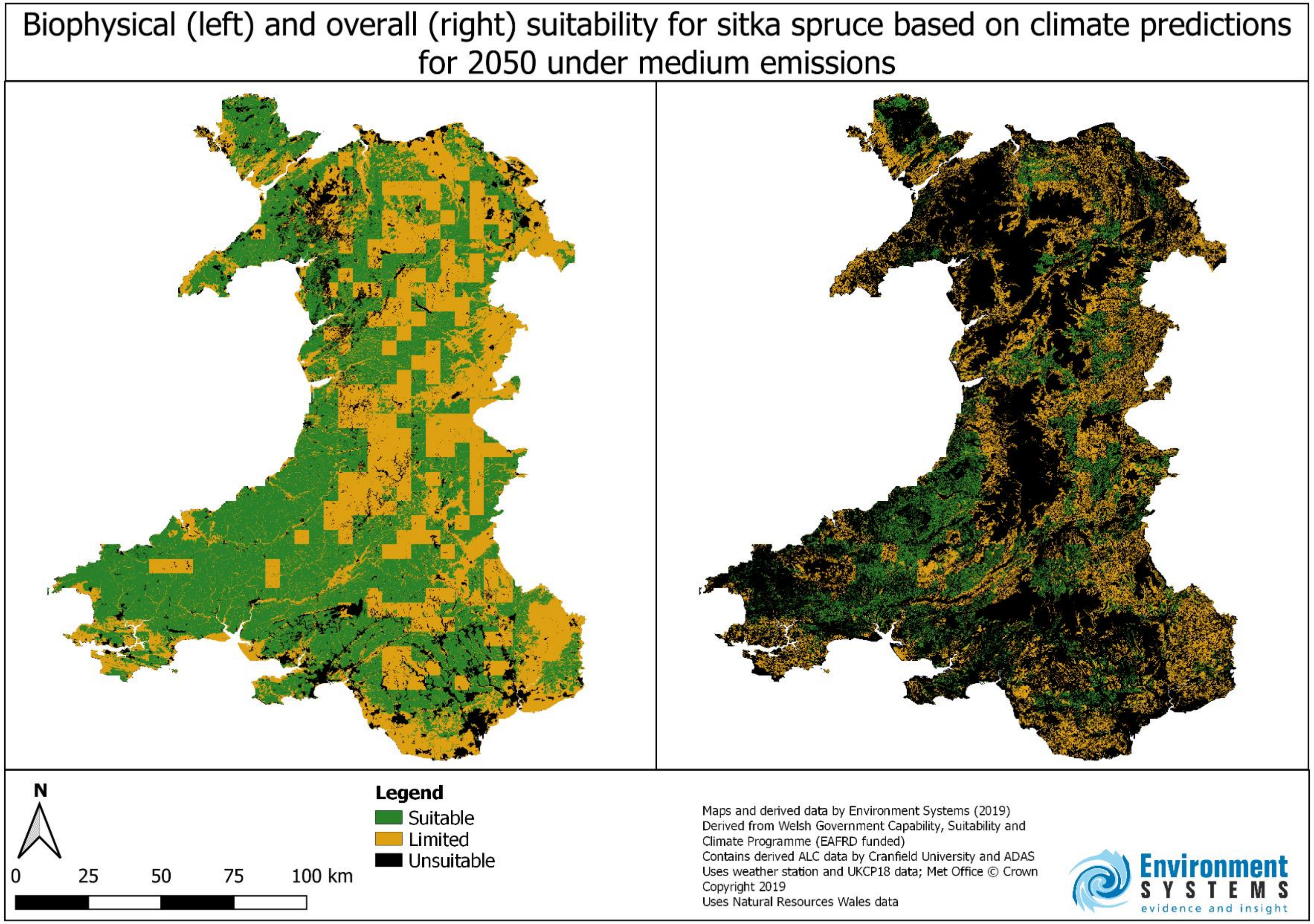


Figure 14. Suitability for Sitka spruce in 2050 under the medium emissions scenario; biophysical suitability versus overall suitability (biophysical suitability plus man-made constraints and sensitivities)

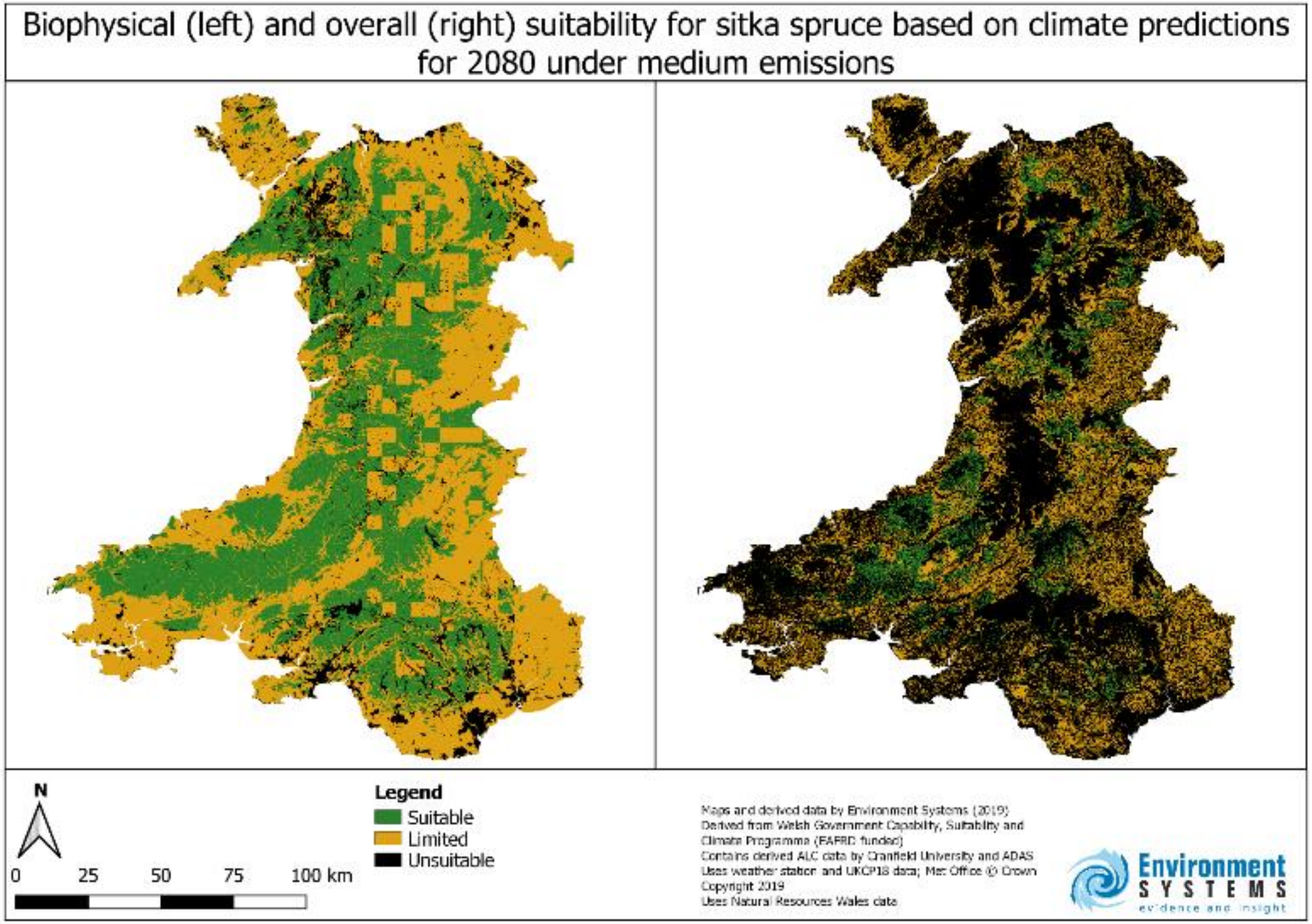


Figure 15. Suitability for Sitka spruce in 2080 under the medium emissions scenario; biophysical suitability versus overall suitability (biophysical suitability plus man-made constraints and sensitivities)

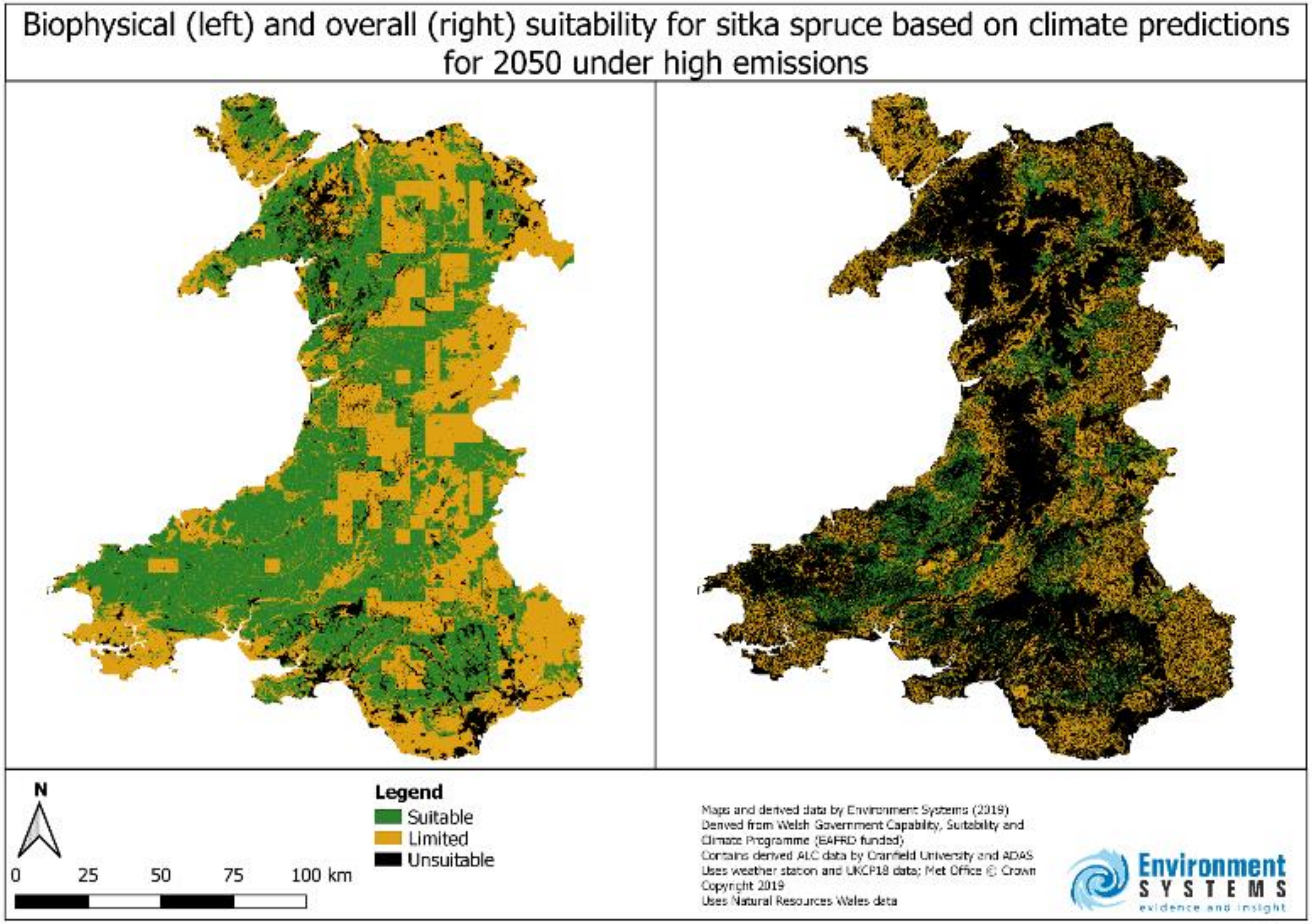


Figure 16. Suitability for Sitka spruce in 2050 under the high emissions scenario; biophysical suitability versus overall suitability (biophysical suitability plus man-made constraints and sensitivities)

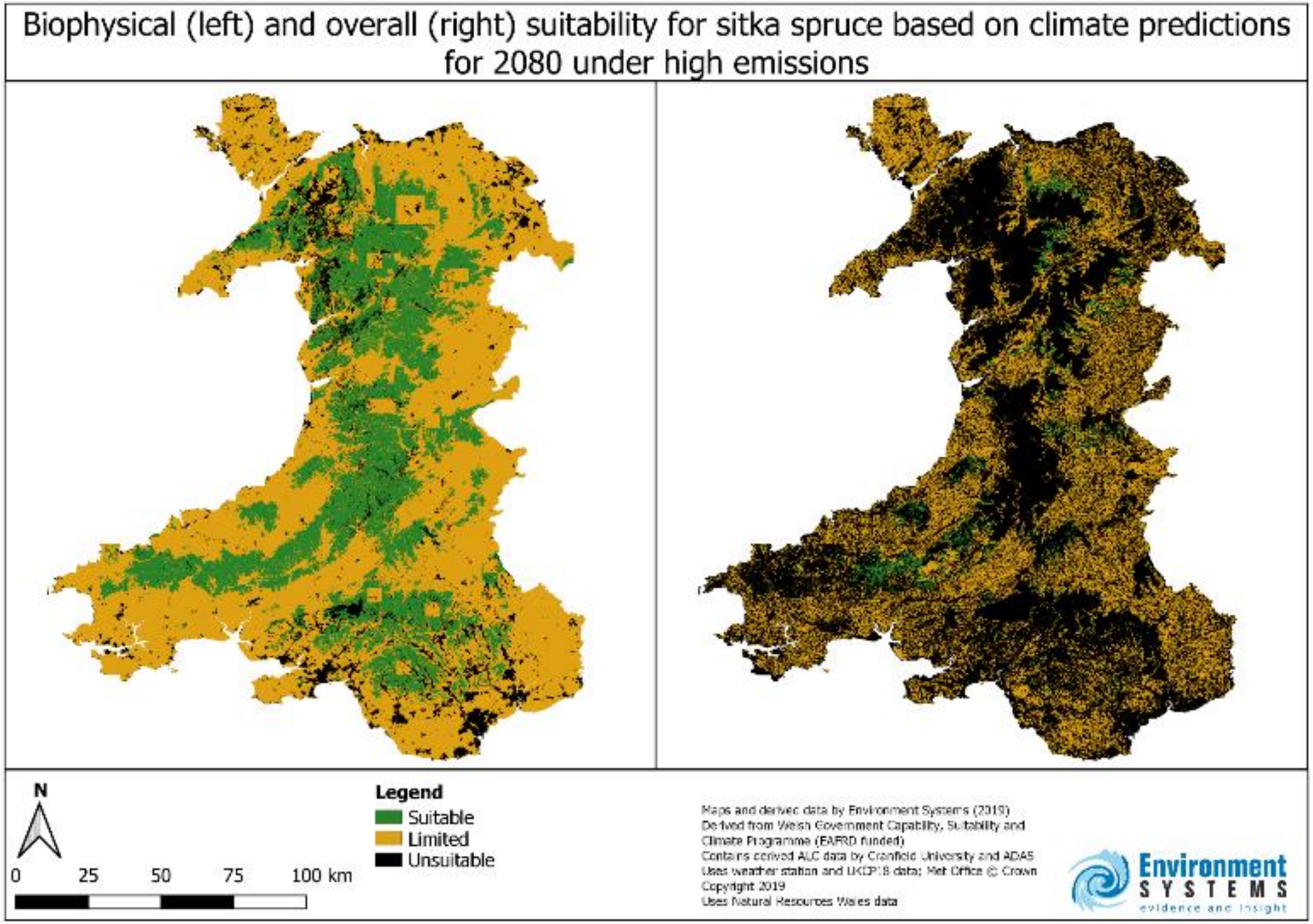


Figure 17. Suitability for Sitka spruce in 2080 under the high emissions scenario; biophysical suitability versus overall suitability (biophysical suitability plus man-made constraints and sensitivities)

Table 6. Summary areas of Suitable/Limited suitability/Unsuitable land for Sitka spruce from the present day to 2080, under medium and high emissions scenarios.

Time/emissions scenario	**Biophysical only (km^2)**			**Biophysical + manmade constraints (km^2)**		
	Suitable	**Limited**	**Unsuitable**	**Suitable**	**Limited**	**Unsuitable**
Present day	11613.4	7341.5	1791.7	3306.2	3337.4	14102.9
2050 medium	10014.1	8887.0	1757.2	2184.9	4654.1	13819.4
2080 medium	7591.1	11314.8	1751.7	1308.9	5530.9	13817.8
2050 high	9165.2	9737.9	1755.3	1919.1	5668.9	13070.4
2080 high	5613.9	13294.6	1749.8	546.2	7043.3	13068.9

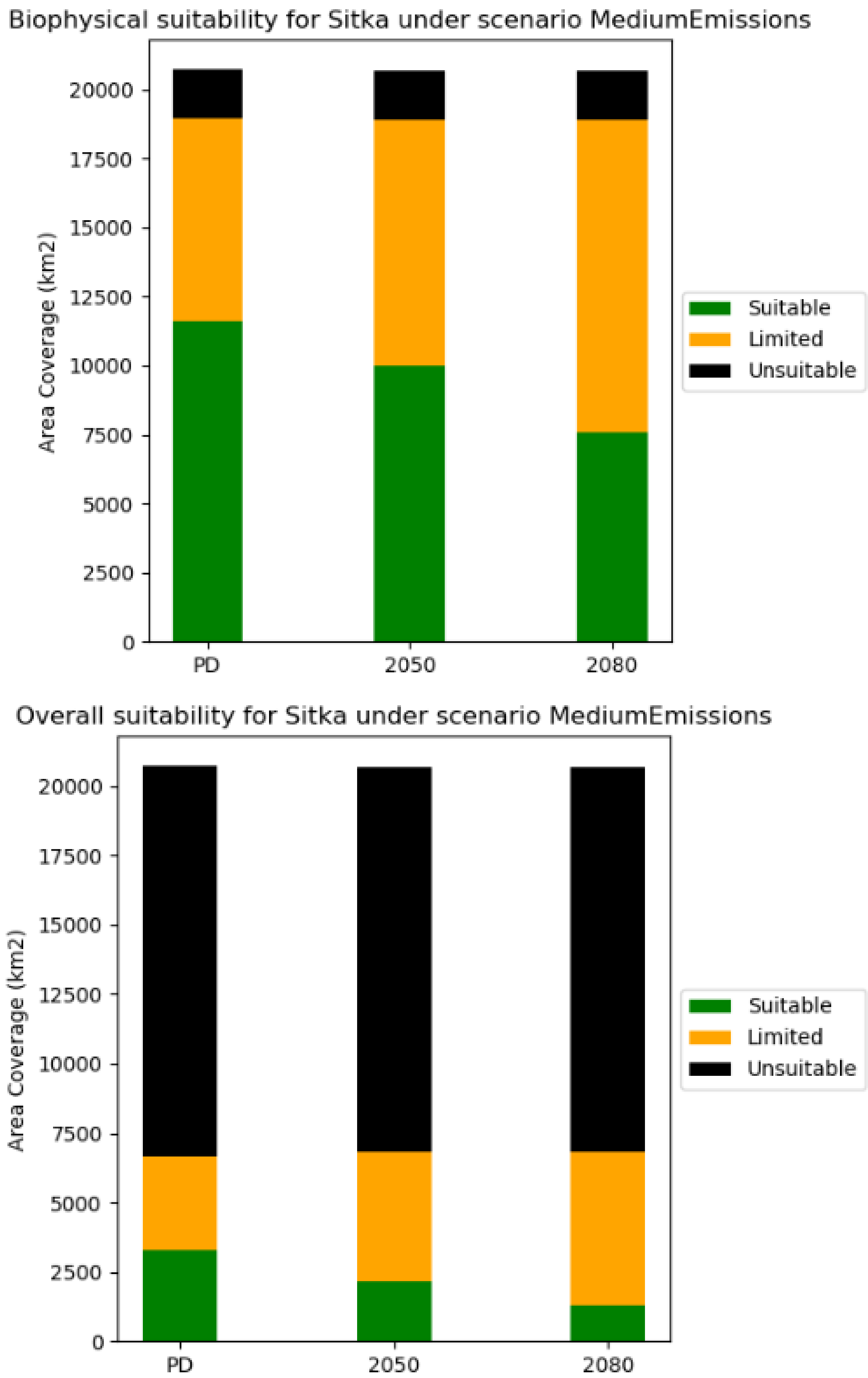
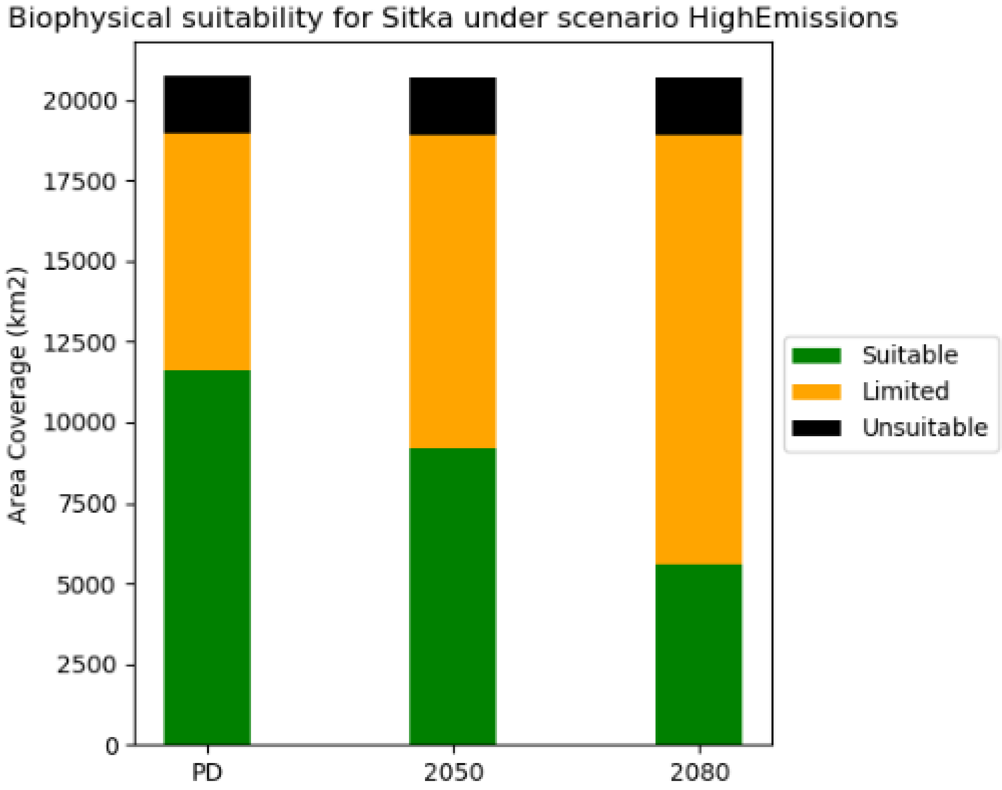


Figure 18. Bar graphs showing changes in the proportion of Suitable/Limited suitability/Unsuitable land for Sitka spruce between the present day and 2080 under the high emissions scenario. Top; biophysical constraints only. Bottom; overall suitability (biophysical plus man-made constraints)



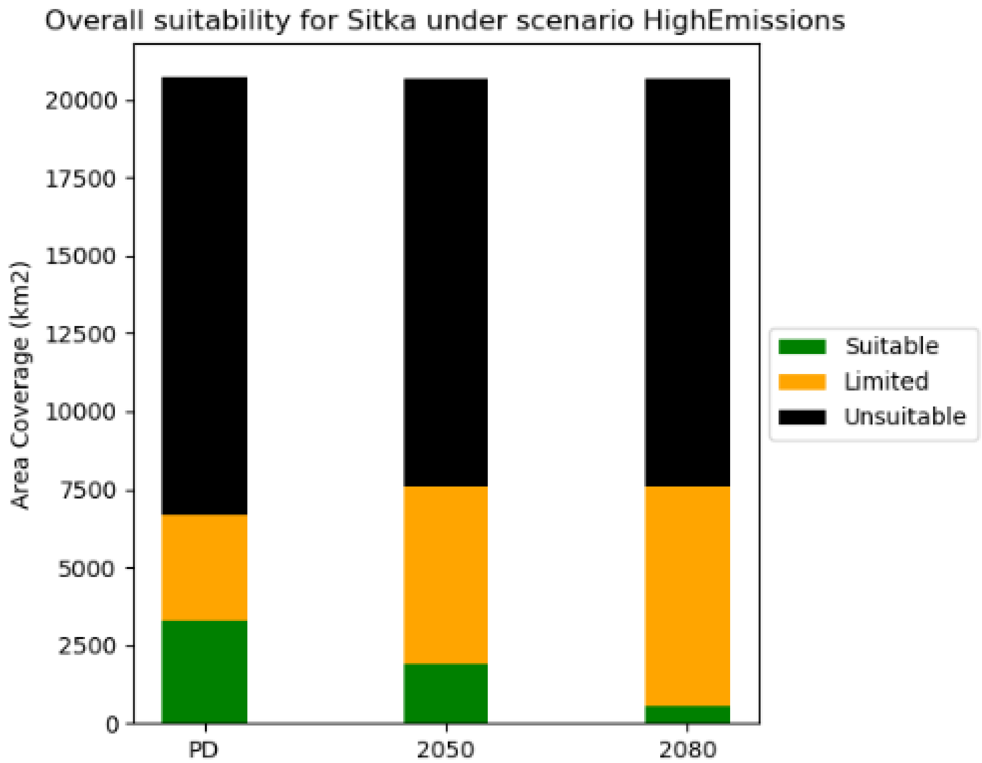


Figure 19. Bar graphs showing changes in the proportion of Suitable/Limited suitability/Unsuitable land for Sitka spruce between the present day and 2080 under the high emissions scenario. Top; biophysical constraints only. Bottom; overall suitability (biophysical plus man-made constraints)

4.5 Areas consistently suitable for Sitka spruce – time series

Figure 20 shows the proportions of Suitable/Limited suitability/Unsuitable areas for Sitka spruce over time, for both the medium and high emissions scenarios; the corresponding area totals are shown in Table 7.

