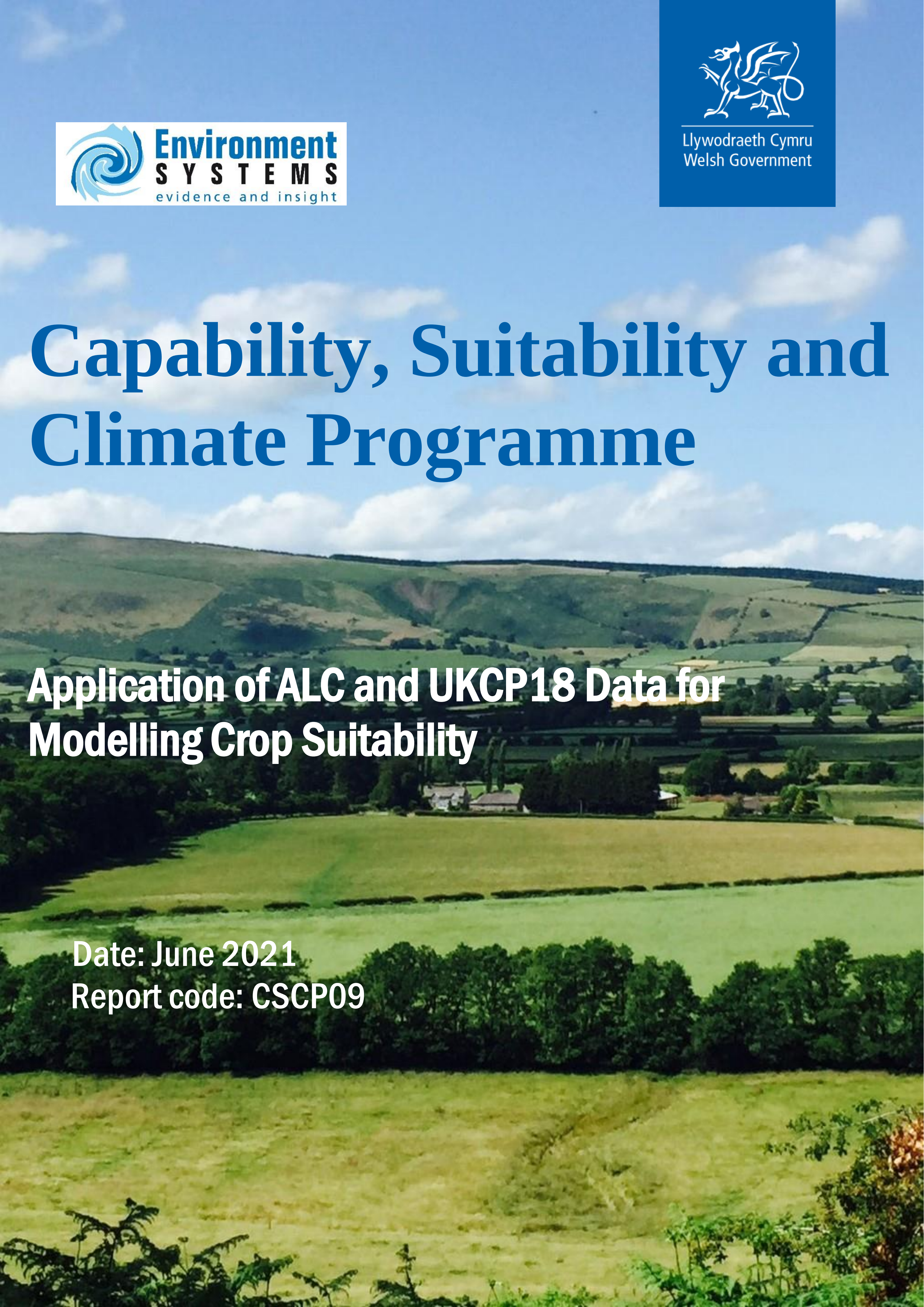

Capability, Suitability and Climate Programme

Application of ALC and UKCP18 Data for Modelling Crop Suitability

Date: June 2021
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Capability, Suitability and Climate Programme: Application of ALC and UKCP18 Data for Modelling Crop Suitability

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This project is led by Welsh Government Land, Nature and Forestry Division with partners Environment Systems Limited, RSK ADAS Limited and Cranfield University.

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Executive summary

This report outlines the work to take soil and climate information, and use it to model the land suitability for 118 crops under nine projected climate change scenarios, as well as under present day conditions. All crops were modelled for suitability on the basis of commercial crop production. Additionally, separate 'environmental suitability' models were produced for tree crop species, representing their broader environmental tolerances.

This work forms part of a wider three-year project which was led by Welsh Government and includes Environment Systems, Cranfield University and ADAS. The project formed part of the Welsh Government response to climate change (Welsh Government, 2019a). The overall project developed and improved the existing soil mapping for Wales, then updated the Agricultural Land Classification (ALC).

The latest climate change predictions from the Met Office, referred to as the UK Climate Projections 18 (UKCP18), provide models of different scenarios reflecting what is expected to happen to key climatic variables under differing levels of greenhouse gas Representative Concentration Pathway. UKCP18 predicts the conditions the UK can expect to experience in a changing climate. The impacts are summarised as wetter winters, warmer and drier summers, increased incidence of storms and extreme weather, and rising sea levels. These climatic factors vary spatially according to altitude and distance to sea amongst other factors.

This report considers key variables from the ALC, UKCP18 and additional biophysical modelling of wind, frost, salt spray, and flood risk; it considers how they affect our ability to grow different crops in different parts of Wales. The study considered present-day conditions, and climate change predictions under different Representative Concentration Pathway scenarios (low, medium and high), up to 2080. For each of the date/time scenarios, crop suitability models were produced at 50 m resolution, covering the whole of Wales.

The project included a variety of crops common to Wales and the UK, as well as crops which are novel to Wales. It included cereals, row crops, horticultural crops, orchard crops, tree crops and specialist crops. This report describes crop suitability modelling undertaken to show how, for each crop, the spatial extent of suitable ground changes with the climate in the different scenarios. The Geographical Information Systems (GIS) data files developed alongside this report contain the crop models for all 118 crops.

For each crop, all classes of the input biophysical factors were scored as "suitable" (growing conditions are optimal for the crop in question), "limited suitability" (the crop can be supported, but harvests might be less plentiful, or adverse weather conditions might destroy the crop in some years), and "unsuitable" (the biophysical condition does not allow for commercial-scale cultivation of the crop). The three features that had most effect on the spatial distribution of many crops were the ALC factors: slope, climate and wetness. Drought, while not significant in the present-day models, is responsible for large decreases in suitable land as climate change progresses.

Nine crop case studies are presented in this report, representing a wide range of crop types. In these models the starting present-day suitability distribution varies greatly between crops, evidencing their very different biophysical tolerances and sensitivities. However, the general trends in suitability change over time are similar for most of the crops, with the models showing a contraction in suitable and limited suitability growing space between the present day and 2080.

Although the models show decreases in the amount of available land for crop cultivation on a commercial basis, the non-commercial tree suitability models show that many tree species will still be able to grow throughout the country, and continue to provide important ecosystem services such as flood mitigation, carbon storage, and supporting biodiversity.

Existing evidence from the climate change and crop suitability models tells us that the agricultural sector in Wales will be required to change in a relatively short period of time. However, not all parts of Wales will be affected in a similar way, or to the same extent. The models represent an assessment of biophysical conditions relating to growing crops; they do not consider emerging technologies in food production.

This report and the accompanying suitability models for 118 crops therefore provide important evidence for policy makers and the agricultural industry as the future is considered. This will be a valuable source of information as Wales prepares to meet the effects of a changing climate, growing conditions, the extent and distribution of crop cultivation, and supporting infrastructure. The information can also help foster public engagement and understanding of the issues, and will contribute to the creation of policy decisions that are likely to have a substantial impact on Welsh landscapes as we know them today.

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Introduction

Background

This summary report forms part of a wider three-year project which is led by Welsh Government and includes Environment Systems, Cranfield University and ADAS (*Figure 1*). The project forms part of the Welsh Governments' climate change mitigation and adaptation plans (Welsh Government, 2019a). It seeks to develop and improve the agricultural land classification model for the whole of Wales with a view to then predicting the land suitability for 118 crops under present day conditions, and under 9 projected climate change scenarios.

It is already apparent that the climate of Wales changing. The latest climate change predictions from the Met Office are referred to as the UK Climate Projections 18 (UKCP18). The projections provide models of different scenarios reflecting what is expected to happen to key climatic variables under differing levels of greenhouse gas Representative Concentration Pathway. UKCP18 delivers a range of UK climate projection data to help decision-makers assess their risk exposure to climate change. UKCP18 sets out the weather the UK can expect to experience in a changing climate. The impacts can be summarised as; wetter winters, warmer and drier summers, increased incidence of storms and extreme weather, and rising sea levels.

This report specifically considers key environmental factors derived from the Agricultural Land Classification (ALC), with climate scenario modelling facilitated by weather variables from UKCP18, to determine how the environment and climate affect the suitability for growing different crops, throughout Wales.

The project aims to help policy makers, farmers and land managers adapt in a timely way to the opportunities, as well as challenges, opening up as a result of climate change. The project aims to show where current practices are likely to come under pressure from the changing climate, and how. It is also intended to assist the agricultural industry and government in making a broad, long-term and cross-sectorial assessment of land use, looking ahead to devise strategic solutions.

This report describes the modelling undertaken for 118 crops, to identify land that is suitable, of limited suitability, and unsuitable for each crop. The modelling was carried out using data relating to the present day, and for nine future scenarios representing low, medium and high greenhouse gas Representative Concentration Pathway, for 2020, 2050 and 2080.

The low Representative Concentration Pathway scenario predicts 2.4^{o}C warming by 2100, modelled from RCP 4.5, which represents a scenario of global greenhouse gas (GHG) Representative Concentration Pathway peaking around the year 2040, then declining. The medium Representative Concentration Pathway scenario predicts 2.8^{o}C warming by 2100, modelled from RCP 6.0, which represents GHG Representative Concentration Pathway peaking around the year 2080, then declining. The high Representative Concentration Pathway scenario predicts 4.3^{o}C warming by 2100, modelled from RCP 8.5, which represents GHG Representative Concentration Pathway continuing to rise throughout the 21st century (Lowe *et al.,* 2018; IPCC, 2019).

To account for uncertainty within the climate model data, the UKCP18 climate change predictions represent a 30-year average: the 2020 models for low, medium and high Representative Concentration Pathway represent the time period 2010-2039; the 2050 models represent 2040-2069; and 2080 represents the period 2070-2099.

A wide range of crop types were considered in order to investigate the likely performance of both traditional agricultural commodities, and those likely to be new in Wales. Traditional crops included cereal crops such as wheat and barley; row crops such as beetroot and cabbage; and horticultural crops such as lettuce and asparagus. The project also considered tree crops for timber and fruit production, looking both at native species such as sessile oak and commercial softwoods such as Sitka spruce. A number of specialist crops including tea, saffron, almonds and olives, were also considered. Tree species were also modelled for their broader environmental suitability, in addition to the commercial suitability models.

In order to calculate the spatial distribution of land suitability for different crops, the differences in agricultural land capability between places needed to be considered. This considered the soil properties, landform and climate throughout Wales, and how these factors may be impacted by climate change.

The interaction between landform, climate and soil type changes spatially across Wales, with the south-east of Wales having different biophysical characteristics to the mountains of north-west Wales, and climatic conditions across the regions are set to alter at different rates as climate change progresses. All of these factors impact on whether a location is capable of supporting commercial crop cultivation; we refer to the spatial modelling of these soil, landform and climatic factors as biophysical suitability modelling.

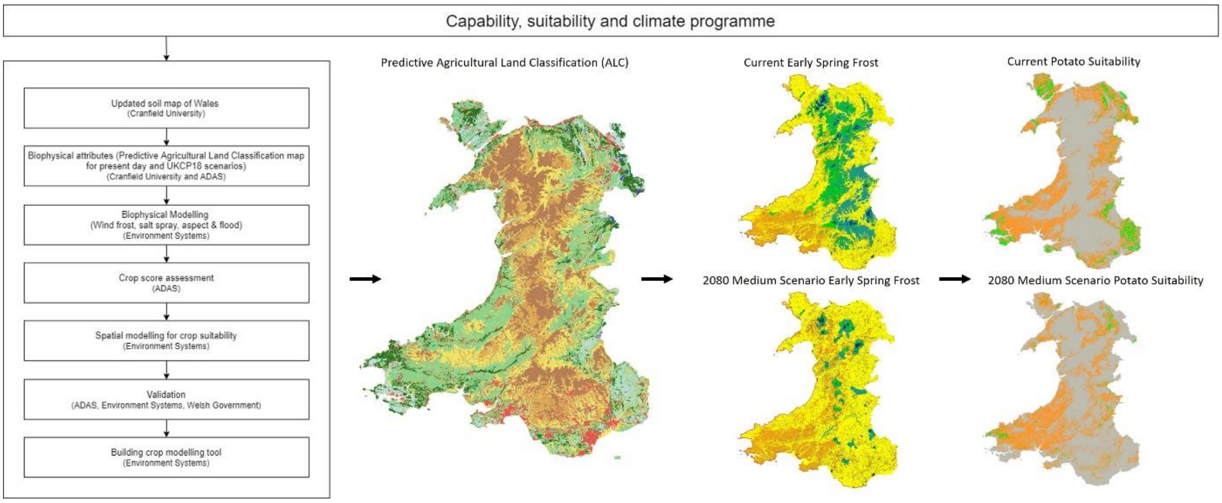

Figure 1: Stages of crop suitability modelling under the Capability, Suitability and Climate Programme

Aims and objectives

The aims of this study were to:

- Model the biophysical suitability across Wales for wind exposure, salt spray, frost risk, aspect and flood risk, to supplement the biophysical factors modelled by existing ALC data.
- Model current land suitability, across Wales, for 118 crops to show: land where they will grow well in the soil (suitable); land where they will grow in the soil with some limitations, which it may or may not be possible to mitigate (limited suitability); and land unsuitable for growing the crops in the soil on a commercial basis (unsuitable).
- Repeat the crop suitability analysis using data derived from UKCP18 to model suitability for 118 crops across Wales under low, medium and high Representative Concentration Pathway climate change scenarios, for 2020 (2010-2039), 2050 (2040-2069) and 2080 (2070-2099).

Disclaimer

The focus of this project is modelling land capability and suitability for growing existing crop varieties *in situ*; it does not consider advances in crop genetics, under-cover cultivation, hydroponics, aeroponics, or other technologies. Furthermore, the crop suitability models assume that cultivation takes place without significant management interventions. For example, frost can limit the growth of many crops but can be mitigated by artificially insulating the ground during the risk period; the crop suitability models assume that such mitigative action is not taken, and makes a purely biophysical assessment using information on soil, climate and location.

The project does not consider legal and policy constraints which restrict the space available for growing crops; for example, protected sites, and areas of deep peat. All non-sealed surfaces have been included in the analyses.

The crop suitability models show where it is biophysically possible to grow certain crop types, but does not make any assessment of the appropriateness of one land use type over another (e.g. agriculture versus urban expansion, sites for renewable energy, or protected habitats). Instead, the models show land managers and policymakers what is biophysically possible on the land in terms of agricultural production, providing an evidence base on which to make such decisions.

Biophysical suitability modelling

The ALC system describes environmental and site conditions relevant to crop cultivation, and provides a means for dividing many of these factors into grades. However, some factors do not have explicit threshold values and/or spatial extents that allow the grades to be defined. Additionally, in some cases there has been insufficient data for spatially modelling the certain factors. Frost risk, wind exposure, and salt spray were identified as the most notable biophysical factors for which this is the case. This project set out to create models representing these factors, to allow for their incorporation into the crop suitability modelling. Datasets representing aspect and flood risk were also prepared. Agricultural flood risk is a factor for which some ALC grade thresholds have been defined, and a separate study was conducted to spatially model the extent and distribution of these grades in Wales (Bell *et al.,* 2020a).

Aspect

In Wales, as a temperate country in the northern hemisphere, maximum growth of crops is expected on land which faces south and southwest, or which is flat. Some more sensitive crops perform best on this type of land whilst other crops grow well on land with any aspect. In order to take this into account in the model three aspect classes were considered. Therefore, aspect was calculated in degrees from the Digital Terrain Model (DTM), dividing the dataset into the three classes:

- “south & south-west facing areas”;
- “flat land”;
- “other aspects”.

Wind exposure modelling

Wind exposure can affect growth of crops in situations where wind either physically damages the crop or leads to reduced yield; wind further affects other biophysical properties, such as the risk of frost (see Section 0). Six wind models were developed for this project; four seasonal models of wind damage risk, and two wind models for use in the winter/late spring frost risk modelling.

Wind models for frost risk

Wind strength influences frost risk; strong winds can prevent cold air from pooling, moderating the risk of frost, while depressions and other areas prone to air pooling can have higher frequency and severity of frost risk. Two wind models were produced to be used as inputs for the frost risk analysis (see Section 00):

- Wind model as input for winter frost risk analysis (November to February): this wind model was used as input to calculate the overall risk of winter frost.
- Wind model as input for late spring frost risk analysis (March to May): this wind model was used as input to calculate overall risk of frost periods in spring.

Wind damage models

Strong gusts of wind can directly damage crops through breakage, or by causing stunted growth. The timing of strong wind events affects the severity in terms of crop productivity; therefore, separate wind models were generated for each of the four seasons:

- Winter (December to February);
- Spring (March to May);
- Summer (June to August); and
- Autumn (September to November)

Wind exposure was modelled using 5 m resolution DTM and digital surface model (DSM) data, and wind speed/direction data from six Met Office weather stations (see section 0).

Preparation of the elevation data

In order to consider the sheltering effect of trees the DTM and DSM data were analysed to identify all features above 2.2 m height; this was done to identify tall hedgerows, lines of trees, and woodlands that could substantially affect local wind patterns and exposure level.

Preparation of weather station data

Met Office weather station data were obtained, capturing wind strength and direction data for six locations; Aberporth, Hawarden Airport, Milford Haven, Sennybridge, St Athan, and Valley. These stations were chosen to provide the widest representation of geographic differences in wind characteristics possible.

The six wind stations were associated with six broad biophysical regions that, when combined, covered the whole of Wales. These regions were based on the broad biophysical regions defined during production of the updated Phase 1 habitat map of Wales (Lucas *et al.,* 2010), modified to better represent regions with similar wind regimes (*Figure 2*).

- Met Office data was supplied as tabular data containing average frequency of different wind speeds (in knots) for each cardinal direction. Averages were supplied for the period 2008-2017. One such table was supplied for each month of the year, and for each weather station.

- For each wind model (spring; summer; autumn; winter; winter frost; late spring frost), the wind speed frequencies for the relevant months were summed to produce a dataset of seasonal average wind frequencies for each cardinal direction, at each weather station.
- Representative wind speeds were identified for each cardinal direction. The selection of this knot value was based on different criteria, according to whether the model related to wind damage or frost risk:
    - For the seasonal wind damage models, the maximum observed wind speed was selected for each cardinal direction; as a single strong wind event can catastrophically damage a crop, the maximum wind speed was considered more appropriate than an average value.
    - For the frost risk models, the most frequent wind speed was selected for each cardinal direction, in order to model the most common conditions; this dataset would then be combined with other inputs to produce an overall frost risk model.
- Wind speeds occurring from all cardinal directions were then combined, using a proportional multiplier to preserve the relative dominance of particular wind directions at each weather station.

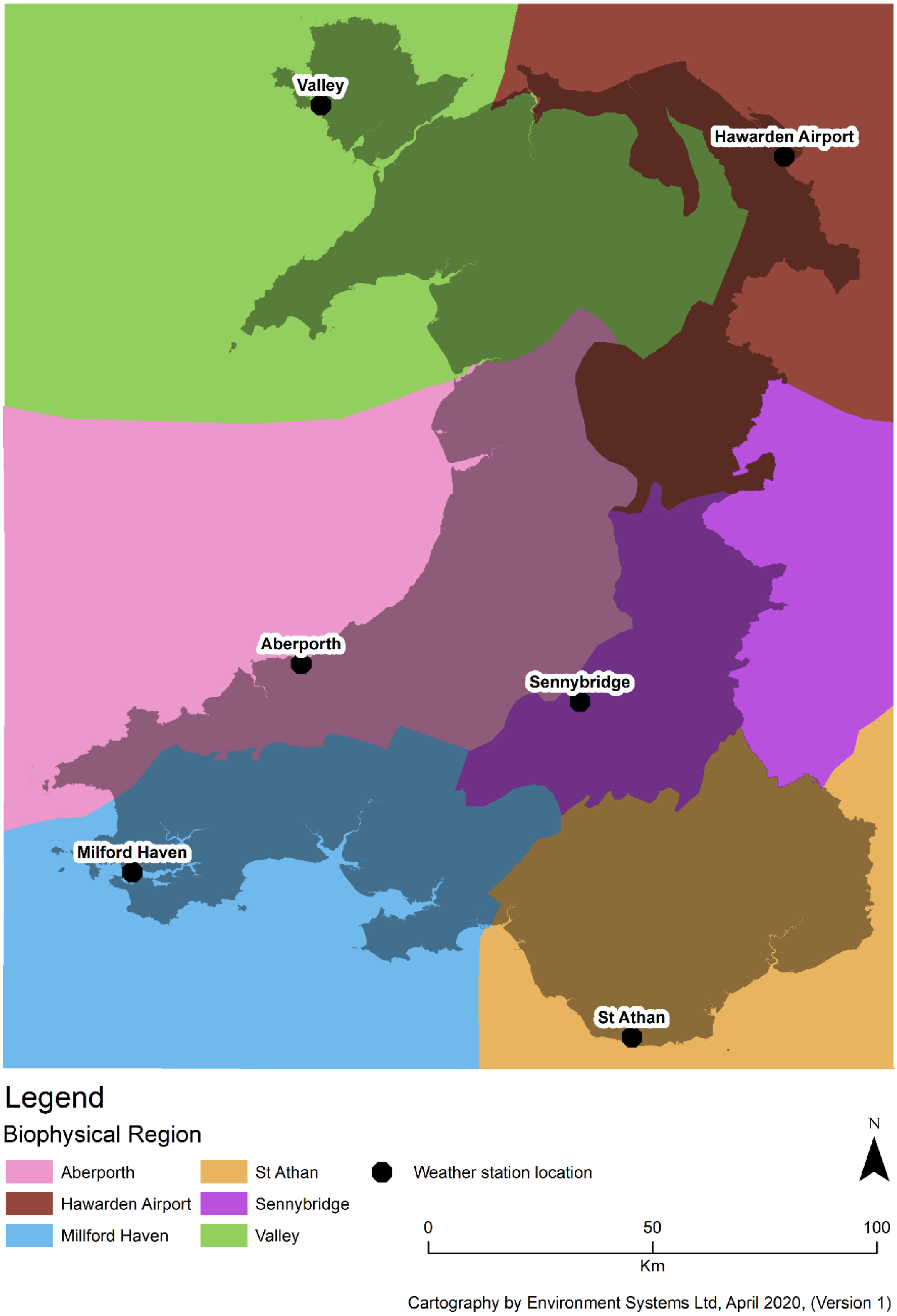

Figure 2: Location of Met Office weather stations, and their corresponding biogeographical regions

Spatial processing of the wind models

Using the merged DTM-DSM dataset (see Section 0), wind exposure was calculated for 12 cardinal directions, for each biophysical region (*Figure 2*). The models for each cardinal direction were then combined to produce a single wind model for each biophysical region, which considered the relative dominance of winds from each direction. This was important because different locations and regions of Wales are subject to differences in the dominant wind direction. The dominant wind direction, or degree of dominance, also changes month by month, which means different places can be more or less exposed at different times of year, depending on aspect and elevation. These differences can be seen in example wind rose diagrams shown in *Figure 3*-*Figure 4*.

