Horticulture Innovation Australia

Final Report

An objective basis for temperate nut industries expansion

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NSW Dept of Primary Industrieă

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An objective basis for temperate nut industries' expansion

FINAL REPORT

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Contents

Summary

The Australian temperate nut industries (Almond, Chestnut, Hazelnut, Pecan, Pistachio and Walnut) have experienced unprecedented growth over the last decade. In 2015 the farmgate value of Australian nuts was $1.2 billion. The high quality and relatively low pest and disease issues make Australian nuts a highly valued product in international markets. Industry expansion is expected to continue.

Many regions are capable of sustaining nut tree growth, however production of a profitable crop calls for a specific set of climatic and agronomic conditions. Key components of tree growth identified in this project were chill and heat accumulation, water availability and soil classification. The aim of this work was to provide an objective basis for expansion of the Australian temperate nut industries.

Nut tree phenology requirements and bioclimatology have been used to generate predictive models and identify regions suitable for productive nut crops. Chill accumulation was determined as the most critical factor limiting regional suitability in Australia. Chill portions were calculated using the Dynamic Model, which quantifies chill accumulation throughout dormancy while accounting for the cancelling effect of heat.

Chill portions and heat units (Pecans and Pistachios) were used to generate high resolution maps of Australia for each temperate nut. Water availability and soil suitability were also deemed important and were added as layers to the chill portion maps. These maps are available online and have been provided to the Australian Nut Industry Council (ANIC).

Information packages have been created to provide supporting information and further resource suggestions. There is one large information package, which includes project background, a guide to interpretation, small discussion of the inclusions and limitations of the maps and a section about the model generation for each nut tree. Six smaller information packs, one for each temperate nut industry, have been created, which provide information specific to each industry. The information in these packs overlaps in some places. The suitability of each information pack depends on the user's needs and offers both general and specific information.

Keywords

Bioclimatology

Chill portion

Almond

Chestnut

Hazelnut

Pecan

Pistachio

Walnut

Soil

Water

Irrigation

Rainfall

Introduction

Australian temperate nut industries are growing rapidly and expanding into new production regions. This expansion is capitalising on economic potential which has arisen from increasing domestic consumption, international investment and export growth. Underpinning this growth, Australia provides adequate stable climatic conditions. Once established, production is rarely disrupted by extreme weather. In this context it is possible to provide reasonable forecasts to guide agricultural investment and maximize the probability of commercial success.

Bioclimatology has been used to generate models for nut industry expansion based on the climatic and agronomic requirements of nut trees. Chilling requirements are key to nut crop productivity, hence were the primary parameter used to generate models. Heat accumulation is also an important factor for Pecan and Pistachio trees. Water availability and soil suitability were included in the models to enable further definition of regional suitability. The aim of this work was to provide an objective basis for expansion of the Australian temperate nut industries.

Winter chill accumulation was determined as a critical factor limiting regional suitability for temperate nut productivity. Nut trees require chill accumulation throughout dormancy (1st May – 1st September) to break dormancy, initiate reproductive processes and ultimately synchronise nut maturation. Chill requirements are commonly quantified as the minimum number of hours between 0-7.2°C, or chill hours. In regions with warm climates, heat can cancel out chill hour accumulation (Pope, 2015). The Dynamic Model of Chill Portions quantifies chill, while accounting for the cancelling effect of heat and has been used in the present work.

Water is required for tree growth and nut development and quality (Iniesta, 2008). Sufficient water is critical to reliable production of high quality nuts, it assists in the survival of plants through frost and heat events and promotes vegetative and tree growth. Water availability has been added to this model as an additional layer incorporating irrigation schemes, rainfall contours, and river catchment areas.

Nut trees grow best in deep, well drained, fertile soils. Soil properties can vary dramatically within a small area and many soil properties can be altered either mechanically or chemically. While there is some awareness of the ideal soils for horticultural use, limited research has been conducted as to the scope of soils suitable for nut production in Australia. Soil suitability has been incorporated into this study as a very approximate guideline and should definitely be assessed on an individual site basis.

This project has developed map-based forecasts of regions which provide guidance for future plantings by highlighting conditions suitable for the production of nut crops. These forecasts are based on environmental factors which are key determinants of physiological performance. It was not the intention of this project to account for all factors with the potential to limit production and inevitably empirical or sentinel plantings will be required.

Methodology

This project examined the Australian landmass to determine regional suitability for temperate nut production. It did this by sequentially applying 'filters' which excluded regions based upon specific criteria. These filters were chill portion, water availability, agronomic risk (frost and inappropriate rainfall) and soil suitability.

Chill Portion

Interpolated temperature data was obtained from the Bureau of Meteorology (Jones, Wang & Fawcett, 2009). This data consisted of interpolated minimum and maximum daily temperatures for each 5 km × 5 km grid (equivalent to $0.05^{o} \times 0.05^{o}$) covering the mainland and Tasmania from 1911 to 2014. The interpolated dataset overcomes the spatial and temporal discontinuities in Australia's temperature records.

The Dynamic Model (Fishman *et al.* 1987, Luedeling & Brown 2011) was used to calculate chill portions based on estimated hourly temperatures for each day. Hourly temperatures are predicted from the daily minima and maxima temperature taking into account the latitude of the midpoint of each 5 km × 5 km grid (equivalent to $0.05^{o} \times 0.05^{o}$) covering the mainland and Tasmania (Figure 1).