- Areas which are suitable in the present day and remain suitable up to and including 2080 are shown in green.
- Areas in yellow represent areas which fluctuate between Suitable and Limited over time; some areas are Suitable in the present day but become Limited by 2080, and some areas are currently Limited but become Suitable either in 2050 or 2080 (and are never Unsuitable).
- Areas which are Limited for the entire period (present day to 2080) are shown in orange. It must be remembered that the reasons for an area becoming Limited may change. For example, an area may be Limited due to wetness in the present day, but in 2080 the wetness may be Suitable and the area is instead limited by another biophysical factor, such as drought. In these cases, the overall suitability class remains Limited.
- Areas shown in grey are either Suitable or Limited suitability for part of the period present day-2080, but at some stage conditions are classed Unsuitable.
- Areas shown in black remain Unsuitable for the entire period present day-2080.

The bar graphs show similar areas unsuitable for Sitka spruce under the medium and high emissions scenarios. There is a larger land area classed as Limited under the high emissions scenario, and less Suitable area, than forecast under medium emissions. These differences can be visualised in the map versions of the data, to identify the geographical locations associated with these trends.

The time-series information is presented in map format for the medium emissions scenario in Figure 21 and for the high emissions scenario in Figure 22. In these maps it can be seen that the areas consistently suitable for Sitka spruce predominantly lie in south and west Wales, but that a large proportion of the country is suitable at intervals, and never worse than Limited (classed as "Mix of limited and suitable").

Excluding pressures from alternative land uses such as agriculture and renewable energy, it is currently possible to deliver the CCC 152,000 hectare planting ambition using Sitka spruce, based on the amount of land that is currently suitable for the species. However, this species is vulnerable to changes in land suitability; it is predicted that, out of the 3306.2 km^2 land currently suitable, only 273.8 - 819.7 km^2 will remain suitable by 2080 (including constraints); therefore site selection for Sitka woodlands will need careful planning, considering the long-term viability of Sitka woodlands, and the anticipated mitigation gains these woodlands could deliver under any limiting conditions.

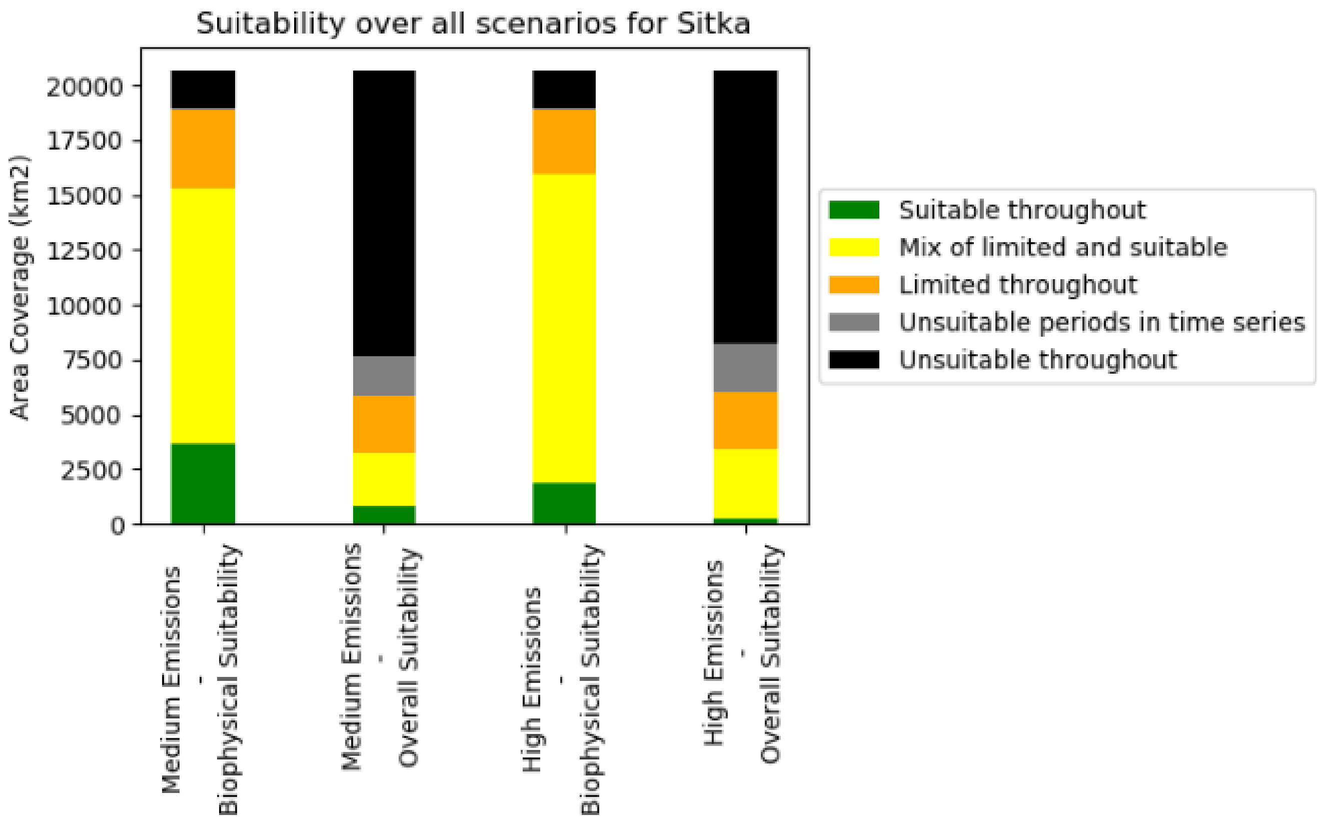


Figure 20. Changes in suitability for Sitka spruce between the present day and 2080 (medium and high emissions scenarios), showing areas that are Suitable at all time-periods (green); areas which fluctuate between Suitable and Limited (yellow); areas that are Limited at all time-periods (orange); areas which are at some point Unsuitable (grey) and areas which are at all times Unsuitable (black).

Table 7. Land area totals for time-series suitability classes for Sitka spruce, representing changes in land suitability between the present day and 2080 under medium and high emissions scenarios

Changes in suitability over time (PD-2080)	**Area under medium emissions (km^2)**	**Area under high emissions (km^2)**
Stays suitable (biophysical only)	3702.5	1851.6
Stays suitable (biophysical + manmade constraints)	819.7	273.8
Mix of limited and suitable (biophysical only)	11616.9	14056.9
Mix of limited and suitable (biophysical + manmade constraints)	2435.6	3132.9
Stays limited (biophysical only)	3548.7	2953.7
Stays limited (biophysical + manmade constraints)	2581.4	2620.9
Unsuitable periods in time series (biophysical only)	53.4	67.0
Unsuitable periods in time series (biophysical + manmade constraints)	1798.3	2166.2
Stays unsuitable (biophysical only)	1735.9	1729.0
Stays unsuitable (biophysical + manmade constraints)	13022.4	12464.3

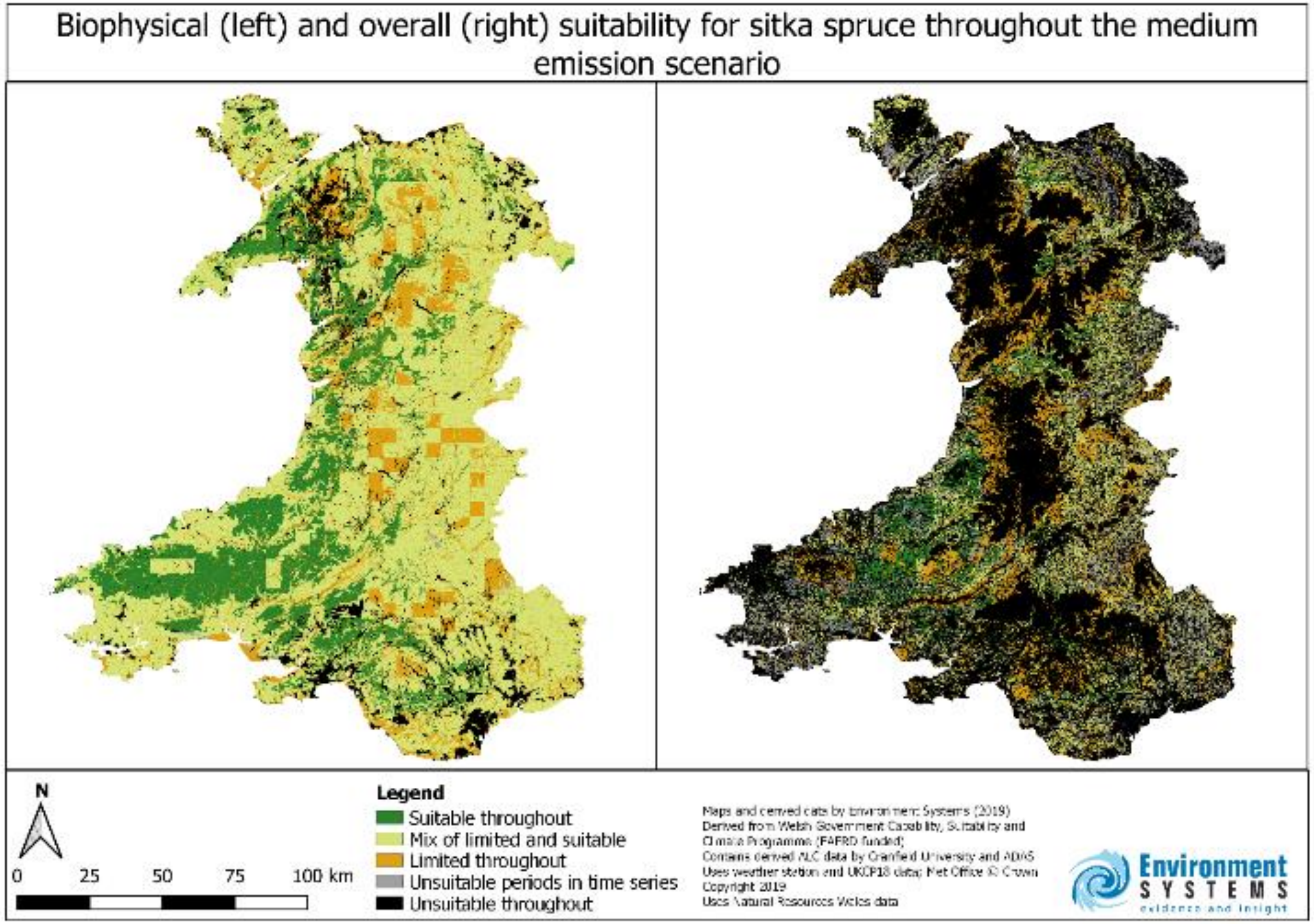


Figure 21. Spatial representation of changes in suitability for Sitka spruce between the present day and 2080 (medium emissions scenario), showing areas that are Suitable at all time-periods (green); areas which fluctuate between Suitable and Limited (yellow); areas that are Limited at all time-periods (orange); areas which are at some point Unsuitable (grey) and areas which are at all times Unsuitable (black). Biophysical suitability is shown on the left and overall suitability (biophysical plus manmade constraints) is shown on the right.

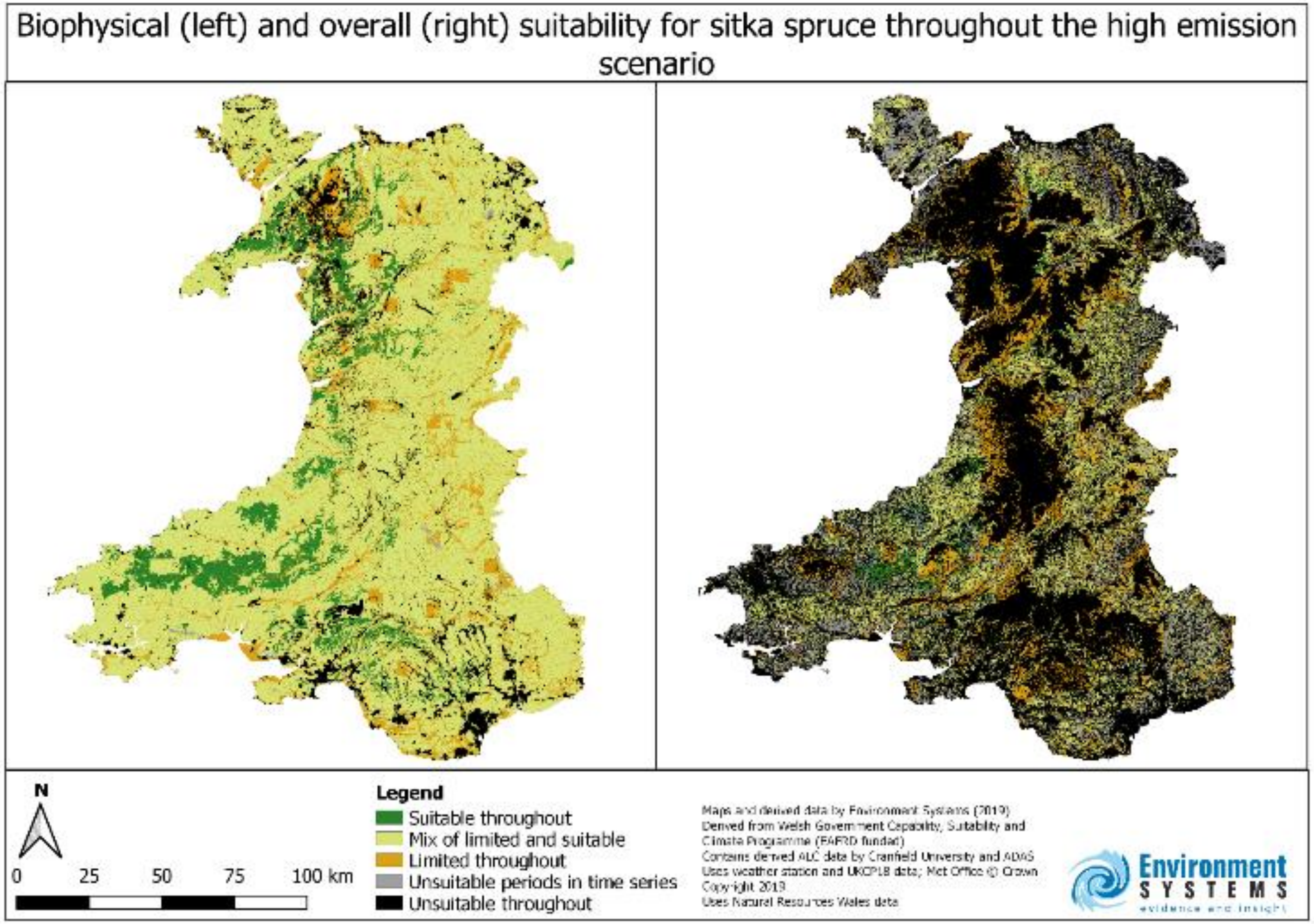


Figure 22. Spatial representation of changes in suitability for Sitka spruce between the present day and 2080 (high emissions scenario), showing areas that are Suitable at all time-periods (green); areas which fluctuate between Suitable and Limited (yellow); areas that are Limited at all time-periods (orange); areas which are at some point Unsuitable (grey) and areas which are at all times Unsuitable (black). Biophysical suitability is shown on the left and overall suitability (biophysical plus manmade constraints) is shown on the right.

5. Discussion

The Agricultural Land Classification and other biophysical datasets provide a means for spatially modelling the changing distribution of land suitability for different tree species under a changing climate, and for providing new insights into national tree planting targets can be achieved. The maps produced are indicative only, and are subject to the assumptions and limitations of the input datasets.

The analysis of suitability for beech showed that careful consideration must be given to species selection when choosing tree species for afforestation, as species are variably adapted to the existing climate and soil conditions of Wales, as well as the climate and soil conditions that are predicted to develop over time.

For all species, a large decrease in suitable growing areas was observed between the 2050 and 2080 time period; a trend which was repeated under both the medium and high emissions scenarios. This suggests that biophysical tipping points for the suitability of these species are likely to be reached within this time window.

For slow growing, long-lived species such as trees, when considering where to locate planting schemes it is important to consider not only the areas that are currently suitable for the species, but also whether or not the area is likely to remain suitable under climate change forecasts.

The maps show that there are significant areas that are biophysically suitable for tree planting throughout Wales at each time period under both the medium and high emissions scenarios, but that the spatial location of the suitable areas changes substantially over time and by scenario, driven largely by changes in soil wetness and drought susceptibility.

The predicted decrease in soil wetness over time is favourable for oak in some small areas, but does not significantly affect Sitka spruce. Drought is the most significant changing biophysical factor, which drives the changing distribution of suitable areas in both species. Increasing droughtiness leads to a predicted decrease in suitable areas for both sessile oak and Sitka spruce.

As a result, the overall areas of suitable land which will remain suitable are much reduced, meaning that careful consideration should be given to the location of tree planting schemes in order to promote their long-term productivity and viability, and so ensuring they deliver the anticipated level of carbon capture. Areas that become limited might well still support trees, but at a reduced growth rate. Trees in biophysically limited are predicted to suffer greater environmental-induced stresses, which could make them more susceptible to diseases and storm events.

Under the high emissions scenario a larger area of Wales is predicted to remain biophysically suitable for Sitka spruce than for sessile oak. However, when man-made constraints and sensitivities (e.g. deep peat areas) are considered in addition to the biophysical factors the situation is reversed; a larger area of Wales is considered suitable for sessile oak (599.7 km^2)than for Sitka spruce (273.8 km^2).

Given the universal trend of decline in land area classed as Suitable, it is likely that future tree planting will need to make use of areas that are subject to certain limitations, given the scarcity of land remaining suitable throughout the time-series, and pressures from competing land uses, such as agriculture, renewable energy generation, biodiversity and urban expansion. Biodiversity and ecological connectivity in particular must be given sufficient consideration, to ensure no net loss of resource and resilience.

Larger areas may be available for tree planting if certain man-made constraints could be relaxed or removed, although the wider impacts of such policy decisions must be considered. For example, Acid Sensitive Catchments are likely to be more of a limitation to Sitka spruce planting than sessile oak, and LANDMAP-derived aesthetic qualities may be considered more or less of a limitation in some cases. Future policy decisions may also change the nature and physical extent of constraints and sensitivities to tree planting. At present the most significant man-made constraints to tree planting are Priority Habitats (many of these habitats are also classed as unsuitable for tree planting due to the presence of deep peat) and Best and Most Versatile agricultural land.

The decision rules applied in these tree suitability models allowed some BMV land to be considered Limited suitability, rather than Unsuitable in all cases; land that is currently BMV, but forecast to become degraded, was classed as Limited suitability for future planting. However, it is possible that policy may continue to prevent tree planting in these areas in the future, and instead focus on irrigation for agricultural production.

A large proportion of non-BMV land in Wales (candidate areas for tree-planting) is currently used for agriculture. Any decision to carry out large-scale tree planting in these areas should be supportive of strategic planning for the future of the UK agricultural sector and maintaining food security under a changing climate, and consider the implications for rural livelihoods in the affected areas.

6 Conclusions

This report built on work for ‘Capability, Suitability and Climate Programme’ for the Welsh Government; a project which is updating soil and agricultural land classification data in Wales, and using the new data to produce crop suitability maps for Wales under a range of climate change scenarios. This is to facilitate visualisation of changes in land suitability for 118 crops under a changing climate.

Within the initial stages of the Welsh Government project three tree species were evaluated. These three tree species were further examined in this study as part of the CCC evaluation of tree planting as part of a multi-faceted climate mitigation strategy. The actual distribution of land suitable for planting under selected climate scenarios was displayed and the changing nature of the suitability of land for woodland species has been demonstrated.

The maps and statistical analyses in this report show that the CCC’s current tree planting ambition for Wales of 1520 km^2 is achievable, but is very likely to require utilisation of land that is biophysically less than ideal (Limited), or land which is forecast to become Limited in the future. This is because the model does not consider competing land uses such as renewable energy generation and the majority of the Welsh agricultural sector (i.e. non-BMV agricultural areas, currently commonly used for grass and fodder crop production in support of the meat and dairy industries), which would further restrict the areas of land available for planting.