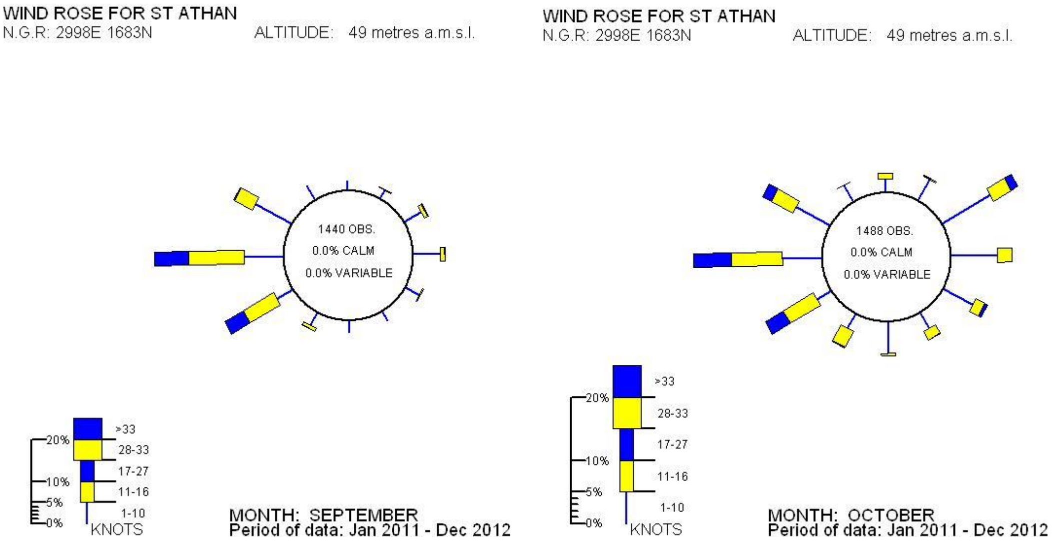

Figure 3: Illustration of differences in the frequency and strength of winds from different directions at St Athan in September and October

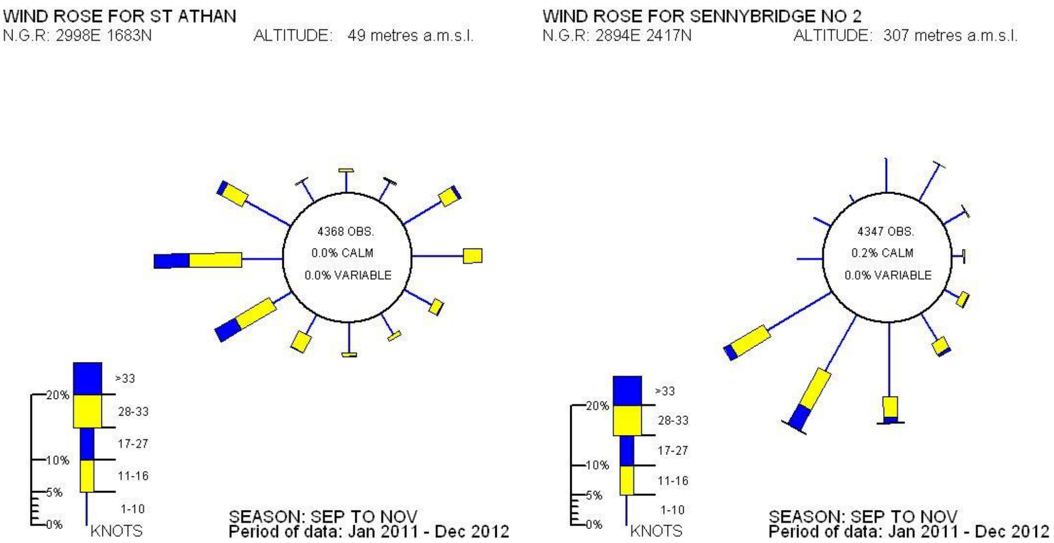

Figure 4: Illustration of differences in the frequency and strength of winds from different directions in autumn at St Athan and Sennybridge

A quality checking process took place once the all-Wales wind models had been created. It was found that hill-top wind exposure in the Sennybridge biophysical region was under-represented when compared with wind models for the other biophysical regions. It was found that, although the Sennybridge weather station is located at high elevation, it is sited in a valley, and likely to experience lower wind speeds than would be the case if it was located on a hill top because of this landscape setting. This resulted in a lack of differentiation between the hill-top and valley wind speeds.

Due to hill-top wind speeds being significantly under-represented in this region, a manual modifier was applied to the hill-top areas. Peaks in the region were identified, and their associated wind model values compared to peaks in adjacent biophysical regions known to experience similar wind strengths. Comparison of these values was used to identify a multiplier, which was applied to hilltop areas in the Sennybridge biophysical region.

Additionally, the eastern and southern biophysical regions of Wales (covered by Hawarden Airport, Milford Haven, St Athan and Sennybridge) were boosted overall (by comparison with areas of similar exposure levels in other regions), as all wind stations in these areas were located in relatively sheltered locations; this was found to affect comparability across Wales to the western and northern biophysical regions, the models for which were based on weather stations located in more exposed areas.

At this stage, the individual wind models for each biophysical region were combined to provide a seamless, all-Wales wind model for each season using distance-weighted blending of boundary areas, to ensure smooth boundaries between biophysical regions and, therefore, a better representation of the gradual change of wind regimes between them; examples of the resulting uncalibrated models are shown in *Figure 5*.

In the last processing step, numeric cut-offs were determined to re-classify the continuous wind models into distinct classes:

- *Strong winds (likely to affect crops)* – used in all models.
- *Moderate winds (might affect crops)* – only used in spring and summer models.
- *Weak winds (unlikely to affect crops)* – used in all models.

The resulting classified wind exposure maps for the four seasons are shown in *Figure 6*.

Validation

No validation data was available on which to test the model. Therefore, the team brought together an expert panel from the consortium members, based across Wales with good experience of the environment and agricultural sector to visually validate and adjust the models. This resulted in two further iterations of the model until the models gave a good representation of conditions for all of Wales, which were backed by the expert knowledge of the team.

Wind model interpretation

The strongest winds tend to come in from the southwest and make the mountains and coastal slopes of west and south west Wales the windiest places, whilst the valleys in the east of Wales are comparatively sheltered.

Figure 6 shows the patterns of wind exposure in spring, summer, autumn, and winter. The pattern of exposure is fairly similar in all four seasons. Key differences are in the winter, when winds tend to be strongest from the southwest, and spring when the winds are slightly stronger on the western side of Wales. Valleys located in south east, central and north east Wales are very sheltered from the prevailing wind in all four seasons.

The effect of wind on crops is most significant in spring and summer. This is because strong winds can affect seed set and detach fruits, therefore significantly reducing yield. This is particularly true for orchard species such as apples and pears, but is also a problem for other insect pollinated crops, such as onions grown for seed. Tall cereals can be at risk of lodging, especially during the summer. In winter the wind generally only affects tree species. Root and cereal crops are generally very short, or the land is fallow in winter when cultivating these crops, and so wind is less of a significant factor.

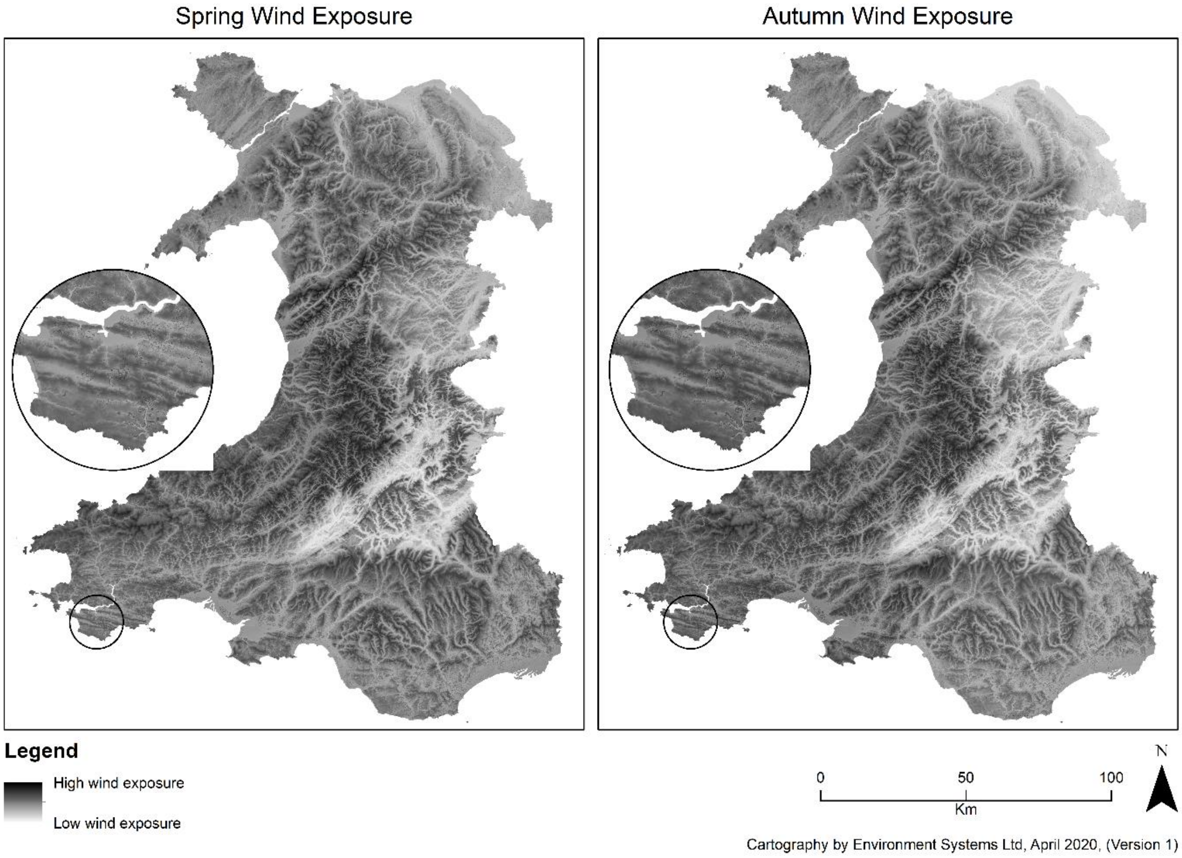

Figure 5: Unclassified wind exposure models (relative, continuous data) for spring and autumn

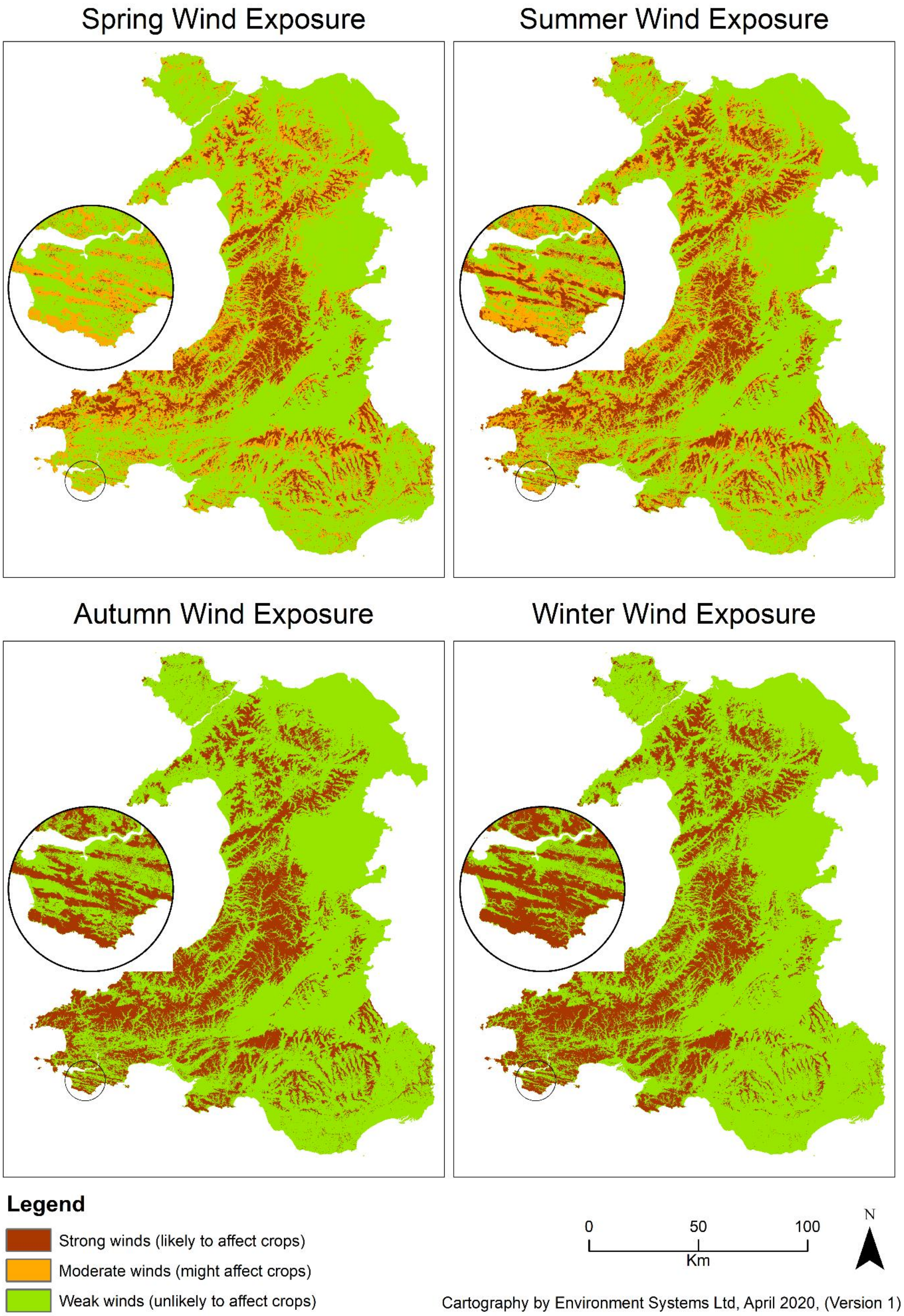

Figure 6: Classified wind exposure models for spring, summer, autumn and winter

Salt spray model

Salt spray is a significant biophysical factor in coastal areas, as a high input of salt can affect soil quality. The sodium and chloride ions in the soil displace other important minerals such as phosphorus; this can lead to yield reduction, in addition to directly harming crops. Salt loading can also affect other soil properties, such as increasing soil compaction.

Crops particularly affected by salt spray include: row crops such as potatoes, carrots and parsnips; fruit such as raspberries; horticultural crops such as daffodils; and tree / orchard species such as pears. Cereals such as oats can also be limited in their growth by excessive salt spray. Conversely, salt spray reduces frost risk and can be beneficial for frost-sensitive crops in that respect.

In order to model the area of land likely to be exposed to salt spray, the coast was initially buffered inland by 500 m, estimated to be the maximum range of coastal salt spray (Jones *et al.,* 2011). Estuaries were not included in the analysis as salt spray is not generally an issue in these places as they tend to be more sheltered. Within the 500m maximum distance, the actual distance travelled by salt spray depends primarily on wind; therefore, an average of the spring, summer, autumn, and winter wind models (see Section 0) was created and a cut-off manually determined based on local knowledge of salt exposure and vegetation visible on aerial photography. Incorporation of the wind models in this way allowed elevation above sea level and slope/aspect effects to be considered. The resulting classified salt spray model is shown in *Figure 7*.

Salt spray model interpretation

Salt spray is heaviest around the south western coastline in wales. This is due to the prevailing south-westerly winds and gales. The coast of Wales has a mild, favourable climate, and soils suitable for a range of agricultural crops. However, salt spray can limit the use of otherwise suitable land nearest the coast.

The area of land in Wales affected by salt spray is comparably low, as the salt only reaches inland up to a maximum 500 m on the most exposed areas. The model identifies coastal areas that are likely to be more sheltered from salt spray, where the risk of cultivation would be lower risk in terms of this factor.

The distribution of land affected by salt spray is not predicted to change with the changing climatic parameters, and this model was therefore used for each of the climate scenarios.

Waves creating salt spray, Pembrokeshire coast

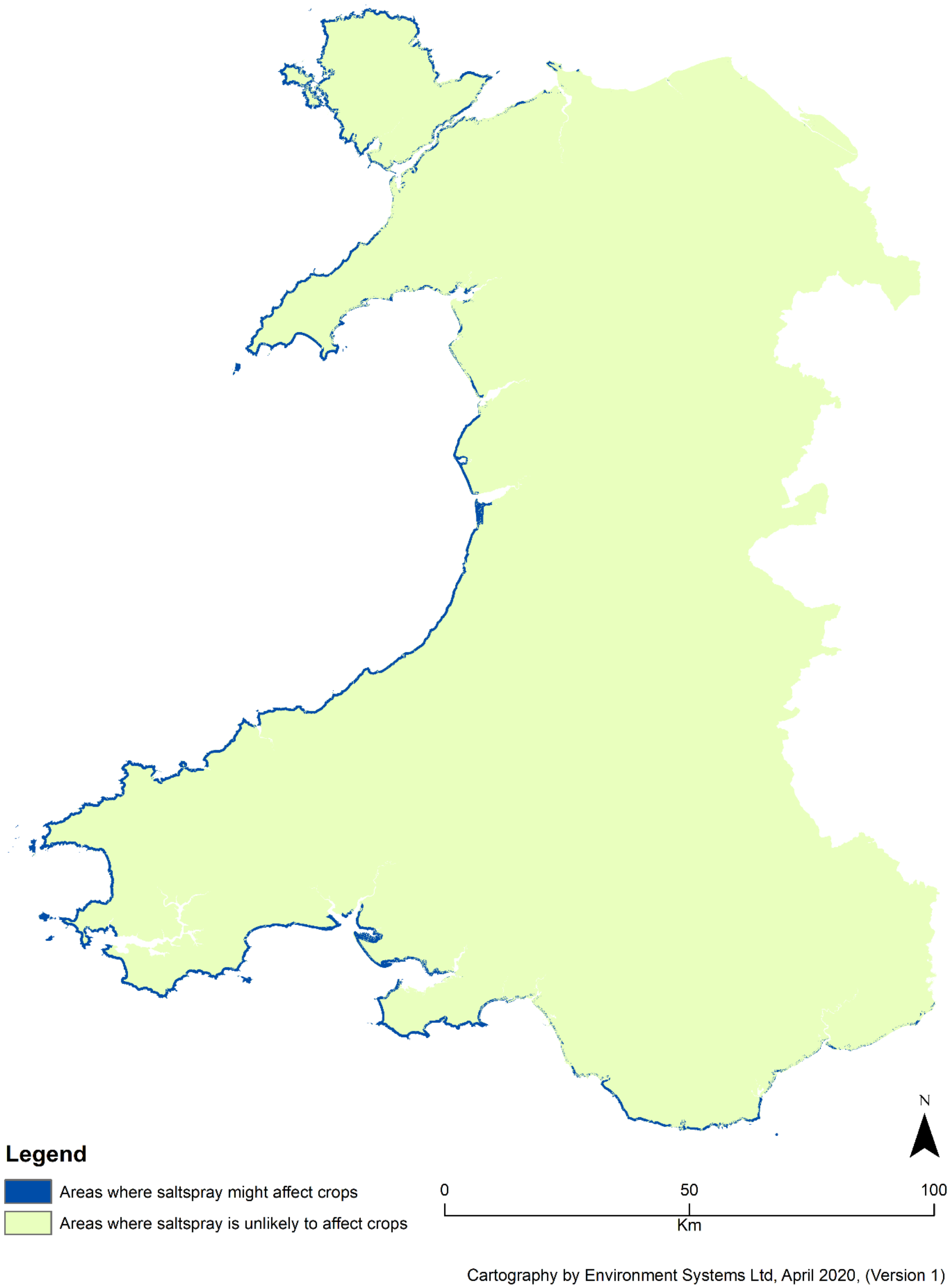

Figure 7: Risk of exposure to salt spray

Frost model

Frost risk is a biophysical factor of great relevance to agricultural cultivation, being one of the key factors which growers take into account when planning which crops to invest in. Frost, and in particular late spring frost, has the potential to kill frost sensitive plants. However, some crops require a winter vernalisation period (a sustained period of cold normally below 4°C) to give a good yield. Additionally, frost events can create a less parasite heavy growing season by increasing pest mortality over the winter months.

Winter frost is a significant factor for winter-sown crops, and areas prone to strong winter frosts would be more suited to spring sowing. Tree and orchard crops are senescent in winter and therefore would only be affected by the most severe and prolonged frosts, which generally occur only at significant altitude.

Late spring frost is a key factor that growers in Wales have to take into account in the present day. Although cereals are generally fairly hardy and can survive short frost, many row crops, particularly potatoes, are frost sensitive. Orchard crops are very sensitive to late frosts; mild winters encourage early blossom, at which point a late frost could destroy the crop.

In order to include the positive and negative aspects of frost in the crop suitability work, separate models were generated for winter and late spring frost risk. Additionally, due to climate change being predicted to alter the pattern of frost risk throughout Wales substantially, separate models were created for present day (*Figure 8*) and all climate change scenarios (*Figure 9*).

Present day

To model frost risk, several properties that increase or decrease the likelihood of frost formation in an area were considered. All seven factors included are listed below, with the most significant factors listed first; the most significant factors were given the highest weighting in the final model:

- Concavity: Concavities are small depressions in the ground, e.g. areas in which water could easily pool during rainfall as there is no direct outflow. Just like water, cold air can pool in these locations; this effect is one of the two major drivers of local variation in frost risk. To incorporate this effect into the frost risk model, concavities were identified from the elevation model. Areas falling within concavities are considered to increase the frost risk of a site substantially, whilst sites not falling into concavities do not alter frost risk at the site.
- Direct solar radiation: The amount of sunlight an area receives is the second major driver for frost risk, and as such has a strong impact on the overall model. To incorporate this effect, direct solar radiation was calculated using SAGA's solar radiation module to calculate the area's exposure to sunlight from the elevation model. The model considers the position of the sun in the sky, as well as any topographic features casting shade. For winter frost risk, solar radiation was considered between 1st November and 1st March; late spring considered the period 1st March to 10th May. Within these time spans, solar radiation was calculated at a temporal resolution of every 14 days and within the day every hour. The continuous values returned by this model were grouped into four classes using natural breaks (Jenks) calculated for the winter raster. The class receiving the least sun light was considered to increase frost risk substantially, whilst the class receiving the most sunlight reduces frost risk somewhat. The two classes receiving medium amounts of sunlight were judged to have either no effect on frost risk (class receiving medium to high amounts of sunlight),

or increased frost risk only to a small degree (class receiving medium to low amounts of sunlight).