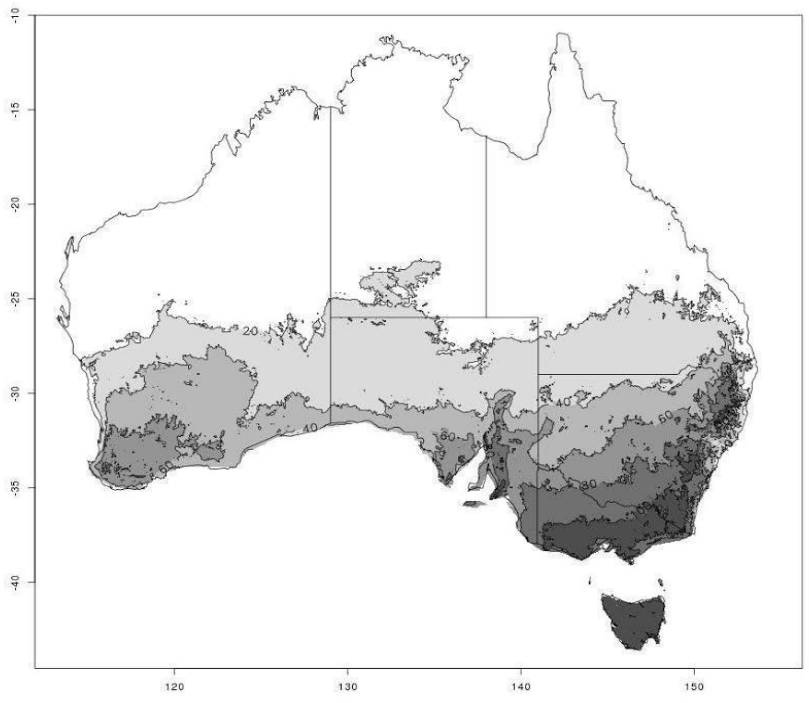
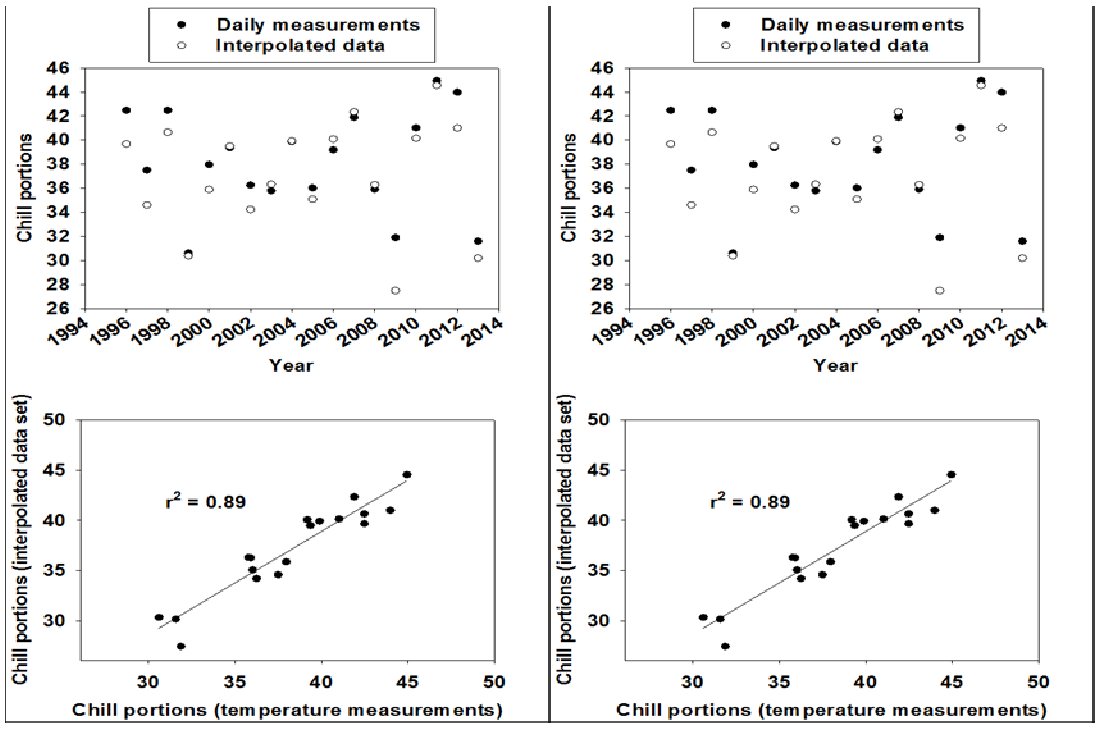


Figure 1. Chill portion map of Australia. Contours are marked at 0, 20, 40, 60, 80 and 100 chilling portions with darker shades indicating higher chilling portions.

The sequence of calculations being followed was:

- estimate hourly temperature for each day for each grid,
- calculate chill portions from May 1 through to August 31 for each grid,
- generate chill portion contours using the R statistical package, and project onto a digital map of Australia to produce chill portion maps across the mainland and Tasmania.

The robustness of the chill portion estimates was examined by comparing chill portions calculated using recorded daily temperature for a location in NSW (Moree) with chill portions calculated using the BoM interpolated temperature data from 1996 onwards. Moree was chosen since it is host to a large pecan operation. The comparison (Figure 2) suggests good agreement between both chill portion estimates. Similar comparisons were performed at other locations e.g. Rutherglen.



Chill portions for Moree estimated from daily temperature records (●) and interpolated daily temperatures (○) for 1996 to 2013.

