Climate smart agricultural development in the Goulburn Broken region

Technical Report: Vegetable Production

Part 2 (Brassica and Lettuce)

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The likely climate change futures presented in this report are based on the development of scenarios which are consistent with climate change scenarios developed by the Intergovernmental Panel on Climate Change (IPCC). They represent a range of possible futures for the Goulburn Broken Region, Victoria, Australia, although none of them may ever eventuate. Observed values of key climatic variables are current at the time of writing; however, new information is being made available on a frequent basis that may impact upon some of the conclusions presented in this report.

PLEASE NOTE: This technical report outlines the land suitability modelling under climate change scenarios undertaken in this project. The report is intended to provide sufficient information to allow other researchers to replicate the modelling. For a succinct overview of the results of the modelling and the implications of the land suitability assessments for the region, please refer to the accompanying ‘Summary Report’.

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Climate Smart Agricultural Development in the Goulburn Broken

1. EXECUTIVE SUMMARY

Climate Smart Agricultural Development in the Goulburn Broken is a climate change adaptation project aimed at informing government (Local and State), the agricultural sector and the broader community, of the possible impacts of climate change on key commodities produced across the study region (comprising the combined boundaries of the seven local governments involved in the project). The information has been developed with the intention of increasing the efficiency of agricultural production, whilst enabling adaptation, transformation and resilience to climate change in agricultural systems.

This project has been funded through the Victorian State Government’s Victorian Adaptation and Sustainability Partnerships (VAS) program. CSAD is a joint project between seven Local Governments and three other partner organisations in the Goulburn Broken Region. The key organisations governing the project are: Moira Shire Council (Lead Agency), Goulburn Broken Greenhouse Alliance, Greater Shepparton City Council, Benalla Rural City Council, Campaspe Shire Council, Strathbogie Shire Council, Mansfield Shire Council, Murrindindi Shire Council, Goulburn Broken Catchment Management Authority (GBCMA) and the Victorian Department of Environment, Land, Water and Planning.

This report outlines an analysis of the potential implications of regional climate change on vegetable crops, through GIS modelling of Brassica and Lettuce. This is a companion report to Vegetable Technical Report Part 1. An expert-systems based modelling approach was used that considers climatic, soil and landscape parameters to map expected yield across the region. The models and maps were validated with local farmers and agronomists then modified according to their input, before running the models again with climate change projection data to understand how yields might change in a future climate. The outputs are intended for strategic, regional-level decision making in relation to agricultural development, infrastructure and water. So, it is important to understand the assumptions and caveats associated with the modelling before interpreting the maps, which are covered in the body of the report. Also, the maps and associated information may assist to inform on-farm adaptation, to guide breeding programs, among other more localised issues. But, decisions at such localised or specific levels will need to be informed by additional, more targeted research.

According to the available climate projection data, the region will become hotter and drier, particularly in the north. The implications on brassica and lettuce production in the region may be significant. Projected changes to the values of key climatic variables, such as rainfall and temperature, could potentially impact the optimal growth conditions for these commodities. Increased temperatures could have negative impacts in terms of increased heat stress, increased evapotranspiration (and therefore increased irrigation requirements) and changes to phenology that impact on sowing and harvest times.

The modelling indicates that the region will experience a slight overall decline in suitability for both commodities, although this is countered by increases in suitability in certain areas 2030 and 2050. Both crops are likely to remain viable options for farmers to 2050. For Local Government and other stakeholders, this has some important implications.

1) Adaptation: It will be necessary to ensure that farmers in the adversely affected areas have access to the latest information in relation to climate adaptation (including information on new plant varieties). The decline in State-level extension officers make this task more challenging and may require the formation of new partnerships between local government, state government and private-sector agronomists or other providers of agricultural services.

2) Water: Maintaining water security, and in some cases ensuring access to greater volumes, will mitigate some of the declines in suitability demonstrated by the modelling. This is a regional-level adaptation that will require continued focus on improved water infrastructure and securing access to alternative water sources. Similarly, farmers will need to adopt more efficient irrigation practices and experiment with varieties, sowing times and other management practices that allow for reduced water use.