- Elevation was incorporated into the present-day frost model to allow for the lapse rate (the rate of decrease of atmospheric temperature with increase in altitude). Locations with an altitude of 300 m or less were considered to have little or no effect on frost risk, whilst locations at 600 m or above were considered to have a substantial effect. Locations between 300 m and 600 m were considered to increase frost risk to some extent.
- Proximity to the coast: Water has a very high heat holding capacity compared to terrestrial surfaces. Therefore, proximity to the coast can reduce the frost risk for adjacent terrestrial sites. Additionally, salt helps to prevent frost, which is another reason for coastal areas experiencing frost less frequently than inland sites. To include this into the frost pocket model, all areas falling within the salt spray zone calculated for this project (see Section 0) were considered to reduce frost risk.
- Wind: At sites with low exposure to wind the stillness of the air creates a higher likelihood of formation of frost pockets; the cold air can easily settle close to the ground and increase the risk of ground frost. To include this into the frost pocket model, the wind effect map calculated for this project for both winter and spring (see section 0) was used. The continuous values from the original wind exposure map were grouped into four classes using natural breaks (Jenks) calculated from the winter data. Areas in the class with the lowest exposure to wind were considered to increase frost risk substantially, whilst the two medium classes were considered to only have a very small frost risk enhancing effect. The highest exposure class was considered to not alter frost risk at all.
- Vegetation type: A dense canopy cover can trap warm air from the day close to the ground, thereby preventing frost risk. It is worth noting that once frost has formed under such a canopy the shading can lengthen the time the frost lasts. Overall, vegetation was considered to have a mild positive effect. To create this layer, all canopy forming habitats within the updated Phase 1 habitat map of Wales were scored based on their average canopy density, with broadleaved woodland having the strongest effect for reducing frost risk and open areas not reducing frost risk in an area at all.
- Soil type: This layer was incorporated to allow for the fact that sandy soils will lose heat much faster than other soil types. Therefore, all sandy soils were considered to increase the frost risk of an area slightly.

Due to solar radiation having been calculated from a merge of DSM and DTM, with DSM being used in areas with a height difference of at least 2.2 m between DSM and DTM, some areas within the frost model present with a speckled pattern, where vegetation switches back and forth between exceeding the 2.2 m threshold and not doing so, which affects the amount of sun calculated to reach the ground.

Frost risk model interpretation (present day)

In the modelling for present day frost risk the warming influence of the sea is seen in the lower levels of frost around the coast of south and south west Wales. The areas subjected to the most severe and prolonged frost in the winter are the highest mountain peaks and the northern faces of the deep valleys, particularly in north and east Wales.

The pattern of late spring frost is slightly different. The majority of western Wales has only a moderate risk of late spring frost, and this risk decreases further in the south and south west. The highest frost risks are the valleys of east Wales and the highest mountain peaks. However, there are also some deep valleys in mid and west Wales where the lack of sunlight leads to an increased late spring frost risk.

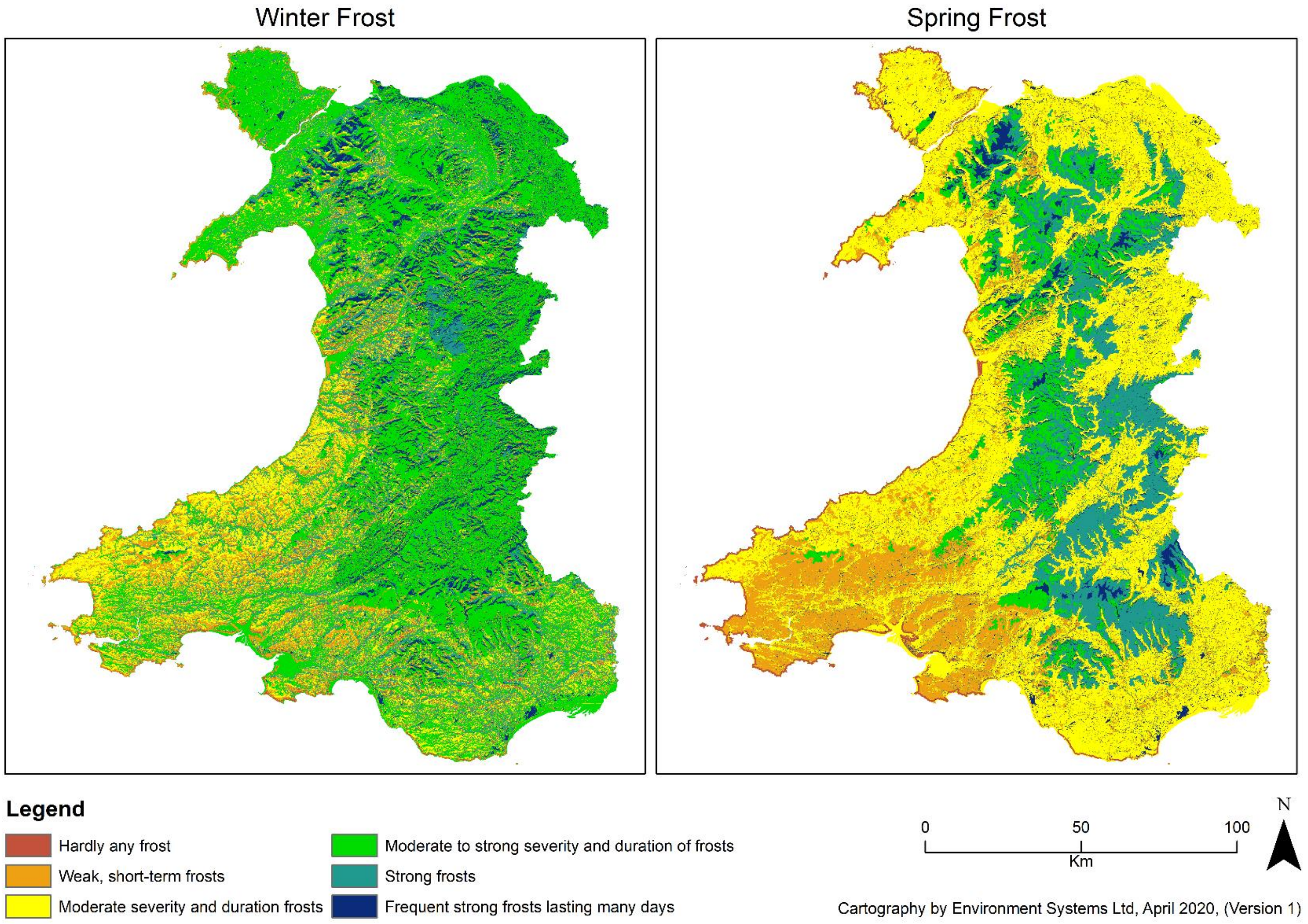

Figure 8: Present day frost models for winter and late spring

Climate change scenarios for frost modelling

Frost risk in winter and spring is one of the variables in Wales that may see the biggest change in 30 and 50 years' time. The spatial distribution of this change is likely to also vary from current day, as mountain areas are predicted to warm faster than the lowlands. Suitable UKCP18 datasets were available to undertake frost risk modelling, therefore the frost risk was modelled for all nine climate change scenarios.

For the climate change scenario frost modelling, the elevation layer was replaced with UKCP18 climate change minimum temperature predictions; this was calibrated against the present day frost models in order to establish class boundaries for different severities of winter and late spring frost risk. This approach allowed for a straightforward comparison between frost models for different climate change scenarios as well as the present-day model, as elevation and the associated lapse effect are considered in the UKCP18 temperature predictions.

Frost risk model interpretation (climate change scenarios)

The distribution and extent of winter frost classes in Figure 9 is similar for each of the three 2020 Representative Concentration Pathway scenarios. In 2050 and 2080 the differences between the low and medium scenario are subtle, but differences between the medium and high Representative Concentration Pathway scenarios are very clear at the national scale.

The general trend is the same under all Representative Concentration Pathway pathways; the extent of very prolonged severe frosts in the high mountains decreases as time progresses. The Brecon Bacons in particular show a more rapid decrease in frost risk than Snowdonia. The eastern side of Wales and particularly the deeper valleys are likely to have higher frost risk than the southern areas, with the west having risk of only moderate severity and duration events.

As for winter frost, the distribution and extent of late spring frost classes (Figure 10) is similar for the three 2020 Representative Concentration Pathway scenarios, but differences between the Representative Concentration Pathway pathways become increasingly apparent in 2050 and 2080.

By 2050 the risk of a prolonged late frost is predicted to be greatly reduced for the majority of Wales; in these models only the highest ground above ~500 m in central Wales, and some of the most sheltered valleys in mid Wales, have a frequent risk of strong late spring frosts. By 2080 the areas subjected to frequent strong frost are very few, and correspond to northern faces of the highest mountain peaks, and some of the steep-sided valleys in eastern Wales.

The predicted changes in frost risk offer some opportunities for the agricultural sector. Where other conditions are suitable for growing frost-sensitive crops, but where the chance of a late frost would currently too high for farmers to take the risk, opportunities could open up as the frost risk decreases. Many of the novel crops considered in the crop suitability modelling (Section 0) require a warmer winter and very little risk of frost, and therefore frost risk is likely to become a far less significant limitation to these crops over large parts of Wales.

On the negative side, many of the tree species and other crops that need a vernalisation period may not experience enough cold weather to produce a good crop every year.

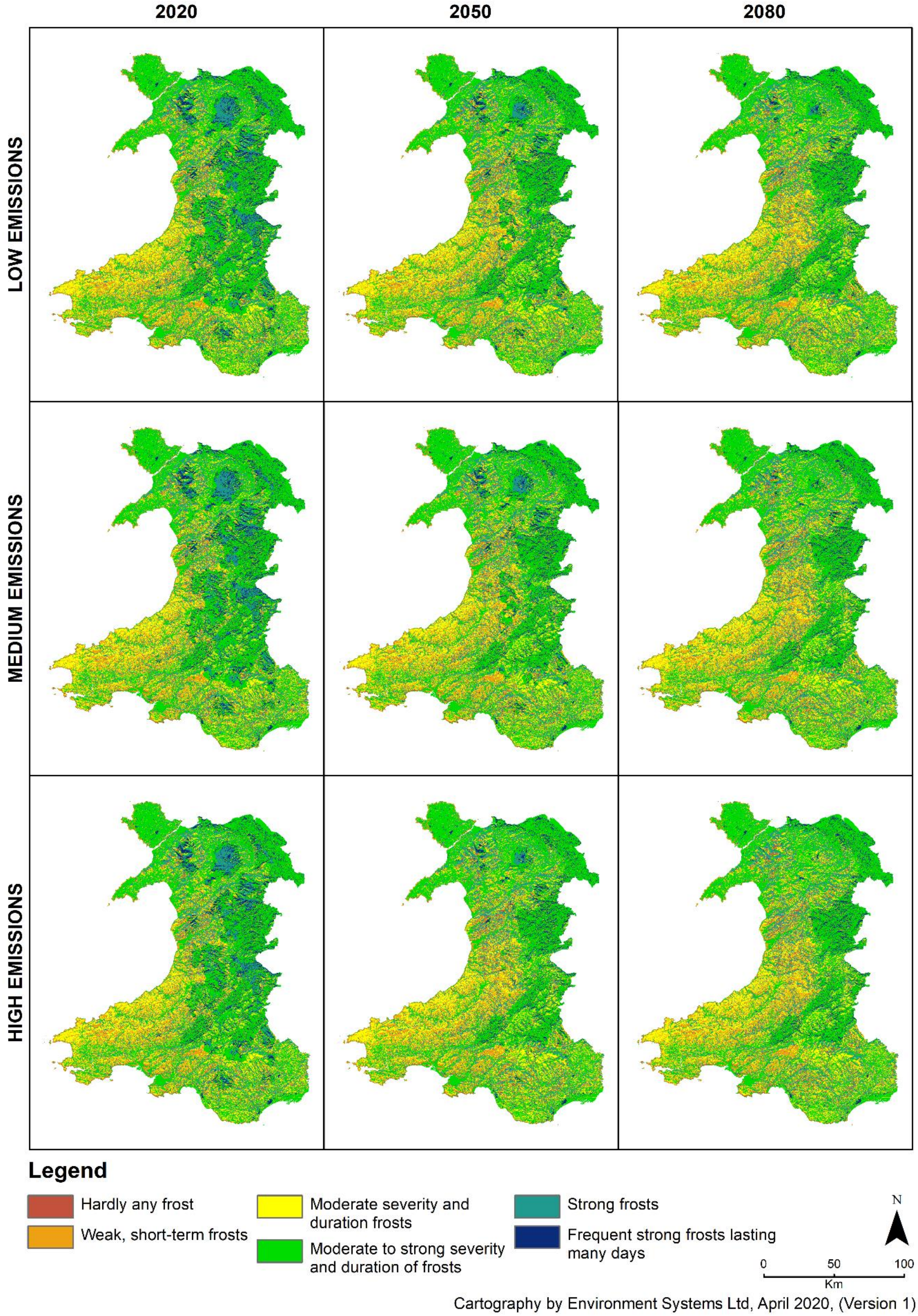

Figure 9: Frost risk modelling for winter; all climate change scenarios

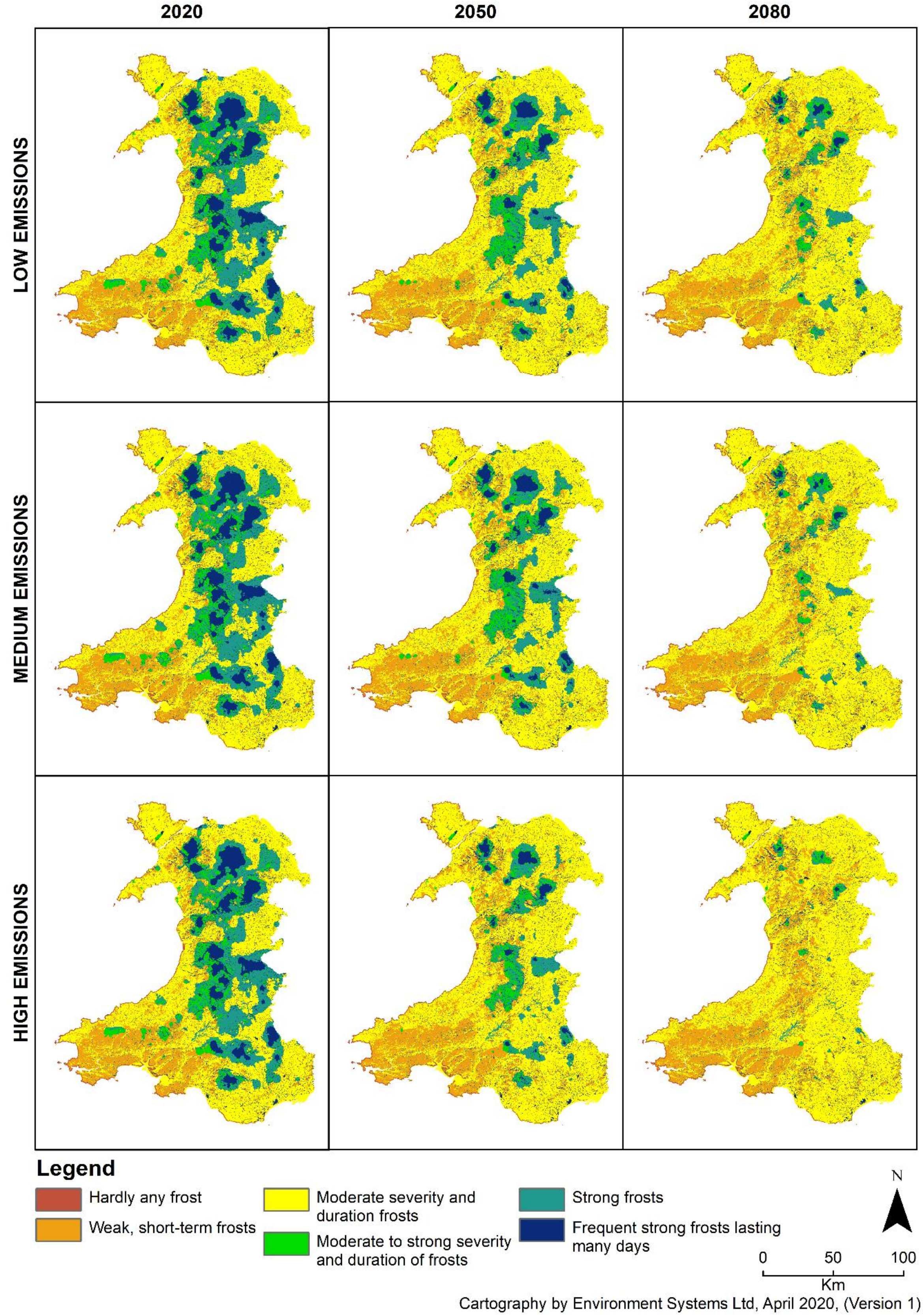

Figure 10: Frost risk modelling for late spring; all climate change scenarios

Flooding extent and duration

Agricultural flood risk is a deciding factor for many high value crops. Flooding has greatest impact when it takes place during summer, but it can be damaging to soil quality at any time of year. For this project, comprehensive data flood risk was sourced from Natural Resources Wales (NRW).

Flood extent data from the NRW Flood Risk Assessment Wales (FRAW) dataset were used to model flooding extent of significance to crops using criteria from the ALC handbook (MAFF, 1988). Pluvial and fluvial flooding frequencies for 1/10, 1/30, 1/100, and 1/1000 event floods were selected for inclusion in the modelling, as well as available tidal flood risk data (1/10 and 1/30 events). These datasets were then combined with their respective maintained flood defences areas.

Flood duration data for pluvial and fluvial flooding was also processed as above, incorporating defended areas. Duration data was not available for tidal flooding.

Incorporating defended areas into the flood risk data means that the models represent a policy scenario whereby existing flood defences continue to be maintained.

Although the FRAW dataset contained a selection of flood models for climate change scenarios, the presence of data gaps (i.e. only two scenarios modelled) and a lack of compatibility with the UKCP18 scenario definitions, it was not possible to use this data. Therefore, for consistency, the present-day flood data were used in all of the climate change scenario crop suitability models.

Crop suitability modelling

Crop suitability modelling was carried out for 118 crops, for ten date/climate change scenarios: the present day; 2020 (low, medium and high Representative Concentration Pathway scenarios), 2050 (low, medium and high Representative Concentration Pathway scenarios), and 2080 (low, medium and high Representative Concentration Pathway scenarios). A wide range of different crops were considered.

*Table 1*summarises the number of crops included in the analysis by category. The result of the crop suitability modelling was 118 ArcGIS projects containing all-Wales models of the spatial distribution of each of the crops, in the present day and for each of the climate change scenarios. This report considers a representative example crop from each broad category listed in *Table 1* to demonstrate the results of the project and the range of outcomes that have been found.

Table 1: Crops considered by type

Crop type	Number of crops	Examples
Cereals	11	Barley, Wheat
Row crops	25	Beetroot, Cabbage
Horticulture	48	Asparagus, Lettuce
Orchard	6	Apples, Pears
Trees	15	Sessile oak, Sitka spruce
Specialist	13	Tea, Saffron

The maps and models show, for the whole of Wales; which areas of land are suitable for agriculturally growing the crop, which areas are of limited suitability, and which areas are unsuitable for growing the crop. The crops included in the modelling are listed in Appendix A.

Methodology

In order to select appropriate input data, a comprehensive list of biophysical factors pertaining to crop growth were considered. For each of those, a decision was made on whether the factor is likely to be affected by climate change; where this was the case, and there was suitable data available, datasets representing the factor under the climate change scenarios were created. A list of all factors used for the final crop suitability models is given in *Table 2*.

The project utilised updated spatial soil classification data contained within the Soils of Wales dataset, and the updated ALC datasets produced by Cranfield University under the Capability, Suitability and Climate Programme (Keay, 2020abc). These datasets, together with further biophysical modelling detailed in Section 0, were used in this report to spatially model the suitability of 118 crops at 50 m resolution for the whole of Wales, for the present day and each of the nine climate change scenarios.

For each crop, all classes of the input biophysical factors were scored as “suitable” (growing conditions are optimal for the crop in question), “limited suitability” (the crop can be supported, but harvests might be less plentiful, or adverse weather conditions might destroy the crop in some years), and “unsuitable” (the biophysical condition does not allow for commercial-scale cultivation of the crop). In addition, each class was assigned a certainty score, expressing how comprehensive knowledge is with regards to the crop and the biophysical conditions under consideration. The biophysical factor/grade scores were assigned by ADAS crop experts.

In addition to the 118 commercial crop suitability models, a range of tree crops were also scored for their broader environmental tolerances, in order to produce parallel environmental suitability models (for occasions where commercial yield is not the main purpose of tree planting). These factor/grade scores were assigned by Environment Systems ecological experts.

Based on all input layers, crop suitability was determined based on the following rules, summarised in *Figure 11*:

- If the biophysical condition in all input layers 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”.

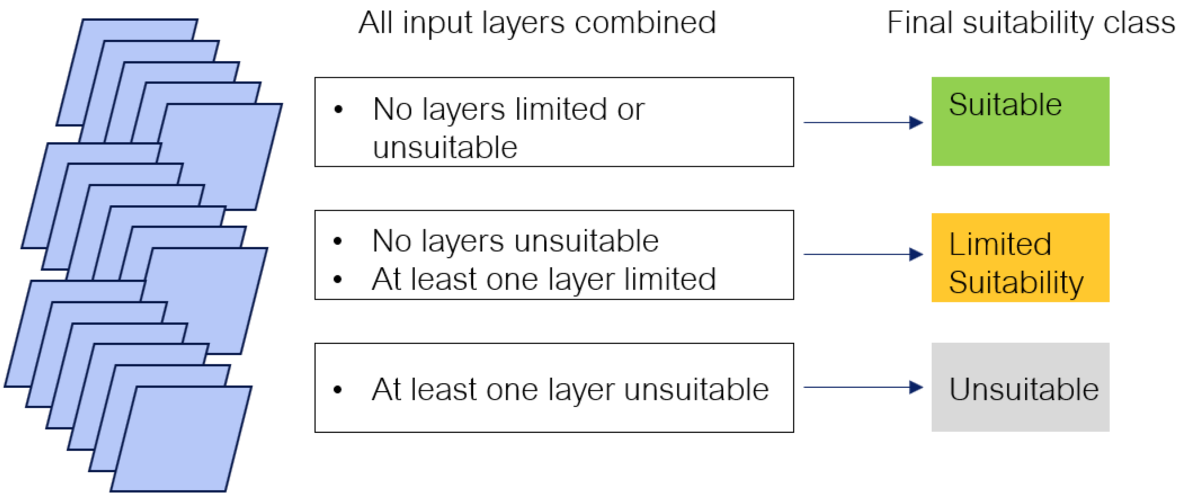

Figure 11: Deriving overall crop suitability through the combination of multiple input layers

The resulting crop suitability data was created in raster format, at 50 m resolution. In addition to the main crop suitability model, certainty of the overall score was estimated by summing the certainty scores associated with all input layers, with the highest scores representing the highest level of certainty in the crop scores for each factor.

To facilitate easier interpretation of the output models, two additional supporting layers were produced; these layers show, for each 50 m pixel, the number of input factors in this location that are of “limited suitability” or “unsuitable”, respectively.

Example suitability maps for each biophysical factor underpinning overall suitability for potato are shown in 0.

