PFR SPTS No. 23011

Growing an Almond Opportunity

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September 2022

Confidential report for:

Central Hawke's Bay District Council
SFFF21152

PUBLICATION DATA

Graham D, Vetharaniam I, Phelps T. September 2022. Growing an Almond Opportunity – Summary. A Plant & Food Research report prepared for: Central Hawke's Bay District Council. Milestone No. 94409. Contract No. 40253. Job code: P/442101/01. PFR SPTS No. 23011.

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September 2022

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The following reports appear in order as below:

Executive summary

Growing an Almond Opportunity – Summary

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September 2022

Summary

Growing an Almond Opportunity is a desktop research project, funded by the Ministry for Primary Industries through their Sustainable Food Fibre Futures Fund with co-funding from Central Hawke's Bay District Council, Hawke's Bay Regional Council, Hastings District Council, Wairoa District Council and Pic Productions Ltd. The community of interest includes Ngati Porou, Tātau Tātau o Te Wairoa Trust, Taiwhenua o Tamatea and HB Future Farming Trust. The project investigates the feasibility of establishing a New Zealand almond industry based on a premium quality product, produced using sustainable agronomic practices.

Three reports have been produced:

1. A consumer market research report, The premium market & the conscious consumer (Plant & Food Research Stakeholder & Consumer Intelligence Team).
2. An economic analysis report, Economics of Almond production in Central Hawke's Bay, New Zealand (AgFirst Hawke's Bay).
3. A land use and climate suitability modelling report, *Suitability modelling and life cycle analysis for almond cultivation in Hawke's Bay and Poverty Bay* (Plant & Food Research Land Use Impacts Team).

The key findings and recommendations from each report are outlined below.

Also included in this summary report are key risks and mitigations for consideration if looking to grow almonds.

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1 Economic analysis report

1.1 Objective

This project set out to analyse the economic feasibility of almond production in the Central Hawke's Bay. Through the use of capital budgeting, multiple scenarios have been stress-tested to help develop an economic budget that a grower can use to base their own almond orchard investment on.

The project has provided:

- The economic information needed for potential adopters to invest in almond growing;
- A detailed report on the major economic factors influencing the viability of growing almonds in Central Hawke's Bay;
- References to the model including expected cost breakdown, return and yield figures, development budgets, cumulative cash flow, and internal rate of return (IRR) results.

A whole business farm approach over a 15-year period was analysed to produce results categorised by several different performance indices. These included total business performance and cost analysis.

Two models were created and stress-tested with variations in price/kg and yield/ha to analyse their effect on economic performance indices over a 15-year period. The models included development budgets which assumed the development of a 10 ha almond orchard. The two models are referenced in the report as:

1. Normal/high input system. This system assumes full irrigation is installed and run. Benefits seen from overseas experience (although limited here in New Zealand) are an increase in productivity and quality/size of almonds.
2. Low input system. There is speculation in New Zealand as to whether almonds require irrigation. Therefore, using the experience and evidence of existing almond producers, this model assumes production and quality is reduced without the upfront development cost of irrigation installation (including bore, headworks and reticulation).

1.2 Key findings

- This study identified that with the right inputs and management structure, it is feasible to invest in an almond enterprise. With no existing industry, in the Hawke's Bay Region it is important to realise assumptions made are to the best of our knowledge and research at this time, and factors such as price per kg of kernel may change.
- This study has highlighted the importance of yield on financial performance in the short and long term. Therefore, it is recommended more research is focused on areas such as irrigation best practice, nutrition and pest and disease control, in a New Zealand context.

- The other key highlight is the influence price has on a 15-year IRR. More research needs to be completed to identify the size of the market and the range of different revenue streams that can be utilised with the production of class 1 and class 2 almonds. Additionally, more research needs to be completed on the requirement for a processing industry to dry and package almond products.

	Normal input system	Low input system
3-yr average yield	2.7t/ha	2.0t/ha
Price per kg	$20.00/kg	$20.00/kg
Cost of production	$6.88/kg	$9.14/kg
Development costs	$71,716/ha	$62,096/ha
Breakeven year	12	17
Internal rate of return (IRR) after 15 years.	5.5%	-4.9%

Two models were created and stress-tested with variations in price/kg and yield/ha to analyse their impact on economic performance indices over a 15 year period.

The sensitivity analysis suggests for a normal input system IRRs after 15 years could range from −19.5% to 32.2%, depending on yield and price performance. With experience from New Zealand growers, we know that with irrigation and passive management it is possible to achieve 2.5–2.7 t/ha. Thus, the likelihood to achieve greater than 2 t/ha over a 3-year average is relatively high.

Price will depend on the market and its potential size in relation to the supply. New Zealand almond growers have reported regularly achieving greater than $35/kg for their products. However, it is of AgFirst's opinion that the demand at this price point could be limited and therefore the price will not stay as high.

2 Landuse and climate suitability modelling report

This report details the outcomes of a study to perform land and climate suitability modelling and a carbon life cycle assessment (LCA) for almonds to support the development of a new sustainably produced almond sector in the Hawke's Bay/Gisborne regions.

The aim of this study was to:

- Apply a model previously developed by The New Zealand Institute for Plant and Food Research Limited (PFR) to evaluate the suitability of almond cultivation using GIS-based information on soil, terrain and weather to identify the most suitable locations in Hawke's Bay and the East Coast, and the most suitable almond phenotypes (in terms of chill and warmth requirements), for the production of sustainably produced almonds.

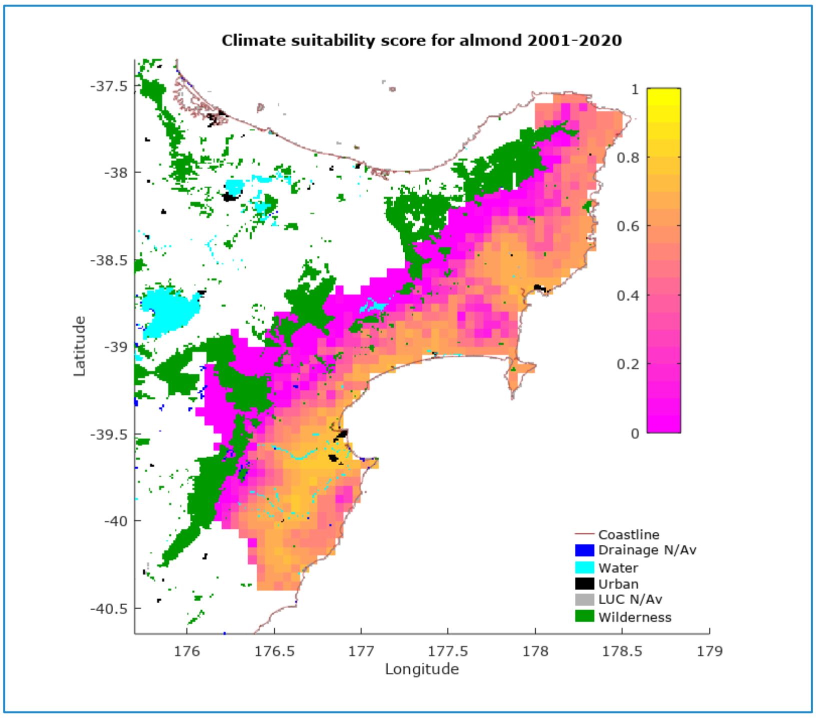
- Use LCA to evaluate the potential carbon footprint associated with growing almonds in the Hawke's Bay, and identify 'hotspots' with the production systems.
- Investigate how climate change could impact the suitability of individual locations under different scenarios of future atmospheric greenhouse gas (GHG) concentrations (and thus different levels of global and regional warming).

2.1 Suitability modelling

Suitability modelling was carried out for a number of criteria related to climate, soil and terrain considerations. Climate-related criteria included sufficiency of winter chill and warmth accumulation for flowering, adequacy of temperatures for pollination, frost risk, moisture-related disease risk, warmth accumulation for crop maturity, risk of rain damage to nuts around harvest, and adequacy of annual rainfall. Soil and terrain criteria included sufficiency of soil depth, sufficiency of drainage, steepness of land, and appropriate land use capability class.

Key findings:

- The modelling results showed that suitability for cultivating almonds is highly variable across both Hawke's Bay and Gisborne regions.
- A number of locations were identified that could provide good conditions for growing almonds, although subject to some limitations to achieving maximum production potential. Some locations in the Heretaunga Plains, especially around Hastings and Havelock North, were found to have the highest cultivation suitability scores, with a number of locations in Central Hawke's Bay District having slightly lower cultivation suitability scores.
- A number of locations around Poverty Bay and inland of the Poverty Bay Flats were also identified as having good suitability scores. Although these locations are likely to be subject to more limitations or extra mitigation costs, they are potential sites for successful almond orchards.
- Large areas of Central Hawke's Bay District and areas around Hastings and Napier were identified as having insufficient annual rainfall to obtain maximum yields without irrigation. However, growers can choose not to irrigate almonds and accept low yields.