3) Transformation: Facilitating the transition of existing production areas to more suitable commodities, is a strategic priority for the region. This may include the development of new horticultural production precincts with a focus on vegetables and associated downstream processing. This study has identified the specific areas and extent of the changing production landscape but taking advantage of that information will require additional research to understand the infrastructure required to facilitate the industry transformation.
4) Horticultural production in general is vulnerable to extreme weather events and in particular temperature shocks (heat and frost), water (shortage or excess) and storms (wind, hail). The modelling carried out as part of this research has not considered extreme events, yet it is expected that they will likely increase in frequency and severity as climate changes. Growers are generally ill-prepared to deal with extreme weather and unable to absorb the economic consequences of repeated events. At a farm level it is possible to mitigate the risks associated with some extreme weather events and at a regional level it is possible to reduce the risks associated with flooding.
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5. ACKNOWLEDGMENTS

The Deakin Project Team would like to acknowledge the various contributions that made this research possible.

We acknowledge and thank the Victorian Government, via the Department of Environment, Water, Land and Planning (and its predecessor, the Department of Environment and Primary Industries), for providing funding under the Victorian Adaptation and Sustainability Partnership, and for providing support and input as a member of the Project Control Group.

We would also like to thank the Project Control Group for their time, guidance and encouragement over the course of the project. Each participating council made a substantial in kind contribution to the project by supplying staff that contributed a significant amount of their time over the course of the research. Some members of the Project Control Group went further by organising meetings with local farmers and accompanying the project team during model-validation sessions. The research would not have been possible without this key input from the Project Control Group.

We are very grateful to the farmers, agronomists and other locals that donated their valuable time to assess our models and maps and to make recommendations on how to improve them. This step is what distinguishes this research from the many, purely academic modelling exercises that can be found in the scientific literature and so we are indebted to the generous Goulburn-Broken residents who provided their local knowledge.

Finally, we would like to specifically thank Tom Brown and Marisa O’Halloran from the Goulburn-Broken Greenhouse Alliance, for their expert project management and facilitation skills respectively. The Deakin project group have conducted many similar studies around the state over many years but none have been managed and run as well as this project, thanks to Tom and Marisa.
6. BRASSICA PRODUCTION

6.1. Brassica Characteristics

Brassicas, depending on their species grouping, have many differing forms and structures. The main agricultural species grouping, *Brassica oleracea*, consists of such crops as broccoli, cauliflower and cabbages, and is mainly cultivated for their leaves or flowering heads.

Broccoli and cauliflower are two types of brassicas that are cultivated for their large flowering heads. The flowering heads of broccoli that are used are immature flowers, they are green in colour, densely packed and angled in a tree-like formation around the main stalk. The stalk grows up from the root and the flowering head is surrounded by leaves. If left to mature, the flowers are small and yellow in colouration with four petals. A mature broccoli plant can grow to 90 cm high and 60 cm wide. As with broccoli, the flowering heads of cauliflower are immature flowers. They are cream white in colouration and densely packed to form what appears to be a single flowering head. This flowering head is surrounded by greyish green foliage, which protects the floret from direct sunlight. Also the leaves prevent the formation of chlorophyll in the flowering head keeping it a creamy white colour. If left to mature, the flowers are small and can be white to violet in colour, depending on the cultivar. A mature cauliflower plant can grow to similar sizes as a broccoli plant. Both broccoli and cauliflower, in general, share a similar growing cycle. The both prefer temperate regions and are planted in early/mid-autumn. Broccoli develops faster than cauliflower and usually is harvested in mid/late winter. Cauliflower can take longer to develop and is harvested in late winter or early spring.

6.1.1. Soils

The ideal type of soils for brassicas are alluvial type soils and other loams and clay loams. Harder textured soils, such as medium to hard clays, can potentially restrict growth. Most brassicas are considered to be shallow rooting species; hence topsoil conditions are important factors for cultivation. A free draining type soil is seen as optimal, if drainage is too quick then water cannot be extracted for use by the plant. Bacterial head and leaf diseases usually cause the most problems in brassica crops such as black rot, leaf scald and bacterial head rots. Brassicas have a low tolerance to acidic type soils; a pH level below 5 can be restrictive to growth. Optimal ranges centre at about a pH of 6, with a maximum of 7 to 7.5.