Table 2: Biophysical input factors for crop suitability modelling

Biophysical factor	Description of biophysical factor	Climate change scenarios
Climate	ALC attribute; combination of Average Annual Rainfall, Median Accumulated Temperature above 0ºC, January to June.	Y
Soil depth	ALC attribute; Depth of soil to the semi-permeable layer	N (not predicted to be affected by climate change)
Drought	ALC attribute; combination of Average Summer Rainfall (April to September) and Median Accumulated Temperature above 0ºC (April to September)	Y
Rockiness	ALC attribute; rock presence / absence mapping	N (not predicted to be affected by climate change)
Slope	ALC attribute; steepness of slope	N (not predicted to be affected by climate change)
Stoniness	ALC attribute; quantity of stones in the soil	N (not predicted to be affected by climate change)
Wetness	ALC attribute; based on Median Duration of Field Capacity Days	Y
Aspect	Orientation of the slope, reflects exposure and sun angle	N (not predicted to be affected by climate change)
Winter frost	Modelled layer; expresses length/duration of winter frost (see Section 0)	Y (modelled using average minimum temperatures, see Section 0)
Spring frost	Modelled layer; expresses length/duration of spring frost (see Section 0)	
Wind damage – Spring	Modelled layer; expresses the risk of wind damage in spring (see Section 0)	N (potential effect of climate change not sufficiently understood at spatial level to accommodate modelling)
Wind damage – Summer	Modelled layer; expresses the risk of wind damage in summer (see Section 0)	
Wind damage – Autumn	Modelled layer; expresses the risk of wind damage in autumn (see Section 0)	N (potential effect of climate change not sufficiently understood at spatial level to accommodate modelling)
Wind damage – Winter	Modelled layer; expresses the risk of wind damage in winter (see Section 0)	
Salt spray	Modelled layer; expresses the risk of exposure to salt spray (see Section 0)	N (potential effect of climate change not sufficiently understood at spatial level to accommodate modelling)
Fluvial flooding (+ defended areas)	NRW FRAW data; shows extent of fluvial flooding	N (level of climate change modelling not sufficient to support

Biophysical factor	Description of biophysical factor	Climate change scenarios
Pluvial flooding (+ defended areas)	NRW FRAW data; shows extent of pluvial flooding	number of scenarios addressed in this project)
Tidal flooding (+ defended areas)	NRW FRAW data; shows extent of tidal flooding	
Flood duration – Fluvial 1/10 event (+ defended areas)	NRW FRAW data; shows duration (hours) of fluvial flooding during a 1/10 flood event	N (level of climate change modelling not sufficient to support number of scenarios addressed in this project)
Flood duration – Fluvial 1/30 event (+ defended areas)	NRW FRAW data; shows duration (hours) of fluvial flooding during a 1/30 flood event	
Flood duration – Pluvial 1/10 event (+ defended areas)	NRW FRAW data; shows duration of pluvial flooding during a 1/10 flood event	
Flood duration – Pluvial 1/30 event (+ defended areas)	NRW FRAW data; shows duration of pluvial flooding during a 1/30 event	
Lakes	Water Framework Directive; presence / absence mapping of lake waterbodies	N (not predicted to be affected by climate change)
Urban areas	Built-up areas Wales 2011; presence / absence mapping of urban areas	N (not predicted to be affected by climate change; predicated change in extent over time not sufficiently understood to facilitate spatial modelling)

Model validation

A review of the first iteration outputs for six crops was carried out in September 2019. Crop suitability models were compared against confirmed locations of each crop (2018-2019 data). This showed a good correspondence between crop locations, and predictions of suitable/limited suitability land.

A more detailed model validation workshop was held in December 2019; this was attended by soil and crop experts from Welsh Government and ADAS (for a list of the crops reviewed during the workshop, see 0). The findings from this workshop were found to be accurate for the majority of the crops. The results were used to revise the crop scores for willow and osiers, which then fed into the final iteration of mapping.

During the crop validation workshop, some crop models displayed obvious straight-line breaks between suitability classes in the overall suitability layer, which were driven by straight cut-off lines present in the ALC attribute Wetness. These lines originate from areas in the Soils of Wales map where data derived from national scale mapping meets that of 1:25k mapping; where one source dataset maps the soils as Manod association, and the other maps the soils as Denbigh series. While the two soil types are very similar in many respects, they have slightly different wetness classes, which resulted in different crop suitability scores.

Loading and interpreting the data within ArcGIS

For each crop/scenario combination, one multi-band GeoTIFF at 50 m resolution was created, containing all information pertaining to the crop under this specific scenario. An explanation of each individual band name, along with guidance on loading and interpreting the data, is provided in 0.

When interpreting the models, users must consider the underlying assumptions and uncertainties of the underlying ALC, UKCP18 and other biophysical datasets, in addition to the crop requirement knowledge.

The overall crop suitability datasets provide an overview of biophysical suitability for each crop. However, in order to fully understand the spatial patterns of crop suitability, the relative effects of the individual factors should be viewed and understood. Some factors affect small land areas, and their impacts can be difficult to see on a national-scale map; detailed querying of the data is required in these cases.

The factors exerting the greatest impact on overall suitability under present day conditions may be different to the most significant factors under the climate change scenarios; some factors impact a small land area in the present day, but are predicted to impact greater land areas under climate change. Therefore, it is also important to query the underlying data when analysing trends in overall suitability over time.

Results for selected crops

It is beyond the scope of this report to provide detailed interpretation of changes in land suitability for all of the 118 crops modelled during the course of the project. This section presents the overall suitability maps for nine crops, selected to provide a broad representation of different types of crop modelled; root crops, cereals, horticultural crops, orchard crops, broadleaved and coniferous trees, specialist crops, and dry-climate crops.

Case study 1: potato

Potatoes were grown on 5,859 ha land in Wales in 2019, and 6,204ha in 2018. Most potatoes are grown in Pembrokeshire, which is known for its new potatoes. Potatoes are also grown near the coast in mid and north-west Wales. Potatoes require well-drained ground and have a low tolerance to waterlogging. They are also frost sensitive. Planting takes place from March for early varieties, and early May for main crop. A warming climate may initially be advantageous for potato growth, but increase in drought would not favour their production.

Figure 12 compares overall crop suitability for potato in the present day and under the 2020 climate change scenario[1]. It can be seen that there is little difference in overall suitability between the two models, although there are decreases in unsuitable areas in south Ceredigion/northern Carmarthenshire, and increases in unsuitable areas in the Vale of Glamorgan and Denbighshire.

Figure 13 shows the crop suitability models for potato under the nine climate change scenarios, representing low, medium and high Representative Concentration Pathway conditions in 2020, 2050 and 2080. The maps show that in 2020 there is little difference in suitability for potato under the low, medium and high Representative Concentration Pathway scenarios. The most suitable areas for growing potatoes in Wales under the three 2020 scenarios are located in lowland coastal areas and along the Welsh border; particularly in Anglesey, Pembrokeshire, Gower, Monmouthshire, Flintshire, and the lower Wye Valley in Powys.

There are large areas of limited suitability in Ceredigion, Pembrokeshire, Carmarthenshire, northeast Powys and northern Conwy/Denbighshire. These limited areas are areas where potato cultivation may still be possible, but more costly (due to the need for management action to address specific limitations) or subject to reduced yield.

[1] The UKCP18 scenarios represent a 30-year window rather than a single year: the 2020 scenario represents the 2010-2039 time period; 2050 represents 2040-2069; 2080 represents 2070-2099.

The areas unsuitable for potato in 2020 are restricted to the uplands, where ALC Climate and Wetness are the driving factors leading to the areas being classified as unsuitable, due to high rainfall and soil moisture. Slope is also an important factor creating unsuitable areas in the both the uplands and lowlands.

There are relatively subtle changes in suitability for potato between 2020 and 2050; some areas in central Powys, unsuitable in 2020, become limited suitability in 2050 due to milder climate and reduced soil wetness. In eastern Wales, areas suitable or limited suitability in 2020 become unsuitable in 2050 due to drought; this is most noticeable in Wrexham, northeast Powys, and Monmouthshire. These trends are visible in all three Representative Concentration Pathway scenarios for 2050, but there are clear differences in the magnitude of these trends between low, medium and high Representative Concentration Pathway scenarios.

The 2080 suitability models show large changes in land suitability for potato compared to 2050, and also the largest differences between the low, medium and high Representative Concentration Pathway scenarios. Under the low Representative Concentration Pathway scenario some suitable land remains in Anglesey, north Pembrokeshire, Gower and Flintshire, but almost all suitable land in Monmouthshire and Powys is lost. Under the high Representative Concentration Pathway scenario almost no land is expected to be suitable for potato, and the amount of limited suitability land is vastly contracted; drought is the factor driving these changes in the lowlands, while climate and wetness remain driving factors for the central uplands.

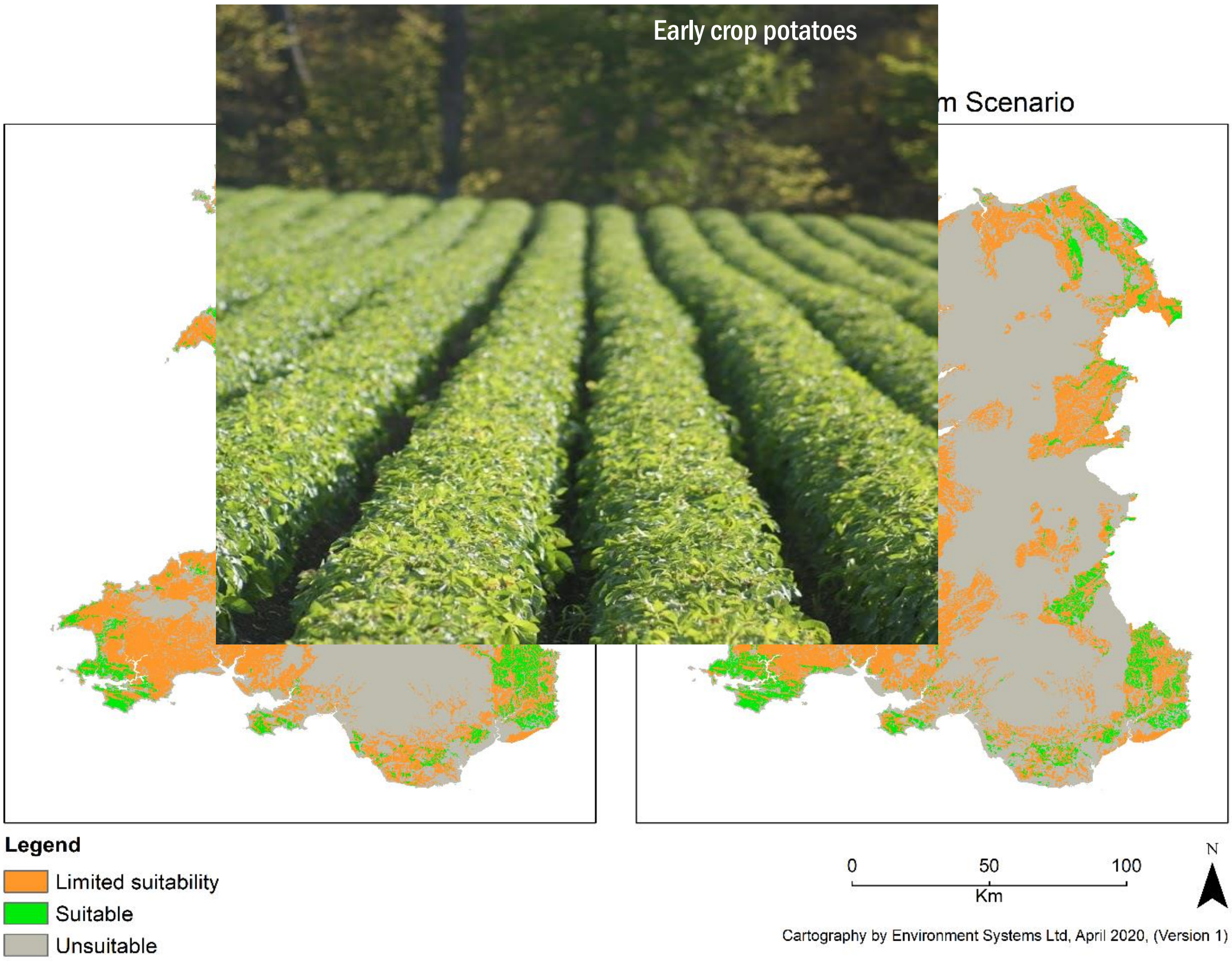

Figure 12: Overall suitability for potato in the present day and under the 2020M climate change scenario

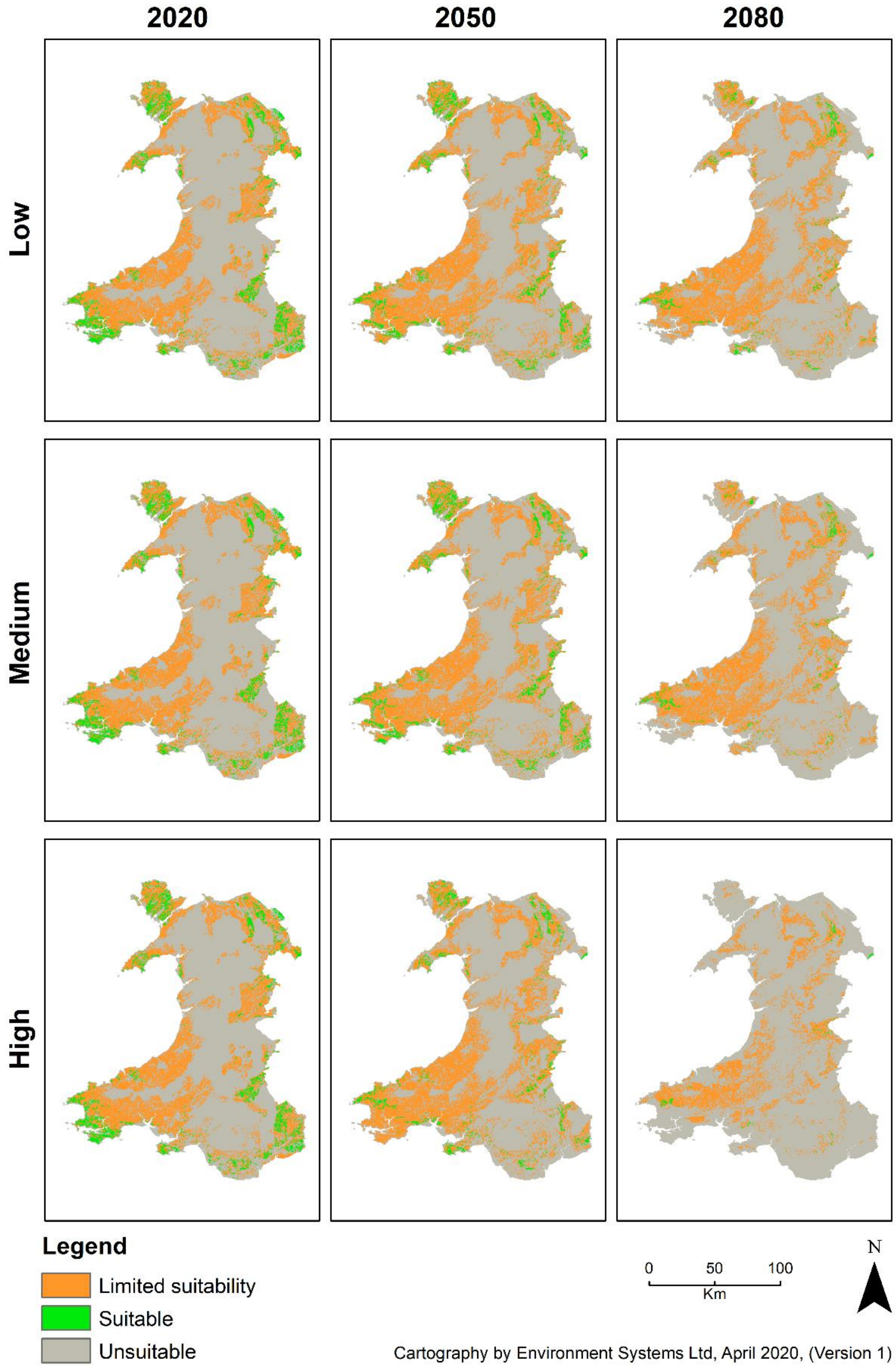

Figure 13: Overall suitability for potato grown on a commercial basis across nine climate change scenarios

Case study 2: wheat

Wheat covers the largest land area of any arable crop in Wales, with 23,352 ha planted in 2019 and 22,179 ha planted in 2018. This has increased over the last 20 years, with just 12,871 ha grown in 1999. The large increase in the area sown for wheat from 2014 follows inflation in wheat prices together with an increase in the cost of feed and haulage, making cereal growing a more appealing option on Welsh farms.

Because of the wet conditions in Wales most wheat is spring sown, and therefore lower yielding and later to mature than winter sown wheat. Spring sown wheat is generally used for whole-crop silage. However, there is increased interest in wheat for milling for local Welsh bakers (CALU (2008)). A warmer climate could reduce the risk of mildews and other diseases of cereal crops common in Wales in years with a wetter summer. *Figure 14* shows the crop suitability models for wheat under the nine climate change scenarios, representing low, medium and high Representative Concentration Pathway conditions in 2020, 2050 and 2080. The maps show that in 2020 there is little difference in suitability for wheat under the low, medium and high Representative Concentration Pathway scenarios. The most extensive suitable areas for growing wheat in Wales under the three 2020 scenarios are located in Anglesey, Monmouthshire, Flintshire, and the lower Wye Valley in Powys, with a smaller area in south Pembrokeshire.

There are large areas of limited suitability in lowland Wales, where wheat cultivation may still be possible, but more costly (due to the need for management action to address specific limitations) or subject to reduced yield.

The areas unsuitable for potato in 2020 are restricted to the uplands, where ALC Climate and Wetness are the driving factors leading to the areas being classified as unsuitable, due to high rainfall and soil moisture. Slope is also an important factor creating unsuitable areas in the both the uplands and lowlands.

There are relatively subtle changes in suitability for potato between 2020 and 2050 under the low and medium Representative Concentration Pathway scenarios; the most noticeable changes occur in Monmouthshire, where areas that were suitable in 2020 become limited by drought in 2050. These changes, due to increasing soil droughtiness, are apparent across the whole of Wales under the high Representative Concentration Pathway scenario, where additional losses in suitable land are seen to occur in Anglesey, Pembrokeshire and Powys.

The 2080 suitability models show large changes in land suitability for wheat compared to 2050, with the loss of almost all suitable land under low Representative Concentration Pathway. Increases in the amount of unsuitable land are apparent; particularly in Monmouthshire and the Vale of Glamorgan coast. There are large differences between the 2080 medium and high Representative Concentration Pathway scenarios, where no suitable land remains, and with the 2080 high Representative Concentration Pathway scenario demonstrating far greater areas of unsuitability, due to increasing droughtiness of the soil.

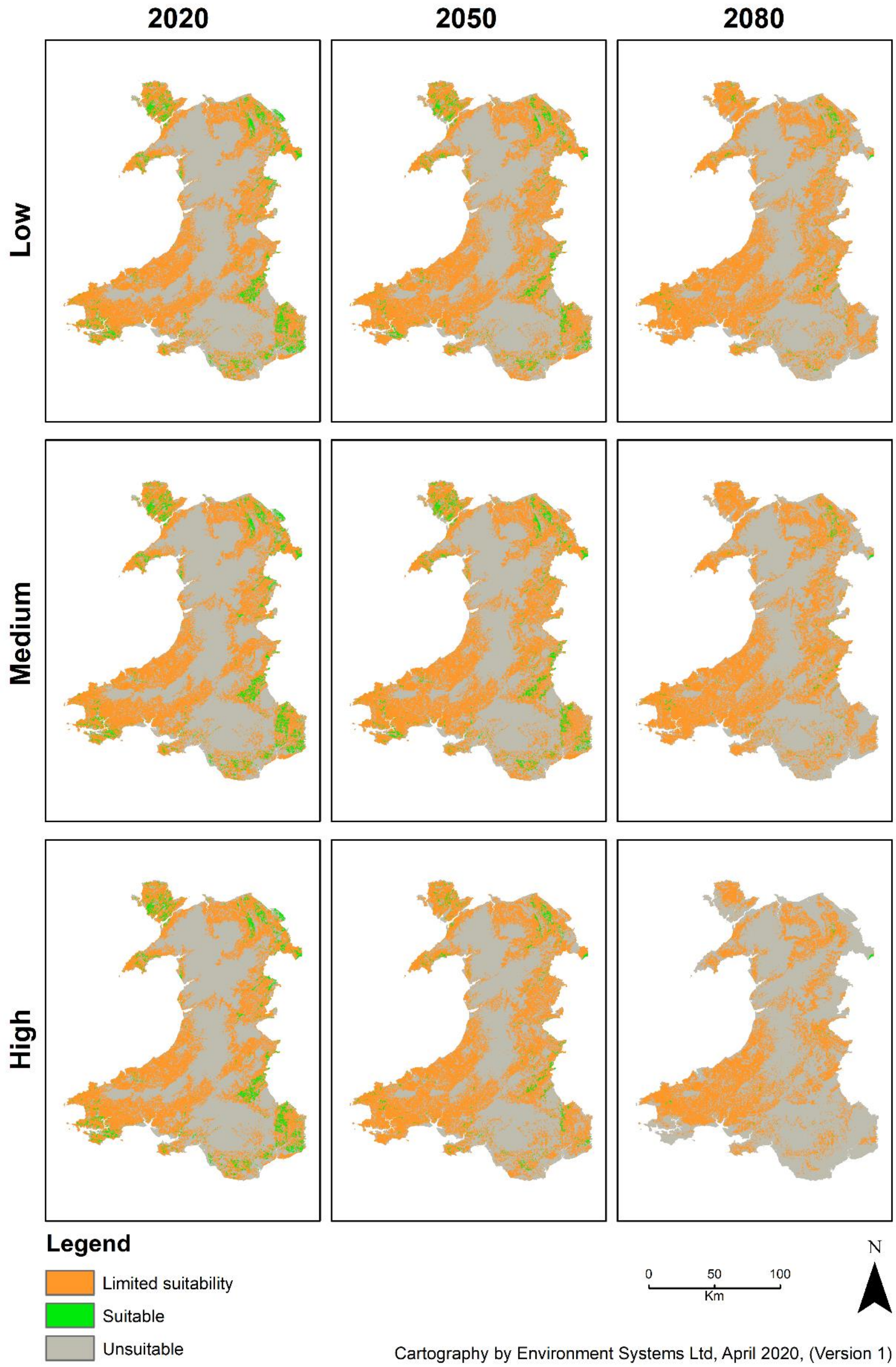

Figure 14: Overall suitability for wheat grown on a commercial basis across nine climate change scenarios

Case study 3: lettuce

Vegetables and salad grown in the open air occupied only 325 ha of land in Wales in 2019. This has fluctuated over the last 20 years, with 2014 seeing the largest land areas dedicated to such crops, with 617 ha of horticultural land (Welsh Government 2019b). One such crop contributing to this total is lettuce.

In the UK whole head lettuce are sown from mid-March to around the middle of May, and the season finishes at the end of October. For salads in general, if the spring has been warm, the first seedlings will be planted around mid-March and the first harvest will take place around April (British Leafy Salad Association, 2020). Most varieties of lettuce are grown outdoors, with only 20% of the crop being grown under glass. A warmer climate could result in quicker maturity and more biomass produced, possibly enabling multiple crops in a year (Armstrong 2016).

Figure 15 shows the crop suitability models for lettuce under the nine climate change scenarios, representing low, medium and high Representative Concentration Pathway conditions in 2020, 2050 and 2080.