There is a high degree of overlap between the areas consistently suitable for sessile oak and Sitka spruce, so decisions must be taken as to how to balance the planting of these species. Decisions will be guided by a range of factors including the relative anticipated growth rate/mitigation benefits expected from either species in a given location; prevalence/susceptibility to pests and disease; and also the relative commercial, wildlife, aesthetic and recreational benefits associated with the species.

Planting schemes should consider the nature of the biophysical limitations (e.g. changing trends in drought, frost risk etc) which are likely to develop in a given area, in order to choose the most appropriate location for woodland creation, and in order to calculate the level of derived benefits from planting. Areas subject to biophysical limitations can be expected to display slower biomass accumulation and lower overall yield, which must be considered when calculating their value for mitigating carbon emissions; should substantial areas of limited land be required to meet the CCC planting target, it may be necessary to further increase the planting area in order to derive the required level of climate mitigation.

Further work could refine the policy constraints and sensitivities applied to the models, for example by including renewable energy sites. Further analysis of Grade 3b land could be undertaken, analysing the extent and distribution of land which is currently 3b, and which is forecast to become upgraded to 3b under climate change; as these areas are likely to be of high importance for food production.

Due to existing and continuing competing pressures on land use, meeting the tree planting target is likely to require tree planting on land that will at some stage become limited by drought. The climate mitigation strategy would benefit from an analysis of the scale of drought likely to be encountered on different soil types, and the subsequent impact this would have on biomass accumulation and carbon sequestration, in order to confirm whether the 152,000 hectare planting target is sufficient to achieve the required level of climate mitigation.

Further work could also incorporate a wider range of tree species, in order to better understand the long-term suitability trends and potentially identify tree species that compete less for the same growing space, in order to increase the range of options for creation of resilient woodlands, for maximum carbon storage potential.

It is clear that there are many opportunities for establishing woodlands in Wales, and that establishing woodlands will be most effective if started sooner, before the climate-induced biophysical changes become more limiting. However, a wider dialogue on the future of the countryside and rural livelihoods must be established in order to develop robust parallel plans for climate mitigation and food production, and to win public support for such large-scale changes.

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Appendix A

Impact of individual constraints and sensitivities on the planting areas available for crops.

Figure 23 -Figure 28 illustrate two of the biophysical factors considered in the analysis; ALC wetness and ALC drought, which were the biophysical factors found to exert greatest individual influence on the suitability of the two species.

Figure 23 -Figure 25 show the changing wetness and drought suitability for sessile oak in the present day, in 2050 and in 2080, under the high emissions scenario. Figure 26-Figure 28 show the same information for Sitka spruce. It can be seen that wetness has a greater influence on suitability for sessile oak than for Sitka spruce, and that the wetness suitability for both species changes little between the present day and 2080; wetness is a strong limiting factor for sessile oak at all points in the time-series, whereas wetness is not a significant limiting factor for Sitka at any point.

Drought is a more variable factor, which has little effect on suitability for both species in the present day, but becomes increasingly significant for both species by 2080, with the emergence of areas of Limited suitability and areas Unsuitable for oak, and in the case of Sitka, large areas of Limited suitability.

The spatial extent and distribution of individual man-made constraints and sensitivities are shown in Figure 29-Figure 34. Sensitivities are shown in orange, and represent areas where planting may still be possible (Limited suitability). It can be seen that there is much overlap between the peat and designated sites constraints (Figure 31); the distribution of these constraints is largely within the interior of Wales. Conversely, the distribution of BMV land (Figure 33 - Figure 34) is largely around the coast and English border; when combined with the other constraints this creates a complex, ‘speckled’ distribution of constraints throughout the country.

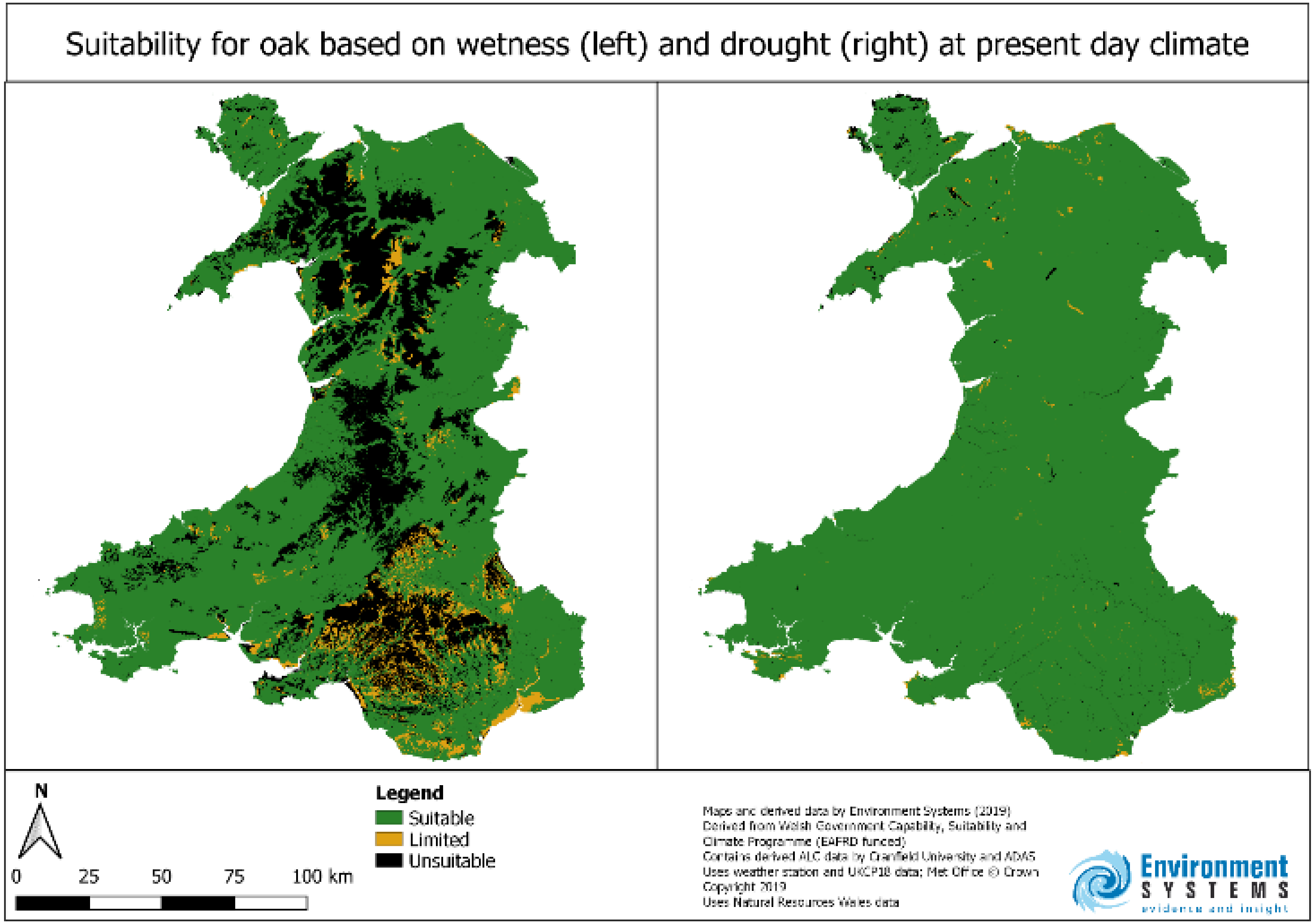


Figure 23. Present day land suitability for sessile oak based on individual biophysical factors: ALC Wetness (left) and ALC Drought (right).

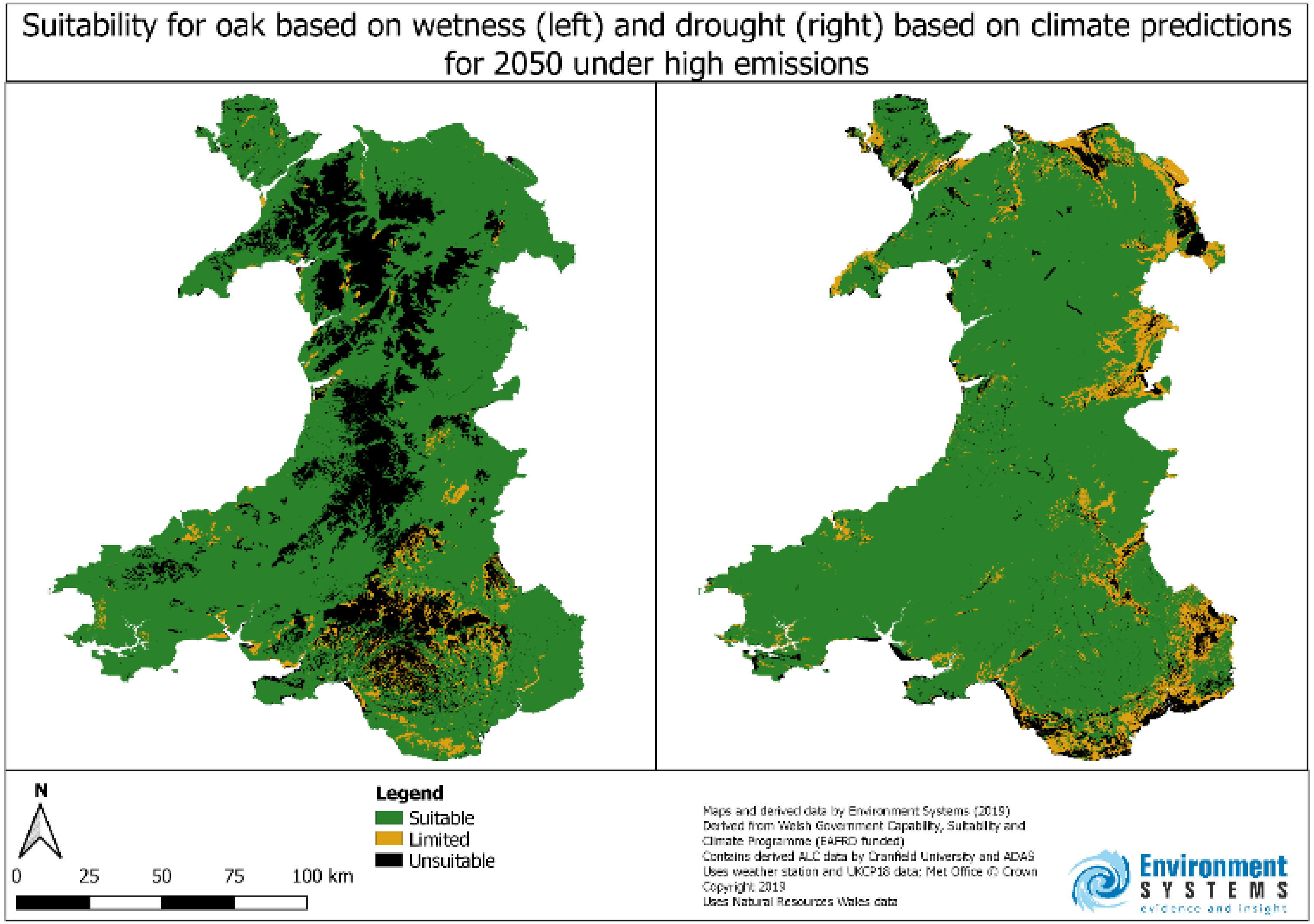


Figure 24. Land suitability for sessile oak in 2050 under the high emissions scenario based on individual biophysical factors: ALC Wetness (left) and ALC Drought (right).

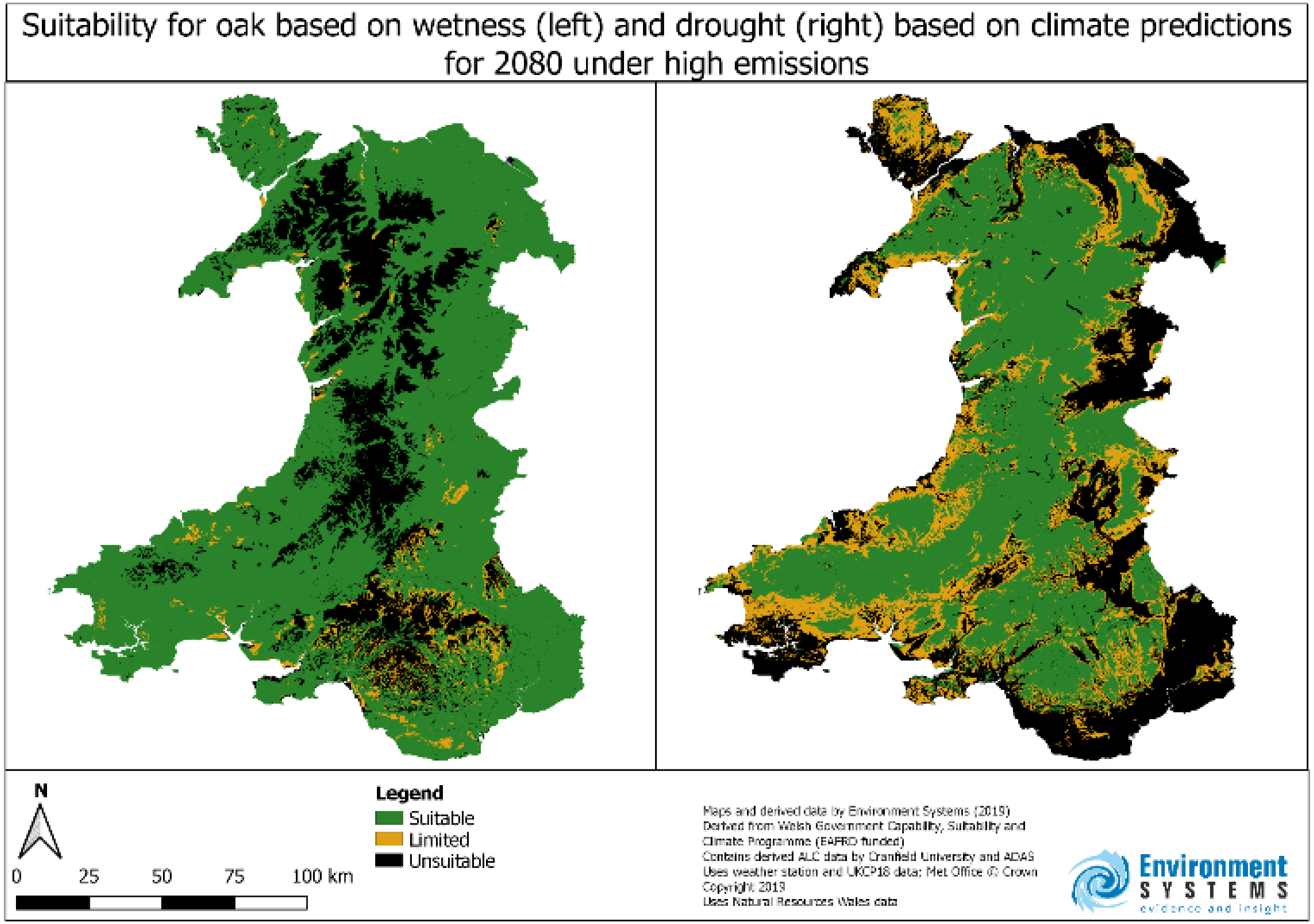


Figure 25. Land suitability for sessile oak in 2080 under the high emissions scenario based on individual biophysical factors: ALC Wetness (left) and ALC Drought (right).

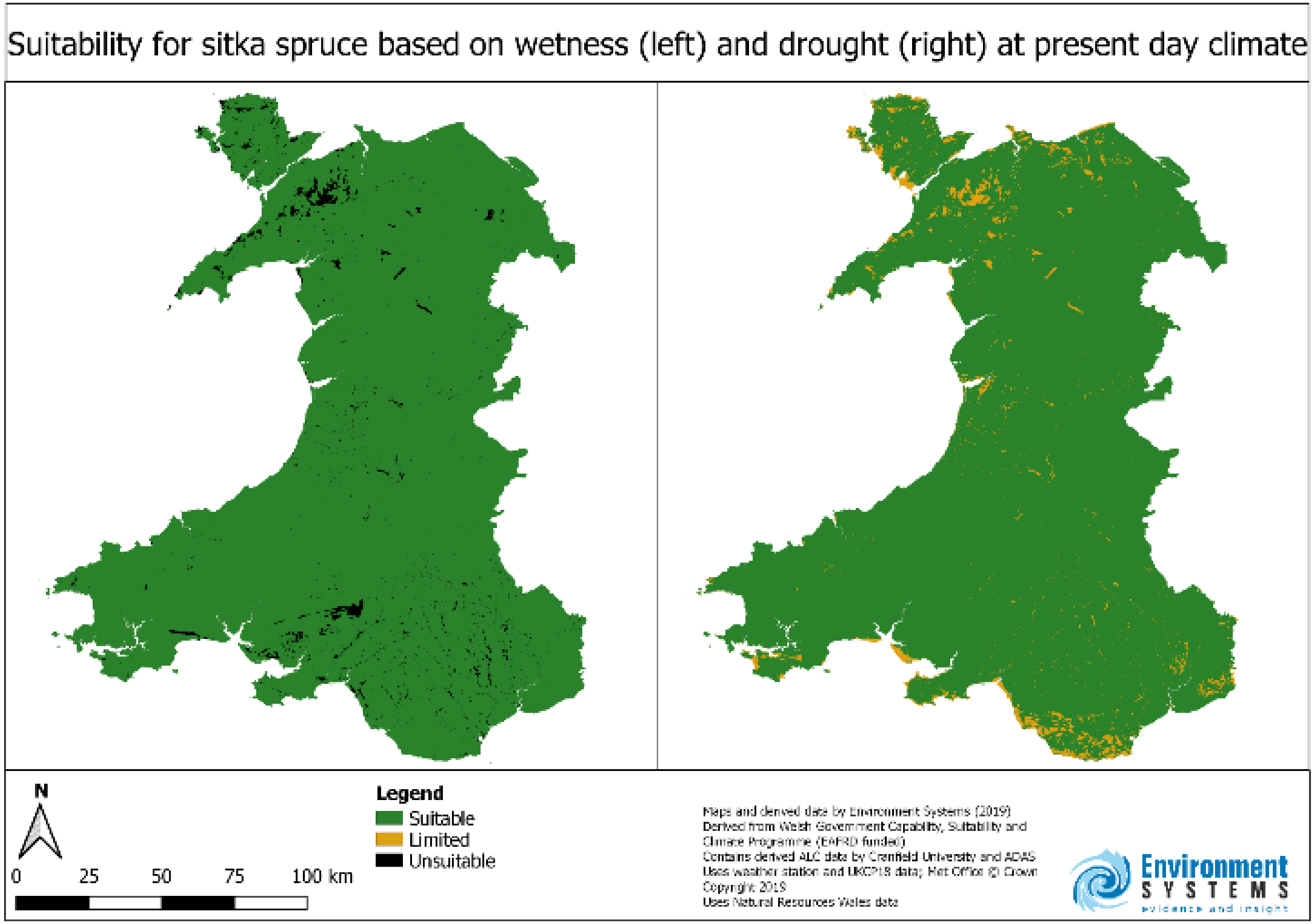


Figure 26. Present day land suitability for Sitka spruce based on individual biophysical factors: ALC Wetness (left) and ALC Drought (right).

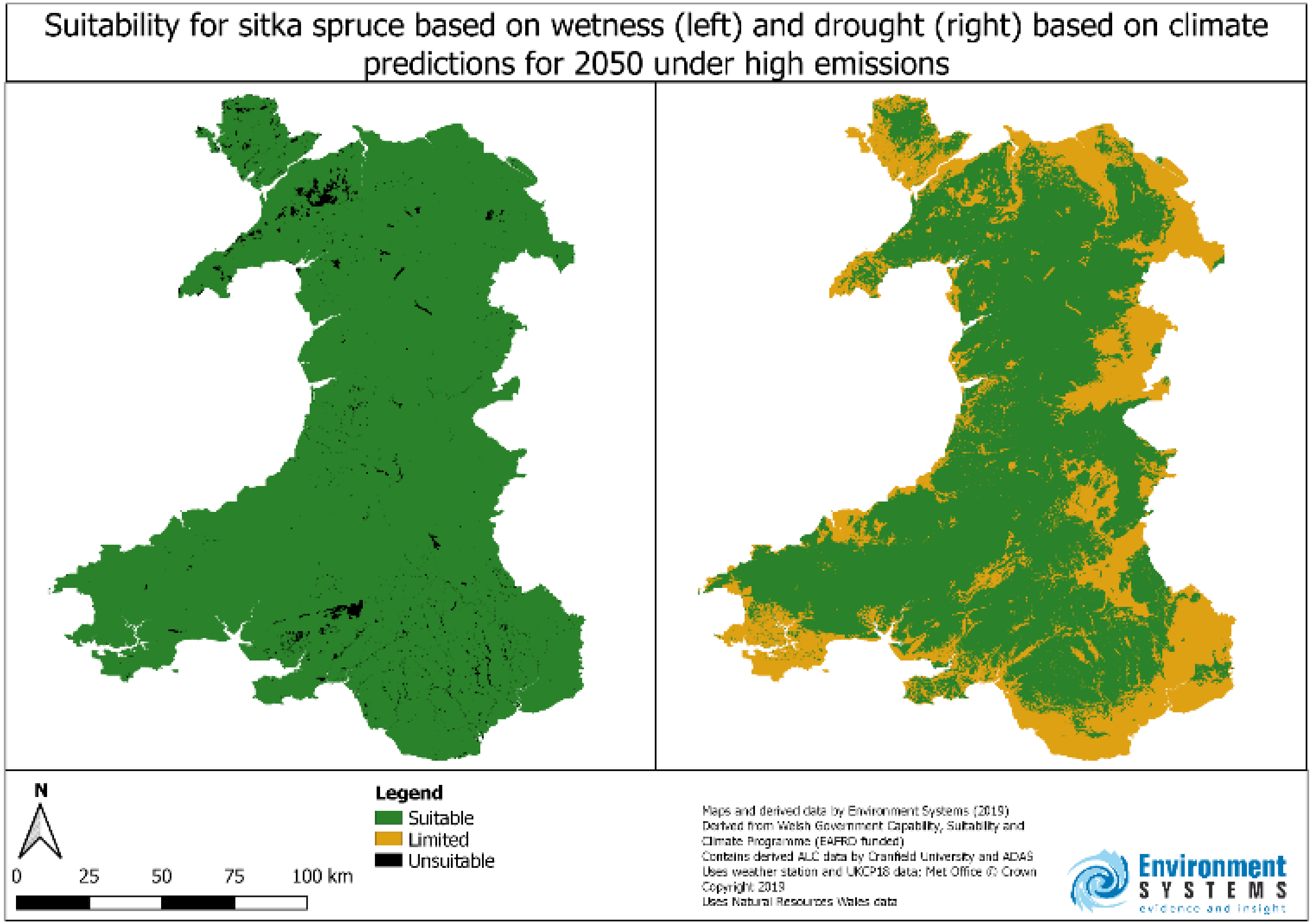


Figure 27. Land suitability for Sitka spruce in 2050 under the high emissions scenario based on individual biophysical factors: ALC Wetness (left) and ALC Drought (right).