Relationship between chill portions based on daily temperature records and chill portions based on interpolated daily temperatures for Moree.

Figure 2. Comparison of chill portions from recorded and interpolated temperatures for Moree.

The chill portion requirements of the six major Australian temperate nut crops were estimated. Optimally this calculation used published records of the crops' temperature requirements for phenological processes (budbreak, flowering, fruiting). When an exhaustive literature search failed to find this information, chill portion requirements were interpolated from the known Australian and global commercial distribution of that variety. Some nut crops had varieties with different chill portion requirements. In these cases the lowest and highest chill portion requirements are provided. Chill portions for each nut crop and notes on their derivation are provided in Table 1.

Table 1. Estimated chill portion requirements for six nut crops based on published phenological data or interpolated from the known global distribution of the crop.

Crop	Chill portion		Derivation
	Low[1]	High[2]	
Almond	23	32	Low from 'Nonpareil', high from 'Ferragnes'
Chestnut	58.1	88	Mount Barker data, 1956-2014
Hazelnut	48	60	Low from 'Hall's Giant', high from 'Ennis'
Pecan	38.8	44	Low from 'Schley', high from 'Wichita'
Pistachio	59	59	Only one estimate available
Walnut	54	72	Low from 'Hartley', high from 'Chandler'

1. Low is the minimum observed or derived chill portion at which critical phenology occurs.
2. High is the maximum observed or derived chill portion at which critical phenology occurs.

Having estimated the chill portion requirements, the calculated chill portions for each nut crop were used to develop chill portion maps (Appendix 1).

Water Availability

The availability of water is a critical factor influencing the productivity of nut trees. Water availability has been incorporated into the bioclimatology model using:

1. Vectors for irrigation schemes – using data from 'Australian Irrigation Areas, (Vector), Version 1A, National Land and Water Resources Audit' (URL:https://data.gov.au/dataset/australian-irrigation-areas-vector-version-1a-national-land-and-water-resources-audit)
2. Contour lines for rainfall – data from 'Average annual, seasonal and monthly rainfall' (URL: http://www.bom.gov.au/jsp/ncc/climate_averages/rainfall/index.jsp?period=wet&area=oz#maps)
3. River Catchment area outlines – data from 'Australia's river basins' (URL: http://www.ga.gov.au/metadata-gateway/metadata/record/42343/)

Irrigation schemes are the most reliable sources of water and regions within these are considered capable of supplying an adequate quantity of water for commercial nut growth.

Soil

Soil data was obtained from 'Australian Soil Resource Information System' (ASRIS) (URL:http://www.asris.csiro.au/mapping/viewer.htm). The depth of green shading on the models increases with increasing soil suitability. Australian soils can be classified according to the Australian Soil Classification system, which groups soils according to acidity, depth, chemical composition (e.g. iron, sodium and calcium concentrations), particle size, clay/sand/loam content, structure and water holding capacity/drainage.

The inclusion of soil suitability in the bioclimatology model is merely a guide, because there is limited research regarding tree growth in Australian soils. Furthermore it is possible to make many different amendments to soils to improve suitability and soil properties can vary greatly within a small area.

Growing Degree Days (Heat units)

For pistachio and pecan, heat units were calculated using the interpolated temperature data. Mean daily temperatures were calculated as the average of the minimum and maximum temperature. The heat units were defined as the sum of the daily mean temperatures minus the base temperature (if greater than the base temperature) from October 1 till April 30, where base temperatures of 15° and 18.3° for pistachio and pecan were used respectively. Heat unit contour maps were created with a critical heat unit contour of 900 for pistachios and 750 for pecans.

Software and computation

The R statistical software environment (R Development Core Team 2012) was used for all computation (except chill portion calculation) and graphics. The *chillR* package (Luedeling 2013) was initially used for chill portion calculations however the time taken for the calculations for each day in the 20 year period for each grid square in Australia was unacceptably high. To overcome this issue Fortran 90 code, which replicated the calculations in the *chillR* package, was used, speeding up the process considerably. The geospatial mapping packages *raster* (Hijmans & van Etten 2012), *rgdal* (Keitt *et al*. 2012), *sp* (Pebesma & Bivand, 2005) and *fields* (Nychka *et al*., 2015) were used for the raster calculations and mapping.

Agronomic risk

Temperate nut production is negatively affected by late spring frosts, high heat events and rainfall during harvest. The incidence of risk factors was not included in the models, however the information packs that accompany the models, guide users to available online resources (i.e. hi-resolution models and the information packs which support models) .

Table 2. Summary of major production regions and phenology of each nut crop. Frost and high heat events during flowering reduce fertilisation, nut set and increase tissue damage. Rainfall during harvest increases the chance of pest and disease spread while also making the harvesting process more difficult.