6.1.2. Landscape

Landscape features that are preferred for the cultivation of brassica are low sloped areas. Elevated areas, such as mountains and hilly areas, dune formations and undulating plains are considered unsuitable for production. Too steep a slope can restrict growth and cause excessive water and nutrient runoff. Also steep slopes can prevent access to production plots by people and machinery.

6.1.3. Climate

Brassica species in general are considered as a winter crop. However, they are tolerant of a wide range of conditions. In most areas of Victoria, brassicas can be grown all year round with the temperate southern regions considered more suited for production. The northern latitudes of Victoria can become too warm for cultivation during the spring/summer months, especially if mean maximum temperatures exceed 25°C in general or 28°C during January. Similarly, extreme cold can be counter-productive to developing brassicas with mean minimum temperatures below 5°C reducing brassica growth. Most brassica species are tolerant to frosts, but severe frosts or extended days with frosts can be damaging to the cultivation of brassica.

Adequate water supply during the production months is required for a high yield crop. Frequent rainfalls during these months are necessary, with average monthly falls in excess of 50 mm preferred by brassicas. If rainfall is not adequate for the crop, then irrigation will be required to supply the necessary amount of water. Brassicas require abundant watering during the growing season and in temperate regions, if rainfalls are not adequate, weekly irrigations may be necessary to ensure a good yield.
6.2. Brassica Biophysical Land Suitability Analysis Model

The brassica Land Suitability Analysis (Figure 6.1) model targets the identification of land capable of producing 10 to 40 tonnes of brassica per hectare per year (t/ha/y). The model used in this report is an adaptation of the model developed and applied in the South West Region of Victoria, as part of the Victorian Climate Change Adaptation Program (VCCAP) (Sposito et al., 2008) as well as the Gippsland Region of Victoria, as part of the Agricultural Industry Transformation – Gippsland project (Faggian and Sposito, 2013).

The LSA Analytical Hierarchy Process model used is made of three branches: ‘Soil’, ‘Landscape’ and ‘Climate’. It indicates that ‘Climate’ and ‘Soil’ are the most influential factors being assigned a weight of 40% (or 0.40), with ‘Landscape’ the least influential (20% or 0.20). In each branch of the hierarchy, there are further branches down the model, each with their own weighting factors. For example, if one progress downs the Climate branch, ‘water availability’ is the most influential factor with a weight of 50% (or 0.50); it includes two branches, with two nodes – ‘Irrigation’ and ‘Rainfall’ – which together inform overall water availability. Each final branch is detailed by several classes the parameter can be defined by, in the instance of rainfall this is defined by water millimetre amounts.

Each class is ranked by a weight, which indicate the influence of this specific value of the parameter. Overall, branches with a higher weighting will have a large influence on the model output whereas branches (and sub-braches) with smaller weightings will have a lesser impact.
Figure 6.1. Brassica biophysical land suitability analysis model – overall hierarchy
6.2.1. Application of Brassica Biophysical Land Suitability Analysis Model

A GIS model-based on the AHP tree was developed using Python modules and presented spatially in the ESRI ArcGIS® software package. The model was then linked with the data required for the analysis. For comparative purposes, observed climate data was created by taking the average historical values of the key climatic variables for a 30-year period from 1961 to 1990. This is referred to as a climate normal period, or within this report, as the historical climate. The use of a climate normal for the current land suitability presents an averaged climate that is representative of the normal and expected climate conditions in the region. It even out any ‘unusual’ climate events, such as extreme weather, generating an even spread of climate data.

Climate data for historical observations were provided by the Department of Natural Resources and Mines, Queensland, in conjunction with the Bureau of Meteorology (BOM) weather recordings, through their SILO program (Department of Natural Resources and Mines, 2010). These data are produced as text files which then can be presented in a map grid at a resolution of approximately 5 square km (grid) (0.05°).