It can immediately be seen that this horticultural crop is restricted to the best quality agricultural land, which has only limited suitability for this crop, with the majority of Wales being unsuitable. As seen in previous sections, in 2020 there is little difference in suitability under the low, medium and high Representative Concentration Pathway scenarios. The differences between Representative Concentration Pathway scenarios become more apparent in 2050, with the greatest increase in unsuitable areas seen between the medium and high scenarios.

By 2080 very little limited suitability land remains; under the high Representative Concentration Pathway scenario the limited suitability land is restricted to very small pockets, distributed throughout south and northeast Wales. Under the low and medium Representative Concentration Pathway scenarios these areas are less fragmented.

Figure 15: Overall suitability for lettuce grown on a commercial basis across nine climate change scenarios

Case study 4: swede

Swedes are a popular choice of fodder crop in Wales. They are mainly planted as a rotation, and used for animal feed for sheep and cattle. They are frost tolerant and tolerate a wide range of wetness and drought conditions; swedes grow well in soils that are moist and wet in spring.

Swedes are often grown as a break crop between cereals and short-term grass leys, and can help control problematic weeds (Limagrain, 2019). Swedes can be grown on a wide range of soils including sandy loams, silts, peat or clay loams with good structure and sound drainage. They are normally sown from April to June. As they grow through to October or November, the steady rainfall in the autumn allows them to add dry weight. They are mostly grazed *in situ*. Some varieties of swede are grown for human consumption.

Figure 16 shows the present-day crop suitability model for swede compared to the 2020 medium Representative Concentration Pathway scenario. The maps show some degradation of suitable areas in Monmouthshire and Flintshire during this time, with the areas becoming limited suitability. However in general, 2020 sees an increase in potential growing space for this crop compared to the present day, with formerly unsuitable areas around the upland margins becoming limited suitability; this is largely due to the ALC climate grade improving.

Figure 17 shows the crop suitability models for swede under the nine climate change scenarios, representing low, medium and high Representative Concentration Pathway conditions in 2020, 2050 and 2080. The maps show that swede is expected to remain a crop that can be widely grown up until 2050, with relatively small changes in suitability during this time. Noticeable exceptions occur in Wrexham and Monmouthshire, where areas become unsuitable. However, narrow strips of land increase in suitability in the valley bottoms between Merthyr Tydfil and Cwmbran; areas that are forecast to be unsuitable in 2020 become either suitable or limited suitability by 2050. During this period unsuitable land also decreases east of the Presheli hills, becoming limited suitability.

The trends between 2050 and 2080 become more mixed; the overall trend is a decrease in land suitability for swede, with large areas of land becoming unsuitable due to drought. However, some areas, particularly in Ceredigion, north Pembrokeshire and north Carmarthenshire, change from being unsuitable to either limited suitability or suitable; these changes are driven by a decrease in soil wetness.

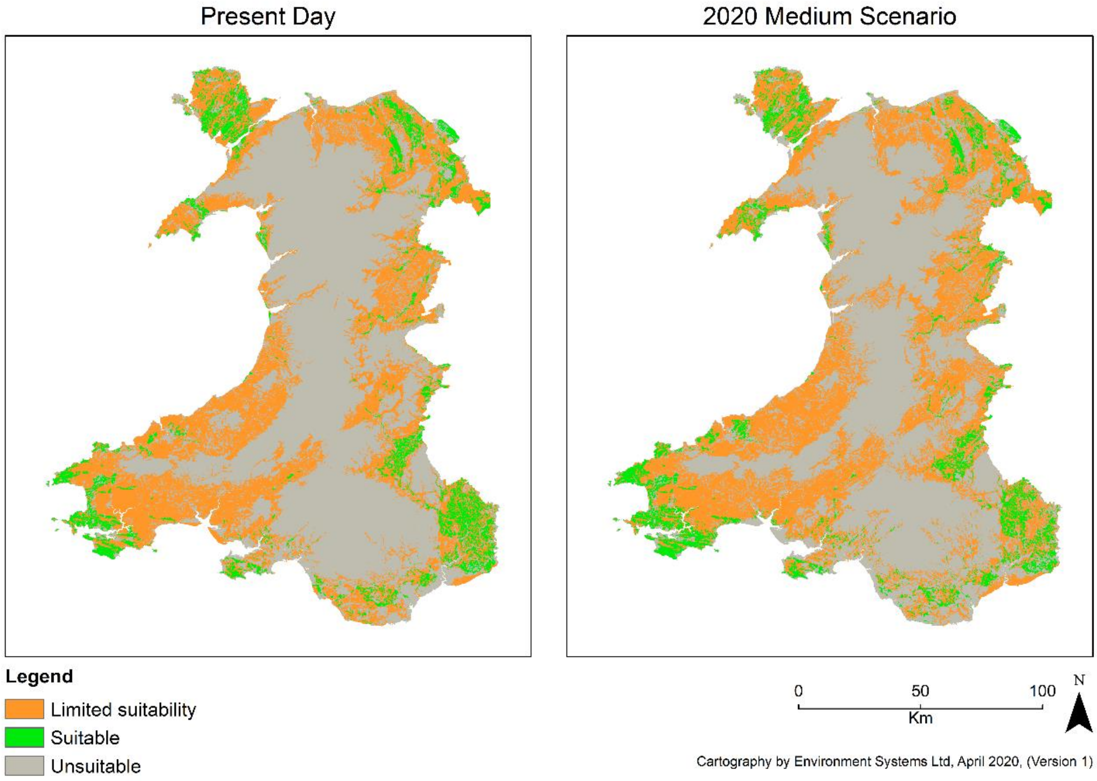

Figure 16: Overall suitability for swede in the present day and under the 2020M climate change scenario

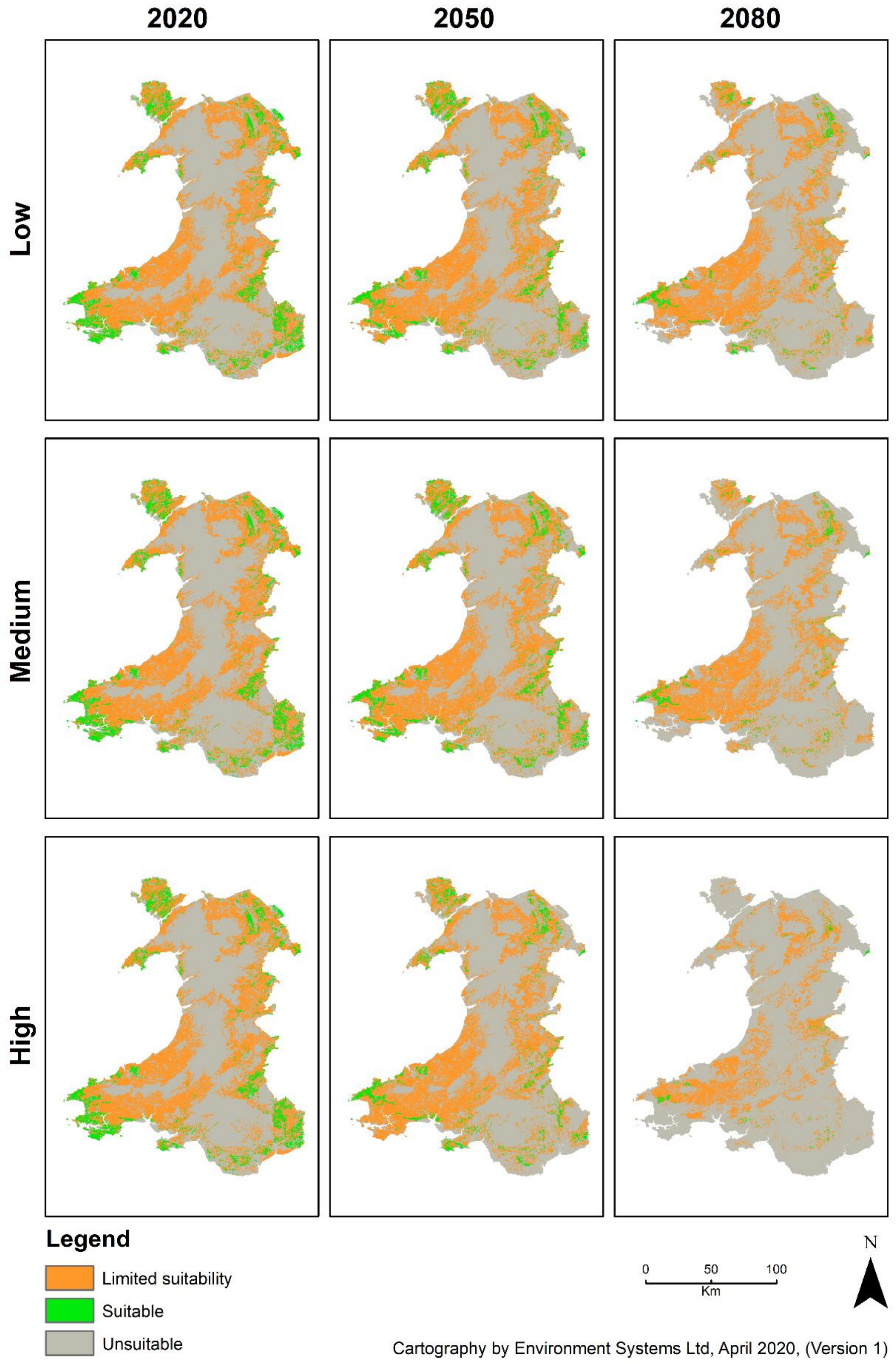

Figure 17: Overall suitability for swede grown on a commercial basis across nine climate change scenarios

Case study 5: tea

Currently tea is seen as a novel crop, with only a couple of farmers undertaking this enterprise in Wales at present. Tea requires a temperate climate which is warm with a steady rainfall and an acidic soil. Tea plants are not drought tolerant, and neither can they cope with excessive soil moisture. They are normally planted on well-drained slopes. Tea bushes reach maturity in 7-8 years, so require a substantial initial investment. Currently, those growing tea in Wales are concentrating on the specialist markets.

The present-day suitability model for tea was validated by crop experts during a model review workshop. During this review process crop experts discussed a current known tea-growing location near Llanrwst, and so model validation focussed on this area. When viewing the suitability map at the all-Wales scale it appears that the entire Conwy Valley has been modelled as unsuitable for tea. However, upon viewing the area in detail, the current fields being cultivated for tea were found to be identified in the crop suitability model as limited suitability, with the surrounding areas mapped as unsuitable (*Figure 18*).

Figure 19 shows the crop suitability models for tea under the nine climate change scenarios, representing low, medium and high Representative Concentration Pathway conditions in 2020, 2050 and 2080.

Tea is a relatively specialist crop which is similar to lettuce in terms of its suitability distribution in Wales, although the models predict a greater area of limited suitability as compared to lettuce; particularly in Pembrokeshire.

The trends over time for tea follow those described for lettuce; in 2020 there is little difference in suitability under the low, medium and high Representative Concentration Pathway scenarios, but the differences between the Representative Concentration Pathway scenarios become greater in 2050 and 2080.

By 2080 very little limited suitability land remains; under the high Representative Concentration Pathway scenario the limited suitability land is restricted to very small pockets. Under the low and medium Representative Concentration Pathway scenarios larger areas of limited suitability remain in Flintshire and north Pembrokeshire.

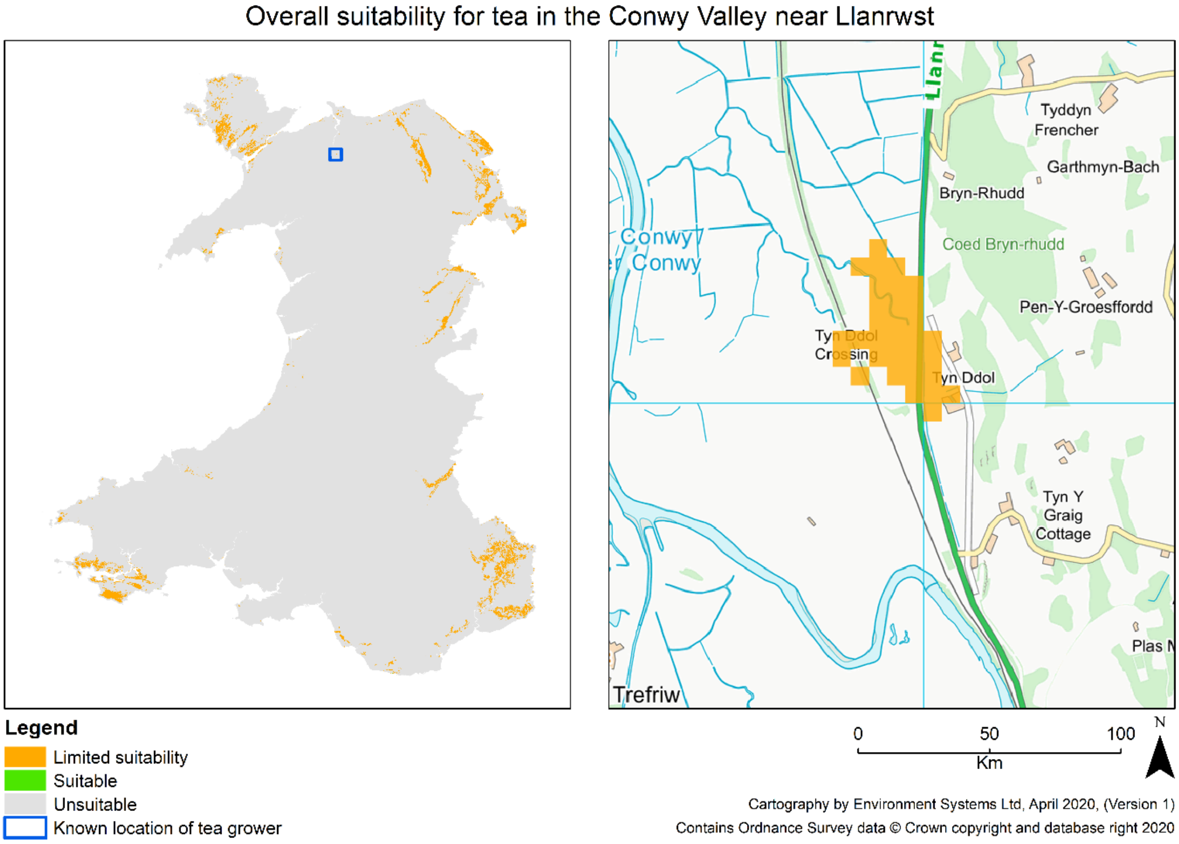

Figure 18: Present day overall suitability model for tea

Figure 19: Overall suitability for tea grown on a commercial basis across nine climate change scenarios

Case study 6: apple

Commercial orchards accounted for 336 ha of land in Wales in 2019 (Welsh Government 2019), with apples making up a significant proportion of this total. Apples thrive in deep loamy soils, require a steady supply of water, and are sensitive to late spring frosts. There are many traditional Welsh varieties of apples which are grown both for eating and cider production.

ALC Climate, late spring frost risk, and wind damage risk in the spring and summer are the dominant factors driving the overall suitability model in the present day (*Figure 20*), with suitable and limited suitability areas being restricted to sheltered lowland areas that are not too wet.

Figure 21 shows the crop suitability models for apple under the nine climate change scenarios, representing low, medium and high Representative Concentration Pathway conditions in 2020, 2050 and 2080. ALC Climate, late spring frost risk, and wind damage risk in the spring and summer remain the dominant factors driving the overall suitability model under the 2020 and 2050 scenarios. However, by 2080, in spite of decreasing frost severity and no change in the input layers used to model wind damage risk, the amount of unsuitable area drastically increases; this is driven by increasing drought.

In the 2080 scenarios, particularly under medium and high Representative Concentration Pathway, the areas of limited suitability for apple shift to higher ground relative to 2020; this occurs due to favourable changes in ALC Climate, in areas that are not significantly affected by drought, or by wind and frost exposure.

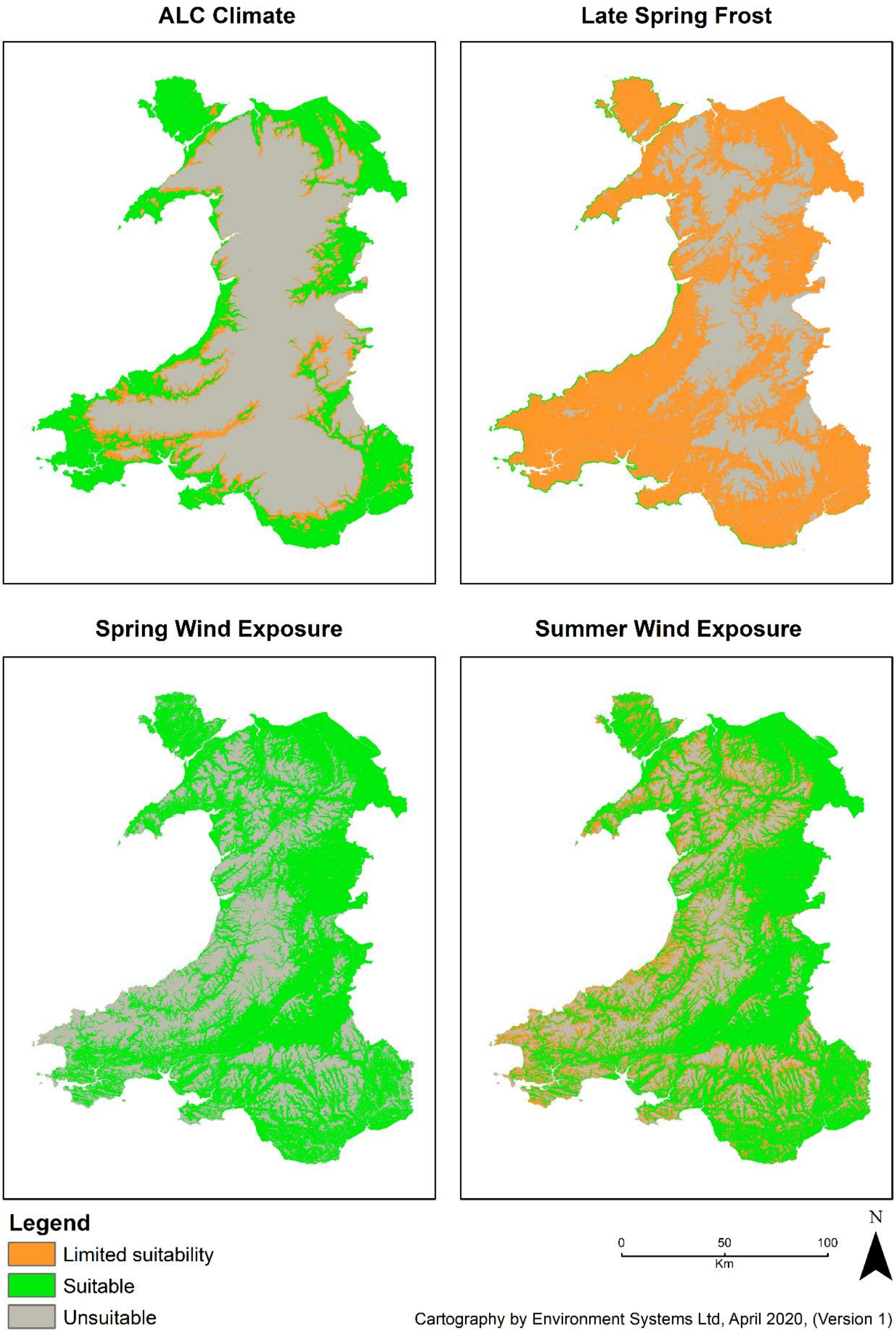

Figure 20: Key biophysical factors driving present day overall suitability for growing apples commercially

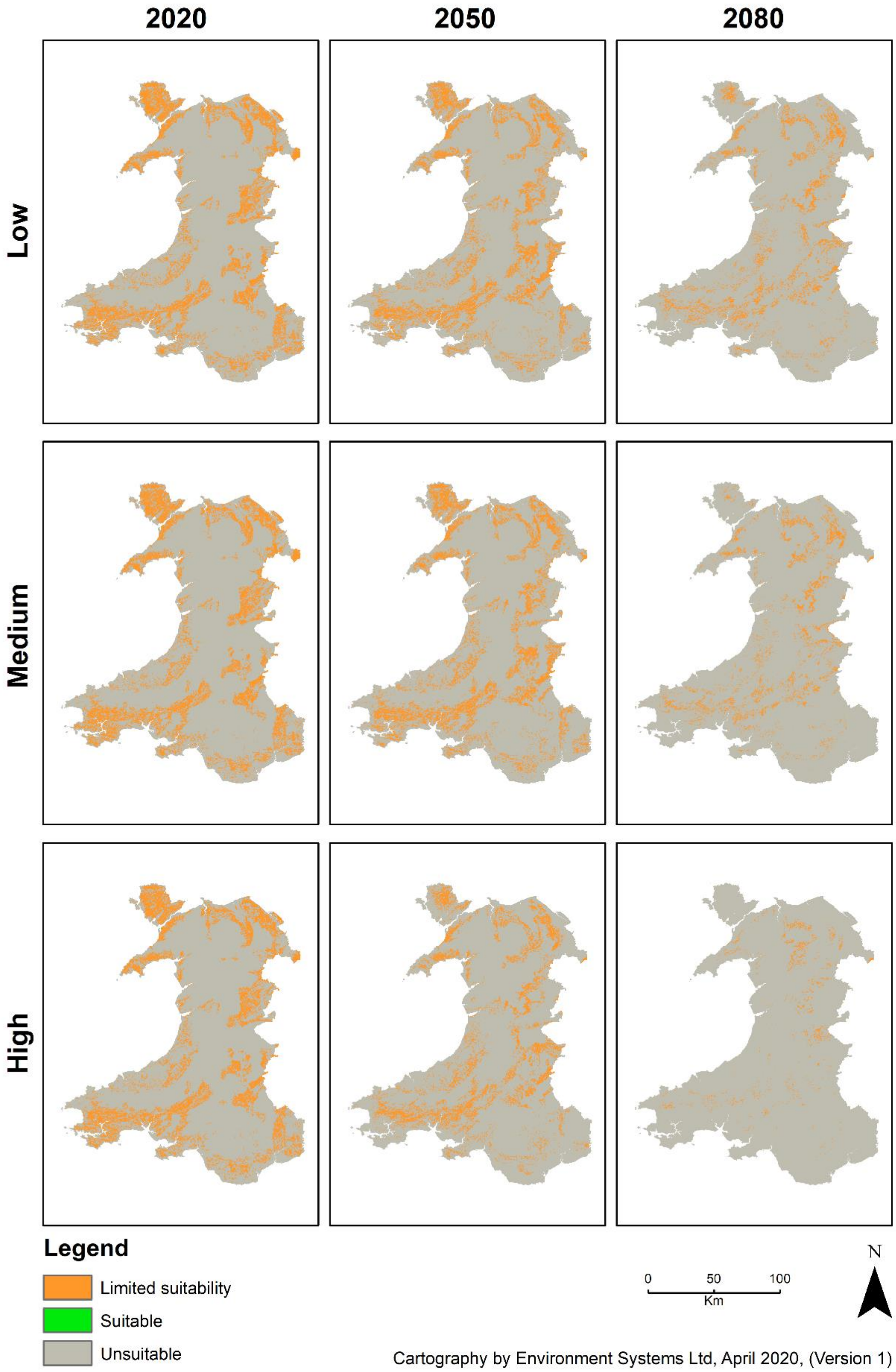

Figure 21: Overall suitability for apple grown on a commercial basis across nine climate change scenarios

Case study 7: sessile oak: commercial and environmental models

Sessile oak is a native tree of Wales with ancient sessile oak woodland being a key component of many Sites of Special Scientific Interest (SSSI's) in Wales. Ditchburn (2018) recorded the stock of sessile oak in Wales as 6,100 ha. When grown commercially sessile oak is a prized hardwood, and is used for flooring, wine barrels, cabinet-making and veneers.