Crop	Region	Flowering	Earliest Harvest (Duration)
Almond	Riverland, SA. Hillston, NSW. Sunraysia, VIC	August to September	February to March
Chestnut	Northern Victoria	November to December	March to April
Hazelnut	Tasmania, Victoria, NSW	Mid-June to Mid-September	February to March
Pecan	Moree, Mundubbera Coastal Northern NSW	Mid-September to October September to Mid-October	March to June
Pistachio	Sunraysia		March
Walnut	Riverina, NSW Swansea, Tasmania	Mid-September to October September to Mid November	March to Mid-May Late March to Late May

Outputs

Maps (Models)

- High resolution maps available online in PDF format
- sent to ANIC
- See appendix 1

Primefacts

- 6 information packages – 1 for each nut industry
- Factsheet type documents available on NSW DPI factsheet page
- Provide background information, direct users to online model resource and provide some insight into the use of the model

Information pack

- Larger publication (PDF) with a general introduction about the methods used to generate the models (maps) followed by more specific
- Includes details of additional resources for risk factors
- Sent to ANIC
- the information overlaps with Primefacts document, however there was interest in a document covering all industries

Summary Page

- Single page summary/ directive flyers to describe how to access the online resources and how to use the maps.
- This is a generic (i.e. same for all nuts) and direct users to the NSW DPI factsheets page (www.dpi.nsw.gov.au/factsheets) where Primefacts and models are accessible
- Appendix 2

Outcomes

Predictive models (appendix 1)

High resolution maps have been generated which provide current and potential commercial nutgrowers with information on regional suitability for the temperate nut industries, Almonds, Chestnuts, Hazelnuts, Pecans, Pistachios and Walnuts. This information has been passed on to the Australian Nut Industry Council (ANIC) for use on their website and distribution across the nut industries at their discretion.

The models generated are available online as extremely high resolution maps. These maps are able to be interrogated, by zooming, to a resolution of 5 x 5km. The models are each based on bioclimatology and the phenological requirements of Almonds, Chestnuts, Hazelnuts, Pecans, Pistachios and Walnuts. As such models are inclusive of:

- Chill portions
    - determined as the critical factor which limits regional suitability
    - calculated using Dynamic Chill Portion Model
- Heat units
    - Only determined as limiting for Pecan and Pistachio growth (in Australia)
- Water Availability
    - Rainfall is included as a contour. The contour represents the water requirement throughout the October-May period as an average of values reported in literature. Australian rainfall is not reliable and this is definitely only a guide.
    - River catchment areas were outlined mainly as a point of reference for sourcing addition information in regards to the water availability of a particular region. This information is best source from catchment management groups.
    - Irrigation schemes are the most reliable sources of water and the most suitable regions falls within irrigation schemes
- Soil Suitability
    - Soil properties have the potential to change dramatically with small regions, the information packages strongly emphasis that sites should be analysed thoroughly prior to orchard establishment. The soil property variation has the potential to alter irrigation requirements and management strategies due to water holding capacity
    - Soil properties are highly amendable (that is in comparison to the availability of chill and/or water), for this reason soil information has been applied to the model as an informative layer, but not as a factor which limits regional suitability.

Information Packages and Resources

Information packages have been created with the aim of providing project and industry background, access instructions and suggestions for further resources. This information covers:

- Australian industry information such as size, productivity and value as well as market and international competitiveness
- Brief tree physiology and phenology information including tree size, reproductive timing and any unique or interesting piece of information
- Information pertaining to risks factors, such as late spring frosts, high heat events and rainfall during harvest.

Individual industry information packages are available online from the NSW DPI website. A larger document incorporating information pertaining to all 6 nut industries will also be available through ANIC and the NSW DPI.

A two page instructional document has been provided to ANIC for dispersal at industry events. This provides information regarding the access and use of the models and online resources (appendix 2). This document includes a brief description of what is and isn't included in the models. There is also a short description describing the steps involved in accessing and interrogating the models. The current images used to create this document are based on

Project presentation to industry

At the time of reporting the project has been presented to the Hazelnut Growers Association at the Master Class for New growers. The outcomes of the project were received well at this event and the presentation seemed to generate considerable interest among the small group. The group expressed interest in accessing online resources once they become available.

There is potential for further presentations to be provided to meetings of other nut growers. In the immediate future an invitation has been extended to present the information at a Walnut Farm Walk associated seminar organised by the Australian Walnut Industry Association (AWIA). Should this eventuate, and definitely during future interactions with industry groups, the summary sheet will be provided to the participants so that they may pursue the Primefacts and Models through the NSW DPI website.

Evaluation and Discussion

Model generation and resource availability

This project has successfully generated 6 predictive models to highlight productive tree nut regions throughout Australia. These models are capable of providing high resolution information regarding chill and heat accumulation, water availability and soil suitability. These models are available online and are accompanied by information packs. There is a detailed information pack for each industry and a larger document incorporating all industries. The information packages provide background, risk factor resources and outline the inclusions of the models.

The Australian nut industry has grown rapidly over the last decade. In order to continue this growth and become an international market player the Australian nut industries need to know how to encourage tree growth in a sustainable and locally stable way. This project provides a strong starting point to guide selection of regions which meet basic growth requirements.

High resolution maps have been generated to model the suitability of Australian locations for the production of each nut type. When viewed in electronic form these maps have a resolution up to 5kmx5km. These maps have been included in Appendix 1, in low resolution.

Without taking advantage of the high resolution maps it is possible to draw some general conclusions about regional suitability of temperate nut industries in Australia:

- the key determinant of regional suitability which limits site selection is chill accumulation. Heat accumulation is also important for Pecan and Pistachio productivity. In Australia the productivity of other nut crops is not limited by heat accumulation.
- the most reliable source of water is through irrigation schemes. Perennial river have the potential to provide reliable water, however sourcing local information is highly recommended. Rainfall in Australia is definitely not a reliable source of water.
- soil properties are highly variable within sites, hence are provided as an approximate guide only.

Limitations

A significant quantity of research is available regarding parameters of nut crop production. The main body of research is based on research from regions with large nut industries, particularly California. This limits the relevance of the information to Australian industry and often growth parameters are interdependent and the conditions experienced in Australia are often unique. It was therefore necessary to take an average of reported values, in many cases. There were some occasions where it was necessary to judge the most reliable source of information to determine the appropriate value to use.