The climate scenarios for the years 2030 and 2050 were generated by using the CSIRO’s coupled Atmosphere-Ocean Global Circulation Model (AOGCM) CSIRO-Mk3.5 model and the IPCC SRES A1FI (high global warming) scenario. These projected climate scenario datasets are furnished, for the needed climatic factors, at a resolution of approximately 5 square km (grid) (0.05°).

The execution of the model produces a composite map that ranks areas in terms of suitability for the growth of brassica. The core of the framework, as established by the FAO (FAO, 1976), is maintained for application in the study region. The two principle suitability orders, Not Suitable and Suitable, are given value ranges of -1.0 and 0.0 to 1.0, respectively. There are four defined classes utilised, which are assigned unique suitability index class values; High (1.0 to 0.8), Moderate (0.7 to 0.5), Low (0.4 to 0.2) and Very Low (0.1 to 0.0). These value groupings are referred to as either suitability index classes or index classes, whereas their associated values are suitability index values of index values.

Therefore, the productivity of a particular area can be estimated by multiplying a value in the yield range defined at the top of the AHP construct by the suitability index. For example, in an area with a suitability of 0.8 (or 80%) we can expect a yield of about (0.8 x 25 t/ha/y =) 20 t/ha/y. Not Suitable is further defined into Permanently Not Suitable (PNS) and Temporarily Not Suitable (TNS), which both maintain a -1.0 value. This distinction is consistent with the FAO Framework. TNS indicates a limitation in the suitability of the land that can be overcome at a certain cost. Temporary limitations are usually related to (chemical) conditions of the soil. In contrast PNS refers to a limitation in the suitability of the land that cannot be overcome.

Percentages are used to enhance interpretation of final outputs, so a suitability index class value of 1.0 can be described as 100% suitability and a suitability index class value of 0.5 is noted as 50% suitability. For each AHP model this process is applied in the historical climate (climate normal period 1961 to 1990) and two climate futures of 2030 and 2050 under the SRES A1FI emissions scenario. It should be noted, however, that existing land uses are the result of many factors including past and current market conditions, whilst the land suitability maps primarily reflect biophysical conditions.
6.2.2. Results of Brassica Biophysical Land Suitability Analysis Model

The biophysical land suitability map for the historical climate for brassica production (Figure 6.2, left panel) indicates that the majority of Goulburn Broken Study Region is ranked in the high (80-100%) suitability to produce 10 to 40 t/ha/y of brassicas. The principal rating found throughout the region are high suitability ratings at 90%, but this is closely followed by ratings at 80%. Areas of 100% are seen throughout the Region, primarily into the north in Campaspe and Moira, as well as into the southern Mansfield area. There are moderate ratings at 70% seen throughout the region, with patchy distributions in the central areas and more consistent zones into the southern areas towards Alexandra.

In the historical climate map (Figure 6.2, left panel), areas of Temporary NS are very limited in distribution, with only a small area seen to the south of Echuca and scattered in the northern Campaspe region. This is related to hard clay type soils found in these patches. Areas of Permanently NS are scattered through the Study Region. In the north this is principally seen to the east of Echuca and along the northern Murray River boundary. This is associated with high electrical conductivity, which relates to high sodium (salt) levels in the soil. To the south, such as near Alexandra and Mansfield, these PNS areas are linked to shallow soils depths and the depth to bedrock.

In Figure 6.2, the sequence of three panels, from left to right, depicts the likely impacts on biophysical suitability for brassica production in the Goulburn Broken Study Region as a result of climatic change. The left panel, as mentioned, depicts the historical climate suitability for the region, whereas the centre and right panels, respectively, show suitability for a future climate of 2030 and 2050.