Figure 22 shows the commercial crop suitability models for sessile oak under the nine climate change scenarios, representing low, medium and high Representative Concentration Pathway conditions in 2020, 2050 and 2080. To grow sessile oak commercially requires an optimum climate to enable fast growth or straight trees for cropping.

Figure 23 shows broader suitability for sessile oak representing environmental tolerances rather than commercial viability. Sessile oak natively grows in a wide range of conditions; an example being Penderi SSSI (Figure 24) which occurs on the cliff edge of the coast in Ceredigion. Here, the oak trees are of considerable age but are mostly less than 3 m tall, and bent with the prevailing wind. They are however, of great biodiversity value. Native oak woodlands help provide multiple ecosystem service such as soil and vegetation capture, water filtration, air quality enhancements, recreation, and biodiversity.

The commercial suitability models show a widespread, albeit largely limited, suitability for sessile oak under the 2020 scenarios, with only upland areas being modelled as unsuitable, driven by the ALC Climate factor. Under the 2080 scenarios ALC Climate is still the factor driving unsuitability in the highest elevations, but ALC Drought becomes the most dominant factor with respect to the unsuitable areas across the rest of the country; under the 2080 high Representative Concentration Pathway scenario in particular, this factor causes a very large contraction of suitable and limited suitability growing space relative to 2020.

The commercial models represent areas suitable for growing sessile oak for timber, where growth rate, timber yield and quality are the most important considerations for business viability. However, there are other reasons for planting woodland where less-than optimal growing conditions would be acceptable; such as establishing woodland for biodiversity benefits, protection from soil erosion, flood mitigation, or CO_2 capture, which could be achieved either by planting or natural regeneration. Under the latter circumstances the environmental suitability models, considering the broader ecological tolerances rather than optimum conditions, provide a more effective assessment of suitable growing space for the species.

The environmental models for sessile oak show a far greater resilience to climate change than commercial-grade oak, meaning that the species should continue to retain a strong presence in woodlands throughout the country, and continue to be an appropriate species choice for environmental planting schemes in most places.

Parts of central Powys are predicted to improve in suitability over time, due to improvement in ALC Climate (the main factor driving unsuitable areas in the present day) and reduction of late spring frost risk (the main factor driving the limited suitability areas). However, some parts of Wales are predicted to become unsuitable for oak by 2080 in Denbighshire, Wrexham, Monmouthshire, the Vale of Glamorgan, Gower and South Pembrokeshire, even under the low Representative Concentration Pathway scenario, due to increasing summer drought (*Figure 25*).

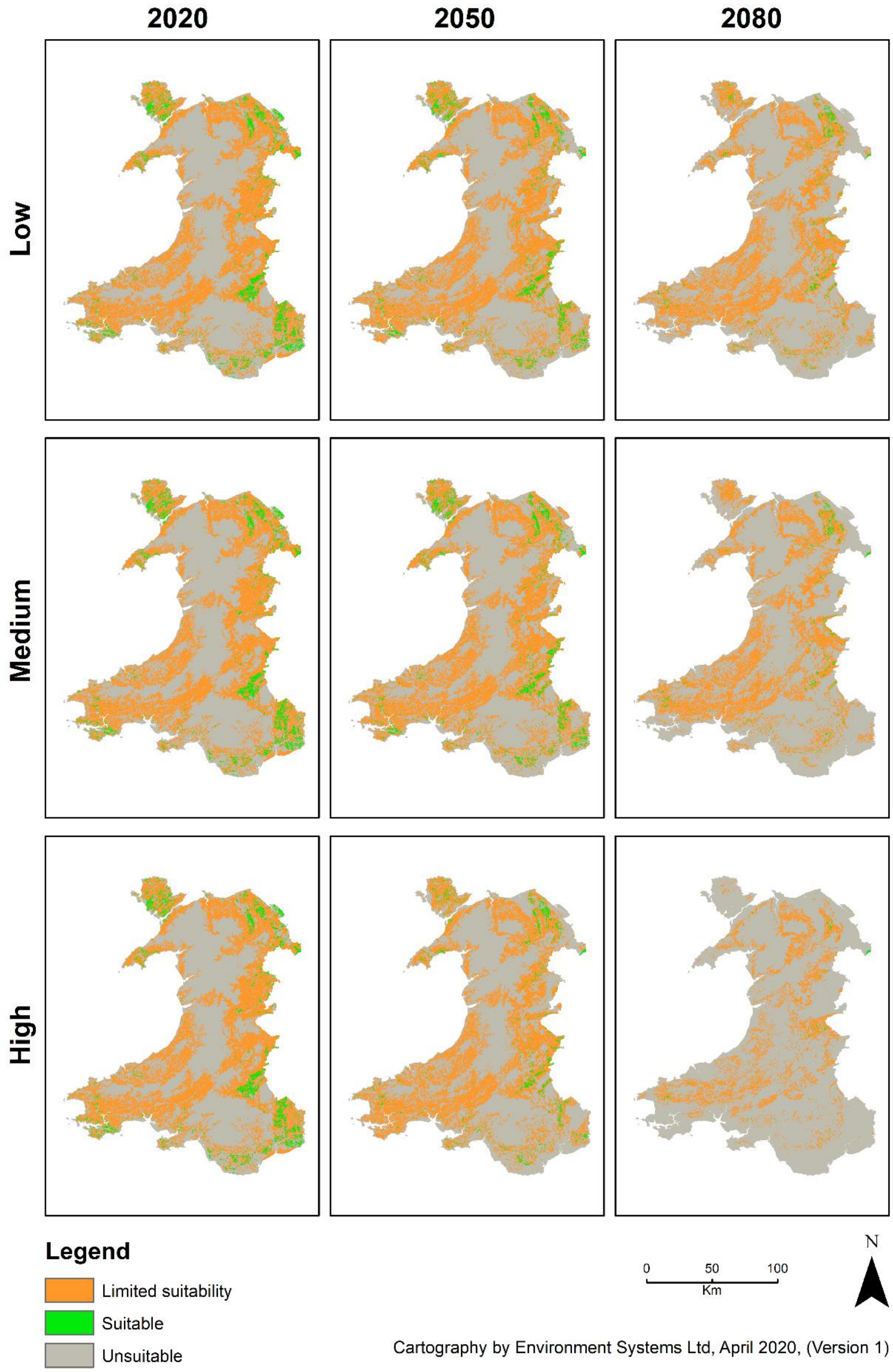

Figure 22: Overall suitability for sessile oak grown on a commercial basis across nine climate change scenarios, based on UKCP18 data

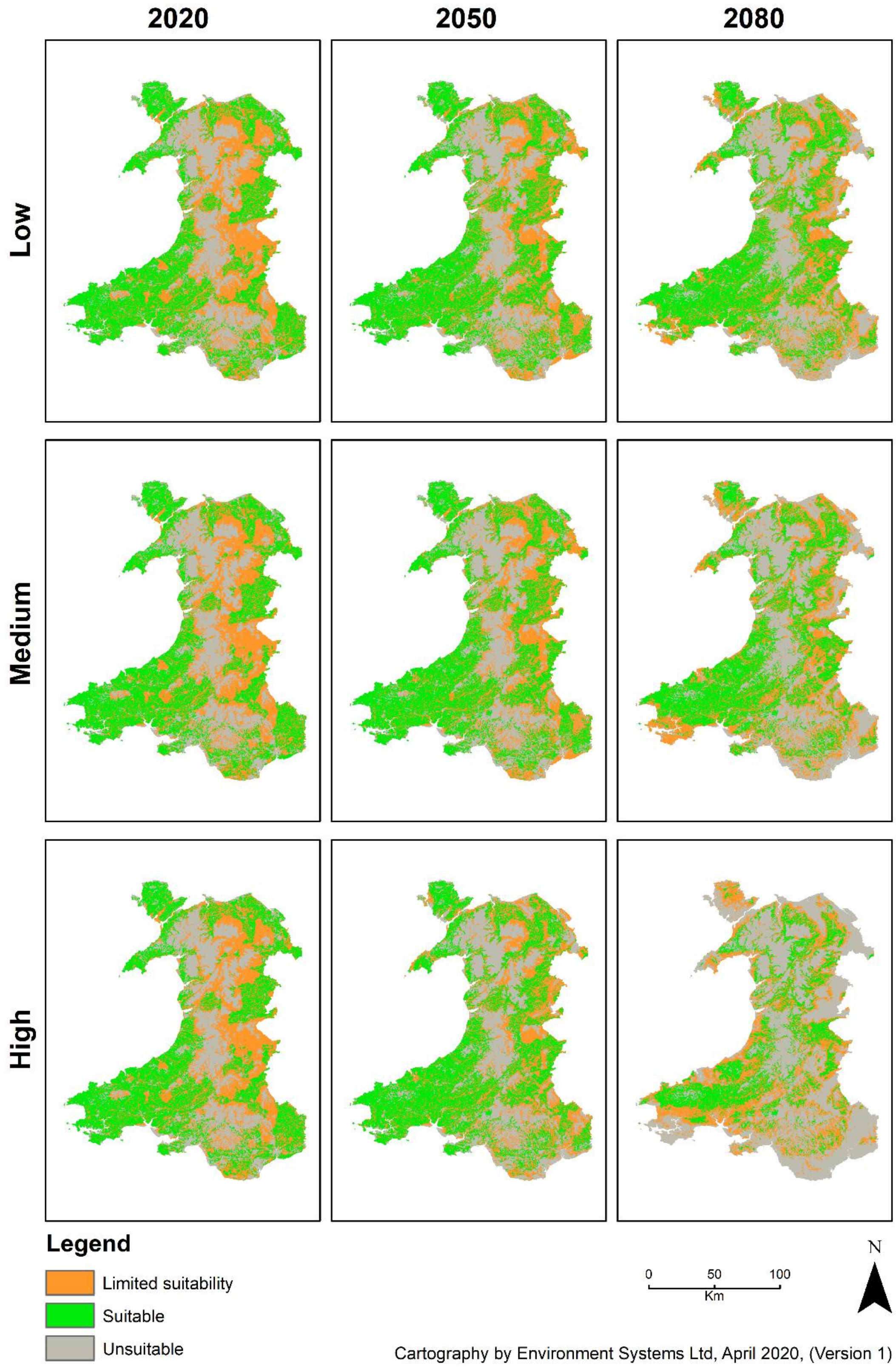

Figure 23: Overall suitability for sessile oak grown on a non-commercial basis across nine climate change scenarios

Figure 24: Stunted ancient oak woodland at Pendri-cliff SSSI in west Wales.

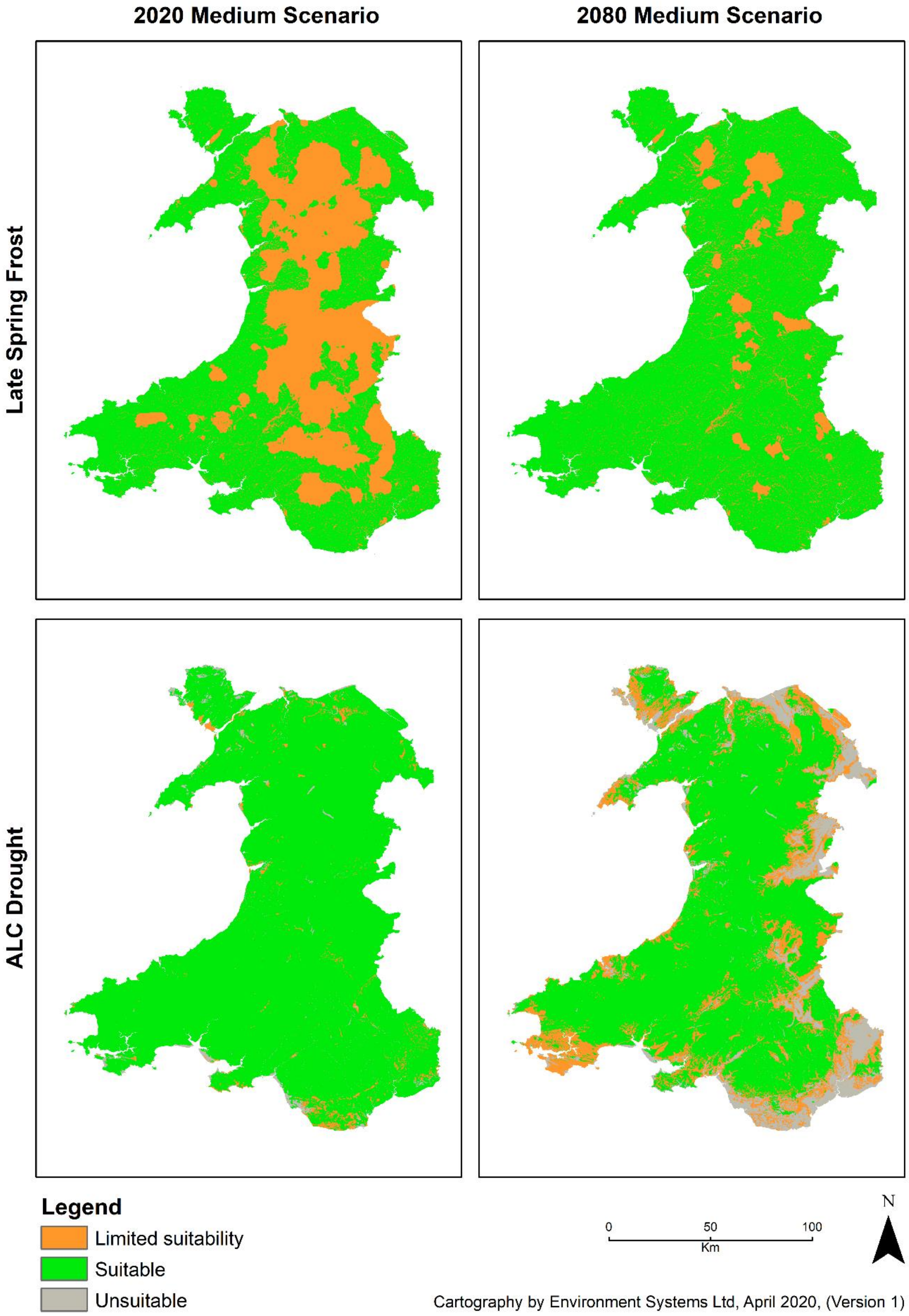

Figure 25: Key biophysical factors driving changes in overall environmental suitability for sessile oak between 2020 and 2080

Case study 8: Sitka spruce

Sitka spruce is a very common softwood with about 70% of Britain's commercial tree plantations comprising this timber species in Wales. It tolerates a wide range of soil conditions including wet and shallow soils. One of the key features of Sitka spruce is that it can be harvested within a 35-year time period. It grows best on deeper soils which are slightly acidic. It does not tolerate drought. It is used for energy generation and paper pulp, as well as for products such as pallets and packing boxes.

In 2020 the main limiting factor for Sitka spruce is late spring frost risk, which creates areas of limited suitability across much of central Wales. Around coastal areas the main limiting factor in 2020 is drought; Sitka is a shallow-rooted tree, and as such is relatively sensitive to this factor. By 2080 the late spring frost risk is predicted to be much less severe across Wales, leading to increases in suitability in the upland areas (*Figure 26*). However, lowland areas throughout Wales become less suitable due to increasing summer drought. The changing dominance of these two biophysical factors can be seen in the overall suitability models for Sitka spruce under the nine climate change scenarios, shown in *Figure 27*, demonstrating an almost complete inversion in the location of the most suitable areas between 2020 and 2080.

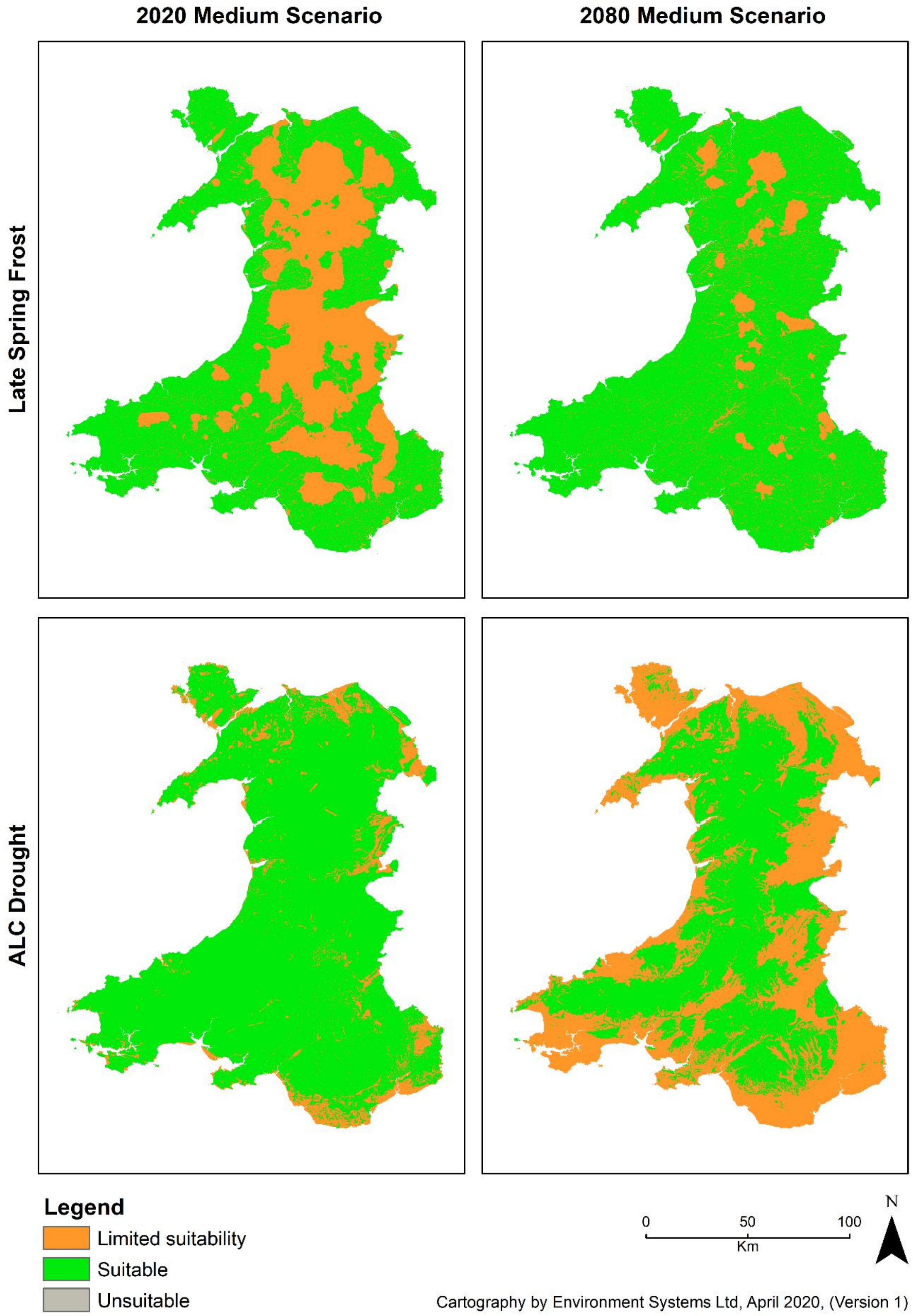

Figure 26: Key biophysical factors driving changes in overall commercial suitability for Sitka spruce between 2020 and 2080

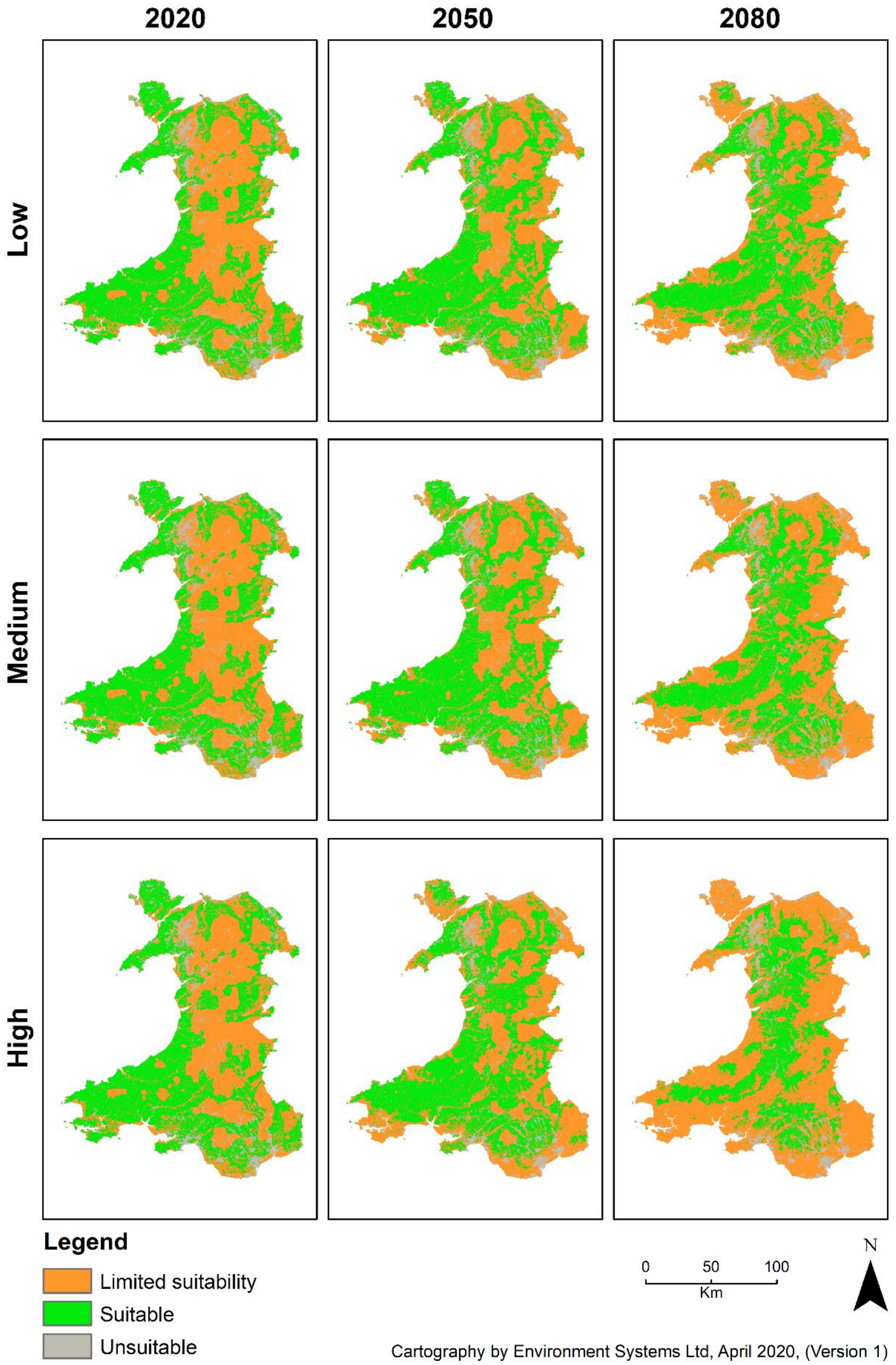

Figure 27: Overall suitability for Sitka spruce grown on a commercial basis across nine climate change scenarios

Case study 9: almond: commercial and environmental models

Almond is a dry climate tree species which is common across Mediterranean Europe and the Middle East. It grows best in a climate that has mild wet winters and hot dry summers, where it is planted on deep loam soils. It does not tolerate waterlogging, but is very drought tolerant. As such, it could be expected that opportunities could emerge for growing this species on a commercial basis in Wales as a result of climate change. The crop suitability models provide an evidence-based approach for investigating such hypotheses.