Extensive literature searches, of both scientific and industry publications, along with industry consultation were used to determine the growth requirements used to generate the bioclimatology models. Throughout the literature interrogation it became evident that no one

factor is responsible for the productive growth of nut trees. For example in Pecan trees, the requirements for chill accumulation seem to be in a balance with heat accumulation (Sparks, 2005). This has highlighted the need for future research.

Risk factors

Many temperate nut crops are negatively affected by risk factors such as late spring frosts, high heat events, and rainfall during harvest. The severity of the risk posed by these factors varies from region to region. It is also possible that there is small area variation, for example a farm at a slightly higher altitude may be more susceptible to late spring frosts than the farm a short distance down the hill. These factors are not incorporated into the model due the high variability between years and within locations.

The risk posed by each factor can potentially be negated or at least reduced by orchard management strategies. Risk reduction can be achieved through water management, establishment of wind breaks, shade or ground cover or canopy management. These means of mitigating risks are orchard specific and it is not feasible to incorporate orchard management strategies into the predictive models generated in this study. In order to provide some guidance in this area we have included information and resource suggestions in the information packs which provide risk factor guidance.

Future work

Future research would ideally investigate the effect of climatic and agronomic factors on phenological processes. Research into nut crop productivity has been conducted internationally, typically by regions with large nut industries, little definitive research has been conducted within Australia. This is important for providing the nut industries with the tools to push nut trees to growth and crop limits. In doing so we would have the potential to more rapidly expand and increase the value of the Australian nut industry.

Sentinel plantings, located in the regions defined in the bioclimatology model, would help assess the realistic regional productivity. By actually planting nut trees at different locations we would be exposing the trees to the full range of conditions in each of the identified areas.

Recommendations

We recommend:

- Using the models to narrow the scope of potential regions for nut industry expansion.
- Initial use would be to guide sentinel plantings to assess the productivity within the predicted regions.
- In addition to the information provided in the models and information packs, specific site analysis should be conducted to more accurately determine soil suitability and water availability as these can dramatically differ within a small area.
- The resources suggested in information packages should be consulted for further information regarding risk factors. Local sources of information pertaining to risk factors should also be consulted.
- Information packs provide some background information and instructions for using the models and the user would benefit from accessing both resources.
- New growers select sites based on regional suitability and objective analysis to maximise their chance of profitable endeavours.

Scientific Refereed Publications

Intellectual Property/Commercialisation

No commercial IP generated

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Acknowledgements

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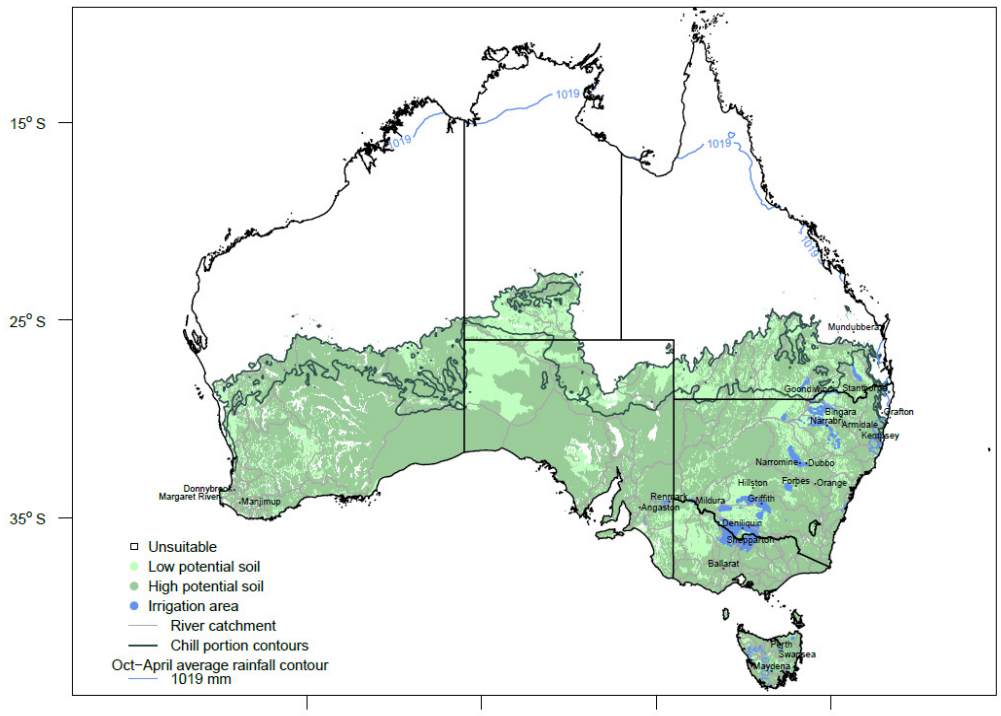
Appendices