Overall suitability for growing almonds in Hawke's Bay and Gisborne areas – yellow/orange indicates best growing conditions – where 1 is very suitable and 0 is not suitable at all.

2.2 Climate change impact

This study investigated how suitability for almonds would change in these regions under two greenhouse gas emission scenarios.

Key findings

- The climate change impact assessment projected that under Representative Concentration Pathways (RCP) 8.5, a high GHG concentration pathway consistent with unabated emissions, cultivation suitability for almond would improve over time, at least to 2070.
- Under RCP 6.0, a GHG concentration pathway consistent with lower emissions than RCP 8.5, cultivation suitability for almond was also projected to improve, but at a slower rate than under RCP 8.5.

2.3 Life Cycle Assessment (LCA)

This study evaluated the potential carbon footprint associated with growing almonds by performing a partial LCA from 'cradle' to the farm gate, rather than cradle to the grave.

Key findings

Energy requirements per unit of water for irrigation will be orchard specific, and vary with the irrigation system, the nature of the water source and its distance to the orchard. In the absence of adequate information on this, irrigation inputs from the LCA software database were used, which reflects a mix of energy sources.

Key findings

- A partial LCA showed that 1kg of almonds at the farm gate has a potential carbon footprint of between 0.59 kg CO_2^{-eq}/kg (unirrigated sites) and 1.83 kg CO_2^{-eq}/kg (maximally irrigated sites).
- For comparison, studies for almond production overseas found the potential carbon footprint to be between 1.6 and 1.9 kg CO2-eq/kg.
- Energy for irrigation was highlighted as a potential system hotspot and an area of consideration for system improvements, accounting for 68% of the total footprint under the case of maximal irrigation demand and a mixed energy source for pumping equipment. This is followed by machinery operations (13%) and fertiliser use (9%).
- Sensitivity analysis revealed that a reduction in the applied irrigation could significantly reduce the overall potential footprint. This may, however, have a negative correlation with the overall potential yield.
- Orchard specific data were limited; therefore, a number of assumptions have been made in the design of the LCA model. It is advised that LCA results are considered alongside other information.
- Future assessments should focus on data quality to improve the reliability and robustness of the current LCA model. Further considerations may include expanding the system boundary or the effect of by-product utilisation for other processes.

3 Consumer market research report

3.1 Research objectives

Undertake consumer focus groups with almond purchasers who also identify as conscientious consumers, to understand the following:

- Given a choice, would consumers prefer to buy a sustainably produced New Zealand almond in favour of an imported alternative?
- Would they be prepared to pay a premium for a local product?
- If they are prepared to pay a premium, what is the approximate size of that premium?

Method

- Used a qualitative research approach, utilising focus groups amongst a semi-targeted sample, to enable in-depth exploratory discussion.
- Two online focus groups: 90 min each session, 11 participants (8 female and 3 male).
- Participants:
  - regularly purchase and eat whole almonds and/or almond products
  - conscientious consumers – consider things other than price when making grocery purchases i.e. health, environment, ethical production.

Key findings

- Key reasons almonds were chosen by these consumers were the perceived health benefits and their versatility and convenience.
- There was almost no experience from the groups of fresh almonds or New Zealand grown almonds, but a curiosity and willingness to try/explore.
- There was little knowledge regarding almond production, and low involvement in almond purchase decisions.
- There was low awareness of the association of bee population decline with almond cultivation in the US, but once it was mentioned it was an emotive topic. Opportunity for a bee friendly strategy for New Zealand?
- There was some frustration that the country of origin was often not provided on almonds sold in New Zealand so consumers were less able to make a conscious choice.
- While most of the small group of consumers said they would be willing to pay a premium for New Zealand almonds, the degree of price uplift was quite limited.
  - Double the price was unacceptable
  - 40% price premium – probably not a sustainable uplift
  - 20% to 30% price premium – least resistance to this possibility.

Future research

This was a very small sensitisation study and requires further research to draw more detailed conclusions and establish any potential for premiumisation:

- Additional focus groups to explore motivations for conscientious consumerism in almond consumption and purchase, as a means to best develop a compelling narrative to support the establishment of a premium New Zealand almond industry.
- Competition in the future healthy snack area could also be explored.
- Conduct a survey which uses the language, attitudes and emotions found in the focus groups to examine the broader New Zealand market.
- Understanding the more physical aspects of New Zealand almonds will be critical in establishing positioning and communications; sensory, nutritionals, shelf-life, residues etc.
- For the longer term, should export become a possibility, greater knowledge of the markets of interest will be required; understanding of usage and attitudes to almonds, potential for premium, gift market etc.

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Growing almonds in New Zealand - some considerations and associated mitigations

Considerations	Mitigations	Comments
Profitability: the study highlights the importance of good almond yields and high per kilo orchard gate return.	• Involves addressing a combination of some considerations such as, weather, water supply and irrigation, orchard design, cultivar selection and marketing. • Profitability compares favourably to grapes. • A better understanding of the NZ market size and future potential returns is needed. • Understanding potential costs for drying and processing is also required	At Gross Margin $12,270/ha, almonds compare favourably to grape growing in Hawke's Bay: • Hawke's Bay non-premium product $1,750/ha (2018) • Hawke's Bay Merlot is $6000 to $10,000/ha 2022. Central Otago Pinot noir gross margins $11,300/ha (2019).
Risks associated with climate and weather: frost, chill requirements for flowering, good weather for pollination, sufficiency of warmth to grow a crop to maturity, risk of rain around harvest and other times that can cause damage or disease to nuts.	• Suitable areas have been identified to a resolution of one square kilometre – more careful interrogation of sites by a local horticultural consultant will likely be required. • Alternative pollinators such as commercially available bumble bees could help address weather-related pollination issues. • Selection of early harvested cultivars or hard-shell varieties can mitigate against issues associated with rainfall at harvest.	There is a trade-off between rain for irrigation vs disease risk from rain, and the modelling suggests there are some areas where the trade-off has a good balance – a number of areas were identified as having high suitability, although not approaching a score of 1 where 1 is highly suitable. In colder climates where there is a risk of rain events or long periods of cold weather with high humidity. Hard shell varieties may be more suited as the shell can hold up to more aggressive handling and drying techniques. Hard shell varieties will also be less effected by weather but this would need to be balanced against market acceptance of almond quality, yield potential of these varieties and the cost implications of getting the fruit processed.
Water supply & irrigation: demand may increase under future scenarios.	• There is potential to manage trees differently to reduce water consumption – e.g. reduced leaf to fruit ratio as with planar/cordon tree architecture. • Site selection: flat with good drainage, adequate soil depth for root development and improved drought tolerance.	Almonds are closely related to peaches and nectarines – possibly more drought tolerant and likely to consume no more water than other types of summerfruit. For good yields, Hawke's Bay growers will likely need access to water rights.
The right cultivars.	• There are cultivars available that could be used for commercial production, e.g. from Waimea Nurseries. In addition, PFR has collected 'wild types' growing in Central Otago that could be evaluated for commercial production.	Worldwide the focus on Almond new variety and rootstock development is significant – current access within NZ has been historically very limited. Waimea Nurseries is keen to assist with identifying and importing more cultivars and rootstocks into New Zealand.
The right rootstocks.	• Currently 'Golden Queen' and Myrobolan plum are used – but	

Considerations	Mitigations	Comments
	are likely too vigorous. Alternative rootstocks that could be imported and investigated are Rootpac and Controller.	
Yield: optimised orchard design and tree architecture.	• There is an opportunity to evaluate intensive plantings with narrow rows and planar trees based on cordon and upright designs. These '2D' trees have already demonstrated a significant lift in summerfruit and apple orchard productivity in New Zealand.	PFR has research projects underway in both New Zealand and Australia investigating 2D almond trees and narrow rows for optimised yield. Low development input costs have been used in the initial profitability models and these calculations would need to be run again using the new costs and yields associated with 2 D systems. Optimising harvest with different growing system structures will also need careful consideration.
Labour and machinery: high value commodities such as apples can currently afford to hire large labour units to produce their crop. Crops such as olives, almonds and grapes become unprofitable with the same labour input and therefore need to utilise specific mechanical equipment to have a positive IRR.	• Specialist mechanical harvesting equipment is available, e.g. 'shake and catch' technology. • PFR is currently investigating new harvesting concepts for high producing planar/cordon almond orchard designs in Australia.	See new 'shake and catch' technology from Californian company Tenias TENIAS ALMOND HARVESTER - YouTube
No almond processing infrastructure.	The study has not evaluated processing requirements for almond groves, e.g. the tonnage and hectares required to support an almond processing facility.	Small-scale processing should be possible, e.g. as is currently undertaken for New Zealand grown walnuts, see Watch Hyundai Country Calendar S2022E29 | TVNZ+ (a Canterbury orchard enterprise, now one of the country's largest walnut orchards, works with local growers to process and sell walnuts).
Profitability will likely depend on achieving a price premium over and above commodity pricing of imported Californian and Australian almonds.	New Zealand produced almonds will need to be, at a minimum, as good as imports or consumers will not pay a premium (i.e. not soft and not rancid). • Think about who the consumers are and how they use almonds. Think about where you want to sell your almonds • Think about what the point of difference will be, i.e. the compelling reasons to support premium positioning (freshness, supporting local, eco-credentials, bee friendly, better taste and nutrition). • Think about the environmental footprint and the opportunity sustainably produced almonds from New Zealand offer compared with almonds from other producing countries.	See the following links to other New Zealand grown, minimally processed products with premium positioning: • Pinenuts – Pinoli premium pine nuts - New Zealand grown – Pinoli Pine Nuts • Hazelnuts – Home - Hazelz New Zealand, Fresh New Zealand Hazelnut Products • Saffron – Kiwi Saffron • Macadamias – Macadamia Nuts NZ - Torere Macadamias - Gisborne, New Zealand All offer good examples of the storytelling – provenance, terroir, imagery and credentials that support a premium proposition. • See also Outstanding NZ Food Producer Awards (outstandingfoodproducer.co.nz) to see how aspirational credentials support super-premium positioning.