Initially there is an overall increase in suitability in progression from the historical baseline into 2030. This is principally seen as increases from a low high at 80% into higher ratings at 90% and 100%. The 80% rating is noted to decrease somewhat into 2030. This increase is primarily noted in the north throughout the Shepparton Region, with large distributions indicating suitability ratings at 90%. Into 2050 this initial increase in suitability is projected to halt and suitability ratings are noted to decline to levels lower than seen in the historical baseline. Increases in the northern Moira, Campaspe and Shepparton Regions are noted to reverse and fall into lower suitability ratings. The majority of this area is still within high ratings, albeit at 80%. Also larger distributions of moderate suitability at 70% is seen to occur throughout the north. The shift in suitability classes in the future is further graphically depicted in Figure 6.3 and the area within each suitability class is depicted in Table 6.1.

This shift is additionally illustrated by the modifications in biophysical land suitability classes between the projected climate changes in future years and the baseline, which is depicted in Figure 6.4 (2030 – left panel, 2050 – right panel). In the keys to the latter maps, a ‘decrease’ indicates that there has been a 10% change from a higher suitability class to a lower suitability class (e.g. from 90% to 80%); conversely an ‘increase’ indicates that there has been a 10% change from a lower class to a higher class (e.g. from 80% to 90%). The categories ‘high increase’ and a ‘high decrease’ follow the same rules except that the changes are in the order of 20% and none of the changes in suitability predicted by the model were of this order. No change means that there has been no change between the baseline and the respective year. Here, as mentioned, there are increases in suitability in the Shepparton Region into 2030 in the magnitude of one suitability class. There are some small areas indicating a one suitability decrease in the south, but coverage is quite low. In progression into 2050, large areas in the north are noted to decrease by one suitability category, with some areas in the south central and south showing one suitability class increases. The 80% suitability class is noted to increase by about a fifth of land coverage into this scenario with a 10% increase in moderate ratings (Table 6.2).
Figure 6.2. Brassica land suitability in the Goulburn Broken study region – Historical (1961 – 1990) (left panel), 2030 (A1FI scenario) (centre panel), 2050 (A1FI scenario) (right panel)
Table 6.1. Brassica land suitability by area and percentage in the study region – Historical, 2030, 2050

<table>
<thead>
<tr>
<th></th>
<th>Temp NS 2</th>
<th>Perm NS 3</th>
<th>0% - 40%</th>
<th>50%</th>
<th>60%</th>
<th>70%</th>
<th>80%</th>
<th>90%</th>
<th>100%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hectares (ha)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Historical 1</td>
<td>-</td>
<td>42,929</td>
<td>-</td>
<td>2</td>
<td>78</td>
<td>45,886</td>
<td>619,93</td>
<td>734,16</td>
<td>162,660</td>
</tr>
<tr>
<td>2030</td>
<td>-</td>
<td>42,929</td>
<td>-</td>
<td>7</td>
<td>11</td>
<td>37,747</td>
<td>468,26</td>
<td>802,17</td>
<td>254,522</td>
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<tr>
<td>2050</td>
<td>-</td>
<td>42,929</td>
<td>-</td>
<td>2</td>
<td>175</td>
<td>194,44</td>
<td>776,88</td>
<td>538,63</td>
<td>52,590</td>
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<tr>
<td>Percentage (%)</td>
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<td></td>
</tr>
<tr>
<td>Historical 1</td>
<td>-</td>
<td>2.7 %</td>
<td>-</td>
<td>0.0001 %</td>
<td>0.00 %</td>
<td>2.9 %</td>
<td>38.6 %</td>
<td>45.7 %</td>
<td>10.1 %</td>
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<tr>
<td>2030</td>
<td>-</td>
<td>2.7 %</td>
<td>-</td>
<td>0.0004 %</td>
<td>0.001 %</td>
<td>2.4 %</td>
<td>29.2 %</td>
<td>50.0 %</td>
<td>15.9 %</td>
</tr>
<tr>
<td>2050</td>
<td>-</td>
<td>2.7 %</td>
<td>-</td>
<td>0.0001 %</td>
<td>0.01 %</td>
<td>12.1 %</td>
<td>48.4 %</td>
<td>33.5 %</td>
<td>3.3 %</td>
</tr>
</tbody>
</table>

Note: 1 Historical is the period from 1961-1990, 2 Temp NS is temporarily not suitable, 3 Perm NS is permanently not suitable