Appendix 1 - Predictive Maps

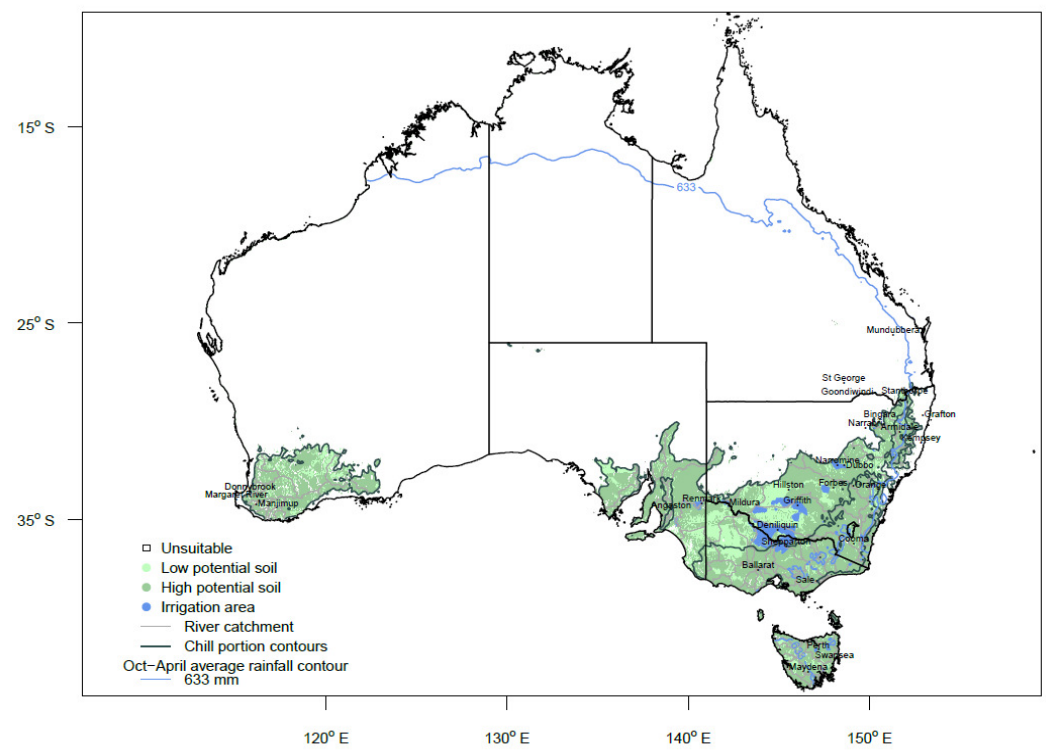
Appendix 2 – Temperate nut industries “how to” access guide

Appendix 1. Predictive models for Australian temperate nut industry expansion - Australian regions where chill portions are sufficient for nut production. Areas with deeper shading are more suitable.