4 Research to progress an Almond Industry in New Zealand

A future SFFF project would progress the development of an almond growing industry in New Zealand; the project would be a collaboration between MPI researchers, growers, nurseries Iwi, almond processors (such as producers of almond milk and almond butter) and horticulture investment entities.

Proposed research activities

1. **Investigate and import top performing almond cultivars and rootstocks**

- The initial research activity would be a desktop study to identify the top performing cultivars in Australia and California that would be most suited to New Zealand's growing environment. Suitability would be based on the modelling methodology used in PFR's report *Suitability modelling and life cycle analysis for almond cultivation in Hawke's Bay and Poverty Bay*.
- A next phase would involve working with nurseries to import the top five cultivars and top three rootstocks – potential rootstocks are likely to be from the Rootpac® series and Controller series.
- Research related activities would include:
    - Visit to Australia and/or California to investigate plant material (including self-fertile varieties to address pollination concerns) and growing systems

Note: the process of importing plant material and establishment in the field could take up to five years.

2. **Establish regional commercial trials in four different regions of New Zealand to assess productivity, suitability and sustainability**

- Using the almond varieties currently available in New Zealand, plant commercial-sized blocks on grower properties in four regions of New Zealand: Hawke's Bay, Central Otago, Marlborough and Canterbury.
    - Trial different varieties and growing systems – utilise learnings from Plant and Food Research's planar growing system project in Australia
    - Assess productivity in each region by collecting data on flowering, pollination, yield and quality.
    - Commit to a target of 3 T/ha of kernels at maturity – this would be a stop/go for the industry.
- Improve the sustainability of almond growing
    - Measure water use of mature trees in each region and compare with other fruit crops
    - Identify areas where pollination can be improved upon, for example the use of self-fertile varieties, bumble bees and other innovative pollination techniques such as micro-hives.

Utilise learnings from PFR Australia's projects investigating harvest machinery for new growing systems and almond drying processes.

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Growing an Almond Opportunity!

Theme 3: The premium market & the conscious consumer

Stakeholder & Consumer Intelligence
Tracey Phelps & Denise Conroy

The New Zealand Institute for Plant and Food Research Limited

Background

- Currently 80% of the world's almond supply is grown in California, US, where there is increasing focus on the unsustainability of almond production. There are growing pressures to reduce water use and address the impact on bee populations and the wider eco-systems. Australia is the world's second largest almond exporter and is also increasingly experiencing extreme drought conditions.
- New Zealand imports $41M worth of almonds annually, mostly from these two countries.
- MPI is currently funding a small project (via SFF Futures) to examine introducing alternative crops into various regions of New Zealand. One potential crop is almonds, which are known to grow well in the same geographical areas as wine grapes. As part of this exploration, the Plant & Food Research, Stakeholder & Consumer Intelligence team has been asked to do a preliminary study to explore New Zealand consumer attitudes towards purchasing almonds grown in New Zealand.

Research Objectives

We will undertake consumer focus groups with almond purchasers who also identify as conscientious consumers, to understand the following;

- Given a choice, would consumers prefer to buy a sustainably produced New Zealand almond in favour of an imported alternative?
- Would they be prepared to pay a premium for a local product?
- If they are prepared to pay a premium, what is the approximate size of that premium?

Research Approach

Method

- We used a qualitative research approach, utilising focus groups amongst a semi-targeted sample, to enable in-depth exploratory discussion in alignment with the research aims.
  - Focus groups are ideal for getting to understand what drives the target market. They can reveal what values drive consumers from consuming or rejecting products and, importantly, why.
  - They allow the targeting of different groups within a purposive sample (premium, conscious consumers in this case). For example: younger people who may be values driven, older people who may be health driven, people who prioritise the environment, people who prioritise seasonal, people who prioritise natural, and/or people who are time poor and want healthy, premium, processed foods etc.
- This investigation was intended as a high-level scoping exercise among a small number of consumers, to support the objectives of the overarching feasibility study. The budget for this exercise was limited, thus an economical approach was designed to achieve as many directional insights as possible.

Online focus Groups

Images are for illustrative purposes only, the identity of all participants remains anonymous

To accommodate the limited budget and continuing COVID-19 limitations, the focus groups were conducted on-line, using Zoom.

Two online focus groups
- Wed 27 and Thu 28 April 2022
- 90mins Zoom meetings
- Total N=11
  - females n=8; males n=3
  - 18-35yo/young=6; 35yo+/mature n=5

Participants
- Regularly purchase and eat whole almonds and/or almond products
- Conscientious consumers: consider things other than price when making grocery purchases (ie. health, environment, ethical production, etc..)

Recruitment

- Recruitment was carried out among personal contacts of the research team, and was extended via snowball sampling.*
- A short recruitment advertisement was developed and shared via email to identify relevant participants. Refer to Appendix.
- All participants were current and regular consumers of whole almonds and almond products.
- All were self-declared conscious-consumers
  - *conscious consumers* are people who may be values driven or health driven; people who prioritise the environment, seasonal, natural; people who are time poor and want healthy, premium, foods etc.).
  - We believe that these are the future consumers for sustainable, locally grown, almonds.

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* *snowball sampling: where existing contacts or study subjects, recruit from among their acquaintances*

Conscious Consumerism

The premium market and the conscientious consumer

Consumer values are shifting and many premium consumers are now focused on products which are:

- Local and seasonal (from concern for carbon footprint to food safety)
- Ethically grown (from environmental concern to fair wages)
- Animal wellbeing is considered (bee health)
- Healthy, delicious and high quality

"Being ethical in our activities and telling the stories about this, attracts consumers with the same values to our food and fibre products "

Agriculture, Food & Fibres Sector Vision and Strategic Direction Towards 2030

What our conscious consumers had to say

The 11 participants in this study each indicated that when making grocery decisions they were not entirely driven by price. To get the focus groups underway, we began with a warm -up discussion about the specific things that these people purposefully avoided, and sought, when shopping for food (not specific to almonds at this stage).

AVOID

- excessive and unnecessary packaging
- overly processed foods
- imported products
  - unsustainable practices/brands
  - unethical practices/brands
  - GMO

SEEK

- locally produced
- transparency of country of origin (COO)
  - trusted brands/COO
- freshness
  - good eating experience
  - health-supporting products

Why are they avoiding…

Excessive and unnecessary packaging?

- Excessive and unnecessary, especially plastic, packaging was mainly viewed as being bad for the environment, unsustainable, and was seen as a chore to dispose of.
- Additionally packaging on fresh produce was perceived as unnecessary by some as it did not allow for selecting your own items of produce, avoiding damaged items, choosing the size you want etc.

"I try and buy things in bigger quantities, in bulk so I'm not buying lots of small you know, plastic things each week I'd rather buy one big thing so that I don't have tons of plastic on my hands" (Natalie, young female)

"I personally try and stay away from prepackaged foods….because of the environmental factor you know, saving on plastic but also because you can actually pick, and kind of feel the produce" (Cathy, young female)

"sometimes some things need plastic to keep them fresh. And I know that there's maybe not alternatives for that yet. So I'm not always avoiding it, but just if I think that it's there and it doesn't seem to have a purpose, and they could've done something else" (Ruby young female)

Overly processed foods?

- Overly processed foods were perceived as 'not real' food, not 'natural' and containing chemicals/additives.
- The terms 'chemicals' and 'additives' were highly charged negative terms and were linked strongly with negative health connotations.

"I don't like to buy anything with preservatives. Anything with chemicals. I always go with the natural things. natural food. Yeah, it's one of the health concerns". (Evelyn, mature female)

"Often, you know, E numbers. So chemicals that I know aren't just some sort of preservative or whatever. If there's a long list of chemicals, that's a real no no! So whats in the actual product is so important to me." (Nicola, mature female)

Why are they avoiding…

Imported products?

- While damage to the environment associated with the high transit-miles required to import foreign products was a frequently cited reason for avoidance, the key reason was that most participants were strong advocates of buying New Zealand-made products.
- This was predominantly motivated by quite practical reasons, such as freshness, supporting local businesses, availability and cost, rather than the higher level conscious consumerism drivers.
- There was some mistrust around foods from other countries, in particular China and the US, that reflected a suspicion of production processes and doubts about ethics. It was interesting that recall of the precise nature of the information upon which these perceptions were based was in most cases very vague, but still influenced attitudes strongly.