Table 6.2. Brassica land suitability change by area and percentage

<table>
<thead>
<tr>
<th></th>
<th>Temp NS</th>
<th>Perm NS</th>
<th>0% - 40%</th>
<th>50%</th>
<th>60%</th>
<th>70%</th>
<th>80%</th>
<th>90%</th>
<th>100%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hectares (ha)</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Historical to 2030</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>5</td>
<td>- 67</td>
<td>- 8,139</td>
<td>- 151,672</td>
<td>68,011</td>
<td>91,862</td>
</tr>
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<td>2030 to 2050</td>
<td>-</td>
<td>-</td>
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<td>- 5</td>
<td>164</td>
<td>156,696</td>
<td>308,625</td>
<td>- 263,548</td>
<td>- 201,932</td>
</tr>
<tr>
<td>Percentage (%)</td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>Historical to 2030</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.0003 %</td>
<td>- 0.00 %</td>
<td>- 0.5 %</td>
<td>- 9.4 %</td>
<td>4.2 %</td>
<td>5.7 %</td>
</tr>
<tr>
<td>2030 to 2050</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>- 0.0003 %</td>
<td>0.01 %</td>
<td>9.8 %</td>
<td>19.2 %</td>
<td>- 16.4 %</td>
<td>- 12.6 %</td>
</tr>
</tbody>
</table>
Figure 6.4. Brassica land suitability change in Goulburn Broken study region – from historical to 2030 (left panel), from historical to 2050 (right panel).
7. LETTUCE PRODUCTION

7.1. Lettuce Characteristics

Lettuce is an annual plant, primarily grown for its leaves, in cool climates and moist soils. There are numerous popular varieties, including crisphead or iceberg, butterhead, romaine and cos. It can be planted in succession and ideally harvested in cooler temperatures. Lettuces are best grown to avoid high temperatures during maturing season, when they are most susceptible to bolting.

7.1.1. Soils

The ideal type of soils for lettuces are loamy soils, fine sandy loam, fine sandy cay loam and silty loam type soils. Harder textured soils, such as medium to hard clays, can potentially restrict growth. Lettuces are considered to be shallow rooting species and topsoil conditions are important factors for cultivation, but still require over 75cm of usable depth for optimum yield. A well aerated, well-draining type soil is ideal for plant growth. Lettuces have a low tolerance to acidic type soils with a neutral pH between 6.0 - 7.0 ideal.

7.1.2. Landscape

Landscape features that are preferred for the cultivation of lettuce are gently sloped, north facing areas. Elevated areas, such as mountains and hilly areas, dune formations and undulating plains are considered unsuitable for production. Planting on steep slopes result in excessive water and nutrient runoff.

7.1.3. Climate

Lettuces species can be grown all year round, with cool temperate regions considered most suited for production. Average maximum temperatures between 16-25ºC are considered optimal, with cool average minimum temperatures of between 6-9ºC.

Lettuces can be susceptible to bolting when subject to a combination of a large amount of accumulated direct sunlight and high temperatures, becoming bitter in taste. Temperatures over 30ºC and greater 8 hours of direct sunlight contribute to bolting. Most lettuce are tolerant to frosts, but severe frosts or extended days with frosts can be damaging to the cultivation of lettuce, particularly the outer leaves.

Adequate water supply during the production months is required for a high yield crop. Frequent rainfalls during these months are necessary, with average monthly falls in excess of 50 mm preferred. If rainfall is not adequate for the crop, then irrigation will be required to supply the necessary amount of water. Lettuce require abundant watering during the growing season and in temperate regions, if rainfalls are not adequate, weekly irrigations may be necessary to ensure a good yield.

7.2. Lettuce Biophysical Land Suitability Analysis Model

The lettuce Land Suitability Analysis (Figure 7.1) model targets the identification of land capable of producing 10 to 40 tonnes of lettuce per hectare per year (t/ha/y). The model used in this report is an adaptation of the model developed and applied in the South West Region of Victoria, as part of the Victorian Climate Change Adaptation Program (VCCAP) (Sposito et al., 2008) as well as the Gippsland Region of Victoria, as part of the Agricultural Industry Transformation – Gippsland project (Faggian and Sposito, 2013).