Figure 28 shows the crop suitability models for almond under the nine climate change scenarios, representing low, medium and high Representative Concentration Pathway conditions in 2020, 2050 and 2080. Present day and 2020 suitability is mostly controlled by ALC Climate and ALC Wetness. The climate factor is dominant, creating almost all of the unsuitable areas in the model (following the cooler, wetter regions of Wales). In the remaining areas the wetness factor is dominant in creating areas of limited suitability.

By 2080 there are two major biophysical factors driving the overall suitability models; ALC Climate, which continues to map large central and upland regions of Wales as unsuitable, and ALC drought, which emerges as an unsuitable factor in the majority of the remaining spaces with suitable climate.

The combination of these two factors leaves very little potential for growing almonds commercially. However, as with other tree species, the environmental suitability models show wider potential for growing almonds for non-commercial purposes under all climate change scenarios, although the drought factor continues to be a limitation in many areas (*Figure 29*).

These models show that in places where it is likely to become unviable to grow commercial crops and trees for timber (e.g. Monmouthshire), dry-climate species and varieties could be considered as an alternative for non-commercial purposes.

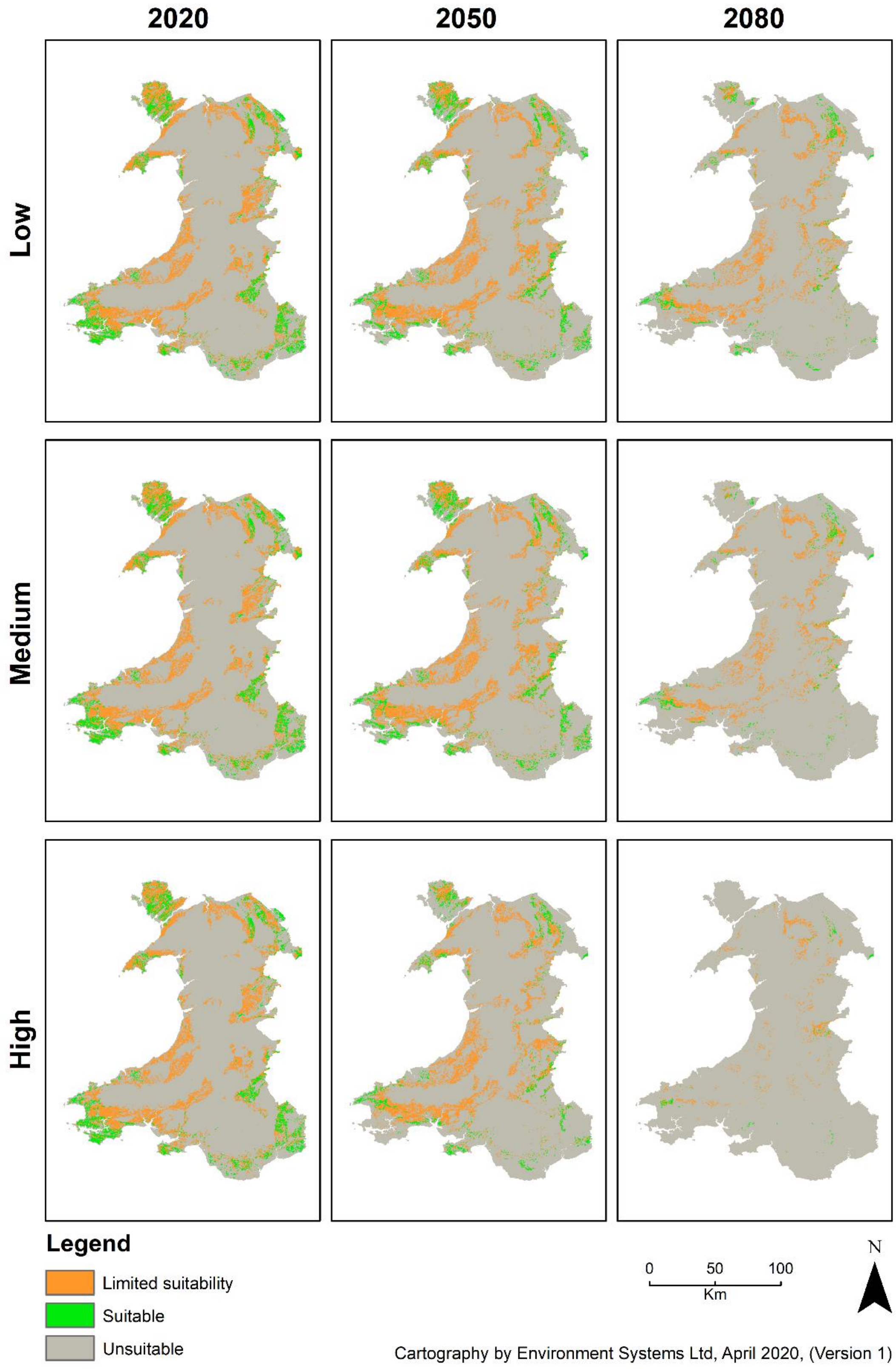

Figure 28: Overall suitability for almond grown on a commercial basis across nine climate change scenarios, based on UKCP18 data

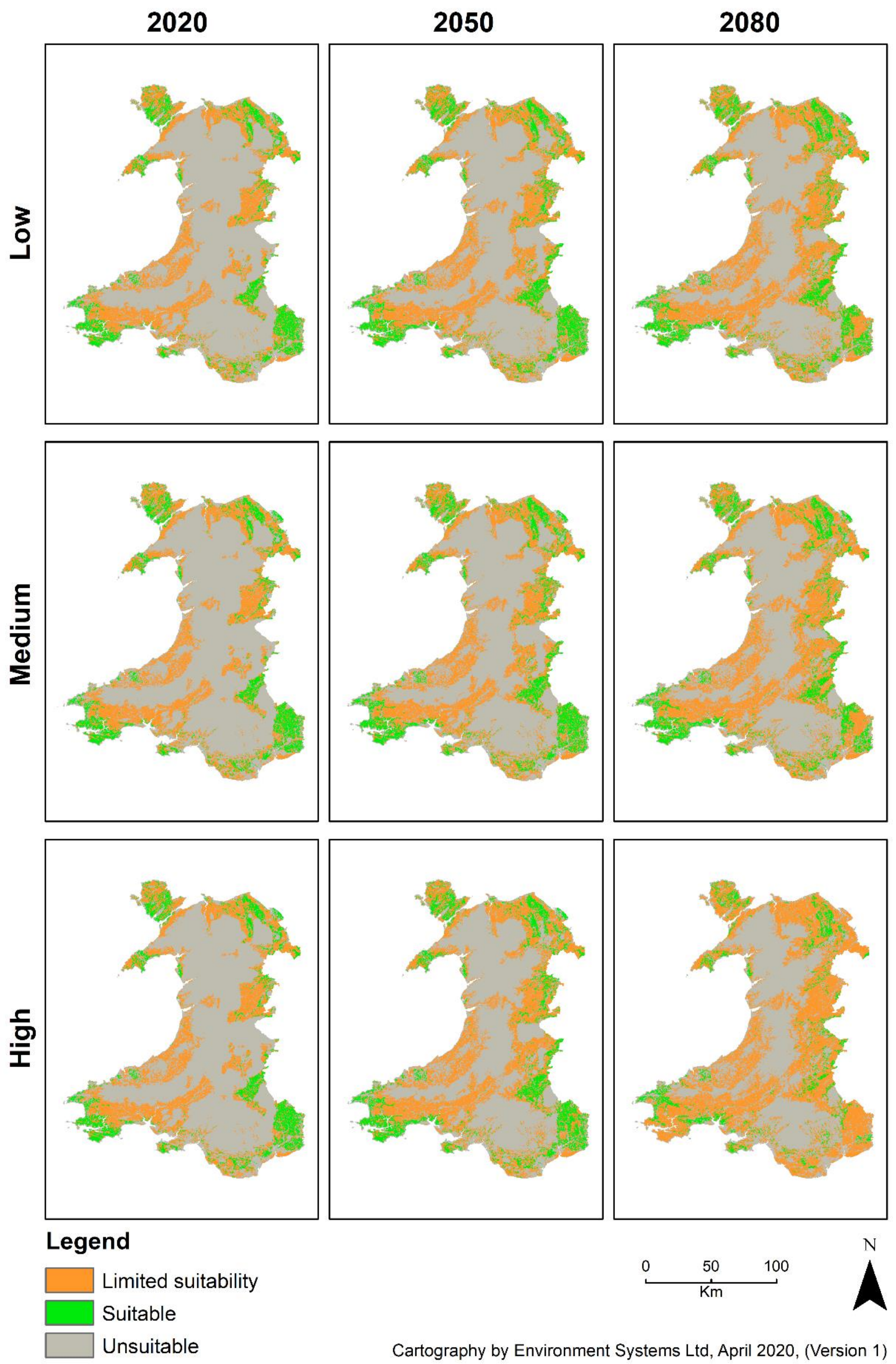

Figure 29: Overall suitability for almond grown on an environmental (non-commercial) basis across nine climate change scenarios, based on UKCP18 data

Key findings and conclusions

This report forms part of a wider project considering land capability and suitability for crops in the face of climate change in Wales. (Welsh Government, 2019a). UKCP18 climate change predictions were used for 2020, 2050 and 2080, considering low, medium and high Representative Concentration Pathway scenarios, to model the suitability of land across Wales for 118 crops. GIS files were created to show land suitability for each of these crops, and how crop performance in different parts of Wales is likely to be affected by climate change.

Biophysical factors

In order to model the changes in spatial extent and location of places where crops will flourish (labelled as suitable land), and that of places which give reasonable returns with some actions to mitigate site limitations (labelled as limited suitability land), a number of biophysical factors were spatially modelled across Wales.

Nineteen biophysical factors have been built into each crop suitability model. Seven of these were sourced from the most recent ALC maps produced by Cranfield (Keay, 2020bc). These were; soil climate, soil depth, drought, rockiness, slope, stoniness and wetness. Aspect and flooding data (NRW FRAW datasets for frequency and duration of flooding) were also included.

The crop suitability modelling began by first modelling the additional biophysical factors exerting significant influence on land suitability for crops; salt spray, frost and the effect of wind. The development of these models for the present day and, where possible, for the climate change scenarios added significantly to the validity of the models.

Salt spray is not predicted to change significantly as the climate changes. This is also likely to be the case for wind. However, no suitable UKCP18 data were available for modelling wind effects under climate change. Conversely, the duration of winter and late spring frosts is predicted to alter significantly and have a spatially distinct pattern under the climate change scenarios.

Salt spray only affects a small area of Wales. However, sensitive crops that might otherwise be grown on flat- or sea-facing land would be limited by this factor; particularly near the western and southwestern coasts. Crops sensitive to strong winds include tree and orchard species, which can be subject to windthrow, and taller cereal crops which are susceptible to lodging near harvest time.

The frost modelling showed a change in the durations, strength and spatial distribution of frost over time, and under different Representative Concentration Pathway scenarios. The changes in spatial distribution of frost patterns is complex, as mountain areas are predicted to warm faster than flatter land; for example, prolonged severe frost is expected to become rare on the Brecon Beacons by 2080 in the low, medium and high Representative Concentration Pathway scenarios, but frost risk in general is predicted to decline across the whole country.

Late spring frost is a particularly significant factor, as many crops are sensitive to frost at the point of growth inception, or flowering; yields of orchard fruits and row crops such as carrots can be dramatically reduced by a late frost. Late spring frost is predicted to become less severe and less frequent as the climate warms, but parts of eastern Wales and the tops of the highest mountains in Snowdonia are likely to remain affected.

Winter frost risk is particularly significant for crops that require a vernalisation period; a decrease in frost strength and duration could affect establishment and yield in these crops. Also, decreasing winter frost could lead to an increase in pest and pathogen survival rates, leading to increased crop health issues.

Crop suitability modelling

Following production of the biophysical models, the second part of this report discusses the crop suitability models, including specific examples of models for different types of crop (row crops, cereals, horticultural, orchard, tree, novel), showing how the distribution of suitability is expected to change over time as the climate changes.

Some data gaps were noted when developing the models; for example, the study did not consider soil erosion risk, which could fundamentally alter the assumed properties of the modelled soil types, through loss of topsoil. The study also did not consider contaminated land, but in practice many parts of Wales are likely to be unsuitable for crop cultivation, due to the presence of high quantities of heavy metals. Climate change scenario datasets were not available for wind, salt spray or flood risk, and so present-day datasets representing these factors were applied to the climate change scenario models.

An important part of each crop suitability model is the data showing the number of limiting factors; this dataset can be used for identifying cost-effectiveness of mitigation strategies. For example, if the dataset reveals that just one factor e.g. drought is limiting at a site, it may be possible and cost-effective to invest in mitigation. However, if the data identifies several combined limitations in effect at the site, for example high stoniness and high salt spray risk, the combination of all three factors may make it too expensive to mitigate for growing the crop profitably.

Although each biophysical factor has its role to play in determining overall crop suitability, the study revealed three factors as being the most common determinant in whether any individual parcel of land is suitable or unsuitable in the present day. These were; slope, climate and wetness. Slope is unlikely to change over time, but climate is forecast to change significantly; this has particular significance for crop suitability in the upland margins, which generally become more suitable for cultivation over time. By contrast, wetness changes less drastically over time, but is forecast to bring improvements in crop suitability in some locations; particularly north Pembrokeshire, north Carmarthenshire, and south Ceredigion.

These three factors remain significant under all climate change scenarios. However, drought emerges as a fourth extremely significant factor, becoming increasingly dominant over time. The drought factor represents summer rainfall and resulting crop moisture deficits during the growing season. Drought is expected to become a problem because although climate change projections expect annual average rainfall to remain similar to the present day, the timing of the rainfall is expected to change; rainfall is expected to come increasingly from more intense events, with longer dry periods between rainfall episodes. This means that during the summer growing period crops are more likely to experience moisture deficits.

The present study modelled the underlying biophysical suitability of land for the different crops, and did not consider the possibility of undertaking man-made interventions such as additional irrigation (other than irrigation activity accounted for in the assumptions of the ALC system). In some places, the problem of increasing summer drought susceptibility may be solved if suitable irrigation or new farming methods could be introduced. This project was very much focused on discussing the current range of agricultural practice in Wales; irrigation is infrequently used at present, but the crop suitability models show there could be clear benefits in encouraging the uptake of such methods in certain areas, in order to maintain crop and farm viability in the short and medium term.

The biophysical models highlight the importance of understanding the spatial distribution and trend of individual key factors, so that the reasons for limited suitability and unsuitability can be understood. They can inform Welsh Government and the industry on the case for new growing techniques and infrastructure such as farm water sources for irrigation; forward planning on these issues is vital to minimise the risk of climate-induced shocks to the sector.

When considering the nine crop case studies presented in this report, the starting, present-day suitability distribution varies greatly between crops, evidencing their very different biophysical tolerances and sensitivities. However, the general trends in suitability change over time are similar for all of the crops, with the models showing a significant contraction in suitable and limited suitability growing space between the present day and 2080.

Some of the crop models show variation between the present day and 2020, and between 2020 and 2050, with a slight expansion of suitable and limited suitability areas due to more favourable ALC climate and wetness grades. However, fluctuations in climatic conditions between wetter and drier years, and the occasional late frost, may actually result in increased risk and failures of current crops, depending on how variable and predictable these environmental conditions are from one year to the next.

By 2080 any gains in suitable area are reversed, and replaced by increasing areas of limited suitability and unsuitable land, due to emerging drought stress. Increasing doughtiness due to changing temperature and rainfall patterns mean that large parts of Wales are expected to become too dry during the summer for the types of crops grown at present, unless interventions are made to mitigate the drought effects.

It is interesting to note that these changes in crop suitability become accelerated between 2050 and 2080, indicating a ‘tipping point’ time window. The models predict that by 2080 much of Wales will experience different climate and related biophysical factors to those experienced today. As a result, new crop varieties, cultivation techniques and technologies will need to be considered.

The expected changes in drought and climate could be expected to increase commercial opportunities for growing dry climate crops. However, the almond example shows that the predicted rate and extent of climate change may not be sufficient for these opportunities to be realised, due to soil wetness (a measure of year-round overall wetness, as opposed to the drought factor, which considers moisture deficits during the summer only). The climate in Wales therefore could be too wet overall for the dry climate species to thrive on a commercial basis (without mitigation), though there may be opportunities to utilise such species for environmental purposes and other ecosystem service benefits, such as habitat for wildlife, soil erosion prevention, flood mitigation and carbon sequestration.

Tree crops are long-lived, and as such long-term environmental modelling is particularly beneficial. For example, Sitka spruce generally is harvest-ready between 30 and 60 years in Wales, and the crop suitability maps show that significant changes in land suitability can occur within this time-frame; land which presents good growing conditions at the time of planting may be no longer favourable at the time of harvest, affecting the crop return value. A related study by Bell *et al.* (2020b) showed that only 32% of land currently suitable for Sitka spruce will remain so by 2080 under the medium Representative Concentration Pathway scenario.

When considering locations for tree planting, the crop suitability models maps will help forest planners decide whether to utilise areas where the land is presently suitable, in order to obtain good establishment and initial growth, or whether to utilise areas where the land is less suitable at present but predicted to improve, to provide better conditions at harvesting.

Two suitability models were produced for tree crops; one for commercial cultivation and one representing broader environmental tolerances. This is because planting a tree to obtain a good yield of timber as a return on investment requires more stringent environmental conditions to planting or maintaining self-seeding in existing woodland, or where timber yield/quality is not the main purpose of planting. Such ‘environmental’ cultivation could occur in areas considered unsuitable in the commercial models, and still provide valuable ecosystem services such as carbon sequestration, shelter for wildlife, and increasing ecological network connectivity.

Conclusions

The crop suitability models used the most current Met Office data on climate change available, and the resulting maps showcase the large-scale changes that are likely to take place between now and 2080. They show there is likely to be losses of existing high-quality agricultural land, even under the low Representative Concentration Pathway scenario which assumes 2.4ºC warming. Therefore, it is important that the sector prepares for change.

Existing evidence from the climate change and crop suitability models tell us that the agricultural sector in Wales will be required to change dramatically in a relatively short period of time. However, not all parts of Wales will be affected in a similar way, or to the same extent.

Monmouthshire is likely to be the first area in Wales to experience a decrease in land suitability for growing crops; drought effects are likely to be experienced in this area within the next twenty years. The area of Wales with most agricultural opportunity between 2050 and 2080 seems to be north Pembrokeshire around the Preseli mountains, northern Carmarthenshire, and south Ceredigion. However, these areas currently hold much land of significant biodiversity value, which also provides multiple ecosystem services. Changes to land-use patterns across Wales could necessitate difficult trade-offs between food production and other land uses.

The spatial models show that large-scale decreases in land suitability for agricultural production are predicted to occur within a generation. The models provide evidence for the immediate development of long-term strategy for farm business security and national food security, which could include investing in education, development of new crop varieties, new food and food production technologies, and waste reduction.

This study should be viewed in the context of predicted changes in land suitability in England, that are expected to occur under climate change (Keay, 2020d). Cross-border planning between the UK and Welsh Governments on issues such as food production, afforestation targets, renewable energy and habitat reserves for biodiversity will be critical in ensuring food security is maintained, as well as biodiversity and the other natural capital and ecosystem services.

The crop suitability models show purely biophysical suitability for the different crops across Wales. However, in reality many legal and policy constraints exist that effectively reduce the suitability status of land from suitable to limited suitability or unsuitable. For example, present day biophysical suitability for sessile oak could be reduced by 60% after considering constraints currently preventing or restricting tree planting, such as protected sites and areas of best quality agricultural land (Bell *et al.,* 2020b). There is a need for further work to apply legal and policy constraints to the crop models, and quantify the effects on suitable growing space.

This report and the accompanying data for all 118 crops, show the significance of the impact of climate change on agricultural land quality in Wales. The models have important messages for policy makers and the agricultural industry. There is an urgent need to prepare for the changing climate, soil conditions, the extent and distribution of crops in Wales, and also the location of supporting infrastructure. There is also an urgent need for public engagement to foster understanding of these issues, and to gain support for policy decisions that impact on Welsh landscapes and land use as we know them today.

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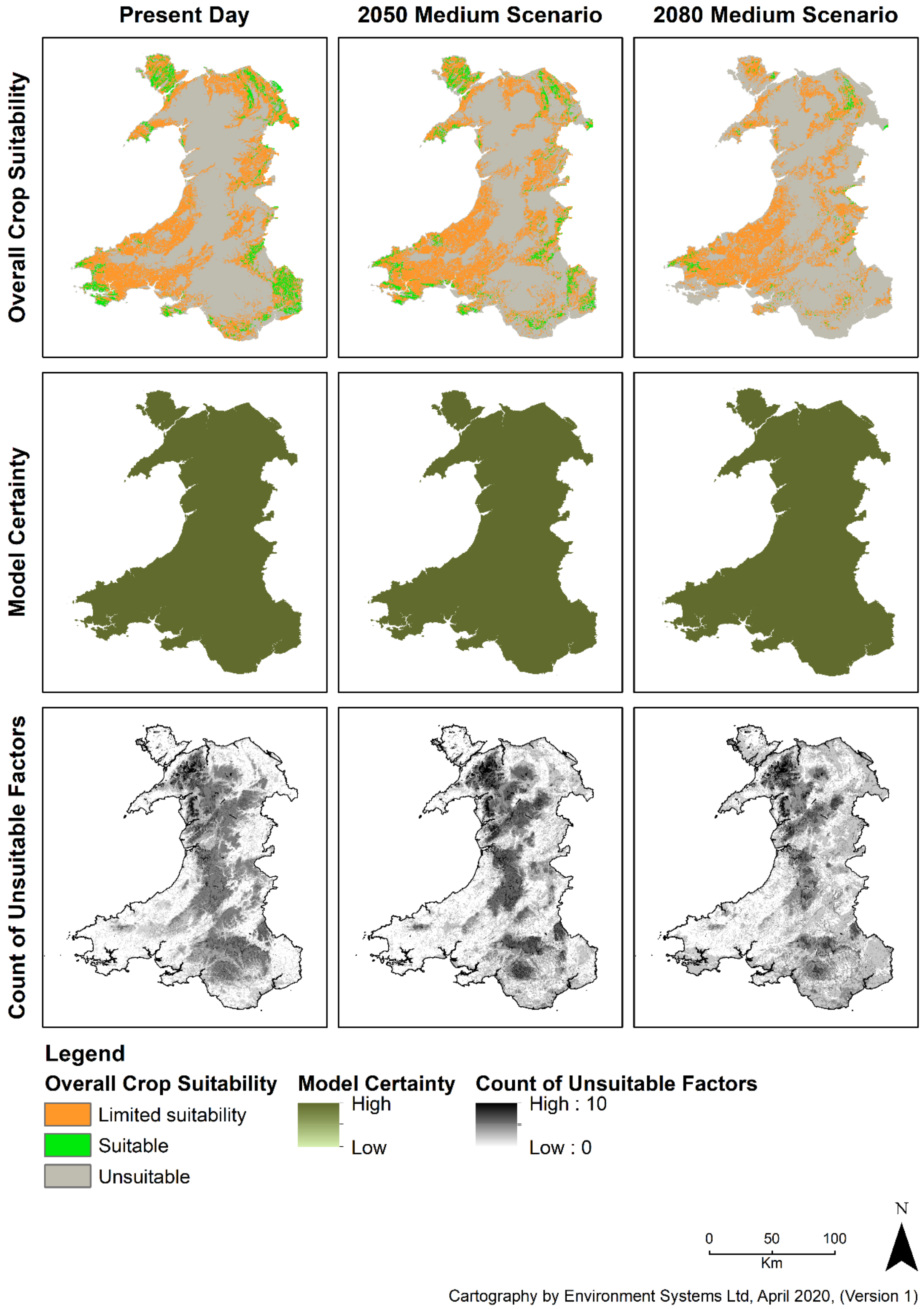
Appendix A.