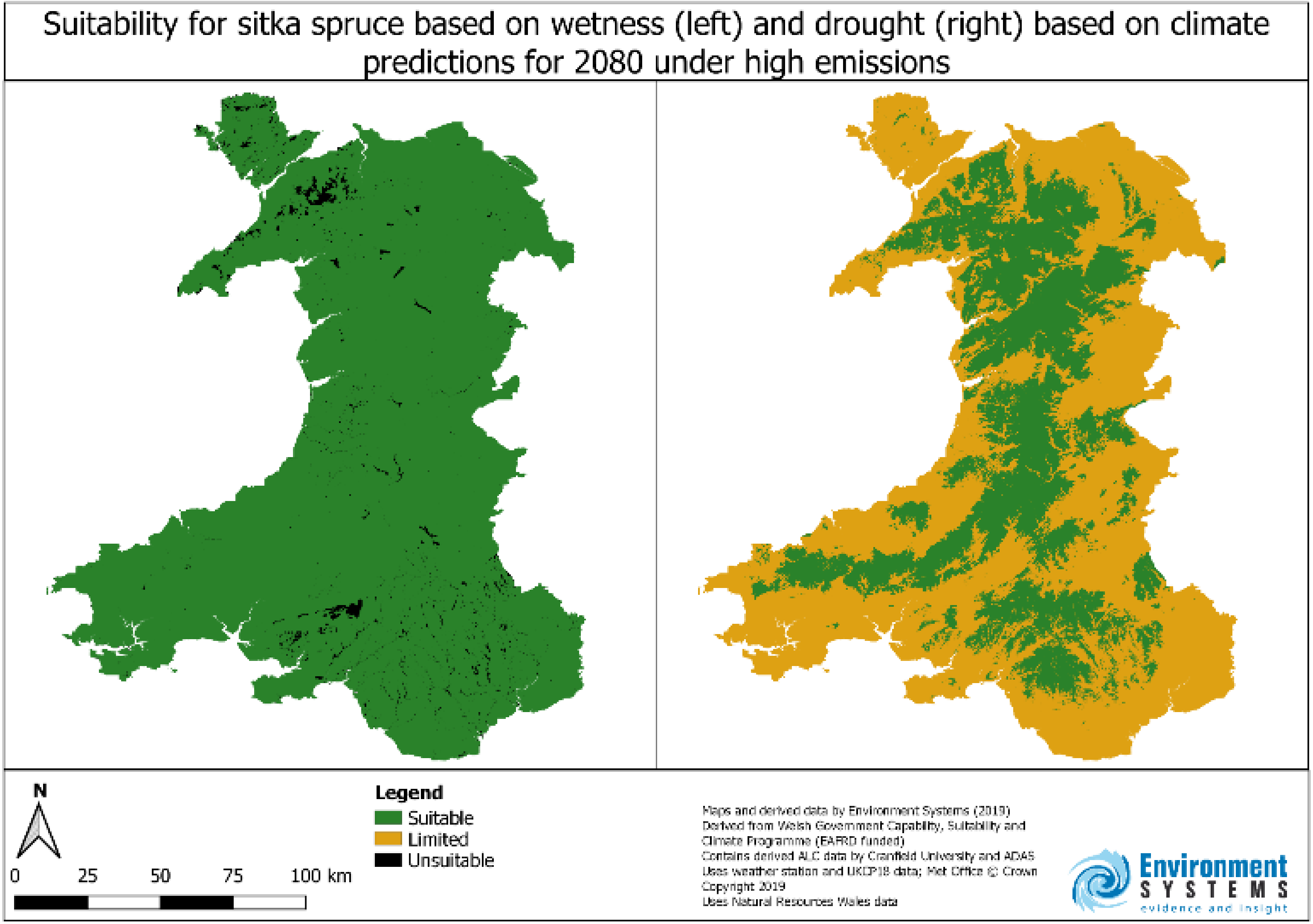


Figure 28. Land suitability for Sitka spruce in 2080 under the high emissions scenario based on individual biophysical factors: ALC Wetness (left) and ALC Drought (right).

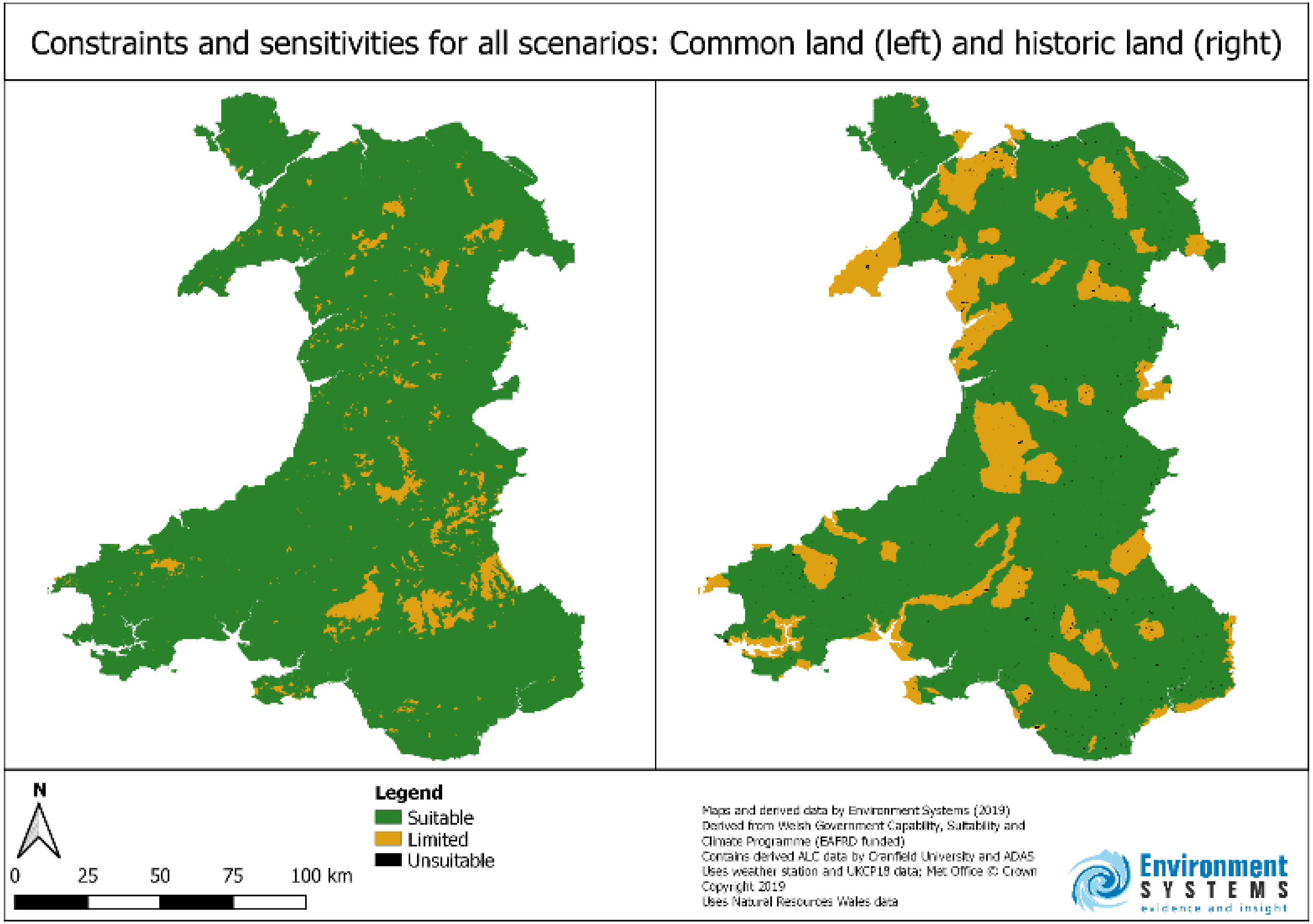


Figure 29. Sensitivities for sessile oak and Sitka spruce tree planting; common land (left) and historic land (right)

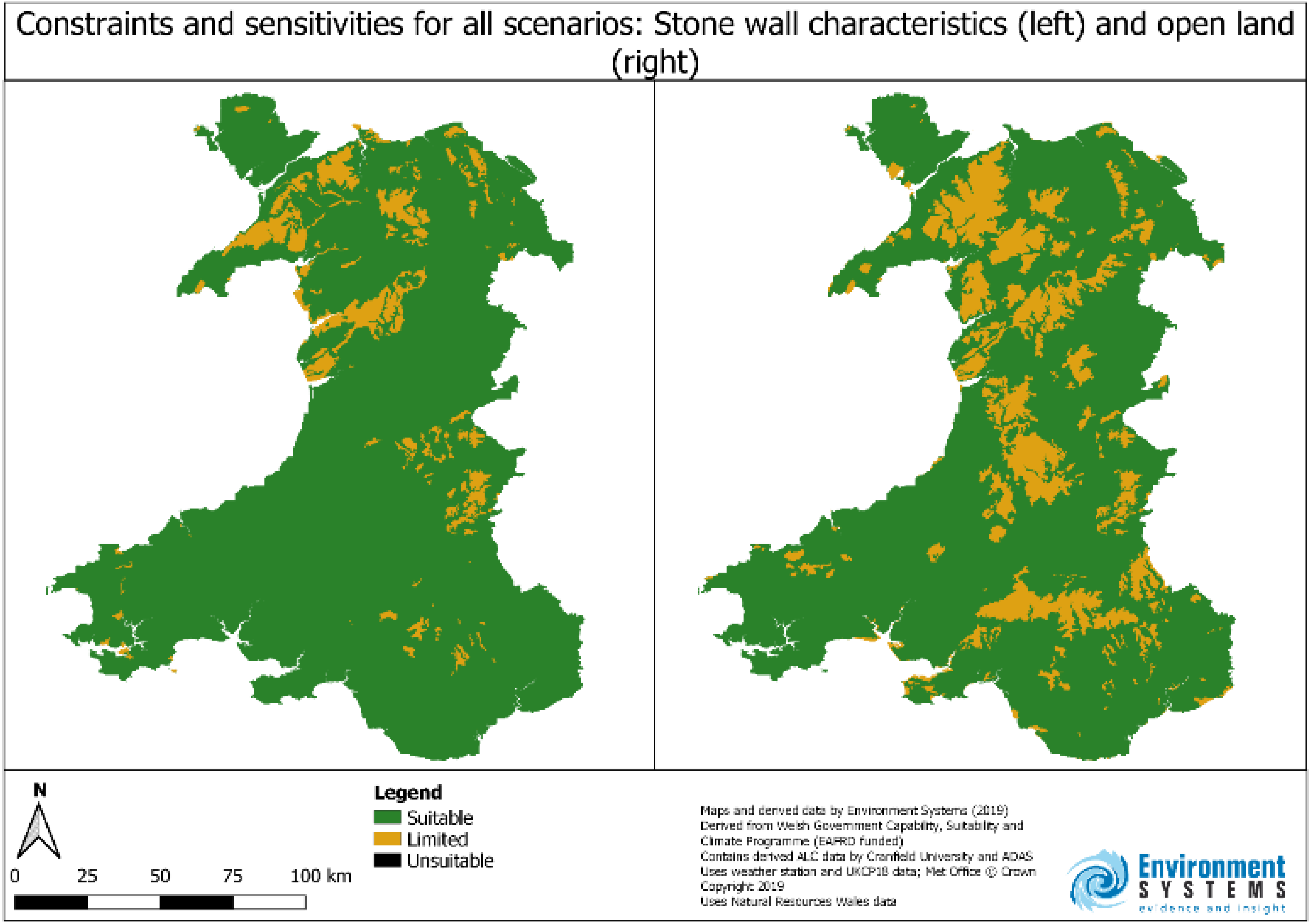


Figure 30. Sensitivities for sessile oak and Sitka spruce tree planting; areas characterised by stone walls (left) and open landscapes (right)

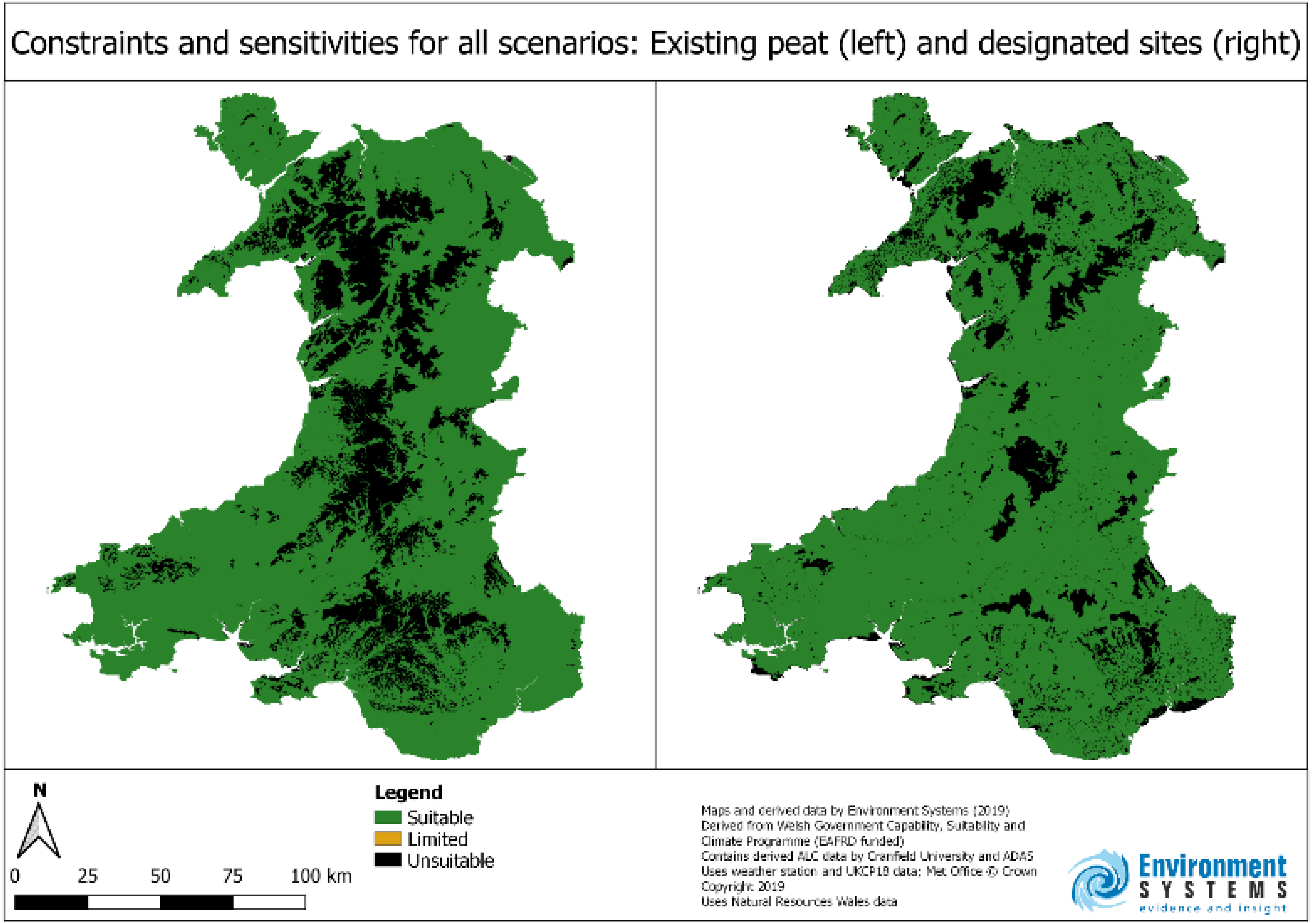


Figure 31. Constraints to sessile oak and Sitka spruce tree planting; existing peat (left) and designated sites (right)

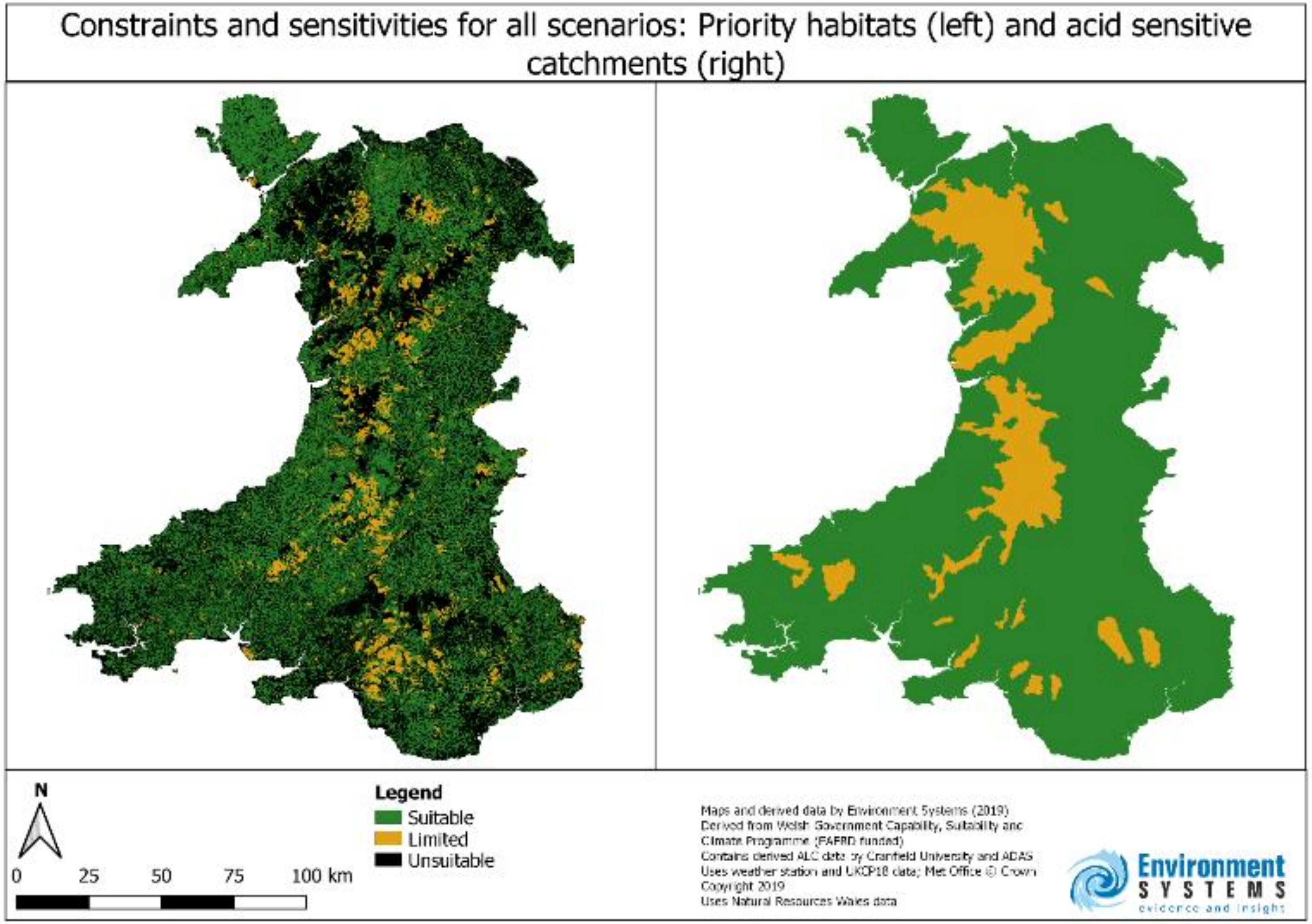


Figure 32. Constraints and sensitivities to sessile oak and Sitka spruce tree planting; priority habitats, urban, arable and existing plantations (left) and acid sensitive catchments (right)

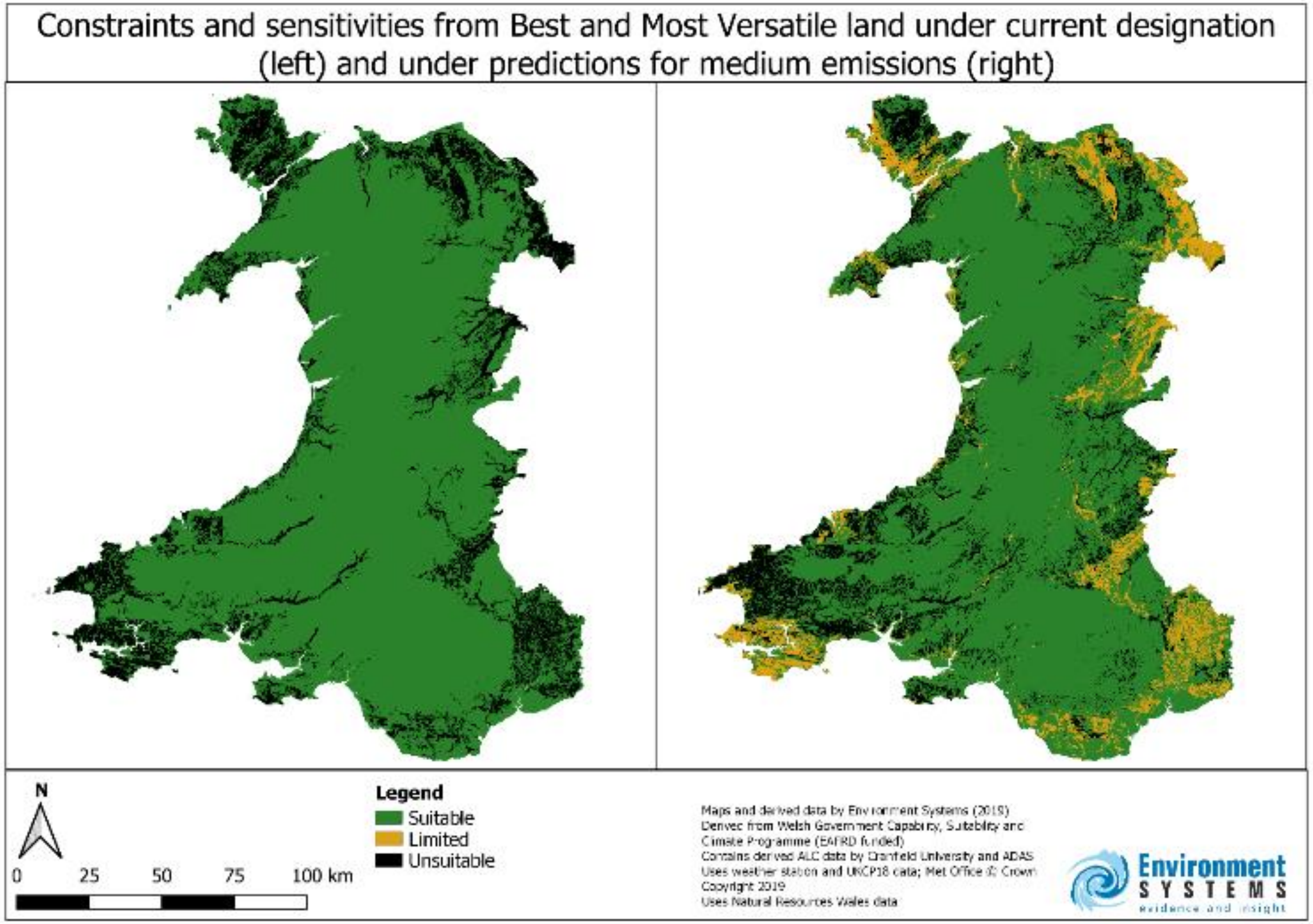


Figure 33. Constraints and sensitivities to sessile oak and Sitka spruce tree planting; Best and Most Versatile Land (BMV) medium emissions time-series. The present day map (left) shows areas that are currently BMV mapped as Unsuitable for planting. The medium emissions scenario map (right) shows as Unsuitable areas that will remain BMV from the present day until 2080, and areas that are not currently BMV but are forecast to become BMV. Areas that are currently BMV but are forecast to lose BMV status are mapped as Limited suitability.