The LSA Analytical Hierarchy Process model used is made of three branches: ‘Soil’, ‘Landscape’ and ‘Climate’. It indicates that ‘Climate’ is the most influential factors being assigned a weight of 55% (or 0.55), with ‘Soil’ the second most influential at 40% (0.40) and ‘Landscape’ the least influential (5% or 0.05). In each branch of the hierarchy, there are further branches down the model, each with their own weighting factors. For example, if one progress downs the Climate branch, ‘water availability’ and ‘temperature’ are equally as influential as one another with weights of 50% (or 0.50). Further down ‘temperature’, it includes two branches, ‘average minimum’ and ‘average maximum’ – which together inform overall temperature. Each final branch is detailed by several classes the parameter can be defined by, in the instance of temperature this is defined by degrees Celsius.
Each class is ranked by a weight, which indicate the influence of this specific value of the parameter. Overall, branches with a higher weighting will have a large influence on the model output whereas branches (and sub-braches) with smaller weightings will have a lesser impact.
Figure 7.1. Lettuce biophysical land suitability analysis model – overall hierarchy

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7.3. Results of Lettuce Biophysical Land Suitability Analysis Model

The biophysical land suitability map for the historical climate for lettuce production (Figure 7.2, left panel) indicates that the majority of Goulburn Broken Study Region is ranked in the high (80-100%) suitability to produce 10 to 40 t/ha/y of lettuce. The principal rating found throughout the region are high suitability ratings at 80% and 90%. Large distributions of 90% are seen into the west of Shepparton and also to the south of the Study Region. Areas indicating 100% suitability are noted in the south central regions, principally in the Strathbogie area. There are moderate ratings at 70% seen throughout the region, with patchy distributions into the northern area.

In the historical climate map (Figure 7.2, left panel), areas of Temporary NS are very limited in distribution, with only a small area seen to the south of Echuca and scattered in the northern Campaspe region. This is related to hard clay type soils found in these patches. Areas of Permanently NS are scattered through the Study Region. In the north this is principally seen to the east of Echuca and along the northern Murray River boundary. This is associated with high electrical conductivity, which relates to high sodium (salt) levels in the soil. To the south, such as near Alexandra and Mansfield, these PNS areas are linked to shallow soils depths and the depth to bedrock.

In Figure 7.2, the sequence of three panels, from left to right, depicts the likely impacts on biophysical suitability for lettuce production in the Goulburn Broken Study Region as a result of climatic change. The left panel, as mentioned, depicts the historical climate suitability for the region, whereas the centre and right panels, respectively, show suitability for a future climate of 2030 and 2050. Table 7.1 shows the area within each suitability class. The shift in suitability classes in the future is further graphically depicted in Figure 7.3.

Overall there is a general reduction in the ratings of suitability in progression into the future. This reduction in suitability, is linked both to declining rainfall amounts in these areas as well as increased temperatures, which impacts upon the ability to grow lettuce. This is principally noticed into the north of the Study Region where there is an increasing downward trend in suitability from high rankings at 80% into more moderate ratings at 70% and below. However, throughout the region most of the change occurs within the higher rankings with suitability shifting from 90% to 80%.

In 2030, most of the change is noted into the areas to the east and west of Shepparton where there are declines form a high suitability at 90% to 80%. In the central regions, such as to the west of Benalla, there are reductions into moderate ratings at 70%, but not in large distributions. Overall about 5% of the land coverage shifts into this lower rating. Also areas in Strathbogie showing 90% and 100% suitability are seen to shift somewhat, but still remain within these categories. Into 2050 there is a further decline in suitability. The majority of the north remains the same as in 2030 apart from areas along the northern boundaries which show moderate ratings at 60%. The central Strathbogie area is seen to decline from the 90% and 100% ratings, but only into lower highs at 80%. Most of the south is seen to remain within high suitability ratings. Overall into 2050 it is projected that over 80% of land coverage will remain within the high suitability ratings, with the majority at 80%.