"…if they're New Zealand grown, it's going to be better quality, that they haven't had to travel as far to get to me, or to get into the supermarket" (Kelly, young female)

"Well, it's not particularly things I avoid like countries of origin particularly, but I like buying things from New Zealand or Australia coz I don't want my food shipped to me, you know, halfway across the world. Mindful of my carbon footprint I guess. So. It's not like I'm saying there's certain countries that I don't want, but I want things that I know they're coming more locally than halfway across the world" (Natalie, young female)

"It was so long ago it was in quite frankly, it was just a horror story that just stuck and now I just stay away from peanut butter from China Yeah, and I don't know whether it was the labour, or how it was grown? Stupid isn't how things stick" (Wendy, mature female)

Reasons for seeking…

Locally produced foods?

There was strong advocacy for New Zealand grown produce amongst all participants. This was grounded in trust for the quality and processes used here, it was supportive of New Zealand people and their businesses, and there was a sense that local produce was going to be fresher as it had not travelled to be here.

There was a widespread perception it was better for the environment to source locally, as it avoided the associated transit-miles of imported goods. If not New Zealand, then Australian produce/products were seen as the next best thing.

"So definitely New Zealand or Australian products…. It's about food miles. It's the freshness that you know, supporting New Zealand growers. Yeah. all, really important reasons for me to buy local, if possible." (Nicola, mature female)

"I know that generally our growers are very good with the way that they use minimum amount of chemicals, so I think it's, it's, it's all down to that pretty much is that trust in the growing system?" (Hugh, mature male)

Transparency of country of origin?

Given that most of the participants in this study were keen supporters of locally sourced products, it was no surprise that there was a sense of frustration at perceived lack of transparency of the COO of ingredients/products in retail. Many commented, if they knew that a product had New Zealand provenance, they would be willing to pay more for it.

As mentioned previously, some participants actively avoided products imported from particular countries, thus they wanted to be able to identify products of these origins.

Additionally, others were keen to know COO so that they could make informed choices, which could also be added by the use of credentials/certifications.

"…like avoiding food products that you know are in terms of like are they really sustainable? Or what type of ethical practices, for instance, more transparency now with especially agricultural companies, so we require, we also evaluate, what type, what are their farming practices and are the employees treated fairly? So that sort of certification." (Tom, young male)

"Quite often you'll find packaged in New Zealand, but usually you'd have no idea where they were sourced, unless you do a lot of Googling" (Wendy, mature female)

Reasons for seeking…

Freshness?

» Alongside the previous reasons given for preferring local products was the perception that they would be fresher.

» We did not explore the perceived benefits of freshness specifically, but these quotes suggest fresher tastes better, potentially has more nutrients, and is likely to present fewer unfavourable sensory attributes, such as rancidity.

» On-pack dates and various visual cues are used as indicators of freshness.

"I grew up on a farm so I kind of have always had that mentality that fresher is better and you know, homegrown is always better as well." (Cathy, young female)

"…and they probably keep some of the nutrients (if fresher),some of them might degrade a bit." (Hugh, mature male)

"I always check thedate, I always get the latest date. I cannot stand rancid almonds , which I had, you know, when I was growing up, everything seemed to be rancid in the old days and so they are as fresh as can be" (Nicola, mature female)

Almonds

Reasons for consuming

Almonds for health

Health was the most mentioned reason for consuming almonds in this small study.

- Participants associated almonds with providing; healthy fats, fibre, high protein, keeps you fuller for longer, good for blood sugar levels, vitamin B12.
  - Retaining the skin was perceived to offer greater levels of "antioxidants".
- Nuts and seeds featured strongly in vegetarian diets as an alternative source of protein, as well as providing nutrients and minerals.
- Those with lactose/gluten intolerances and allergies looked to almonds as an alternative milk and baking ingredient.
- Overall, there was a general perception that almonds were a healthier option compared with other processed snacks.

"So basically I'm pre diabetic. So it's a good sort of reasonably high protein snack. It's got a lot of fibre in it, so it doesn't affect blood sugars as much and not a lot the taste and a lot the crunch". (Hugh, mature male)

"'I use almond flour in baking because it's better for your blood sugar….and then it's got better healthy fats in it and stuff and keeps you fuller for longer. So that's probably the health benefit. Higher in fibre as well." (Ruby, young female)

"I'm a vegetarian, so I eat lots of nuts and seeds and grains…..I'm definitely looking at the health benefits of nuts." (Nicola, mature female)

The almond eating experience

Most participants consumed almonds as a raw or roasted whole nuts. While they generally enjoyed the flavour and crunchy texture of almonds, an optimal eating experience seemed to be defined more by the absence of the negative sensory attributes; rancid flavour and/or soft texture

- A good flavour and texture experience was associated with freshness, while nuts that were older or had not been stored well were linked with softness and rancidity.

Avoiding a bad almond eating experience

- There was some frustration that the eating quality of almonds can vary, and is not easily predicted before trying.
- A few people had strategies to minimise the potential to select a bad batch of almonds; dates on pack, visual cues (shrivelling, shrinking, shape), only buying from large stores with high stock turnover, and brand (learned from experience).
- Some participants froze almonds to extend their shelf-life and freshness, or dried them in the oven if they were too soft.

"I think for me probably a good almond and there's you got flavour and then you got crunch. I think good almonds are quite crunchy. You can get some really bad ones that are quite soft." (Hugh, mature male)

"I have noticed the quality of the almonds I buy from the bin differs. Some days….they are really crunchy, and the flavour is really nice. And some days they are a little bit soft. So I had to put these almonds to the oven for few minutes to get the right crunch. So I don't know whether it's because they come in different batches."–(Evelyn, mature female)

"Sometimes when they stay longer on the shelf, they have that funny taste, which from the from the oil, nuts oil usually have that funny taste. And I really hate that. So then I'm buying the roasted if I cannot find the fresh" (Adam, mature male)

"I always check the date, I always get the latest date. They must hate me because I root through all the packets but anyway. And I put them in the freezer. Oh, that's where that's the place to keep your nuts because it keeps them fresh" (Nicola, mature female)

Almonds are versatile and convenient

The versatility of almonds was a valued characteristic.

While most participants ate whole raw or roasted almonds, many also used processed almonds as ingredients in baking (almond meal, sliced almonds, etc.), and others consumed almonds as almond milks and almond butter. One participant even made her own almond butter.

Being dry, sturdy, small, lightweight, non-messy made them a convenient and easily transportable snack.

While eaten on their own by many, others mixed their almonds with other nuts to provide greater sensory interest as well as a broader nutritional profile.

"I use them in lots of different things like baking and making almond butter. yeah, they're just quite versatile. And they're good for snacking on." (Ruby, young female)

"I really like almonds because they're really convenient and also a healthy snack. So I'm a PhD student so I spend a lot of time at my desk at work, doing quite long hours. So I like having food available to me that's convenient, really easy to have at my desk, but also, it's slightly more healthy than having things like muesli bars packed with sugar." (Natalie, young female)

"I also supplement them with other more expensive nuts, but they're more of a treat. You know, in a few days, I might have a few pistachios or I might have a few Brazil nuts for the selenium. So I'm definitely looking at the health benefits of nuts" (Nicola, mature female)

Almonds were childhood snacks for some – looking to exports?

While one of the (mature) New Zealand participants recalled almond trees growing when they were a child, they did not mention eating the nuts. While two people who grew up overseas (Sri Lanka and China), both talked about eating almonds as a snack in their childhood.

It will be important to understand consumer usage of and attitudes to almonds in different countries if export of a New Zealand product is ever contemplated.

"Even as a child I used to eat almonds. Yeah, but I was born in Sri Lanka, it was really expensive in Sri Lanka. And most of the time, you don't actually get the right kind. But after moving to New Zealand, I started eating almonds a lot. And I still like it. For my baking, and also normal." (Evelyn, mature female: Sri Lanka)

"Well, for me is different to others because like when I was little don't have the chips, I don't have the lollies. My parents just gave me the almonds. Like, when I got a memory, I have the almonds as a snack." (Annie, young female: China)

Almonds
Purchase behaviour

Almond products purchased by participants

Brands purchased

- Countdown
- Graze
- Macro (Australian almonds)
- Mother Earth
- Pak & Save - Pams
- Tasti
- Bulk Food Store- loose almonds
- Good For Refillery- loose almonds
- Pak & Save - loose almonds
- Fix & Fogg - almond butter
- Sanitarium So Good- almond milk

Formats purchased

- Roasted
- Raw/natural
- Flavoured - tamari, spicy (chilli & lime)
- Mixed with other nuts/dried fruit/scroggin
- Ingredients- slivered, ground
- Chocolate dipped
- Milk
- Butter

What was clear was that participants did not necessarily shop around for their almonds; they tended to purchase what was readily available in the place they typically shopped. The Graze brand was unknown to Countdown shoppers, while the Macro brand was unfamiliar to Pak & Save and New World shoppers.