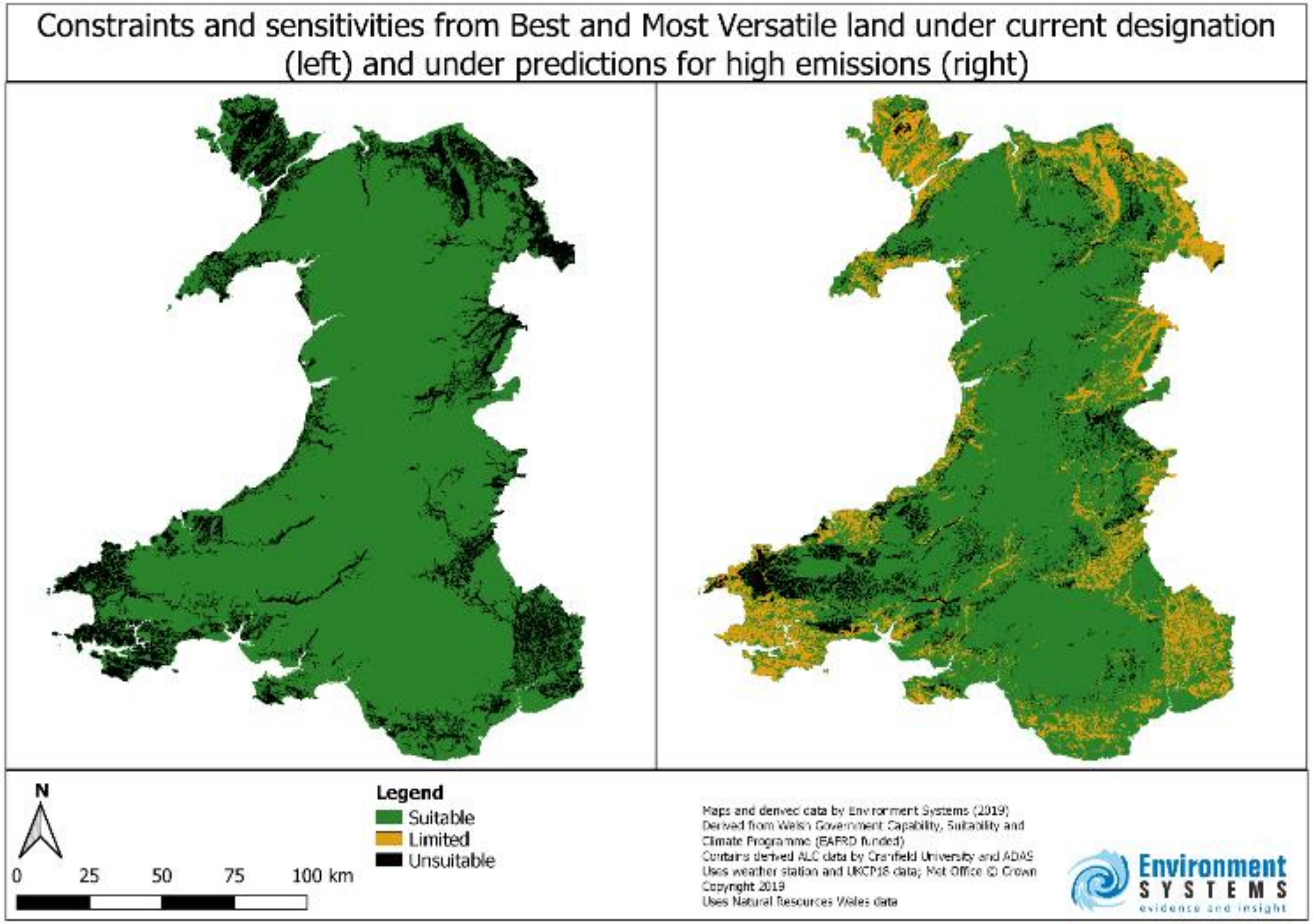


Figure 34. Constraints and sensitivities to sessile oak and Sitka spruce tree planting; Best and Most Versatile Land (BMV) high emissions time-series. The present day map (left) shows areas that are currently BMV mapped as Unsuitable for planting. The high emissions scenario map (right) shows as Unsuitable areas that will remain BMV from the present day until 2080, and areas that are not currently BMV but are forecast to become BMV. Areas that are currently BMV but are forecast to lose BMV status are mapped as Limited suitability.

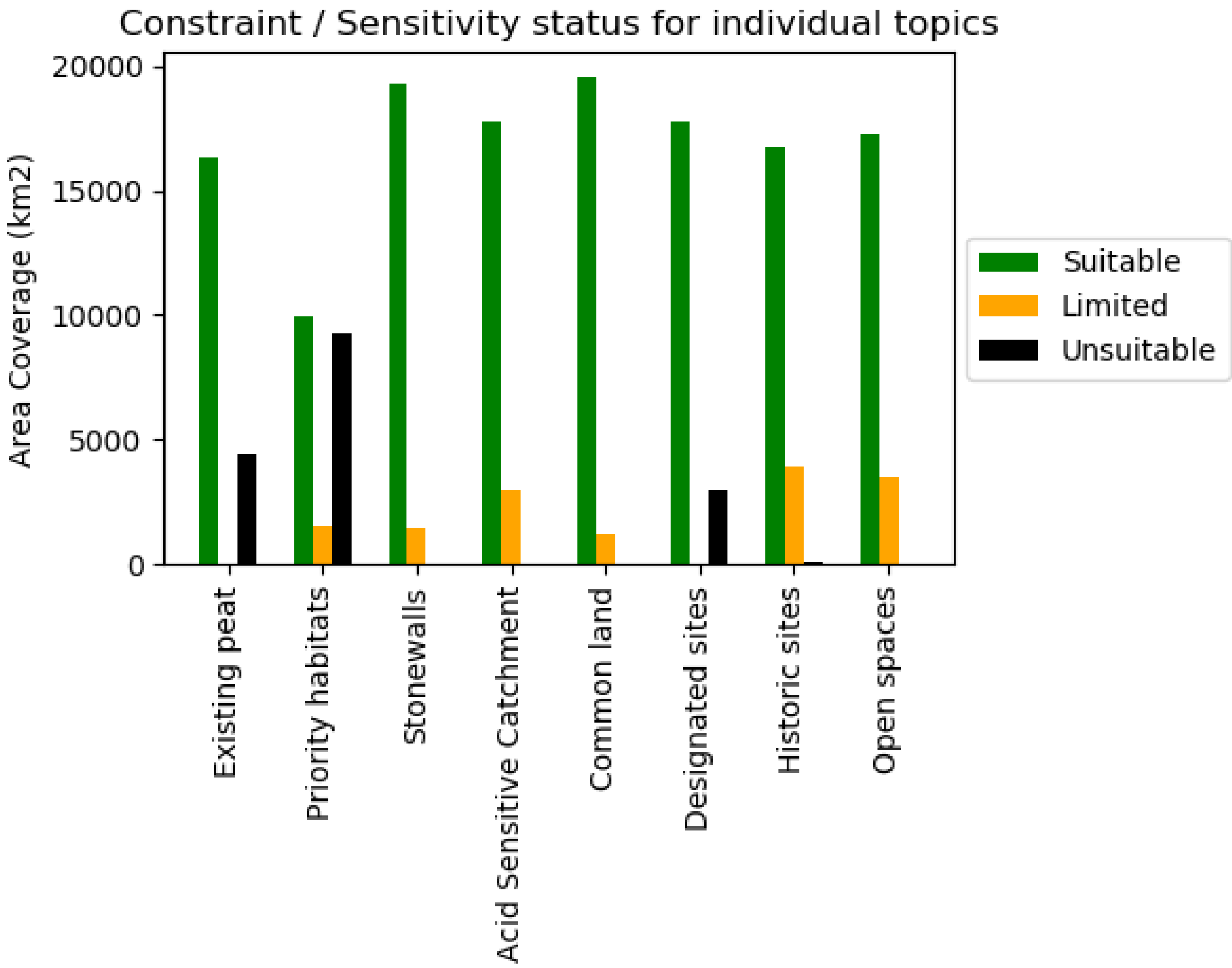
Appendix B

Analysis of area covered by each constraint/sensitivity; bar graphs showing the proportion of land that is Suitable/Limited Suitability/Unsuitable underneath each constraint/sensitivity. These graphs consider constraints and sensitivities singularly, not in combination (biophysical suitability is considered as a single factor).

When interpreting these graphs it must be considered that an area may be covered by multiple constraints/sensitivities, and that removing one constraint/sensitivity will not necessarily lead to an area becoming Suitable.

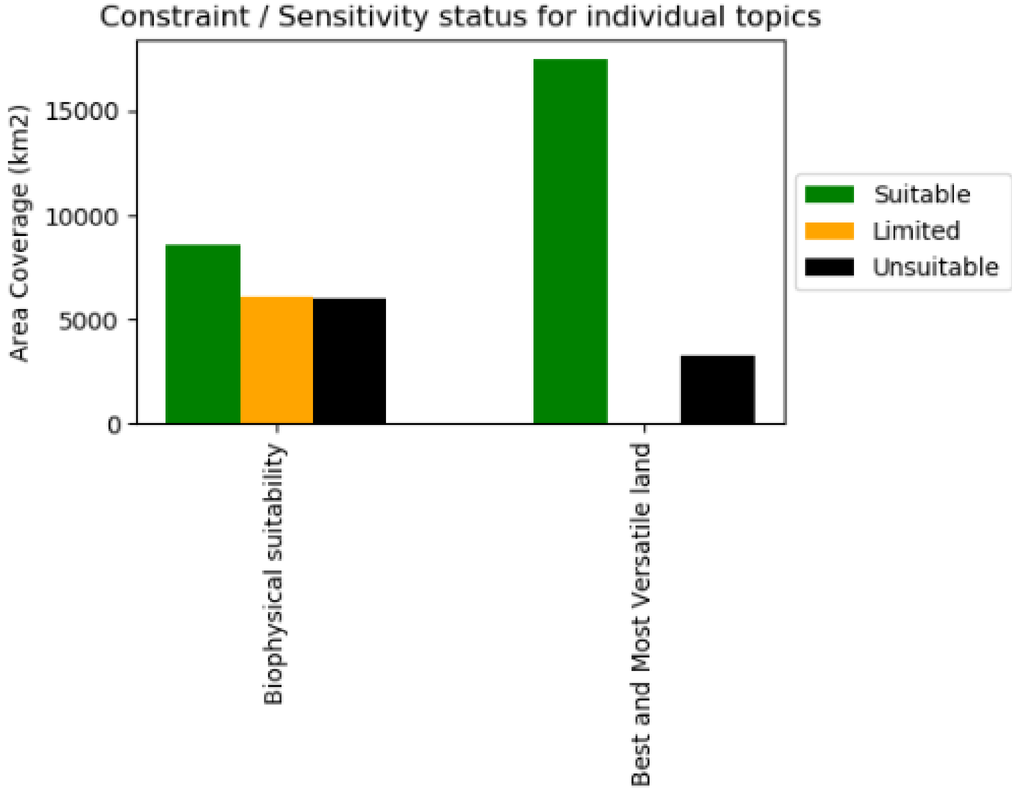
Multiple constraints are further considered through analysis of areas affected by only one constraint/sensitivity, considered in Appendix C

1. Constraints and sensitivities applied equally to all tree species and time periods/emission scenarios (i.e. constraints and sensitivities for which the same dataset was used for the present day, 2050, 2080, medium and high emissions, and for oak and Sitka spruce). This graph shows how the land area of Wales is divided into Suitable/Limited Suitability/Unsuitable for each type of constraint/sensitivity.

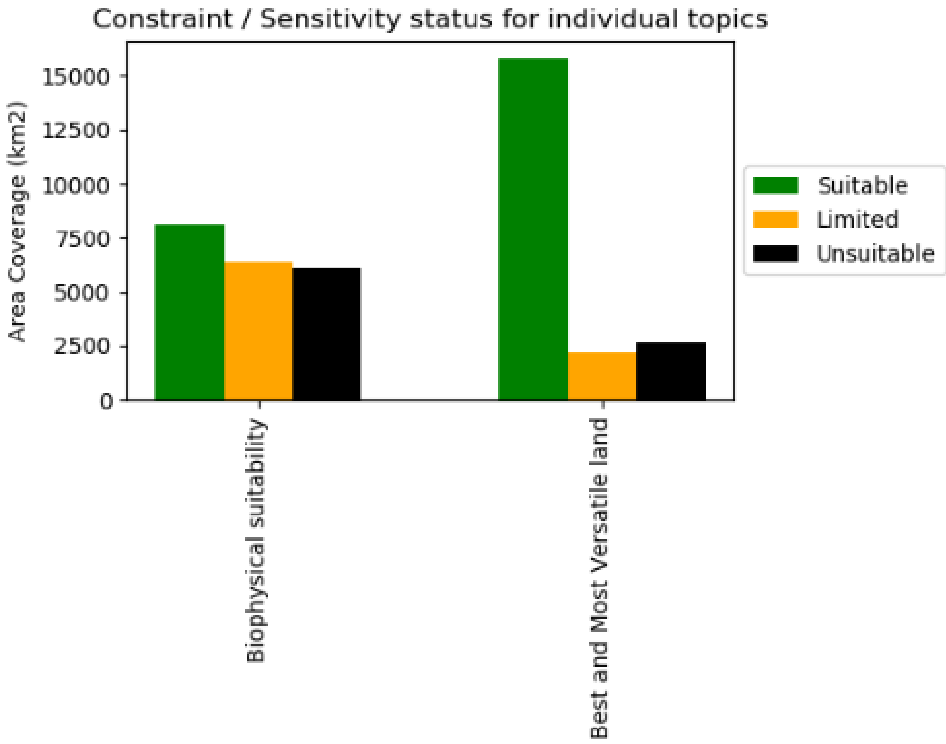


2. Constraints and sensitivities varying by species/time/emissions scenario (Best and Most Versatile land, and biophysical suitability)