This shift is additionally illustrated by the modifications in biophysical land suitability classes between the projected climate changes in future years and the baseline, which is depicted in Figure 7.4 (2030 – left panel, 2050 – right panel). There are decreases in suitability in the north in the magnitude of one suitability class. This is conversely linked with localised increases in the south of one to two suitability classes. The 90% suitability class is noted to decline by about one fifth of its former land coverage, with subsequent increases in area coverage in the 80% class by about 12% (Table 7.2).
Figure 7.2. Lettuce land suitability in the Goulburn Broken study region – Historical (1961 – 1990) (left panel), 2030 (A1FI scenario) (centre panel), 2050 (A1FI scenario) (right panel)
Table 7.1. Lettuce land suitability by area and percentage in the study region – Historical, 2030, 2050

<table>
<thead>
<tr>
<th></th>
<th>Temp NS</th>
<th>Perm NS</th>
<th>0% - 50%</th>
<th>60%</th>
<th>70%</th>
<th>80%</th>
<th>90%</th>
<th>100%</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Hectares (ha)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Historical</td>
<td>-</td>
<td>42,929</td>
<td>-</td>
<td>117,606</td>
<td>733,357</td>
<td>659,252</td>
<td>52,511</td>
<td></td>
</tr>
<tr>
<td>2030</td>
<td>-</td>
<td>42,929</td>
<td>-</td>
<td>192,134</td>
<td>850,145</td>
<td>474,727</td>
<td>45,720</td>
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<tr>
<td>2050</td>
<td>-</td>
<td>43,377</td>
<td></td>
<td>21,845</td>
<td>231,534</td>
<td>941,553</td>
<td>362,762</td>
<td></td>
</tr>
<tr>
<td><strong>Percentage (%)</strong></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Historical</td>
<td>-</td>
<td>2.7%</td>
<td>-</td>
<td>7.3%</td>
<td>45.7%</td>
<td>41.1%</td>
<td>3.3%</td>
<td></td>
</tr>
<tr>
<td>2030</td>
<td>-</td>
<td>2.7%</td>
<td>-</td>
<td>12.0%</td>
<td>52.9%</td>
<td>29.6%</td>
<td>2.8%</td>
<td></td>
</tr>
<tr>
<td>2050</td>
<td>-</td>
<td>2.7%</td>
<td>-</td>
<td>1.4%</td>
<td>14.4%</td>
<td>58.6%</td>
<td>22.6%</td>
<td>0.3%</td>
</tr>
</tbody>
</table>

Note: ¹Historical is the period from 1961-1990, ²Temp NS is temporarily not suitable, ³Perm NS is permanently not suitable

Figure 7.3. Lettuce land suitability area by percentage amount in the study region – Historical, 2030, 2050

Table 7.2. Lettuce land suitability change by area and percentage

<table>
<thead>
<tr>
<th></th>
<th>Temp NS</th>
<th>Perm NS</th>
<th>0% - 40%</th>
<th>60%</th>
<th>70%</th>
<th>80%</th>
<th>90%</th>
<th>100%</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Hectares (ha)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Historical to 2030</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>74,528</td>
<td>116,788</td>
<td>-184,525</td>
<td>-6,791</td>
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<tr>
<td>2030 to 2050</td>
<td>-</td>
<td>448</td>
<td>-</td>
<td>21,845</td>
<td>39,400</td>
<td>91,408</td>
<td>-111,965</td>
<td>-41,136</td>
</tr>
<tr>
<td><strong>Percentage (%)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Historical to 2030</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>4.6%</td>
<td>7.3%</td>
<td>-11.5%</td>
<td>-0.4%</td>
<td></td>
</tr>
<tr>
<td>2030 to 2050</td>
<td>-</td>
<td>0.03%</td>
<td>-</td>
<td>1.4%</td>
<td>2.5%</td>
<td>5.7%</td>
<td>-7.0%</td>
<td>-2.6%</td>
</tr>
</tbody>
</table>
Figure 7.4. Lettuce land suitability change in Goulburn Broken study region – from Historical to 2030 (left panel), from Historical to 2050 (right panel)
8. REFERENCES


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