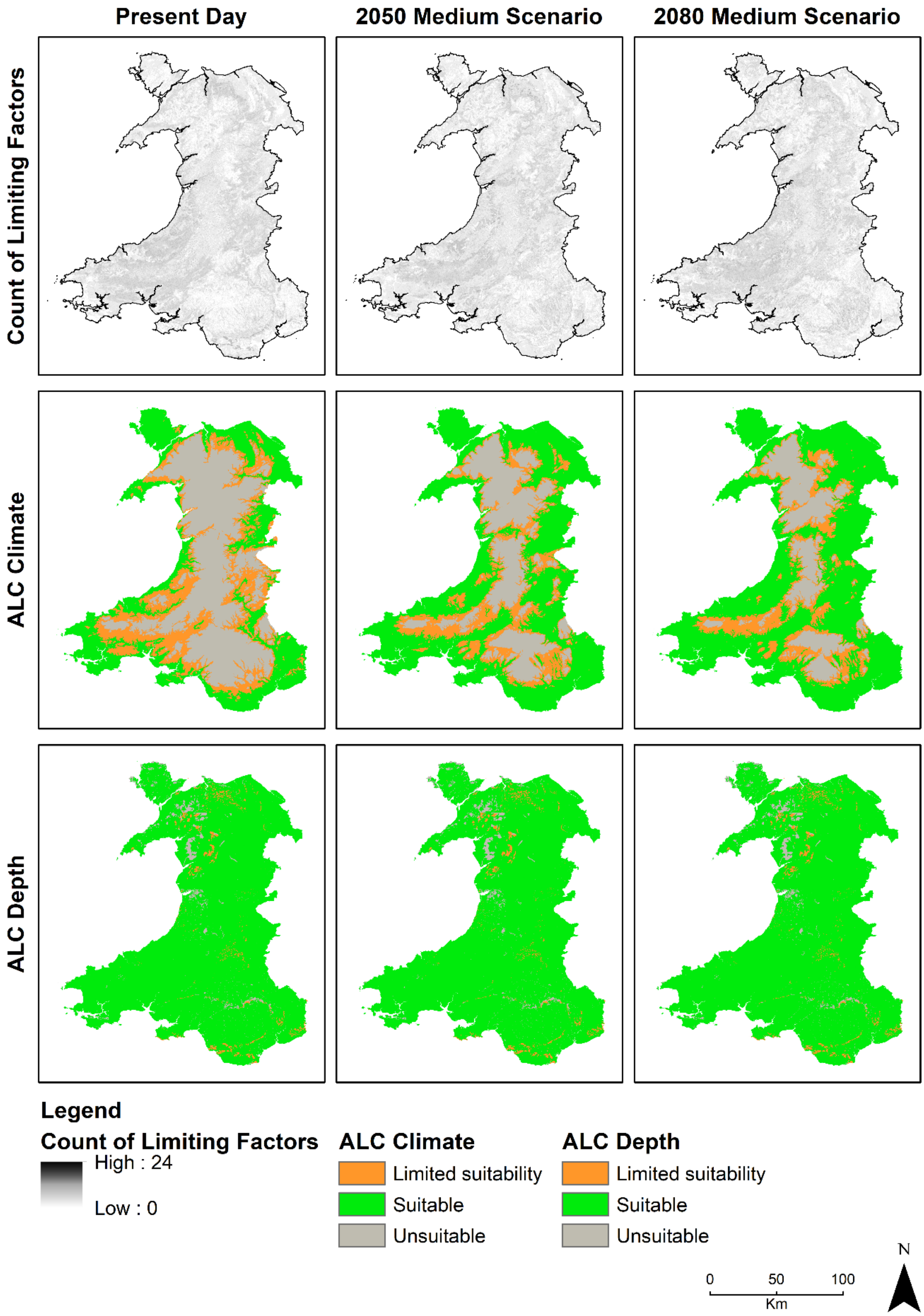
Crops included for crop suitability modelling

Almonds*	Chestnut*	Melons	Saffron
Apples*	Chicory	Mibuna	Sage
Artichokes	Comfrey	Millet	Sain Foin
Asparagus	Courgette	Mint	Seed Potatoes
Aubergine	Currants	Miscanthus	Sessile Oak*
Barley	Daffodils	Mizuna	Silver Birch*
Beans -Field	Douglas Fir*	Mustard	Sitka Spruce*
Beans -Green; Runner; Broad	Echium	Naked Oats	Spelt Wheat
Beans -Mung	Evening Primrose	Norway Spruce*	Spinach
Beans -Soya	Fennel	Oats	Squash
Beech*	Flax	Oilseed Rape	Strawberries
Beetroot	Forage Rape	Olives	Sugarbeet
Beets-Mangolds	Garlic	Onions	Sunflowers
Bilberries	Grapes	Osiers*	Swedes
Blackberries	Greengages-Cherries*	Pak Choi	Sweetcorn
Black Medicks	Hazelnut*	Parsley	Tea
Borage	Herbage Seed	Parsnips	Thyme
Broccoli	Hops	Pears	Trefoils- Common Birdsfoot
Brussels sprouts	Horseradish	Peas	Triticale
Cabbages	Kale	Plums-Damsons*	Tulips
Calendula	Komatsuna	Poppy	Turnips
Camelina	Lavender	Potatoes	Typhon-Colza
Canaryseed-Reed Canary	Leafradish	Pulses	Vetches
Cannabis sativa	Leeks	Radish	Walnuts*
Carrots	Lentils	Raspberries	Western Red Cedar*
Cauliflower	Lettuce	Rhubarb	Wheat
Celeriac	Linseed	Rocket	Wild Cherry*
Celery	Lucerne	Rosemary	Willow*
Chard	Lupins (Sweet)	Roses	
Cherries*	Maize	Rye	

*Denotes crop for which two suitability models were produced; environmental and commercial suitability

Suitability maps for each biophysical factor contributing to overall suitability for potato (climate change scenarios).





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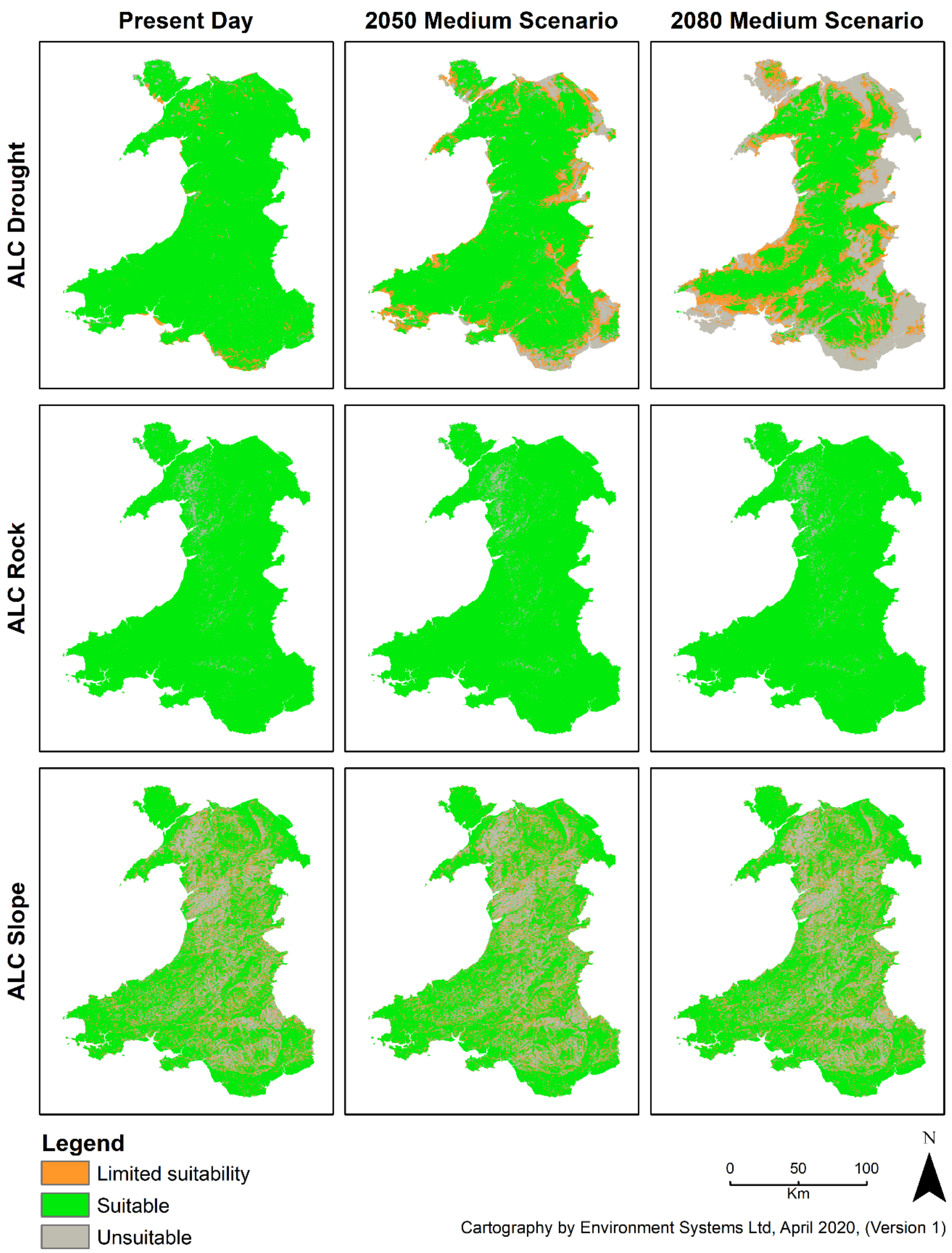
Present Day
2050 Medium Scenario
2080 Medium Scenario
ALC Drought
ALC Rock
ALC Slope
Legend
Limited suitability
Suitable
Unsuitable
N
0
50
100
Km
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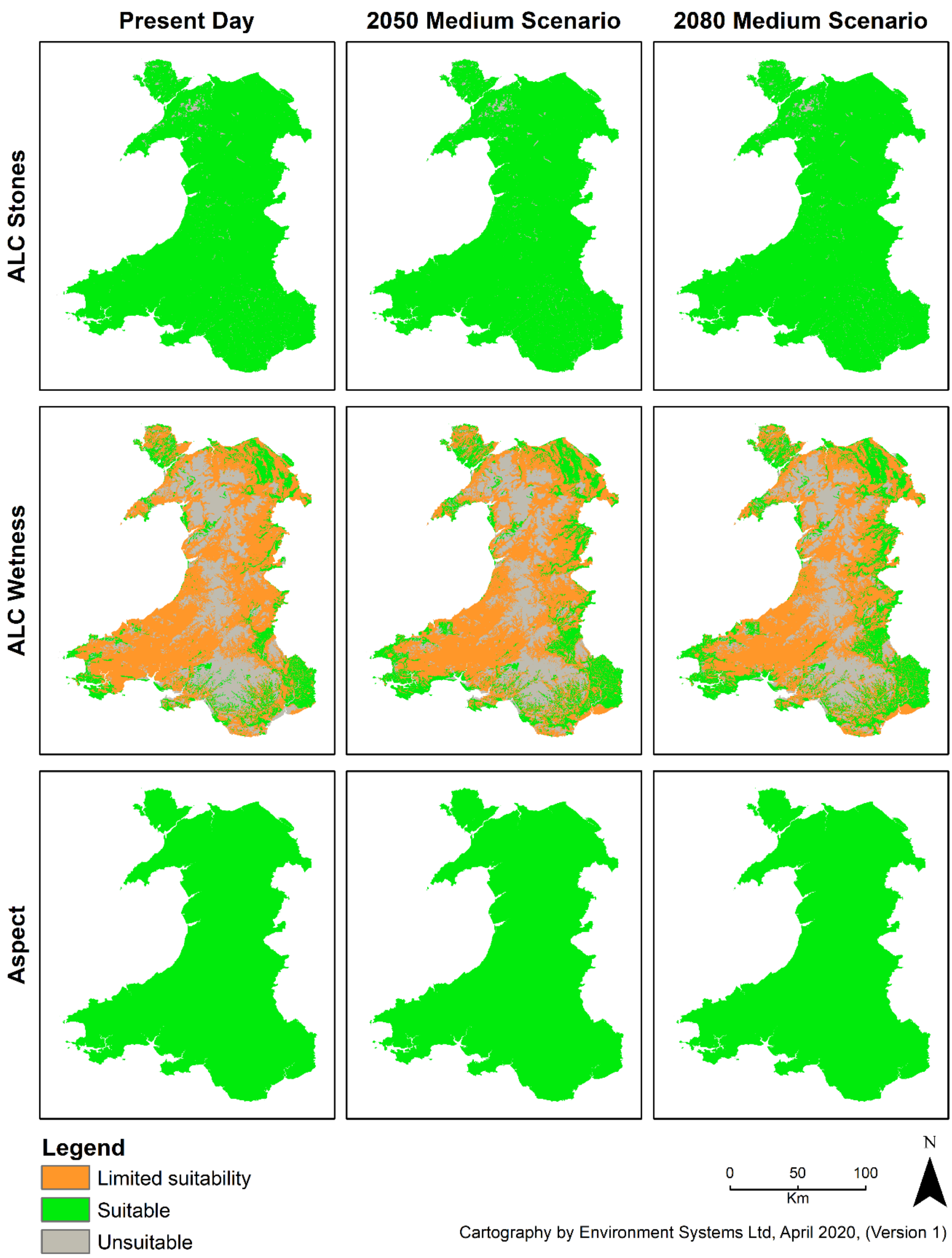
Present Day
2050 Medium Scenario
2080 Medium Scenario
ALC Stones
ALC Wetness
Aspect
Legend
Limited suitability
Suitable
Unsuitable
0
50
100
Km
N
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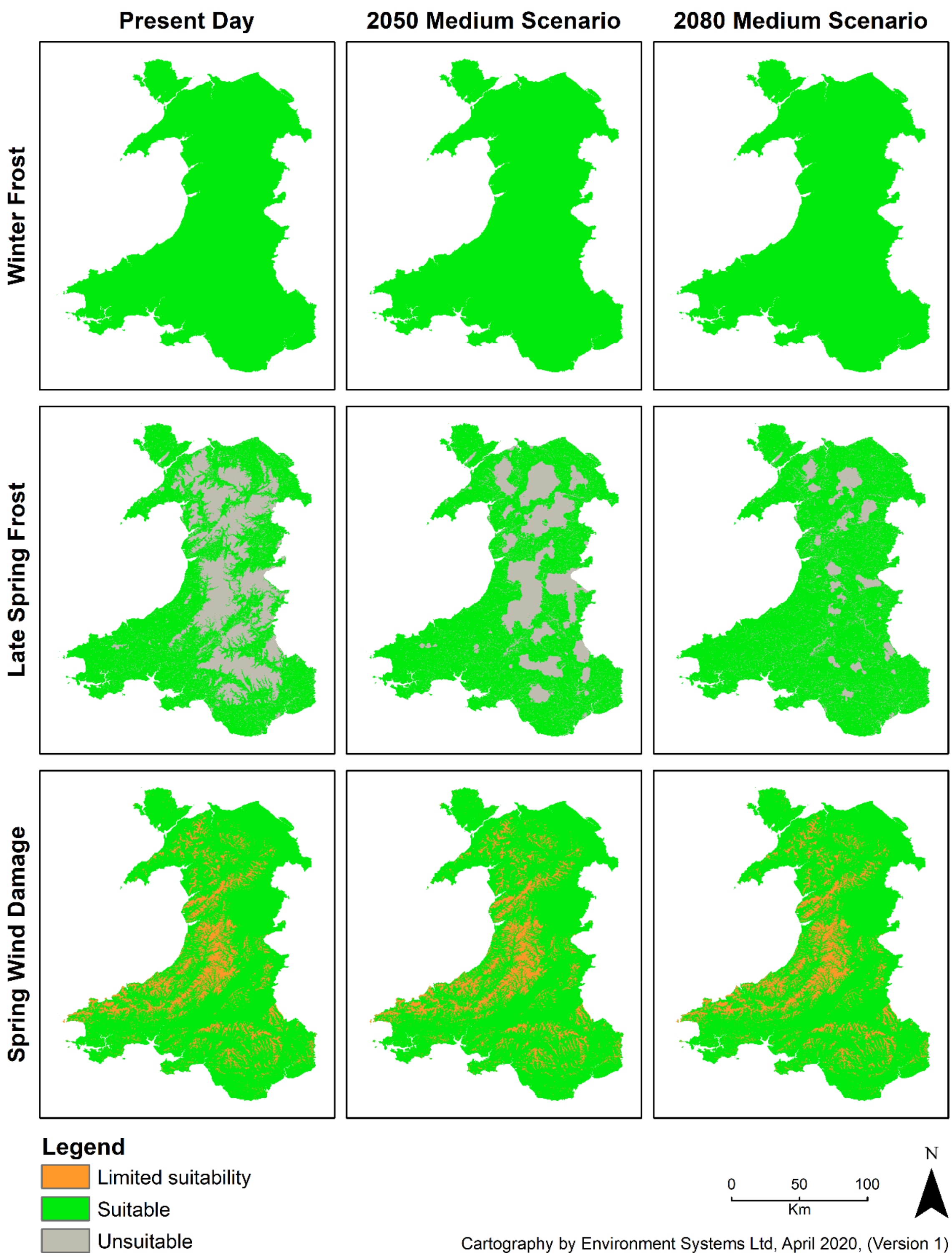
Present Day
2050 Medium Scenario
2080 Medium Scenario
Winter Frost
Late Spring Frost
Spring Wind Damage
Legend
Limited suitability
Suitable
Unsuitable
0
50
100
Km
N
Cartography by Environment Systems Ltd, April 2020, (Version 1)


Present Day
2050 Medium Scenario
2080 Medium Scenario
Summer Wind Damage
Autumn Wind Damage
Winter Wind Damage
Legend
Limited suitability
Suitable
Unsuitable
0
50
100
Km
N
Cartography by Environment Systems Ltd, April 2020, (Version 1)


Present Day
2050 Medium Scenario
2080 Medium Scenario
Salt Spray
Fluvial Flood Frequency
Pluvial Flood Frequency
Legend
Limited suitability
Suitable
Unsuitable
0
50
100
Km
N
Cartography by Environment Systems Ltd, April 2020, (Version 1)
© contains NRW FRAW data


Present Day
2050 Medium Scenario
2080 Medium Scenario
Tidal Flood Frequency
Fluvial Flood Duration (1 in 10 event)
Fluvial Flood Duration (1 in 30 event)
Legend
Limited suitability
Suitable
Unsuitable
0
50
100
Km
N
Cartography by Environment Systems Ltd, April 2020, (Version 1)
© contains NRW FRAW data

Present Day
2050 Medium Scenario
2080 Medium Scenario
Pluvial Flood Duration (1 in 10 event)
Pluvial Flood Duration (1 in 30 event)
Lakes and Urban
Legend
Limited suitability
Suitable
Unsuitable
0
50
100
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Guide to loading and interpreting the data within ArcGIS.

For each crop/scenario combination, one 28-band GeoTIFF at 50 m resolution was created, containing overall crop suitability data, as well as crop suitability for each individual biophysical factor.

The output bands for each GeoTiff are listed in *Table 3*.

Table 3: Output bands in the crop suitability output GeoTIFFs

Band	Band name	Information
1	CropSuitability	The overall suitability score for the crop in the area under the given climate change scenario.
2	ModelCertainty	The certainty, based on available evidence, with which the input attributes could be scored for the crop. Values < 40 = low certainty. Values 40- 56 = medium certainty. Values > 56 = high certainty.
3	CountUnsuitable	The number of biophysical input factors that render the area unsuitable for cultivating the crop commercially.
4	CountLimited	The number of biophysical input factors that render the area as of limited suitability for cultivating the crop commercially.
5 to 28	Names of input biophysical properties	Crop suitability score assigned for the individual biophysical input layers.

The crop suitability datasets follow the naming convention <crop>-<scenario>_SuitabilityModel.tif. Each GeoTIFF has pyramids built to allow for quick loading in GIS software, and has an associated raster attribute table for each band to allow for easy interpretation of the data. This information is contained within the .tif.aux.xml and .tif.ovr files. Further, metadata in both English and Welsh has been produced for each file, following the naming convention <crop>-<Scenario>_SuitabilityModelling_MetadataEnglish.xml and <crop>-<Scenario>_ModelAddasrwydd_MetadataCymraeg.xml.

ArcGIS MXD projects (one per crop, containing models for all scenarios) have been supplied, that contain all data relevant to the crop, with styles applied. These MXDs are saved with relative pathnames; they will open on any PC, so long as the file structure between MXDs and GeoTIFFs remains consistent. The file structure is one folder called “MappingData”, with two sub-directories; one called “Data” (containing the crop directories and their associated GeoTIFFs), and one called “MXDs” (containing the ArcGIS projects). The styles are applied so that in the Table of Contents the numeric raster values are presented as text legend entries.

If data is loaded into a new MXD project using the GeoTIFFs directly, data should be loaded band by band through ArcCatalog, in order to facilitate colouring by unique value (as is appropriate for categorical data). All bands have descriptive names regarding the information contained in them. Translation from raster values to text legend labels is contained both within the raster attribute tables (RATs) and the corresponding metadata. When colouring the band by unique values, “CLASS” can be selected as target column instead of “Value”, to automatically generate a style using the more easily interpretable text strings.

When interpreting the models, users must consider the underlying assumptions and uncertainties of the underlying ALC, UKCP18 and other biophysical datasets, in addition to the crop requirement knowledge. The uncertainty layer supplied with the crop models provides information relating to the level of certainty of the crop suitability scores for each biophysical factor; it does not provide an assessment of the accuracy of the biophysical datasets themselves. For example, widely cultivated crops such as potato generally have a good level of certainty as to how the different ALC grades for each biophysical factor affect the crop, whereas there is less available information to support the scores underlying some less common crops, and therefore the certainty scores are lower.

Crops reviewed during crop suitability validation workshop

Apples	Douglas Fir	Parsnips	Sunflowers
Asparagus	Grapes	Potatoes	Swedes
Beans -Soya	Herbage Seed	Rhubarb	Tea
Bilberries	Maize	Rye	Triticale
Cannabis sativa	Miscanthus	Saffron	Vetches
Carrots	Oats	Sessile Oak	Walnuts
Cauliflower	Oilseed Rape	Sitka Spruce	Wheat
Cherries	Olives	Strawberries	Willow
Daffodils	Osiers	Sugarbeet	