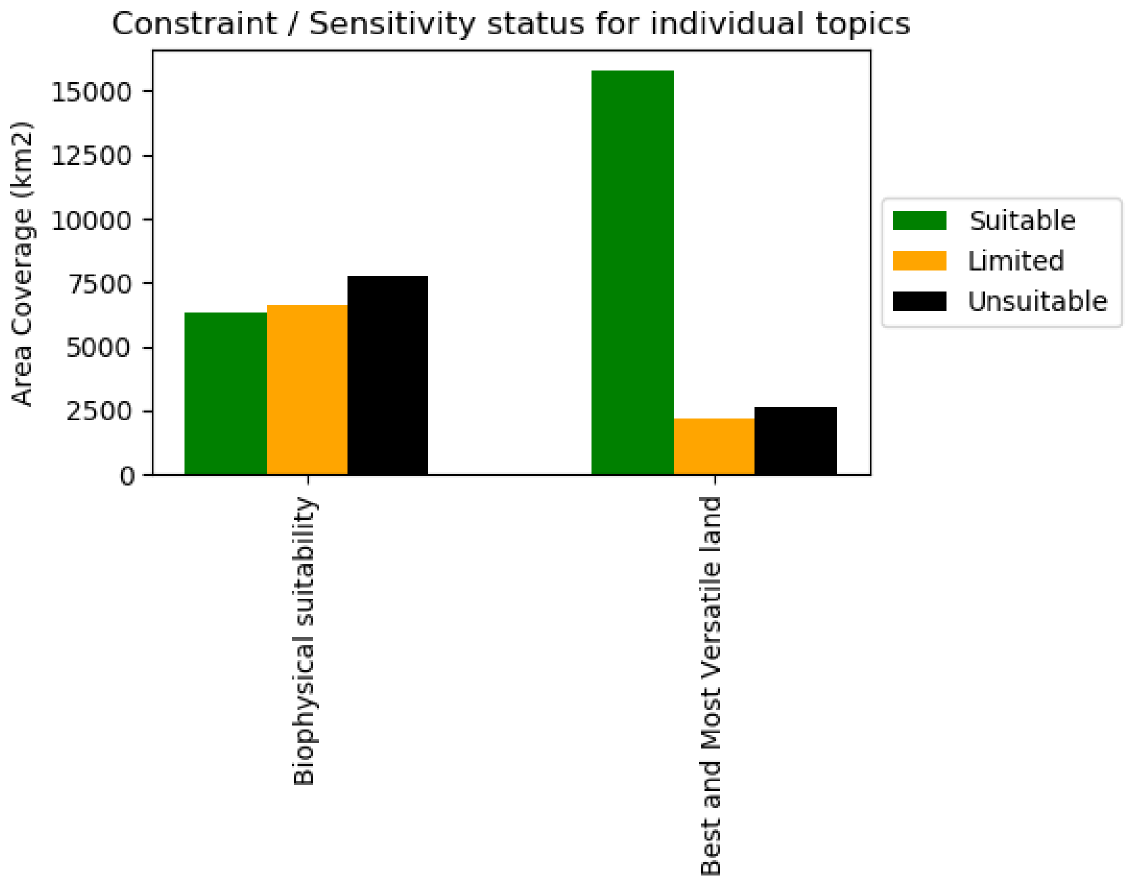
Sessile oak present day



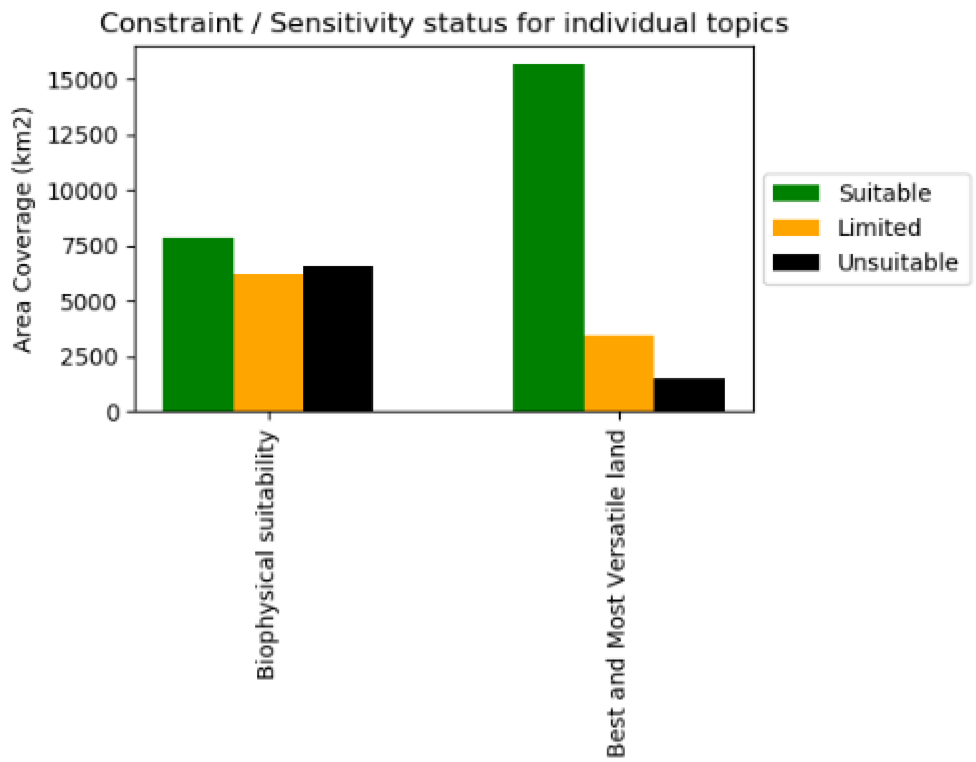
Sessile oak 2050 medium emissions



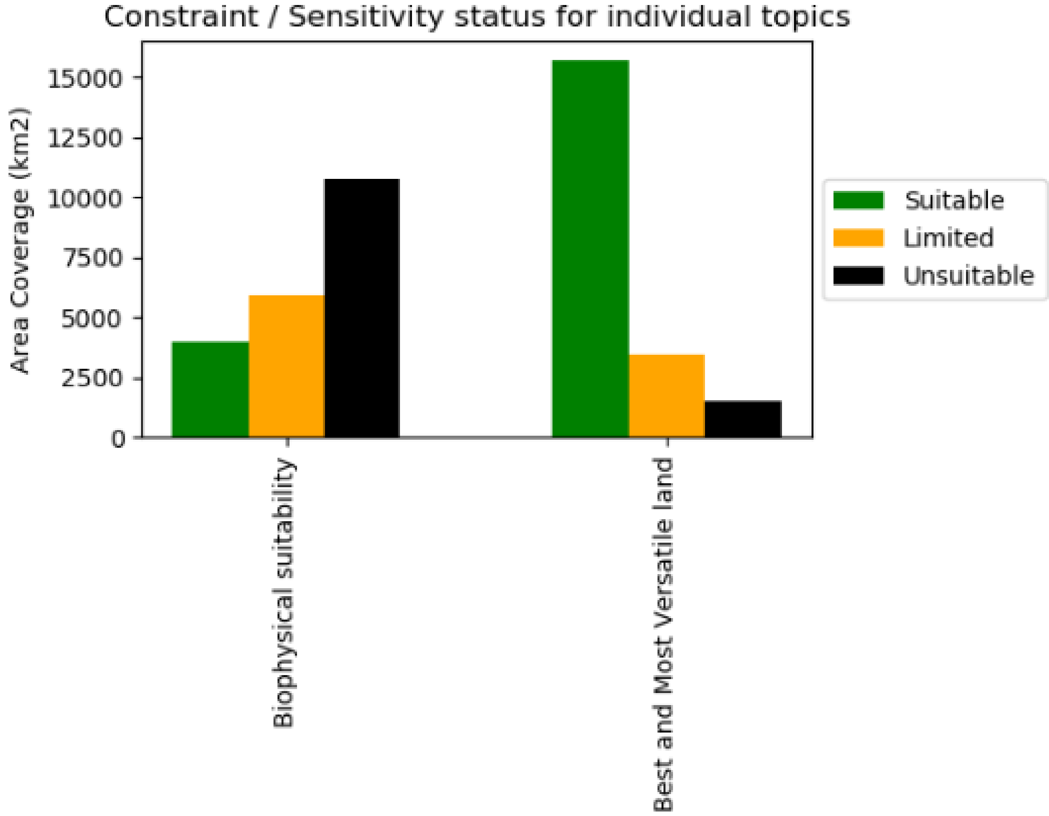
Sessile oak 2080 medium emissions



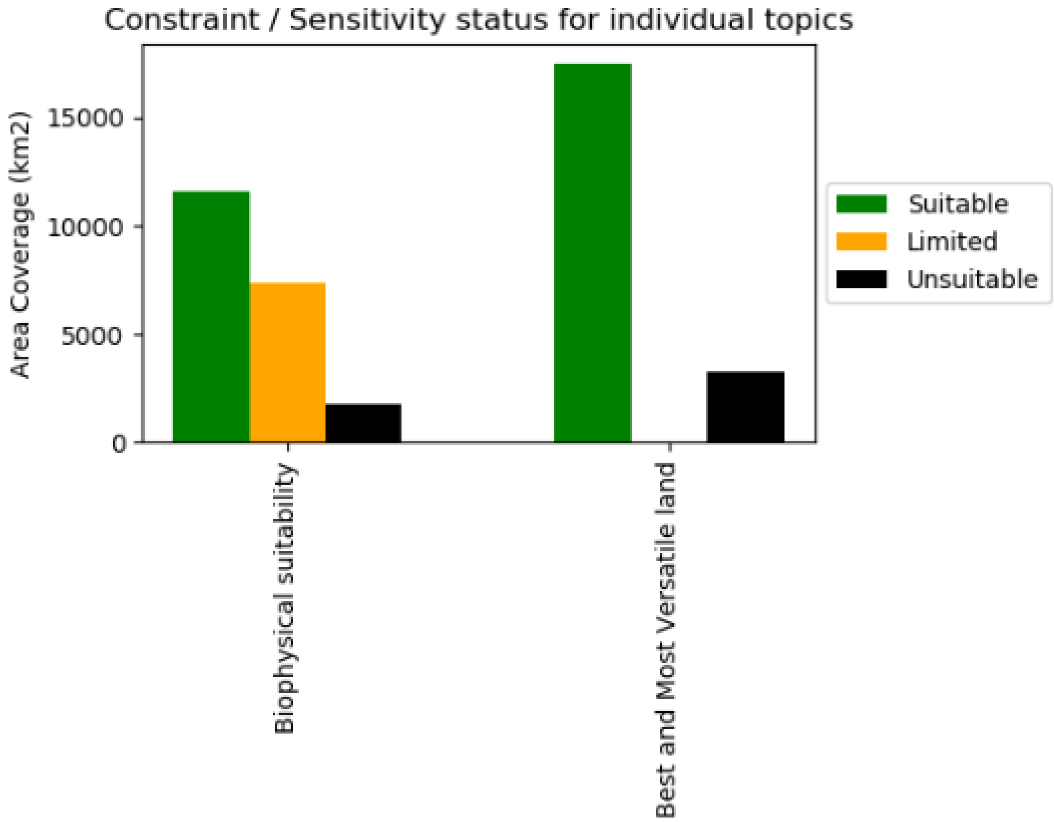
Sessile oak 2050 high emissions



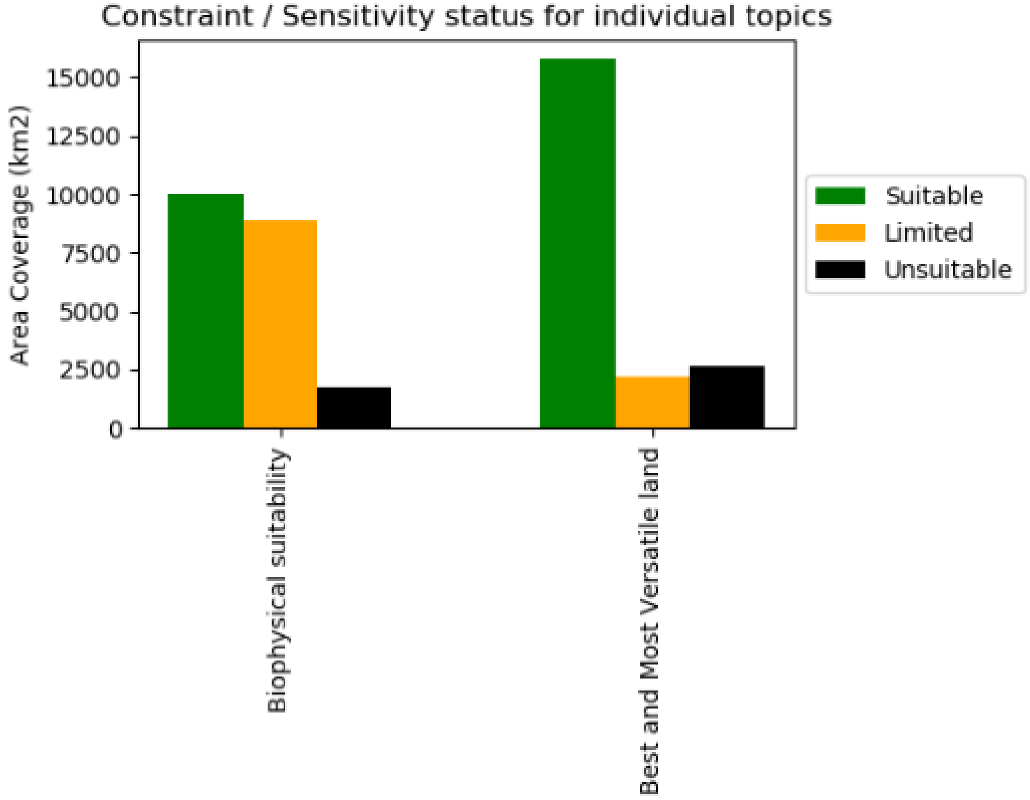
Sessile oak 2080 high emissions



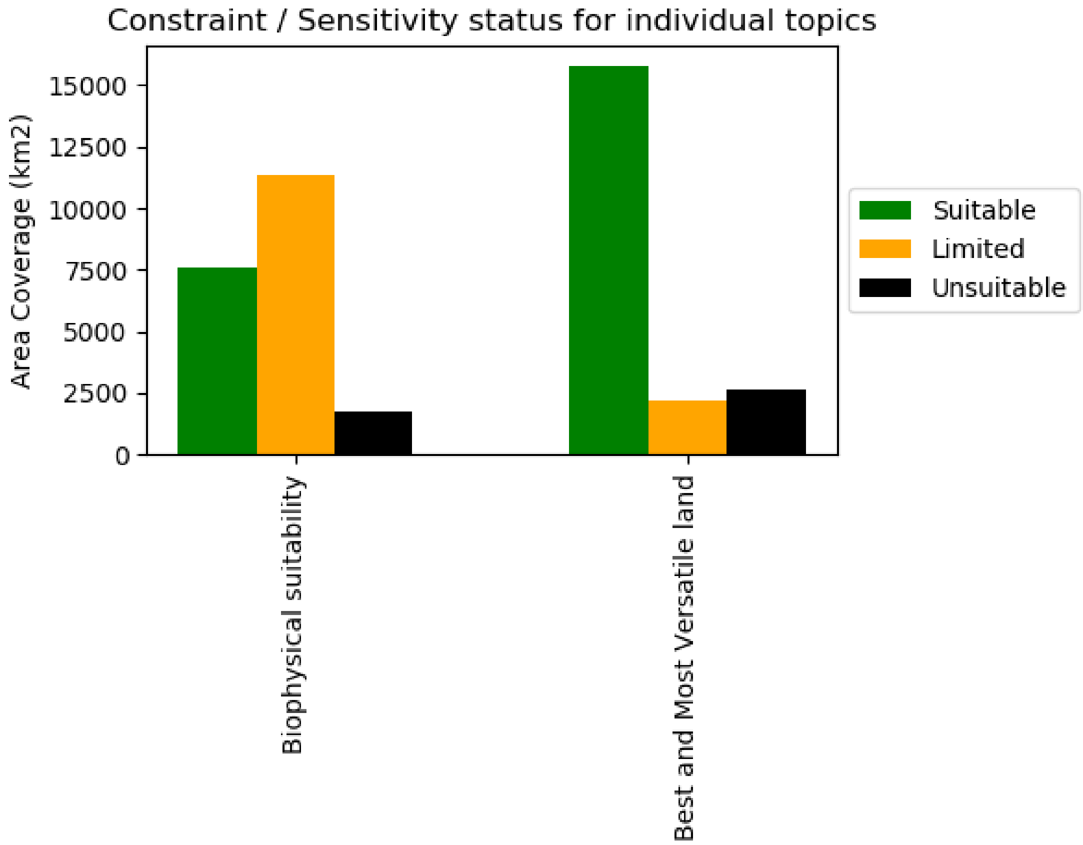
Sitka spruce present day



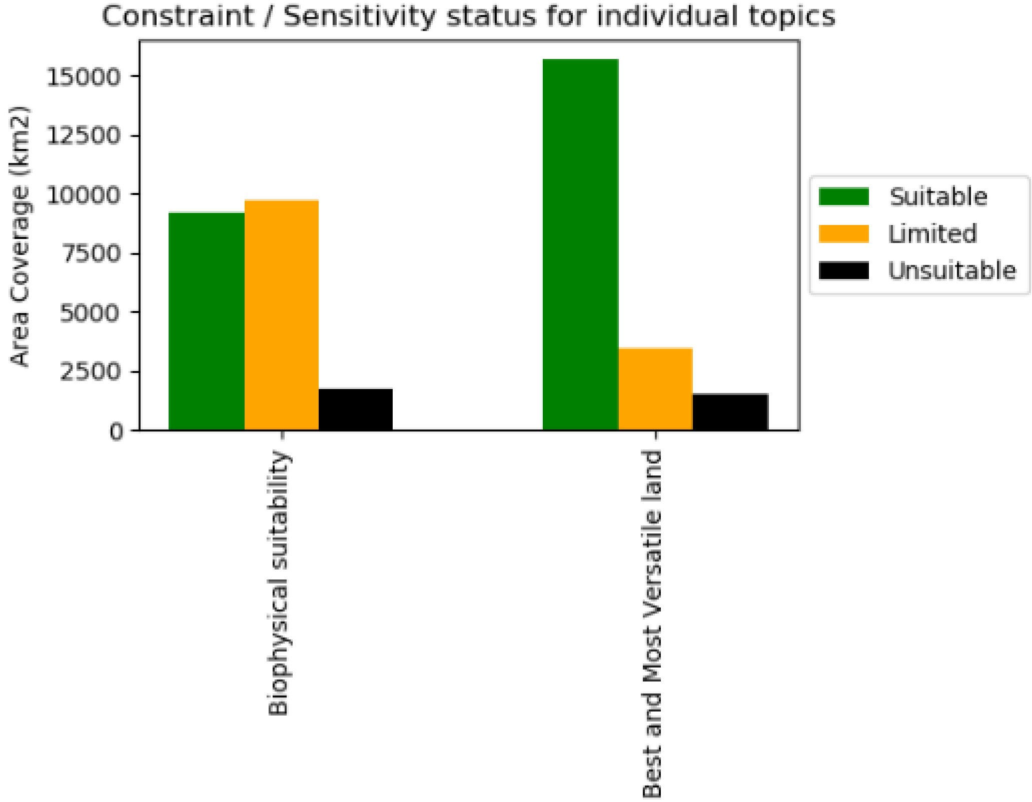
Sitka spruce 2050 medium emissions



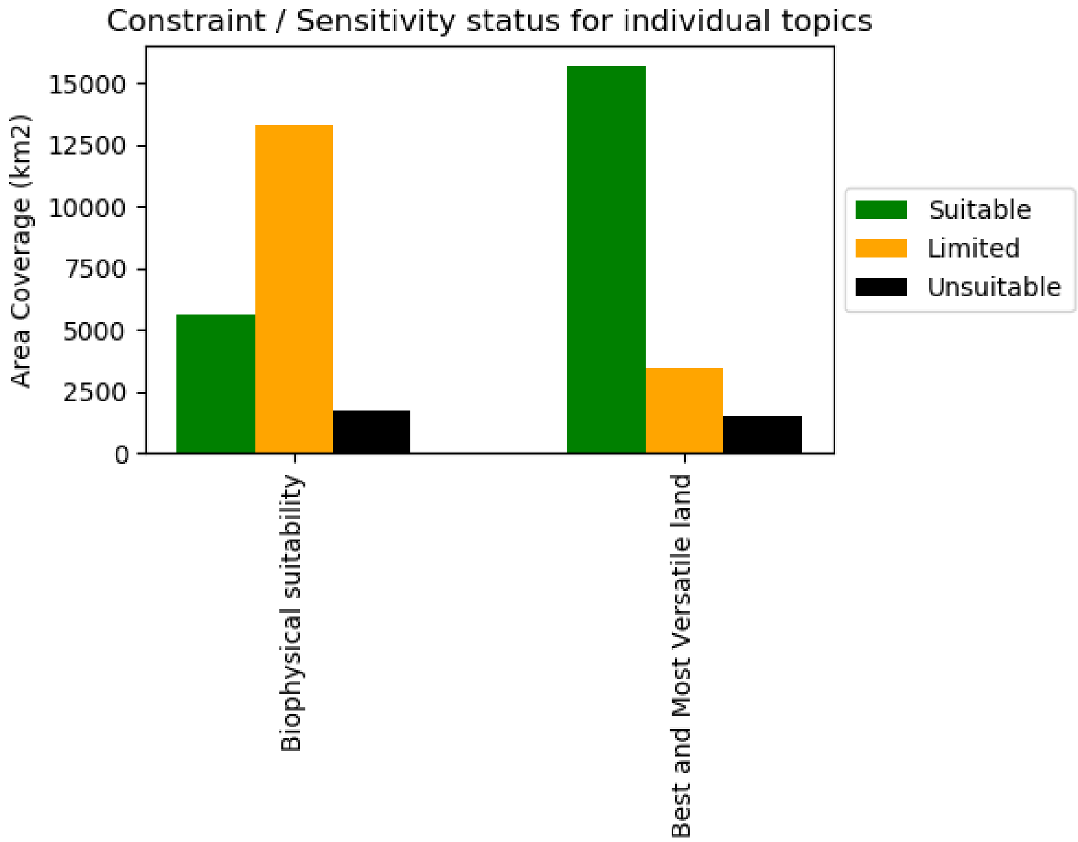
Sitka spruce 2080 medium emissions



Sitka spruce 2050 high emissions



Sitka spruce 2080 high emissions



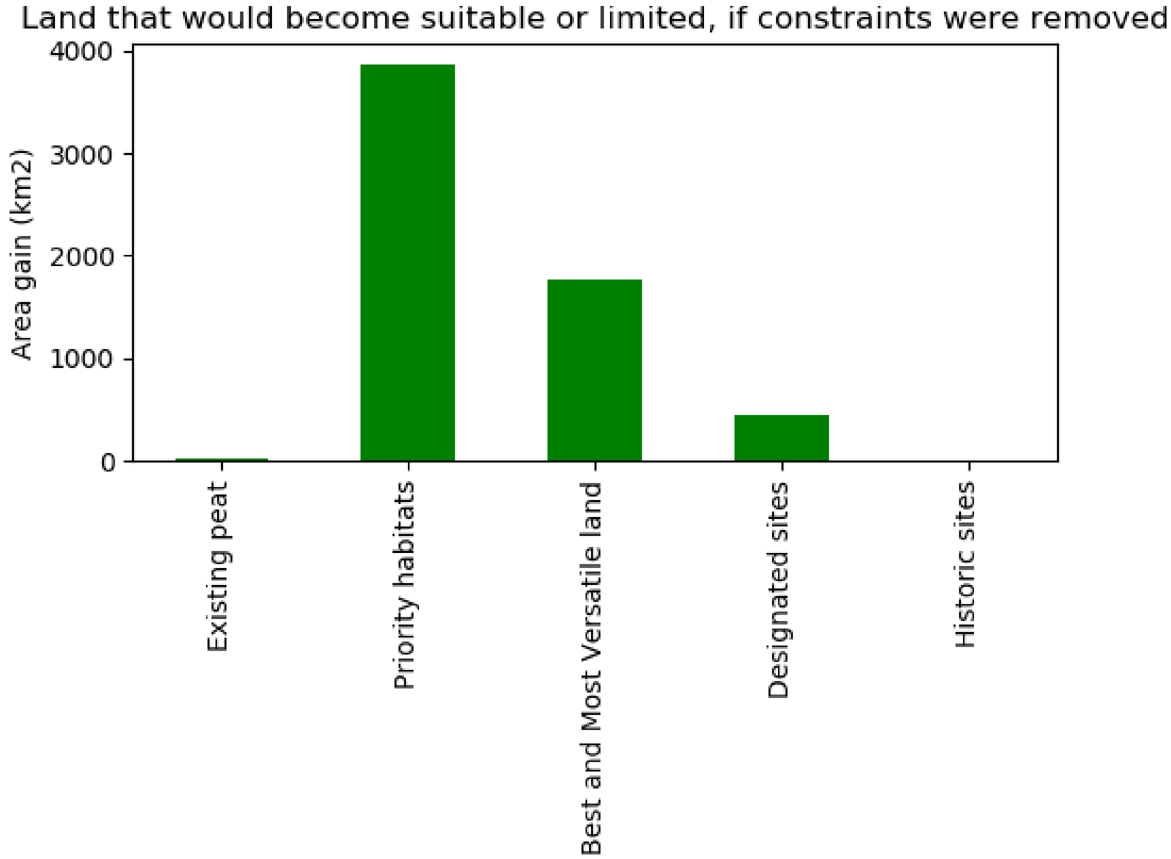
Appendix C

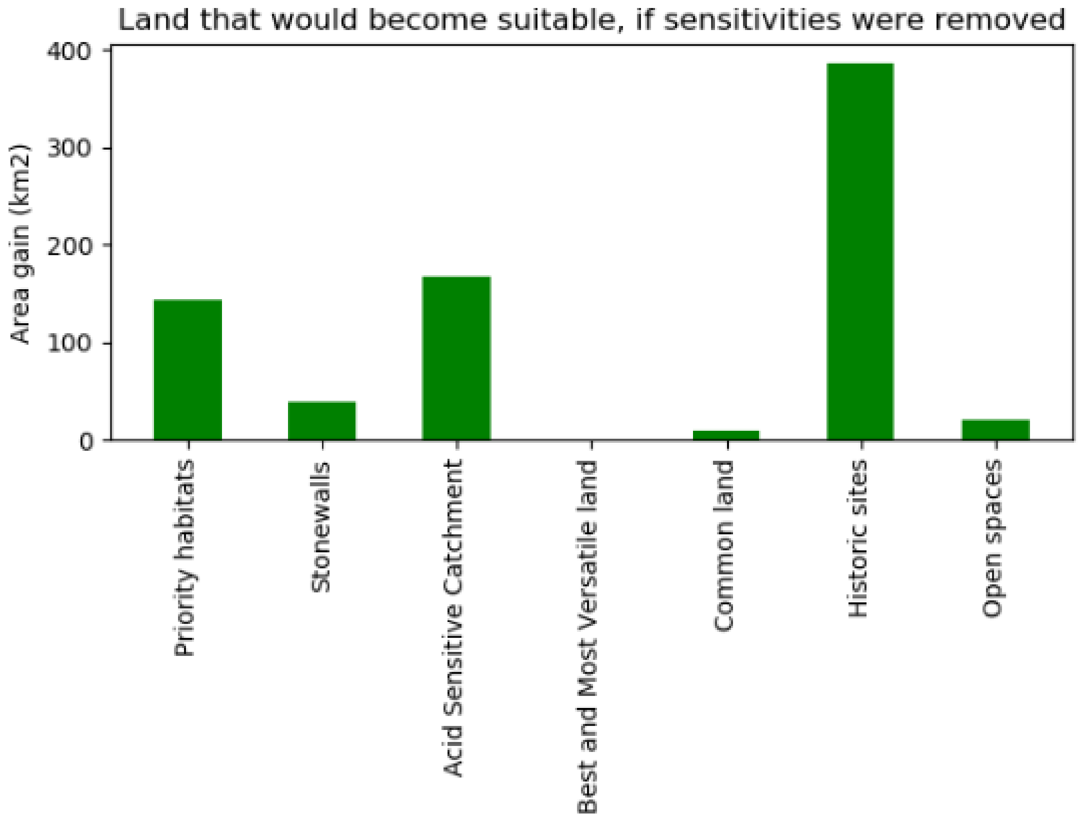
Analysis of land area classed as a constraint or sensitivity; bar graphs representing how much land would become either Suitable or Limited Suitability, if a specified man-made constraint / sensitivity were to be removed / no longer a constraining factor.

These graphs consider the impact of overlapping constraints and sensitivities, and only show areas that would be gained for places where the chosen factor is the only limiting factor. Areas do not become Suitable in situations where there are several overlapping constraining factors.

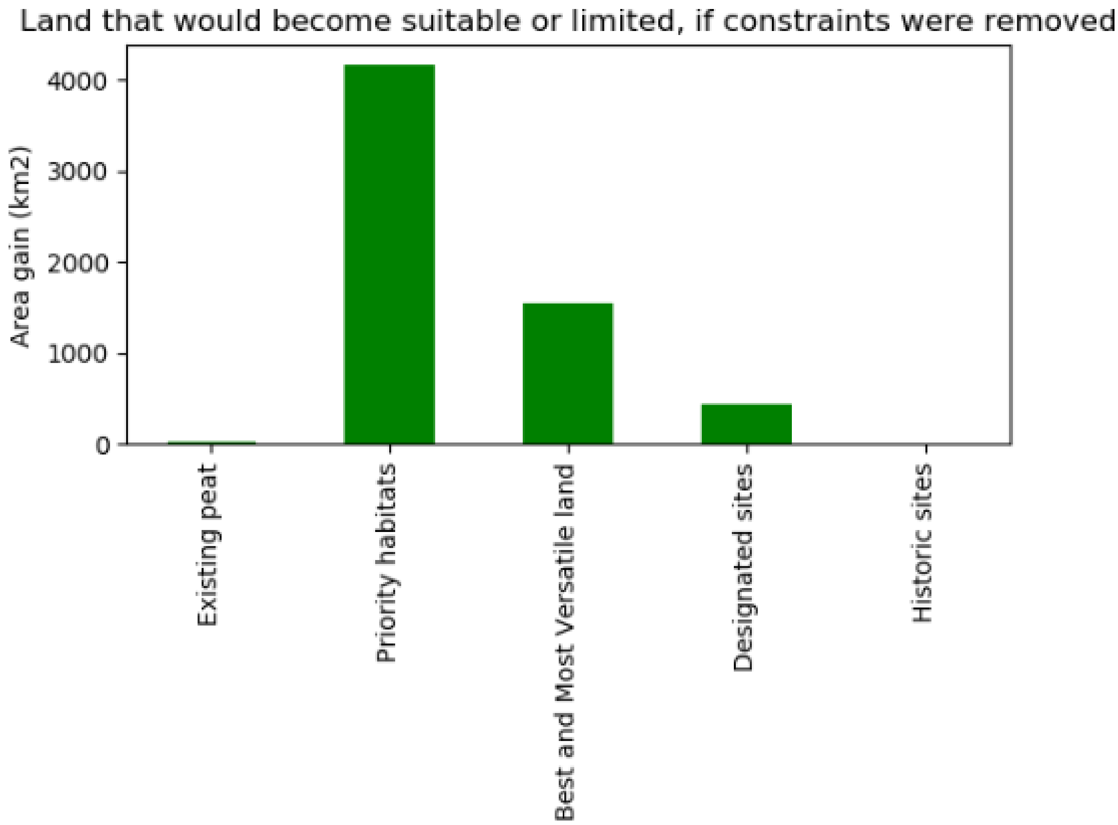
Example: bar graphs showing area gain the case of removing Priority habitat as a constraining factor only show the area calculations for locations where Priority habitat is the only constraining factor. If Priority habitat overlaps with another factor, such as Deep peat, the area will not become suitable and so is not reflected in the graph.