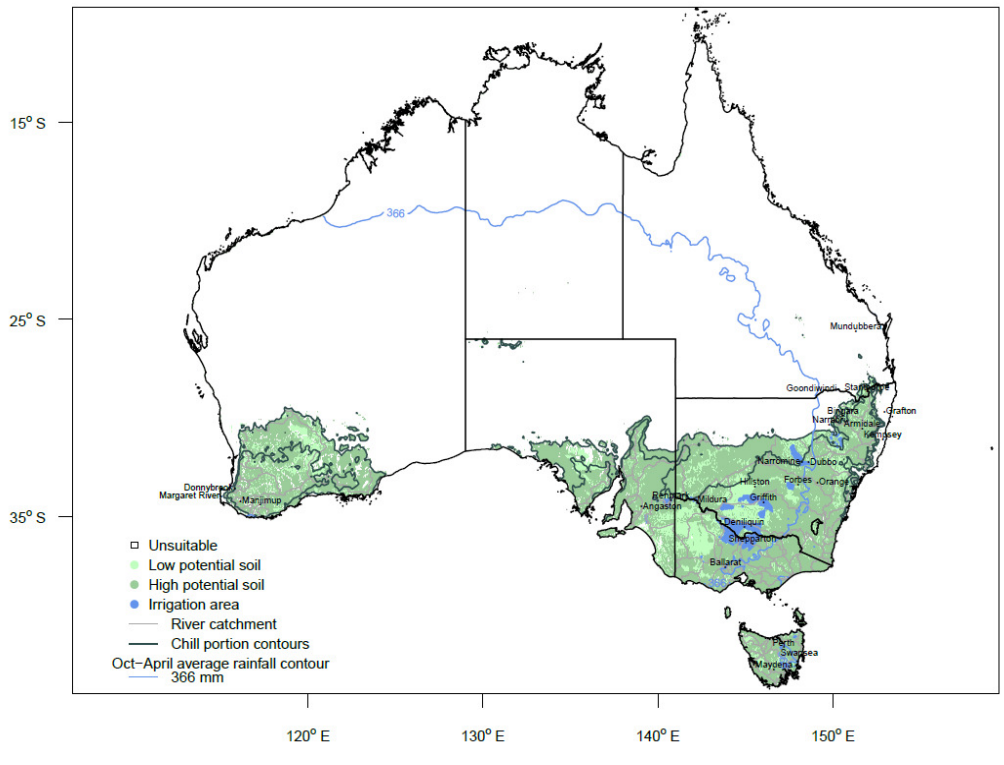
Almond



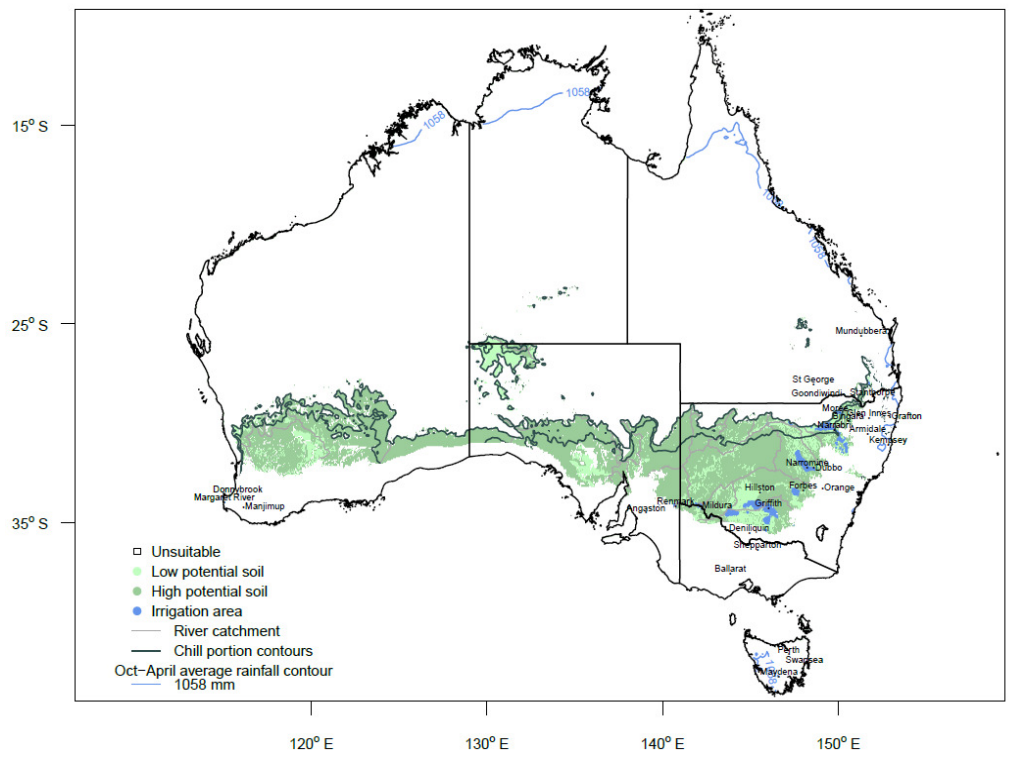
Chestnut



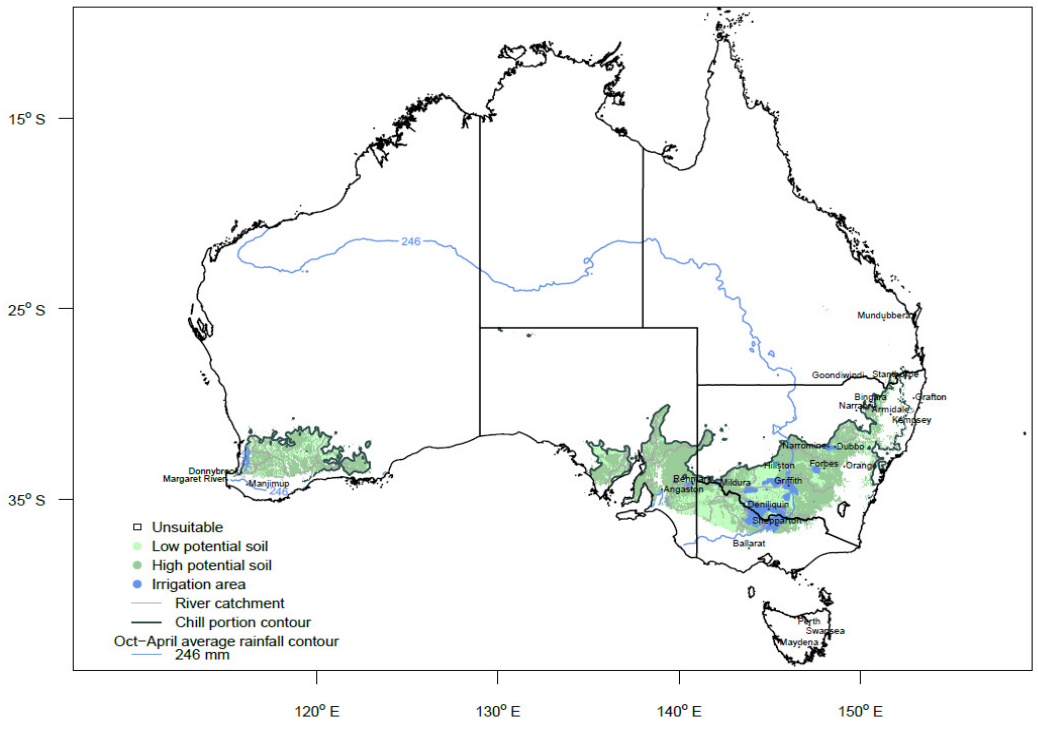
Hazelnut



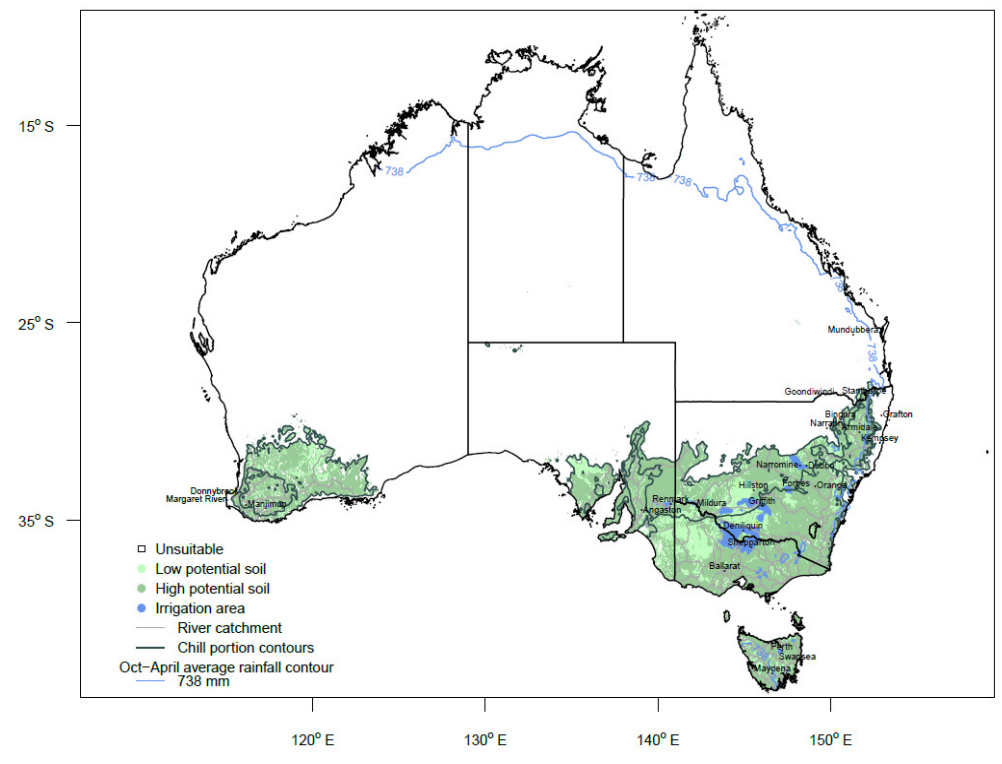
Pecan



Pistachio



Walnut



Appendix 2. Summary page with details to access the outputs of this project (included to assist in direction to these outputs as necessary)

Department of Primary Industries

BIOCLIMATOLOGY MODEL FOR

Temperate Nut Industries' Expansion

November 2015

We have developed predictive models to guide the expansion of the temperate nut industries (Almond, Chestnut, Hazelnut, Pacan, Pistachio and Walnut). Information packs have been created to accompany these models. These are web based resources, available from both the NSW DPI and Australian Nut Industry Council (ANIC).

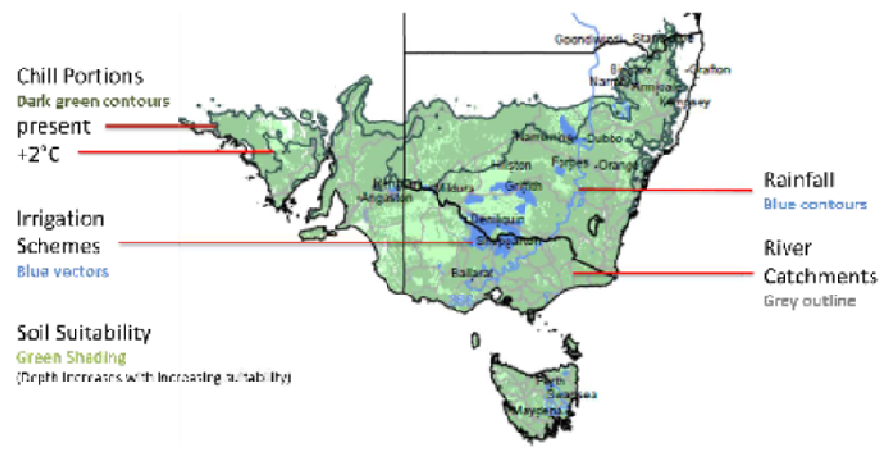
The models generated are available online as an extremely high resolution maps. These maps are able to be interrogated, by zooming, to a resolution of 5 x 5km. The models are each based on bioclimatology and the phenological requirements of Almonds, Chestnuts, Hazelnuts, Pecans, Pistachios and Walnuts. As such models are inclusive of:

- Chill and heat requirements – Critical factor, calculated using Dynamic Chill Portion Model, heat units only for Pecans and Pistachios
- Water Availability - Rainfall, river catchment areas and irrigation schemes included, further suggestions for information on river systems
- Soil Suitability – varies locally and highly amendable, general information only and not a limiting factor