Reasons for purchase choice

- Format
- Familiarity, previous experience has proved acceptable taste and texture, volume, price
- Flexibility of volume
  - Via loose almonds in bulk bins
  - Pack size
- Price
- Country of origin
  - Preference for local
  - Reducing transit miles
  - Avoiding specific countries (US, China)
- Flavour options

There were a number of reasons given for almond purchase choice.

- First and foremost being the format, depending on the anticipated use of the almonds.
- In most cases each person had a preferred brand (inc. loose) based on their previous experience with this product. They had established that the taste and texture were aligned with their expectations, the volume suited their needs and the price was acceptable.
- If purchasing outside of their regular format/brand, the volume required and price became the dominant drivers of choice.
- Only two people mentioned purposefully seeking almonds from a specific country of origin, though most wished that local almonds were available.
- One person was loyal to a particular brand because of the range of flavour variants that it offered.

Transparency of country of origin of almonds

Most participants displayed a strong preference for locally produced products. Though very few were aware of the origin of the almonds that they regularly purchased, they did know that they were imported. Several commented that the specific country of origin was often not provided on the pack or at point of purchase.

Two people specifically sought the Macro brand (Countdown), as these almonds are clearly labelled as Australian on the pack. The rationale for this preference was different for each person;

"I buy the Australian almonds. It's the Macro brand. Yes from it is Countdown. The reason why I buy the Australian almonds is it's either that or I think the Californian almonds, I think about food miles. But I also think I have read about some of the processing in terms of export of almonds from the United States. And I think there was something that put me off, what they actually do to the almonds for export. So I thought, I liked the ones that the packet that says Australian almonds, so I always buy those" (Nicola, mature female)

"I'm concerned about US products, because US is working a lot on genetic modification….US will be the last I will choose. When I'm buying pre packed. I'm reading and looking for Australian." (Adam, mature male)

In each focus group the moderator provided some information about the environmental impact of large-scale almond cultivation in California (refer to slide 26), after which several people recalled hearing about some of these issues, though not to the point where it was affecting their purchase decisions. 'Nicola' was the only person who spontaneously mentioned avoiding specifically Californian almonds based on information that she had heard.

While not specific to almonds, a few recollections of information about potentially unethical food practices in China had initiated some bias against foods from here – though the facts were vague.

"I'm very choosy about which countries I will purchase products from. I'm afraid that I am often sceptical even with organic material, from China. I have some issues with the validity of some claims made." (Nicola, mature female)

Almonds
Existing knowledge

Unprompted knowledge/awareness of almond production

Participants were asked if they knew where almonds were grown, and if they knew anything specific about how almonds grow and/or almond cultivation.

» There was very low awareness of how and where almonds were grown generally.

> *"it's like a fruit, isn't it? its a stone of fruit?" (Hugh, mature male)*

> *"I didn't even know how they were grown, this is probably going to sound really bad but I didn't even know that New Zealand didn't really make almonds." (Cathy, young female)*

» Only one person was familiar with almonds growing on trees, and the specifics of what they looked like, though this was not experienced in New Zealand.

» A few people had vague recollections about aspects of almond cultivation that they had heard about (high water usage, bee population decline), but these did not appear to be impacting their purchase decisions.

» Almond production has been the topic of two recent documentaries that were mentioned, one about association of Californian almond production and the decline of bees, the other about almond farming in Japan.

> *"I watched this documentary on Netflix. Yeah, it was called Rotten...it was about bees. And there was a part in that, and they showed you like the almond production in California and just like the huge scale that it's on, they had to ship in all these bees to pollinate the trees and there was all this, like, the kind of bee politics and people stealing each other's bees and stuff. And so I don't know, it was a different spin on it and made me feel kind of a little bit guilty for indulging in my tasty almonds. Also the I know that they take a lot of water to grow. Yeah. That's kind of all my knowledge" (Kelly, young female)*

» Interestingly, one person had heard that Hawkes Bay was potentially a good place to grow almonds (she had worked/lived in Hawkes Bay previously).

> *"What did they say 90% or something? I can't remember. I read something about 90 something a huge percent of almonds are grown in California. Although the Hawkes Bay is evidently a potentially good place to grow them. How exciting would that be?" (Wendy, mature female)*

Responses to facts about Californian almond production

Very few people claimed to be aware of the situation, and were surprised. Some voiced discomfort with learning these facts, and said that they would be more mindful of looking to see where their almonds came from before they bought them in future. While many had not heard these facts, there were some who had heard something, but they had forgotten the details and did not appear to be acting on what they had heard.

The following quote, made by a person who had seen the Netflix documentary about the decline of bees associated with the Californian almond industry, highlights that even those consumers with some awareness of the issues are not changing their purchase behaviours - though in reality are they able to?

"I think a lot of people are kind of uneducated about almonds, like you know, we all buy almonds but we didn't know some of the stuff you were talking about. So I think if they were using it in their marketing and I think a lot more people would probably be onboard with spending the extra money." (Ruby, young female)

It is suggested that while consumers may be concerned about the impacts of Californian almond production, it is not easy for them to avoid these almonds.

It was noted that the country of origin (COO) is not overtly displayed on most almond products for sale in New Zealand, and even if it were, there are limited alternatives to US almonds, the Macro brand being the only product differentiated by its COO – Australia, and this brand is limited to only Countdown stores

While the environmental benefit of reduced transit miles is a key motivator for avoiding imported almonds, the impact on bee populations was particularly confronting to some, suggesting that an overtly bee-friendly New Zealand strategy for almond production could be an additionally compelling benefit for consumers

Almonds

Response to New Zealand production

Previous experience of New Zealand grown (or fresh) almonds

There was very low awareness of how and where almonds grew generally. The incidence of experiencing fresh and/or New Zealand grown almonds was almost zero. Of the 11 participants in this study, one had eaten almonds grown in New Zealand, so she was able to share her experience with the focus group.

"I have bought them from the Parnell Farmers Market. Yeah, there's (New Zealand) almonds there. They are exceedingly expensive. But you know, they're next level for sure. But they are a real treat." (Nicola, mature female)

This participant relayed a wholly enjoyable experience that was quite removed from the typical sensory experience associated with imported almonds.

"They was so crisp, I think that that would be the word for it, just crisp and the milkiness. And the sweetness. It's the milkiness and the lusciousness. You know, they just don't seem at all dry in terms of the texture" (Nicola, mature female)

It is most likely that the textural experience described is a result of these locally produced nuts being consumed considerably closer to when they were harvested (ie. fresher) than imported nuts.

"It's something that you don't experience everyday with an almond. So really nice." (Nicola, mature female)

While this person was extremely positive about this different eating experience, it must be noted that this is the opinion of a single person, and so more research would be required to establish precisely how different varieties/cultivars of locally grown almonds differ from what is currently available to New Zealand consumers, and if in fact other consumers find these differences as desirable as this person did.

Response to establishing a New Zealand almond industry

New Zealand almonds expected to be more expensive but fresher and with fewer transit miles.

» Responses to the idea of locally grown almonds were positive. While expectations were that a local product would be more expensive than imported alternatives, many participants were immediately attracted by the idea that locally grown almonds would be fresher, and the improved environmental credentials were viewed as a big benefit too.

» There was expectation that as a new industry for New Zealand, there would be a focus on sustainable production, and ensuring a high-quality product – particularly as a means to differentiate from imported Californian almonds.

"For me, I quite positive on the New Zealand almond. Firstly is more freshness for the consumer. Like the quality will be better than the overseas one." (Annie, young female)

"Yeah. even if it's just to reduce the transport miles and I'd be interested in. I mean, if it was more sustainable, that would be like a huge bonus as well." (Ruby, young, female)

"..if we could find a way to grow them sustainably…you know is some kind of way that we can scientifically do it in New Zealand I would be fine with that as long as it still held the new same nutritional value." (Cathy, young female)

What do fresh almonds taste like??

» While very few people had experienced a fresh almond, participants were curious about what the eating experience would be. Overall there was a strong sense that fresher would be better.

"I'd much prefer knowing that I'm eating an almond that, I don't know, two weeks, three weeks old compared to like two or three months." (Cathy, young female)

» There was a perception that New Zealand is a country rich in natural resources, with plenty of water and rich soil, which would translate into good-tasting almonds. And there was even a suggestion that a locally grown product may have a uniquely New Zealand flavour, similar to New Zealand Sauvignon blanc.

» Understanding how the sensory experience of fresh New Zealand almonds compares with current offerings will eventually be a critical aspect to pursue. Currently there is no evidence to suggest that a different eating experience will be preferred, so this will need to be established and detailed if it is to contribute to a premium positioning.

» It will also be key to understand comparative nutritional profiles and shelf-life characteristics.

Response to establishing a New Zealand almond industry

Diversification of New Zealand agriculture away from dairy/beef

» Several people thought about the need for land-use diversification in New Zealand, away from dairy and beef. Almond cultivation was viewed as a potential means to not only make greater returns from pasture, but also to reduce the negative impacts on the land associated with dairy/beef farming.