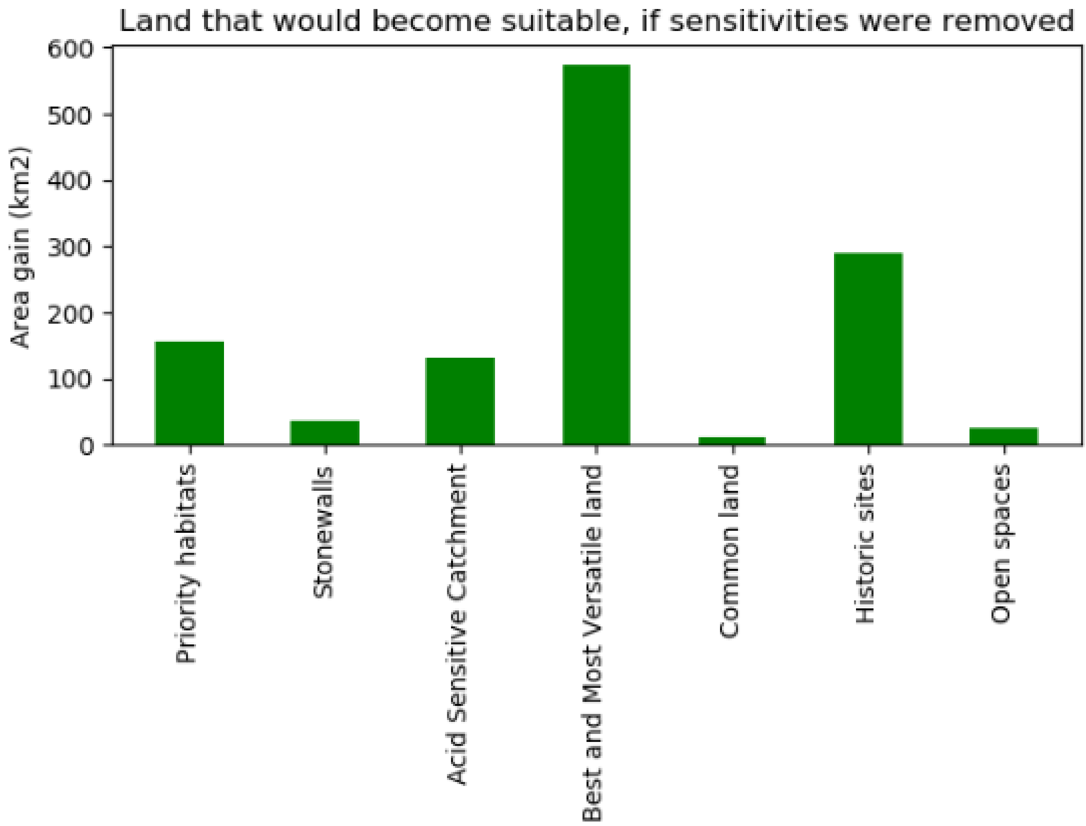
Sessile oak present day



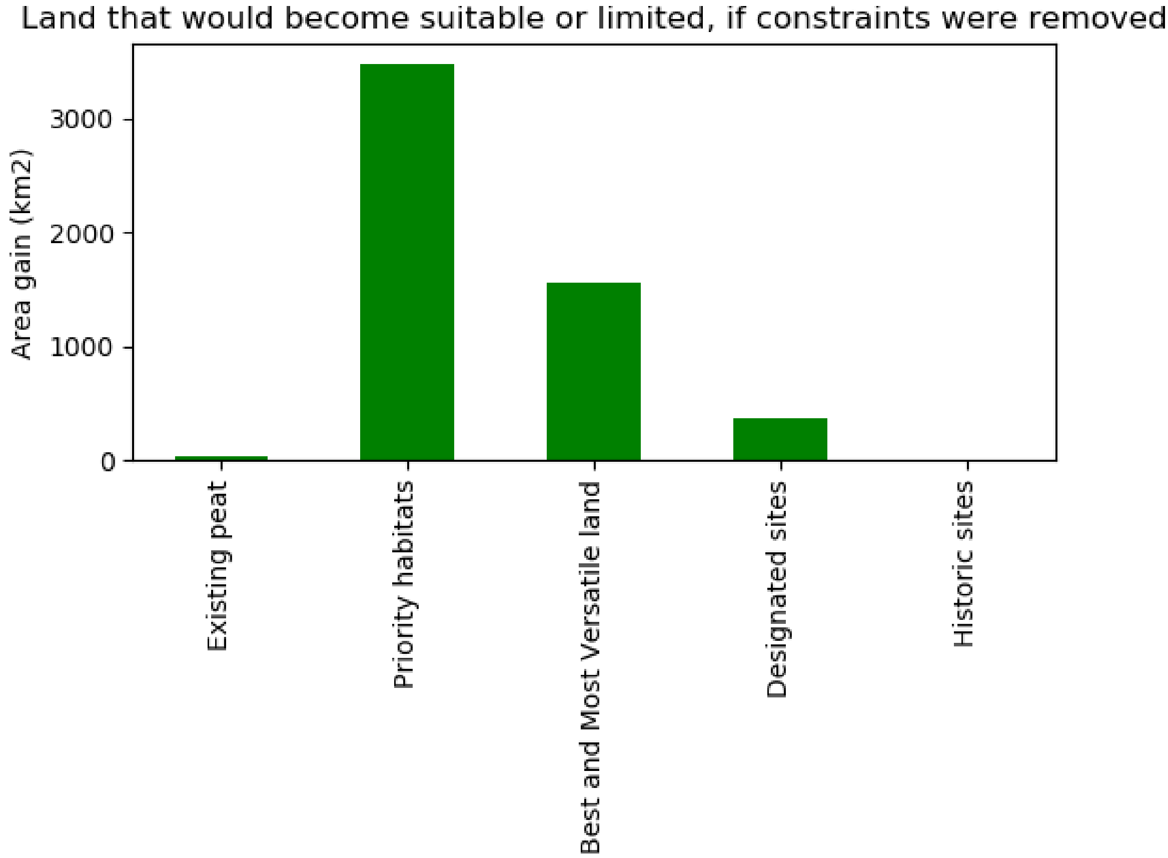


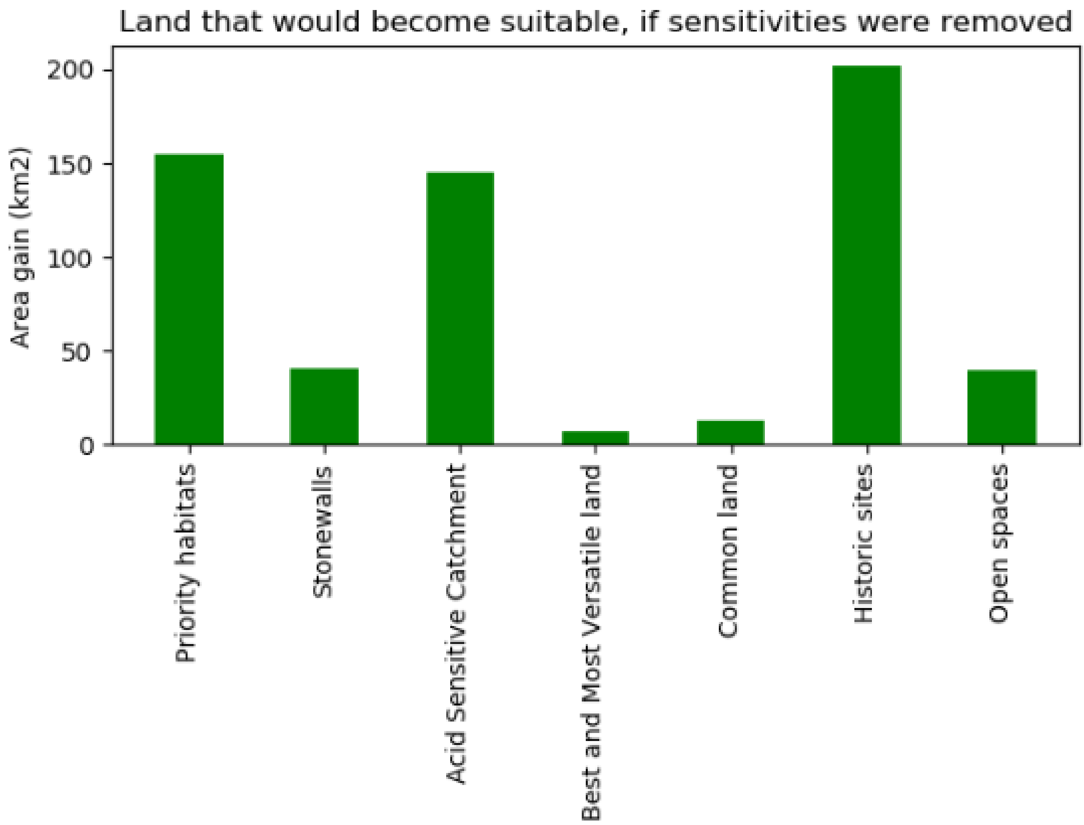
Sessile oak 2050 medium emissions



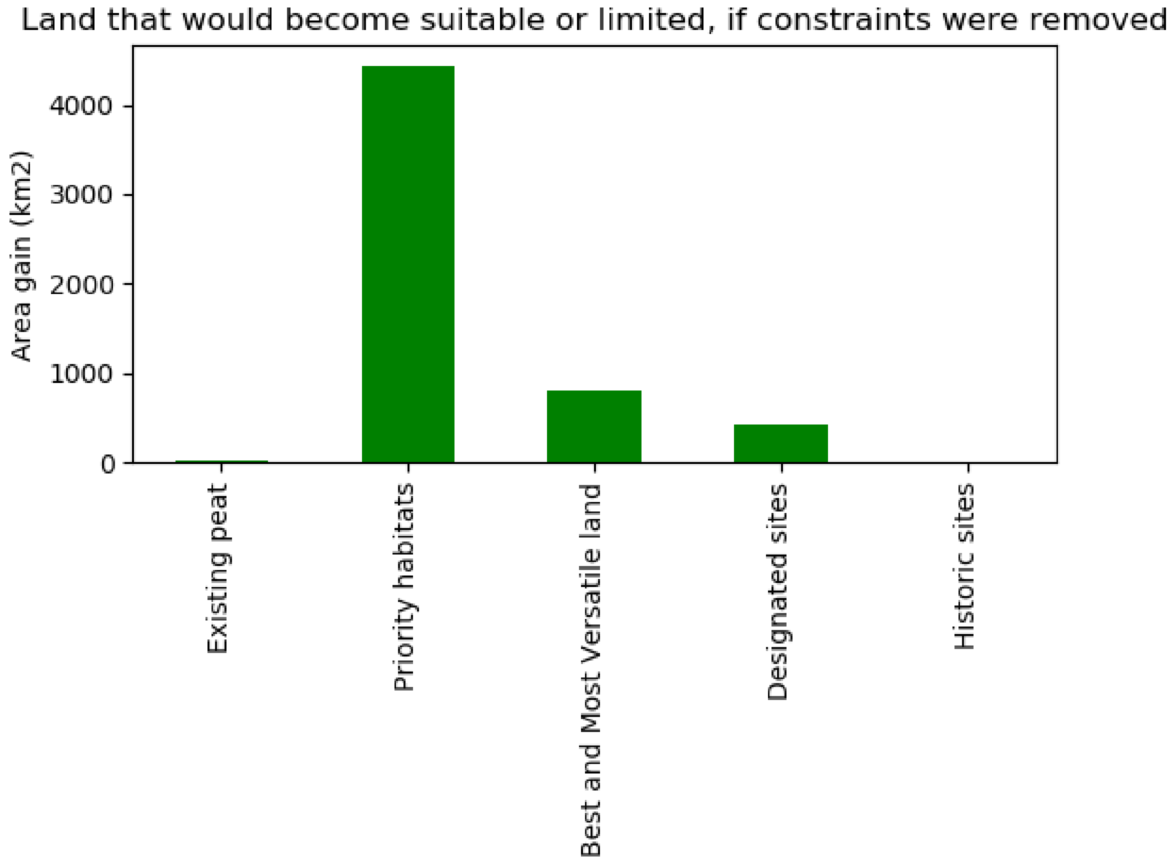


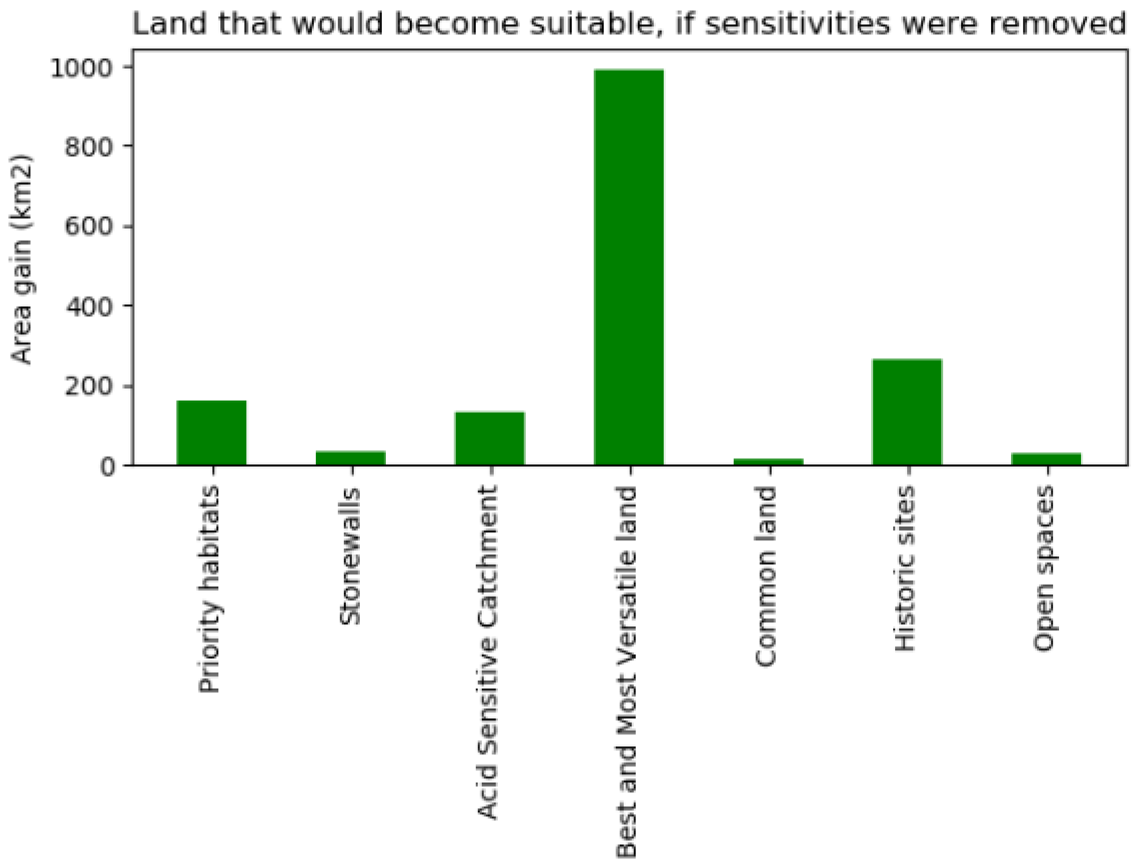
Sessile oak 2080 medium emissions



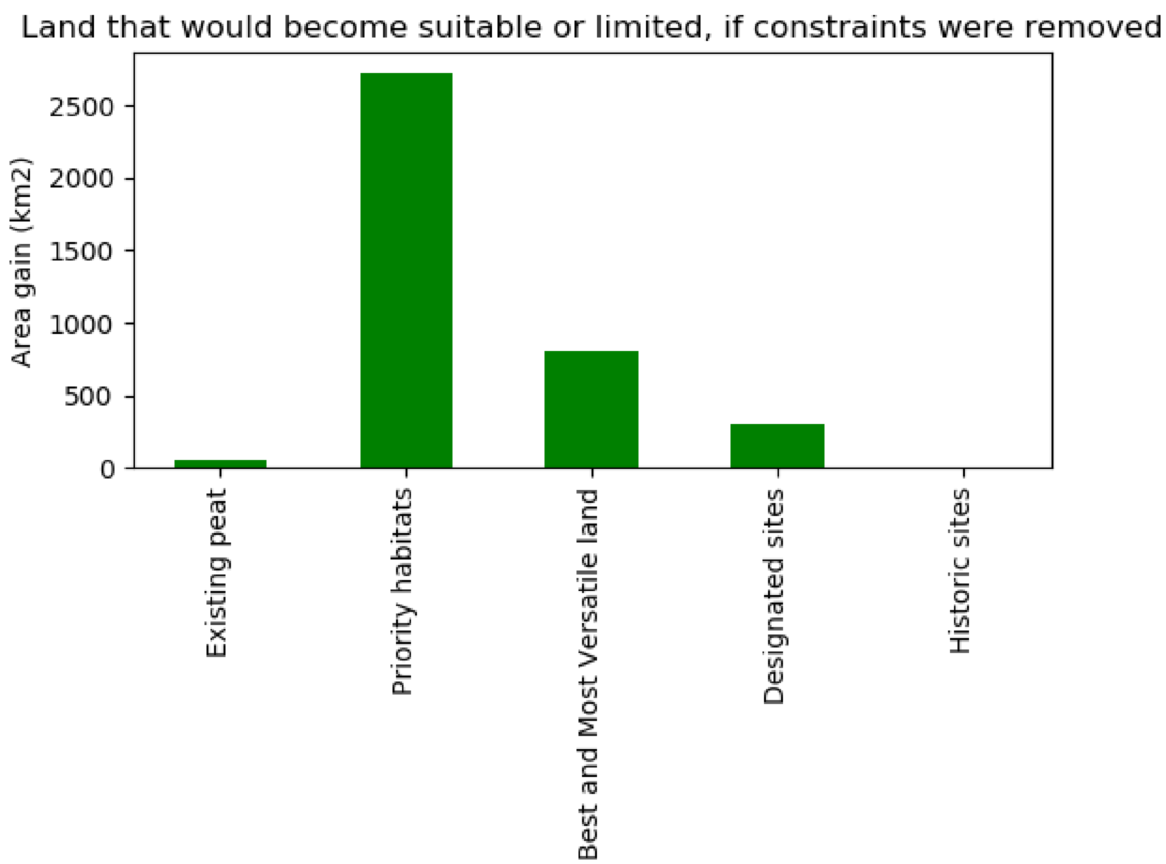


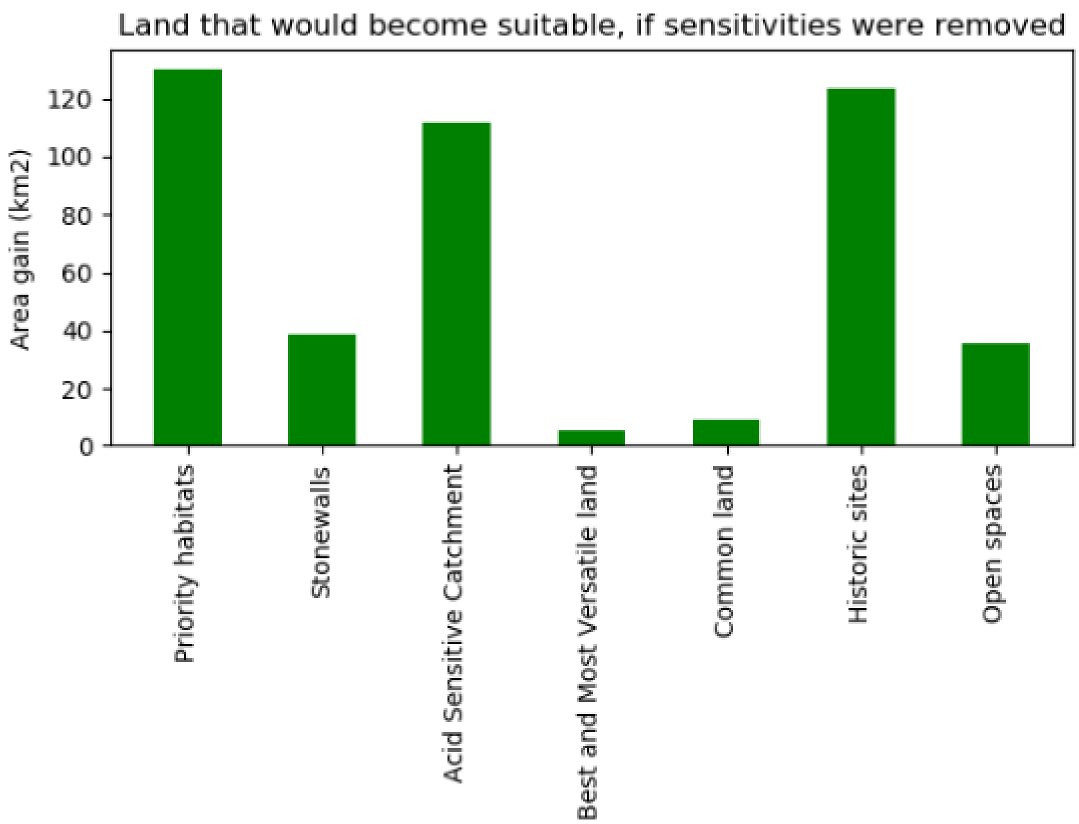
Sessile oak 2050 high emissions

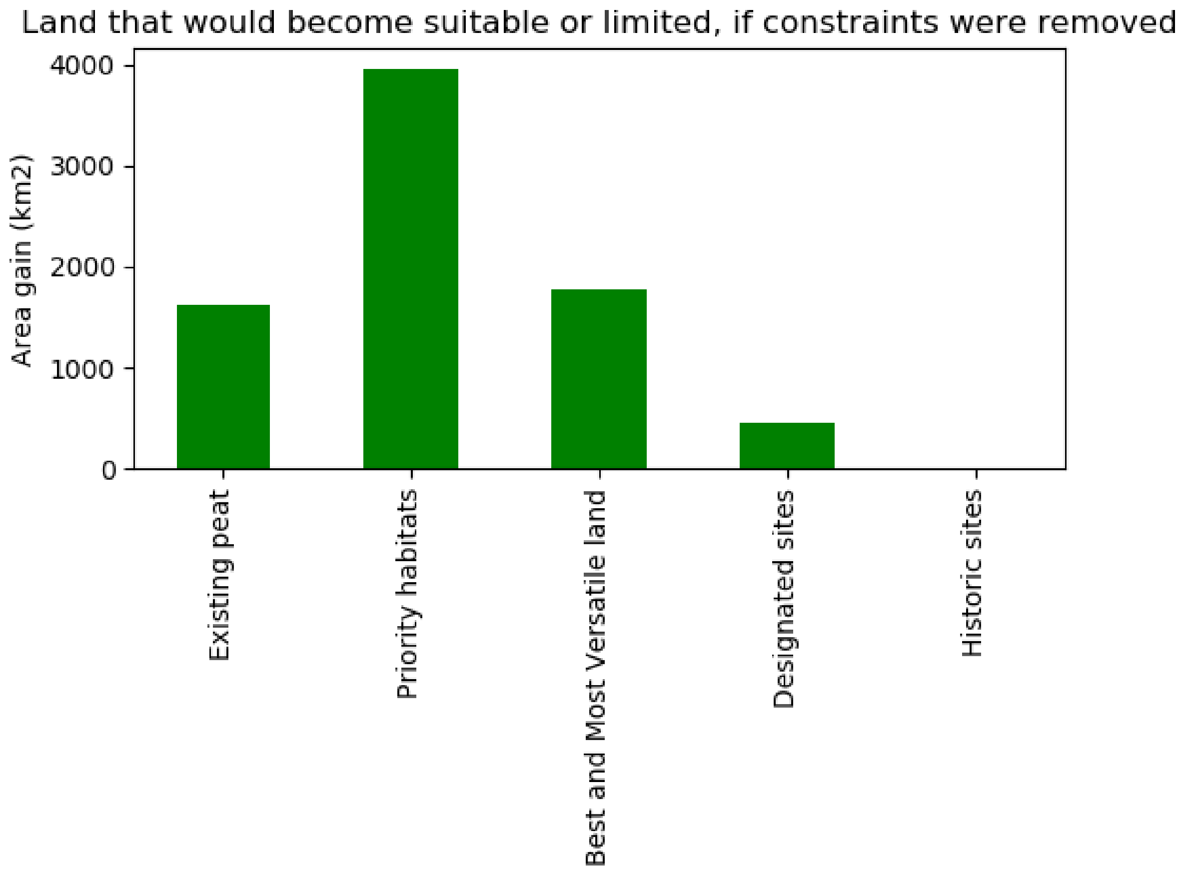


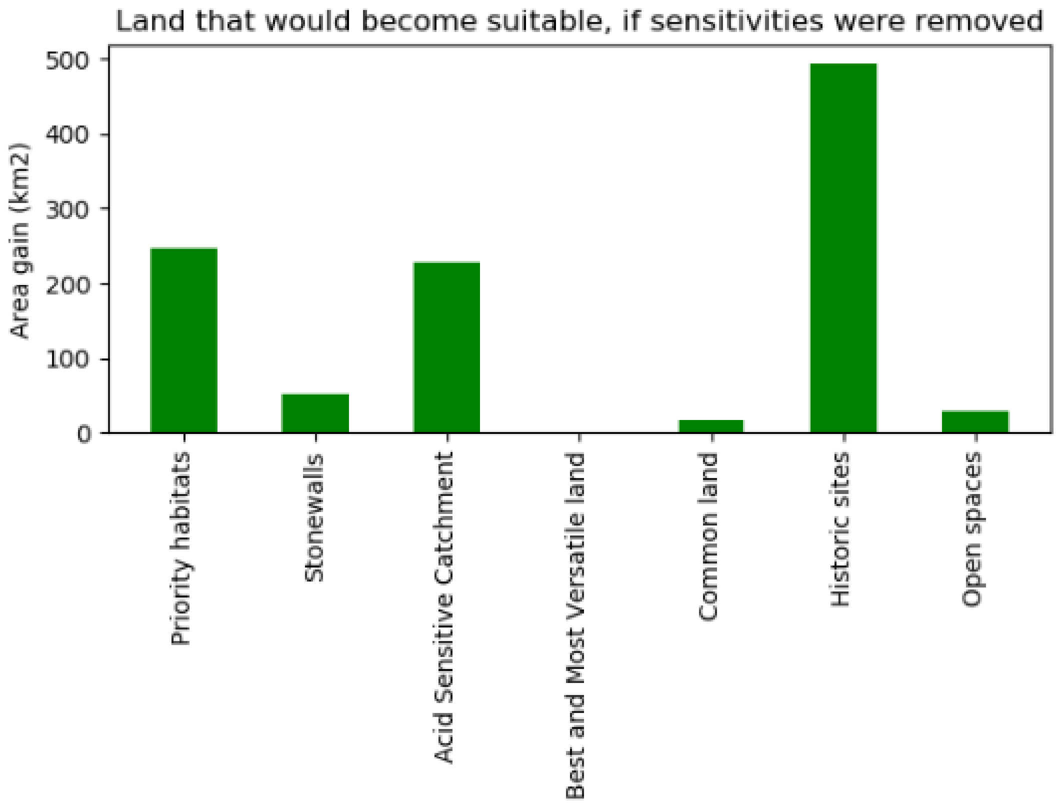


Sessile oak 2080 high emissions

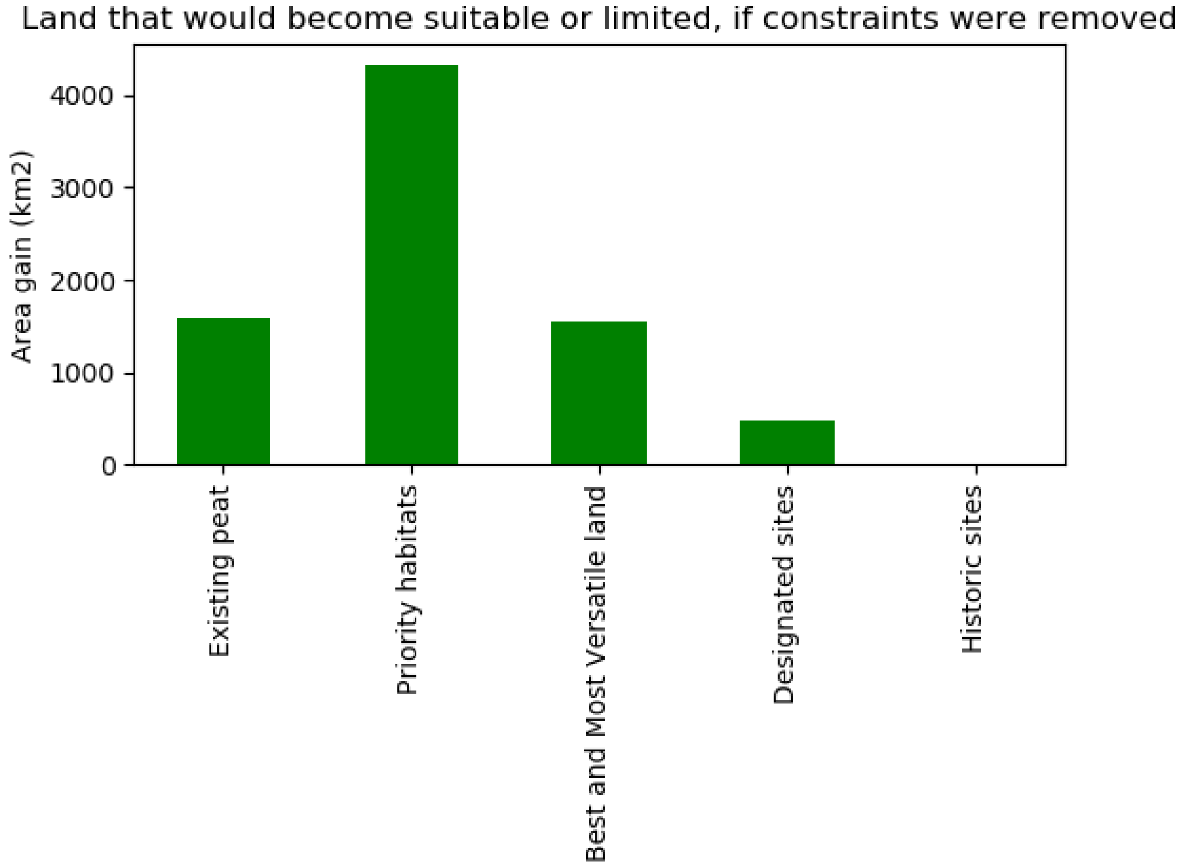


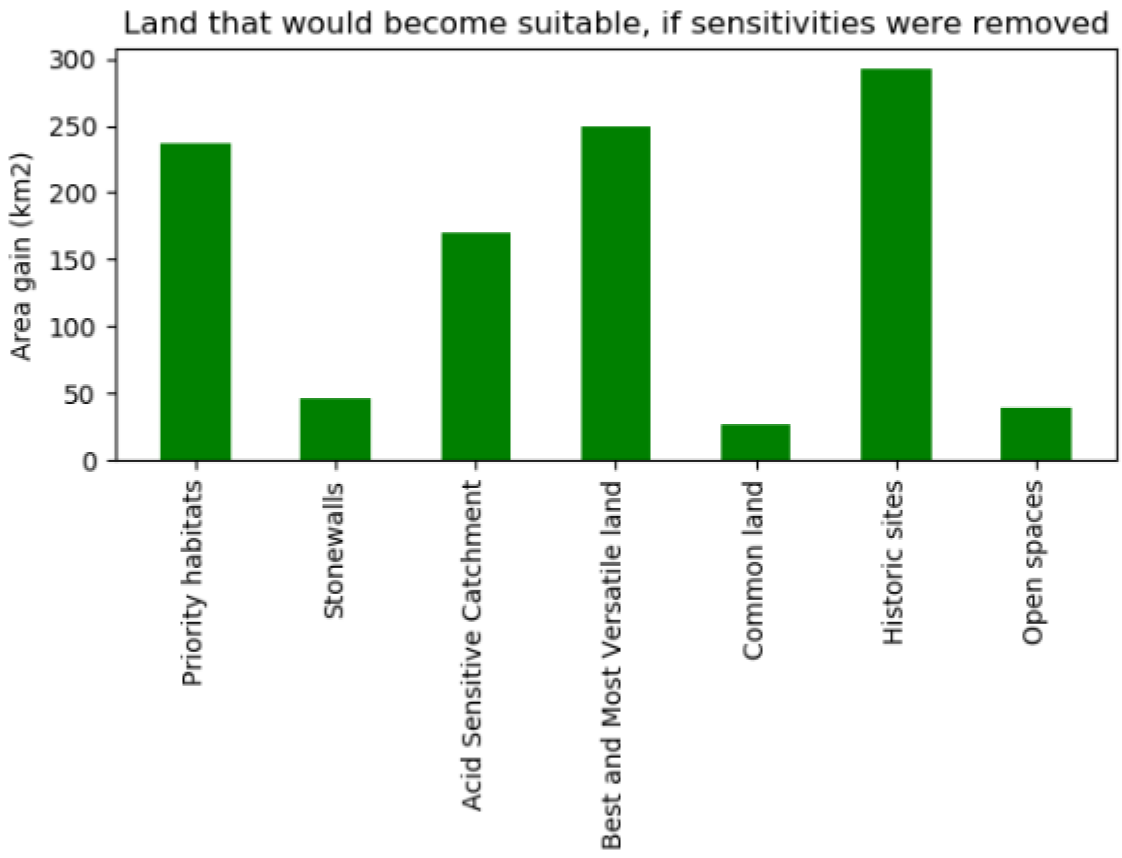



Land that would become suitable or limited, if constraints were removed