There are some limitations in the models, which are addressed in the information packages. These include:

- Inclusion of filters or layers for risk factors (e.g. late spring frosts, excessive heat) – resources and information regarding these are included in the information packages.
- Australian based information due to limited pool of knowledge - The values and properties used to generate these models are largely based on international research

Interpreting the Model – example using hazelnut industry model



Accessing Online Resources

Online resources are accessible through e NSW DPI website at www.dpi.nsw.gov.au/factsheets

Enter a search term (e.g. almond)
OR
Click on Agriculture Factsheets

Click on Horticulture

Browse through fact sheets for relevant industry expansion link (i.e. Pistachio industry expansion, or Chestnut industry expansion, etc)

The information packages and maps are available as PDFs. You may need to download a PDF viewer to do this (available from https://get.adobe.com/reader/)

Once open use the magnification options at the top of the window to increase the zoom (alternative - hold [CTRL] and use the mouse wheel) and the sliders to the right and bottom of the screen to pan (alternative – hold [SPACE] and click /drag the document).

Acknowledgments

This project has been funded by Horticulture Innovation Australia Limited using the almond and chestnut industry R&D levies, co-investment from the Australian Nut Industry Council and funds from the Australian Government

For updates go to www.dpi.nsw.gov.au/factsheets

Published by the NSW Department of Primary Industries.[Insert Reference number]