"I think the other, the other big thing would be if they could get decent returns, you know, can you convert some of the pasture land into growing almonds? And that's a huge benefit, then environmentally. So it's one of the things we should be looking at is more horticulture and less dairy. So I think there's, there's potential there. If you can get the money." (Hugh, mature male)

Protect New Zealand bees and the New Zealand mānuka honey industry

» Having heard about the plight of bees in Californian almond production, one participant was particularly concerned that cultivating this crop in New Zealand could be equally as damaging to the local bee population.

» They were also mindful that this could raise risks to the mānuka honey market.

» Again reiterating the need to have a New Zealand bee friendly strategy to almond production.

I think it is something that we have to think twice, because bees are very important to New Zealand because honey is one of our main products. And if we are growing something to destroy or harm other bee population, that probably will impact our honey production. So it's kind of..... Yeah.... I still don't know how far we can go with almond industry." (Evelyn, mature female)

Pricing of New Zealand almonds

Anticipated pricing

Participants were unanimous that they would expect New Zealand almonds to cost more than the currently imported offerings. Their rationale for this belief;

» Cannot grow at the scale of the US, therefore smaller more premium crop.

» Big start-up costs, pricey to start with until the technology develops, build up infrastructure.

» Expensive converting beef or dairy farms to almonds.

» Land costs are higher here than in Australia.

"I mean, because we're never going to match the Californian scale, for example. So I think there's probably an expectation, it's gonna be more of a premium product, it's going to be a smaller scale, and we'd hope it'd be sustainable. And so I guess, you can expect there's going to be a price tag associated with those things as well" (Natalie, young female)

Though their comments suggested a degree of price sensitivity…

» Most indicated a willingness to pay more for locally produced almonds though 'not too much more'.

» Definitely not double current prices.

» Paying a higher price may need an improved experience for some.

» Some would limit their purchase to special occasions or eat (New Zealand) almonds less frequently.

"I think I would buy them first off, like just out of curiosity you know, it stands out on the shelf. But then in terms of repurchase, they'd have to be really, really good for me to buy them all the time, if it was double the price. Yeah, for something I'd usually pay a few dollars for." (Kelly, young female)

Size of acceptable price premium for New Zealand almonds

Participants were shown prices for a selection of currently available retail brands and formats, and were asked to provide some guidance on how much more they might be willing to pay for New Zealand grown almonds. While it is key to note that these guidelines are indicative only, as they are based on qualitative feedback from **only nine people**, it is clear that paying double current prices would be unacceptable. A 20-40% uplift on current prices may be acceptable to some, particularly if there are multiple benefits, not least of all a noticeably better eating experience.

	Acceptable	Not acceptable
20-30% price premium	• *"So if there was no difference, I'd maybe pay $6 or maybe $6.50 just because it's New Zealand."* **Hugh** *(A)*	
40% price premium	• *"Yes. I think I'd pay $7."* **Kelly** *(A)*	• *"So if it went up to like $7...maybe. But like we've kind of mentioned, it would be a one off, to see what it would be like, I wouldn't actively switch immediately."* **Cathy** *(A)* • *"Probably up to $7. If it was really good almonds. But then it's not something you probably buy every week."* **Hugh** *(A)*
50% price premium	• *"I was thinking for 50% more as well. I'd be happy to pay."* **Ruby** • *"I'll be happy to pay 50% more on mine."* **Nicola**	
100% price premium (double)		• *"You wouldn't want to be paying double for them, I mean we're already paying a fortune for them....I wouldn't mind paying a little bit more but you wouldn't want to be paying double."* **Wendy** • *"Maybe not double."* **Hugh** • *"But if the New Zealand almonds will be $5 or more, then I think about well, that is a double up, then I take the cheaper rather than the New Zealand almond to be honest, but few a few cents or a dollar different I definitely go for New Zealand almond. But as double up, then I will need to think about it...or have less."* **Annie** • *"If it goes double the price, I might reduce the amount I buy, and keep it as a treat. Not like a usual snack. If it is three or four times more, I probably would have to think twice before I buy it."* **Evelyn**
Other	• *"I think probably that $72 a kg is probably a bit too expensive. So maybe I can on the on the higher end of the other side. It's $36 and $48. I'd maybe consider something in that range, I think, possibly $72 would be too high."* **Natalie** *(B)*	

Comments are made relative to the following products shown in pricing stimulus
(refer Appendices)

(A)

$33/kg
$4.99 / 150g

(B)

Bulk foods (loose)

$36/kg

Summary

Summary

- The key reasons almonds were chosen by these consumers were the perceived health benefits and their versatility and convenience.
- A positive almond eating experience was distinguished by the absence of the adverse sensory attributes of softness and rancid flavours. There was almost no experience from the groups with respect to fresh almonds, or New Zealand grown almonds, but a curiosity and willingness to try/explore.
- This small group of 'conscientious' New Zealand consumers indicated a keen interest in New Zealand grown/produced products generally, as they were perceived to be fresher, supporting New Zealand businesses and less damaging to the environment (fewer transit miles).
- However, while this sentiment was reiterated specific to the idea of New Zealand grown almonds, in reality purchase tended to be driven by the more practical aspects of format, availability and cost, rather than conscientious considerations around sustainability.
  - Despite recruiting 'conscious consumers', there was no strong evidence to suggest that their 'conscientious' beliefs were the main driver for their almond purchase decisions. This may have been driven by the lack of any real choice in almonds in the New Zealand retail market, or simply a social desirability bias among participants More research is required to understand this paradox more fully.

Summary

- There was little knowledge regarding almond production, and low involvement in almond purchase decisions. Most purchased the almonds that were readily available at their usual supermarket, and as such were not aware of brands/origins/credentials of almonds from other retailers.
- There was some frustration that the country of origin was often not provided on almonds sold in New Zealand, so consumers were less able to make a conscious choice.
- While some had heard negative stories about almond production in California, it had not affected their purchase choices, though it was clear that the country of origin of almonds currently sold in New Zealand was often difficult to establish, and difficult to avoid.
- While most of this small group of consumers said that they would be willing to pay a premium for New Zealand almonds, the degree of price uplift was quite limited.
  - ***NB: indicative only, based on feedback from nine people only***
  - Double the price was unacceptable – would lead to avoidance/reduction in consumption
  - 40% price premium – probably not a sustainable uplift, especially if the quality/credentials are not perceivably better than current offerings.
  - 20 – 30% price premium – least resistance to this possibility, though it is questioned whether New Zealand origin alone will be enough to sustain this price uplift, or whether other claims will be required to justify the premium in this market (e.g. improved sensory, nutrition, sustainability credentials, etc).

Future research

Future Research

This is a very small sensitisation study and requires further research to draw more detailed conclusions and establish any potential for premiumisation;

- Additional focus groups need to be conducted to explore what the conscious consumer means – particularly in the snack market. These focus groups could also explore the purchases consumers do apply their 'conscious consumer' attitude to and why
- Competition in the healthy snack area could also be explored
- This work needs to be followed by a survey which uses the language, attitudes and emotions found in the focus groups to examine the broader New Zealand market. This would allow the further unpacking of the credence attributes – among with a ranking of them.
- Understanding the more physical aspects of New Zealand almonds will also be critical in establishing positioning and communications; sensory (flavour, texture, appearance), nutritionals, shelf -life, residues, etc.
- For the longer term, should export become a possibility, greater knowledge of the markets of interest will be required; understanding of usage and attitudes to almonds, potential for premium, gift market, etc.

Together this work would not only help identify the potential market and its needs in New Zealand, but also allow for positioning/education of the product.

Appendices

Recruitment Advertisement

We are looking for people to participate in an on-line focus group, where we will be discussing perceptions and eating habits of ALMONDS.

The focus groups will take place between **6-7.30pm** on **Wed 27th April** and **Thurs 28th April**. They will be conducted on-line (using Zoom), so you do not need to travel to join us, but you do need the capacity to stream a video-call for 90mins.

Do you regularly purchase & eat whole almonds or almond products?

Do you consider things other than just price when making your grocery choices?

If you answered yes to both of these questions and you are available for at least one of the above session times please email: tracey.phelps@plantandfood.co.nz to sign up.

If you have any questions before committing, drop us an email at the address above.

We look forward to hearing from you.

Plant & Food™ Research
Rangahau Ahumāra Kai

PARTICIPANT INFORMATION SHEET | ALMOND STUDY

Introduction

We would like to invite you to participate in this study being conducted by The New Zealand Institute of Plant & Food Research Limited (PFR).

This study is being conducted to explore consumer attitudes to, and purchase behaviour of almonds. You do not need to be an expert or have any specialist knowledge – you are being invited to attend because you eat and purchase almonds.

The topics discussed in this study are not directly connected to the views of The New Zealand Institute of Plant & Food Research Limited.

Who can take part?