Area gain (km2)
0
1000
2000
3000
4000
Existing peat
Priority habitats
Best and Most Versatile land
Designated sites
Historic sites

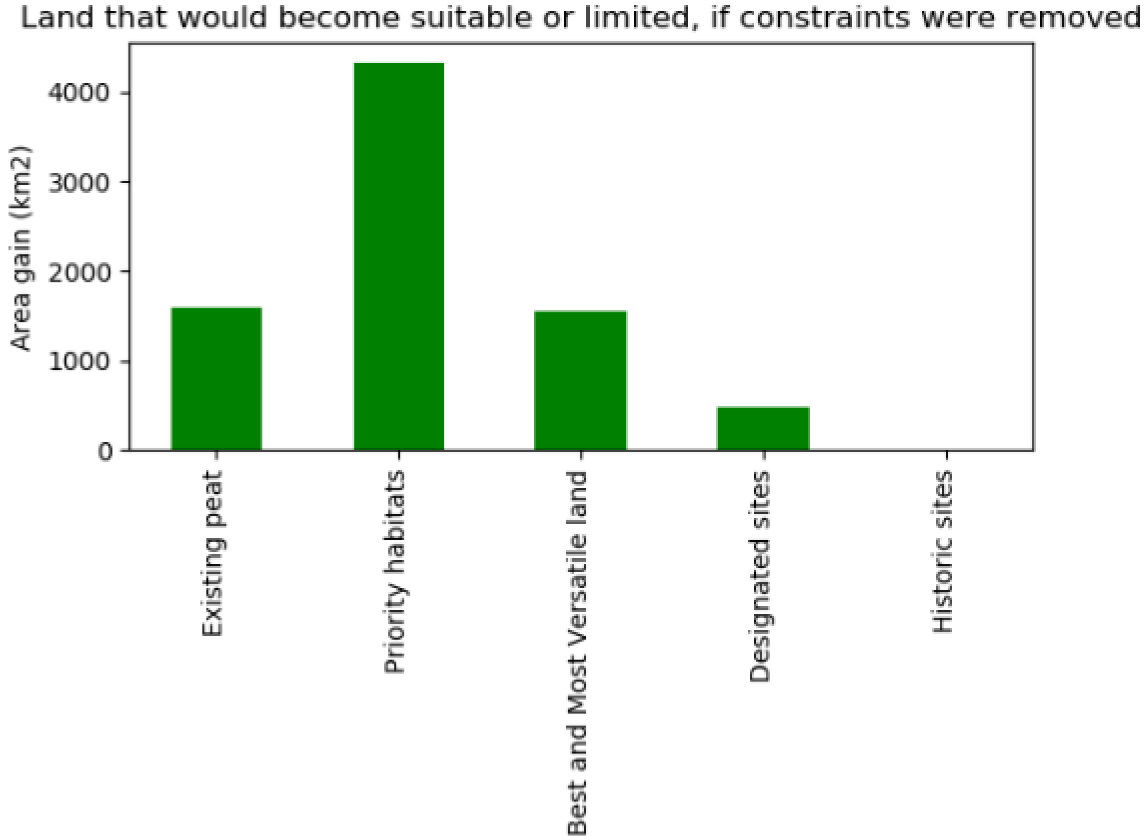

Land that would become suitable, if sensitivities were removed
Area gain (km2)
0
100
200
300
400
500
Priority habitats
Stonewalls
Acid Sensitive Catchment
Best and Most Versatile land
Common land
Historic sites
Open spaces

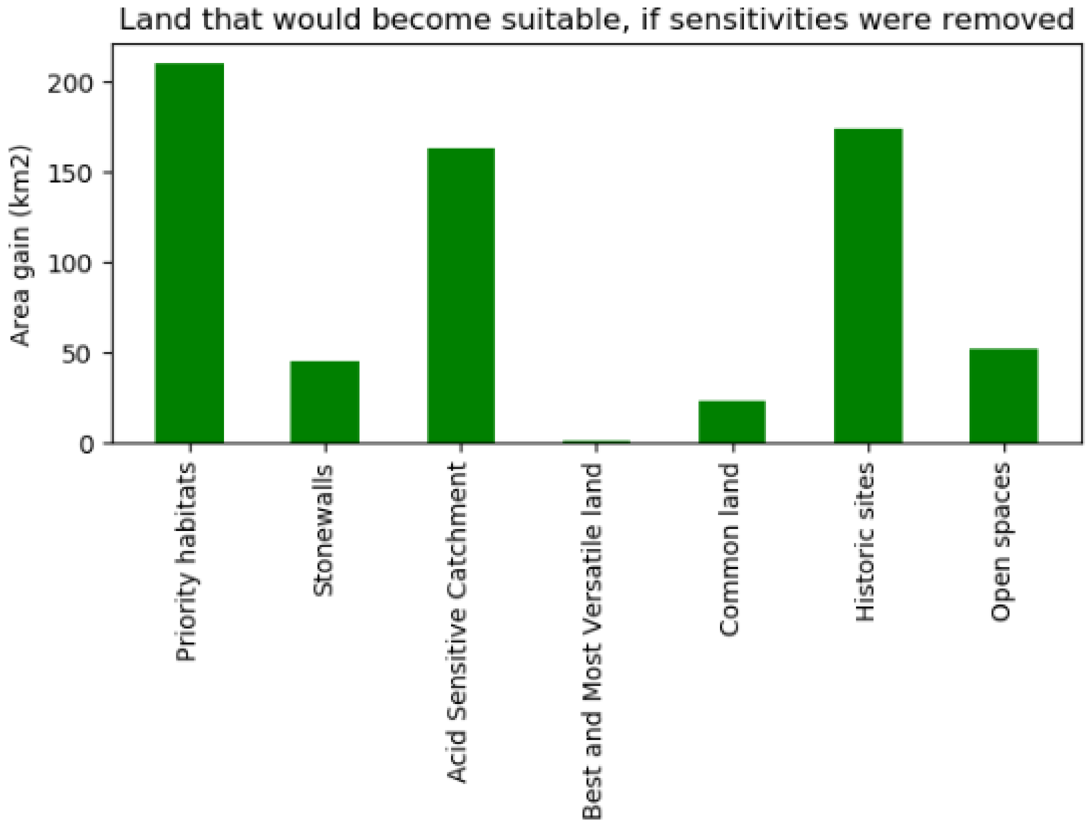
Sitka spruce 2050 medium emissions



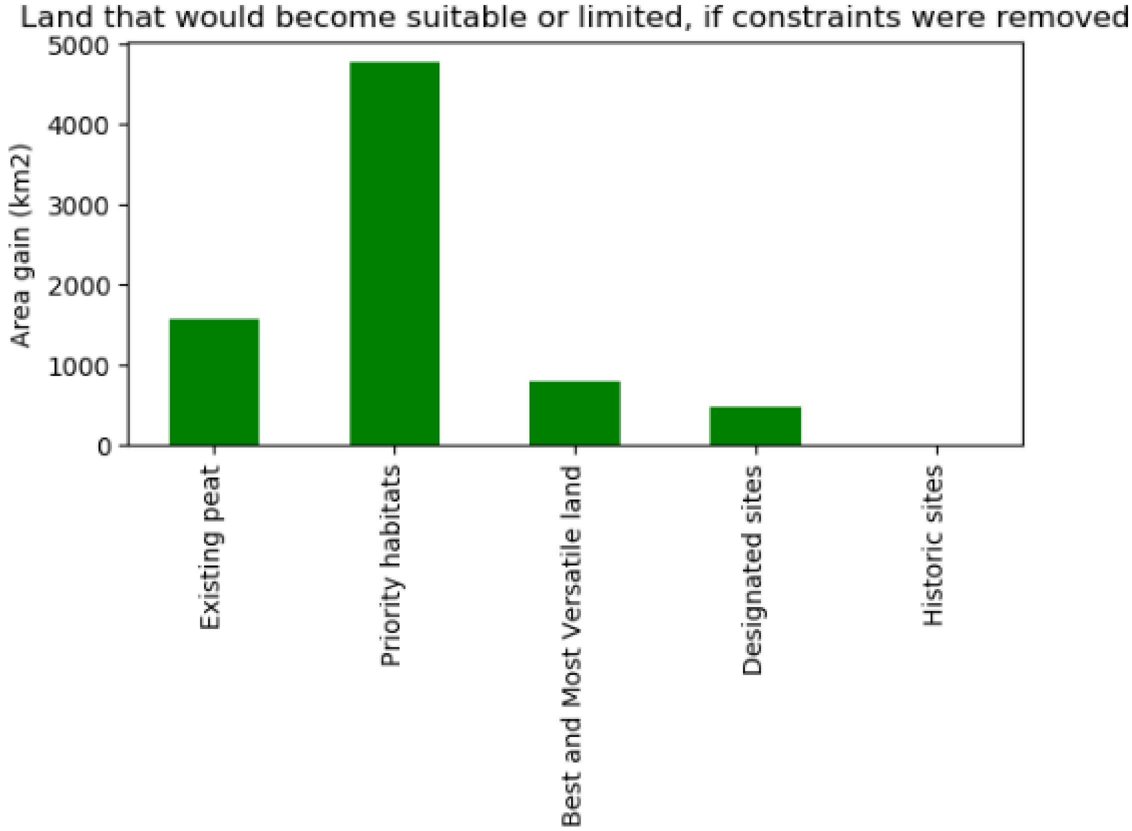


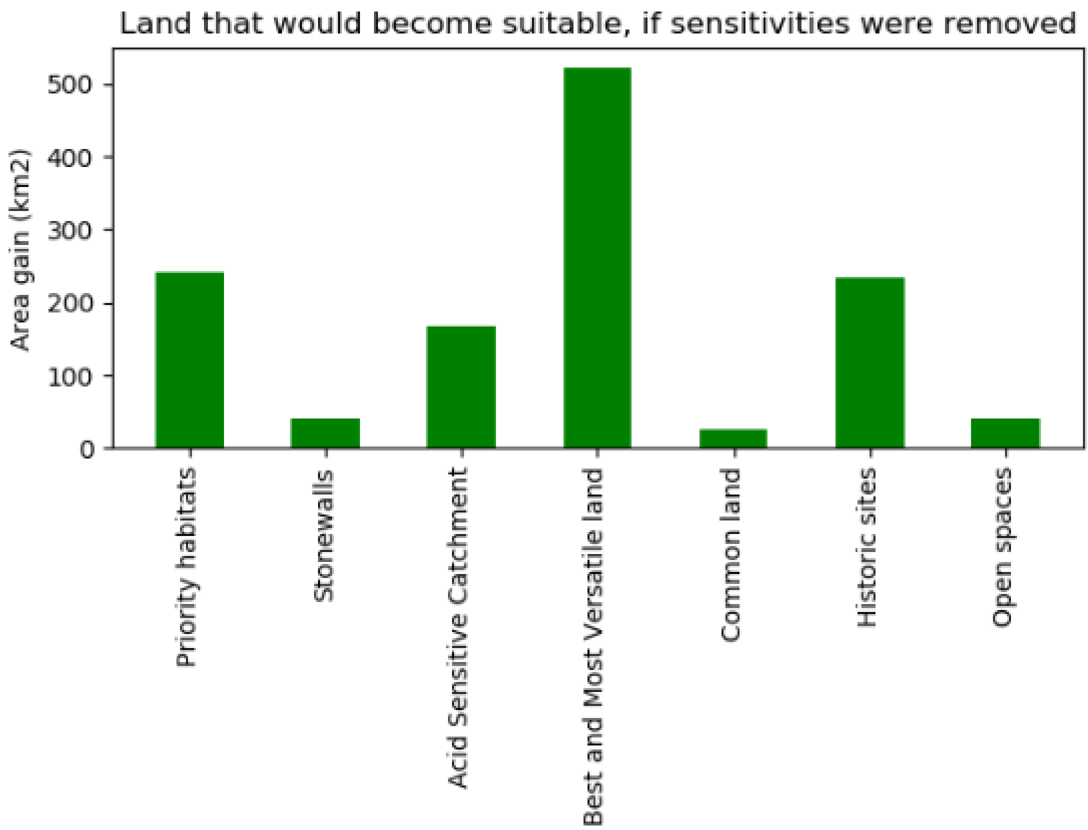
Sitka spruce 2080 medium emissions





Sitka spruce 2050 high emissions





Sitka spruce 2080 high emissions