We invite you to participate in one of our group discussions if you:

1. **eat and purchase whole almonds**
2. **you consider values other than price when making your grocery purchase decisions**
3. **you consent to being video & audio recorded while you participate in an on-line group discussion.**
    - *We record the group discussion so that we can accurately capture what you tell us, our data management policies are outlined below.*

What will my participation involve?

If you agree to participate, you will be invited to attend an online focus group discussion with another 4-5 participants who also agree to participate in this study. All discussions will take place in English. The focus group will be conducted via the online meeting platform Zoom, last no longer than 90 minutes, and two researchers from PFR's Stakeholder & Consumer Intelligence Team will be moderating the group discussion. You will be given instructions regarding how to join the Zoom meeting.

In the group discussion, you are encouraged to share your views and thoughts openly with other participants. There are no right or wrong answers. We would like to video record the focus groups so that we can accurately capture what you tell us. The recording of the focus group discussion will be transcribed into a written record using an automated transcription tool. Your contribution is extremely valuable to us and we greatly appreciate your time and views.

Token of appreciation

Upon the completion of the interview, you will receive $50 in the form of a Prezzee e-voucher as a token of our appreciation for your time and efforts in participating in the study.

What will happen to my data?

You own the information that you provide to us in this study, and you have the right to access this information at any time.

CONSENT FORM

Research Team: Stakeholder & Consumer Intelligence, Plant & Food Research

You have been offered a place to participate in an on-line focus group as outlined in the separate Participant Information Sheet that you have been provided. Before the group you are asked to read through this form, and decide whether you consent to participate or not. If you have any questions please contact one of the research team listed below.

- If you decide that you do not wish to participate, please email us immediately and let us know
- In order to accept the offer to participate you must agree to each of the following statements.

As the focus group will take place using Zoom the on-line video conferencing tool, we will capture your consent verbally at the beginning of the focus group. You will be asked to say the following statement, which will be video recorded as proof of your consent to participate.

"I (*say your full name*) have read and understand the consent form and have had the opportunity to ask questions. I agree to take part in this study".

I have read the Participant Information Sheet and have understood the nature of the research and why I have been selected.	Yes / No
I have had time to consider whether to take part.	Yes / No
I know who to contact if I have any questions about the study, and have been given the opportunity to ask questions before I decide to take part.	Yes / No
I am aware that I will be video-recorded as part of this focus group, and that this recording will be transcribed into a written record using an automated transcription tool.	Yes / No
I understand that I will receive $50 Prezzee e-voucher as a thank you token and that I can retain this money even if I decide to withdraw from this research.	Yes / No
I am aware that the recording and its transcript collected from me during my participation in this study, and personal information will be kept in a secure area at Plant & Food Research.	Yes / No
I understand that as part of the reporting process, quotes from me may be used in reports, presentations, and/or publications, but no information that personally identifies me will be used.	Yes / No
I am aware that the topics that are discussed in this study are not directly connected to the views of The New Zealand Institute of Plant & Food Research Limited.	Yes / No
I understand that the content of this study is confidential and agree to not discuss it outside of this focus group.	Yes / No
I understand that I can withdraw at any time, without having to give a reason for doing so.	Yes/No

Researcher contact details: Tracey Phelps on 027 527 8929, or by email tracey.phelps@plantandfood.co.nz
Non Research contact: Dr Marian McKenzie, Email: Marian.Mckenzie@plantandfood.co.nz

Declaration of consent

"I (*say your full name*) **have read and understand the consent form, and I have had the opportunity to ask questions.**

I agree to take part in this study".

Semi-structured interview guide

A semi-structured discussion guide was prepared to ensure key points were covered in each focus group. This guide provides an approximation of the order of each discussion point, particularly the points at which prompting of issues and current pricing occurred.

- Conscious consumerism – what things do you consider other than price when shopping?
- Why do you choose almonds?
- How do you use almonds?
- How do you choose your almonds?
- Direct discussion towards country of origin…
  - Do you know where your almonds come from? Is this important?
  - Do you know anything about almond production in other countries?
- Direct discussion towards (negative) environmental issues of almond production ...
  - water, bees, US example.
  - (prompt) if no knowledge provide an overview of the Californian issues
- What if New Zealand grown almonds were available?
  - expectations of costs, quality, environmental impact, etc.
  - Willingness to pay more, how much more? (unprompted)
  - (prompt) Provide current New Zealand retail prices for a selection of brands/formats - willingness to pay more, how much more?

Current almond pricing stimulus

Disclaimer

Presentation for:
Central Hawkes Bay District Council, July 2022

Publication data:
Phelps T, Conroy D . July 2022. Growing an Almond Opportunity Theme 3: The premium market & the conscious consumer. A Plant & Food Research PowerPoint presentation. Job Code : P/442101/01, SPTS No . 22706.

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June 2022

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Economics of Almond production in Central Hawkes

Prepared for: CHBDC

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June 2022

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1.0 Background

The scope of this project is to investigate the economic feasibility for establishment of a New Zealand almond industry. This industry would be based on a premium quality product, produced using sustainable agronomic practices including, optimised light utilisation for higher yields and quality, lower water and nutrient footprint and integrated pest management approaches for reduced use of synthetic crop protection compounds.

New Zealand has a temperate climate, good water availability and a strong reputation for producing high quality food. Even though high quality almonds can be grown in New Zealand, currently there is no commercial almond production, just a few small growers scattered across the country.

This project provides a method of financial analysis for individual business performance scenarios. The outcomes have been the development of a capital budgeting model used to analyse current business performance in almonds and development of a series of important financial indices. A simple group of financial benchmarks has been created, to compare potential results from future almond businesses in Central Hawkes Bay, New Zealand with actual results being achieved with existing almond growers. This system of analysis can assist an individual manager's understanding of their business, while measuring critical factors (and risks) in a development proposal. It can also act as a catalyst, to improve the industries competitiveness in the international scene as the New Zealand almond industry potentially grows.

2.0 Acknowledgments

Funding:	MPI, SFFF, CHBDC, HBRC, HDC, WDC, Picot Productions and PFR
Co-operators:	Tony Kuklinski, almond grower CHB Graham Farnell, almond grower, Marlb

3.0 Executive Summary

This project set out to analyse the economic feasibility of almond production in the Central Hawkes Bay. Through the use of capital budgeting, multiple scenarios have been stress tested to help develop an economic budget that a grower can use to base their own almond orchard investment on.

The project has provided:
- The economic information needed for potential adopters to invest in almond growing
- A detailed report on the major economic factors influencing the viability of growing almonds in Central Hawkes Bay
- References to the model including expected cost breakdown, return and yield figures, development budgets, cumulative cash flow, and IRR results.

A whole business farm approach over a 15 year period was analysed, to produce results categorised by several different performance indices. These included total business performance and cost analysis.

Two models were created and stress-tested with variations in price/kg and yield/ha to analyse their impact on economic performance indices over a 15 year period. The models included development budgets which assumed the development of a 10ha almond orchard. The two models are referenced in the report as:
1. Normal/high input system. This system assumes full irrigation is installed and run. Benefits seen from overseas experience (although limited here in New Zealand), is an increase in productivity and quality / size of almonds.
2. Low input system. There is speculation in New Zealand as to whether almonds require irrigation. Therefore, using the experience and evidence of existing almond producers, this model assumes production and quality is reduced without the upfront development cost of irrigation installation (including bore, headworks and reticulation).

The primary findings of this study show the results of several financial performance indices, demonstrating how differences in yield and price/kg will alter the IRR of the potential almond orchard investment. Although data was limited, the analysis took into account the experience of a few scattered New Zealand almond producers and the knowledge gained from overseas industries.

Table 1. Primary study results.

	Normal input system	Low input system
3-yr average yield	2.7t/ha	2.0t/ha
Price per kg	$20.00/kg	$20.00/kg
Cost of production	$6.88/kg	$9.14/kg
Development costs	$71,716/ha	$62,096/ha
Breakeven year	12	17
Internal rate of return (IRR) after 15 years.	5.5%	-4.9%

3.1 Key Recommendations:

This study identified that with the right inputs and management structure, it is feasible to invest in an almond enterprise. With no existing industry, it is important to realise assumptions made are to the

best of our knowledge and research at this time, and factors such as price per kg of kernel may change.
This study has highlighted the importance of yield on financial performance in the short and long term. Therefore, it is recommended more research is focussed on areas such as irrigation best practice, nutrition and pest and disease control in a New Zealand context.

The other key highlight is the influence price has on a 15 year IRR. More research needs to be completed to identify the size of the market and the range of different revenue streams that can be utilised with the production of class 1 and class 2 almonds. Additionally, more research needs to be completed on the requirement for a processing industry to dry and package almond products.

4.0 Introduction

Almond production in New Zealand has been lightly explored with only a few scattered growers throughout the country. Like anywhere in the world, growing almonds requires skill in management, production and business. For the growth of an almond industry in New Zealand, we need to have the documentation to support starting a venture such as this.

The development of an economic feasibility study is the process of determining whether a new venture is worth the cost and time investment. This project is set out to assist new adopters in almond growing and to stress test the viability of an almond industry in NZ. This economic feasibility study is particularly important in an NZ context, because the business structure and climate are so different to major almond growing regions around the world such as Australia and the USA.

Although profitability is a key driver to successful almond production, factors such as cashflow, sensitivity and risk need serious consideration or potential financial difficulty is likely. Capital budgeting is used to analyse a farm business over a 15 year period, helping to calculate economic indices such as gross margins, cumulative cashflow, internal rate of returns and breakeven years.

For the purpose of this study two major models have been created to base stress-tested assumptions around. The difference in the models consider environment and climatic factors, more specifically the impact of higher rainfall in comparison to international almond growing regions. The two models are referenced within the report as:

1. Normal/high input system. This system assumes full irrigation is installed and run. Benefits seen from overseas experience (although limited here in New Zealand), is an increase in productivity and size / quality of almonds.
2. Low input system. There is speculation in New Zealand as to whether almonds require irrigation. Therefore, using the experience and evidence of existing almond producers, this model assumes production and quality is reduced without the upfront development cost of bore and headwork installation.

Both models were stress-tested under a number of different scenarios through a sensitivity analysis, which led us to identify several economic drivers where the viability of almond production is feasible in the Central Hawkes Bay, New Zealand.

5.0 Global almond industry overview

USA and Australia are the main producers of almonds around the world. The climate is consistent with the need of an almond tree and with the addition of irrigation, they are successful in producing mass quantities. The USA (California) and Australian almond industries are very industrialised, operating on vast areas achieving very low costs of production, using machinery to do the majority of physiological tasks such as pruning and harvesting.

New Zealand imported 3,900 tonnes of almonds in 2020, totalling NZD $41 million – mostly from countries with limited water resources and increasingly experiencing extreme drought conditions (USA and Australia). The New Zealand retail market for snacking almonds in 2020 totalled NZD $19.4 million and is forecast to grow by 6% annually over the five years to 2025. As stated earlier, the current production of almonds in NZ is made up of only a few scattered growers will small area so is therefore negligible.

The difference in eating experience from a supermarket bulk buy almond to a fresh almond is greatly improved. A premium could be expected on fresh NZ grown almonds in quality food stores, or likely those sold in local markets or farmers markets. No attempt has been made to judge the size of the potential market for NZ locally grown almonds in the economic section of this project.

The potential New Zealand almond industry is likely to be based on a low area, high price, niche model. It has been discovered there is a premium market for locally grown, fresh consumption almonds in New Zealand by existing almond growers in both Central Hawkes Bay and Marlborough. The New Zealand climate has been identified as being potentially suitable for almond production, therefore a feasibility study looking at its viability has been undertaken.

The New Zealand almond industry is yet to be developed and likely to look considerably different to that of the USA and Australian industries. Almonds in NZ are going to be produced to fit into a niche market - a high value premium product, giving growers the ability to be price makers not price takers. Economic consideration of this factor has been made in this study, and comparisons to an international scenario are made throughout.

6.0 Project Aims

The project aims to analyse the financial performance of a potential almond industry in the Central Hawkes Bay of New Zealand. It sets out to use capital budgeting over a 15 year period and to establish economic performance indices and information to give a clearer picture of the economic performance or viability of an almond orchard in NZ.

The project will aim to deliver:

- Feedback on the key management issues that affect business performance
- A detailed report on the major economic factors influencing the validity of a New Zealand almond industry.
- A model allowing property performance, development proposals and 'what-if' scenarios to be assessed and stress-tested.

7.0 Methodology

7.1 Data gathered

A complex financial development budget was developed, to assess the viability of an almond orchard over a 15 year period. The model uses input and outputs of a business. Then while considering current value costs of these inputs and outputs, it will produce a series of performance indices including gross margins, development budgets, sensitivity analysis, cumulative cash flow and IRR.

7.1.1 Inputs

The inputs include land size, water, chemicals, fuel, machinery and labour. These inputs have been valued at current prices with the use of NZ grower experience and the knowledge of the AgFirst team in relation to the cost of production for other relative tree crops grown in NZ. The cost based analysis indicates where major costs are incurred in almond production.

Other inputs include block information such as area, row and tree spacing and total tree numbers. The block assumptions for all examples are as follows: n Orchard development of 10ha with trees planted at a 5.0m row spacing and a 6m tree spacing, totalling at 333 trees/ha. The planting distance has a large bearing on early production and needs further research to ensure it is optimised for NZ conditions. The spacings used in this model are based off New Zealand experience and standard practice in Australia. The model assumes market results for an average of a range of varieties.

7.1.2 Outputs

For this analysis, the value of the almond product has been split into grades and set at a standard value per kilogram. No market analysis has been undertaken in this study. We have gathered a range of prices that have been achieved for the almond crop (all varieties) and assumed a reasonable long-term price of $20/kg for class 1 premium almonds and $10/kg for class 2 almonds. Average yields over a 3-year period were used to account for biennial swings in the almond crop.

8.0 What-if analysis

The model allows analysis of the way changes in inputs and outputs effect the project's outcome. Factors such as timing of yield growth, machinery investment, market performance can be stress-tested to give a measure of viability and potentially, a performance strategy to help growers plan for different performance outcomes.

The what-if analysis included in this feasibility study will include a low input method of low water which will result in limited yield and a high input/high yielding scenario. Each of which will have sensitivity analysis done to assess the impact of price and yield on IRR.

9.0 Key performance indicies for almonds

Using the whole farm approach to examine a business, the data was analysed to produce several performance indices. They can be categorised into:

- Total business performance
- Cost analysis

The three important components of profit can be divided broadly into yield, price and costs. The performance indices focus on aspects of each of these components.

9.1 Total business performance

The performance indices allows analysis of selected scenarios using different levels of performance to compare their likelihood of success. As a result of information gained in the study, the most critical financial indices are those that had the greatest impact on profits or the bottom line. These basic concepts allow analysis of data that is usually readily available from growers, and represents accepted standards in economic analysis. Keep in mind, the level of performance from New Zealand almond growers in this study are based on very few real-life examples and the experience AgFirst has with the almond crop. The performance indices that have significant representation of an almond orchard viability are described below.

9.1.1 Best average 3-yr yield

Like all horticultural production systems, the climate is a risk that can be extremely hard to manage. The almond crop is susceptible to frosts, poor weather at pollination, wind, hail and increased disease pressure with high humidity or rainfall, all of which can happen in any given season. By using a 3-year average yield as opposed to a snapshot in time, a clearer long-term view is given, of yields that are possible in a NZ almond context. Yields in this study are based off existing NZ almond growers and although this data is limited it gives us a good indication of what is currently achieved, to then assume what could be achieved with a full-time production system.

9.1.2 Price of almonds

The price is not always an economic factor the grower can manage or change. It is up to the marketing business, which in some cases is the grower, to set the price. The price achieved has a direct relation to the supply and demand ratio. If the demand is high the price can be high, if the supply is high the price can drop. Price in this study is quoted at $20kg of kernel class 1 and $10/kg class 2. This study also assumes the marketing and selling of the product is outsourced.

9.1.3 Cost of production

The cost of production per kg kernel includes all annual cash costs, overheads, machinery costs and labour. The cost of production is measured against yield ($/kg) as it acts as an indicator that is independent of price and property size. The cost of production is an area which can be manipulated to the analysis of a low or high input production system. Keeping in mind, the difference in low and high input systems will result in changes in production in terms of yield per ha.

9.1.4 Cumulative cash flow

Cumulative cash flow is critical to the success of almond investment. It will determine, in part, the viability of the project and an almond investment and is therefore an important consideration. Almonds, being a permanent crop, can result in substantial peak debt, hence calculating cumulative cash flow and determining peak debt is important. Cumulative cash flow provides an indication of the year in which peak debt will occur. The number of years to a positive cumulative balance is the point at which the project has paid for itself.

9.1.5 Years to positive annual cash flow

The number of years to positive annual cash flow is the point at which annual income is greater than annual cash costs, which indicates the point at which debt can start to be reduced. These potential early returns can be a valuable aspect of the profitability of a particular crop and being able to bring forward early yield cumulation benefits the 15 year investment IRR. In an almond crop, this point is likely to be reached in year five or six, but delays from weather or management decisions will have impacts on profitability. In a New Zealand model the cash spent on an almond investment is likely to be vastly different to that seen in the USA or Australia due to the nature of the production system being of smaller scale with higher costs per kg of kernel.

9.1.6 Gross margin

Gross margin provides a simple tool to easily assess enterprise performance between years, crops or similarly equipped properties without the need for complex financial analysis. Gross margin is a traditional measure of a particular crop's price for the product by the gross yields per hectare less cash costs. For example labour, chemicals, fuel and irrigation pumping costs are included in the analysis and no allowance is made for overheads such as machinery depreciation, accountancy or development costs.

9.1.7 Water sustainability

Almonds internationally are a relatively high water use crop especially at important times during the growing season. CHB is a high rainfall area in comparison to common almond growing areas such as desert land in Australia. No attempt has been made to judge the need for irrigation for CHB in comparison to a desert growing environment. We know that for best practice almond production, water is vital at key parts in the growing season and therefore the normal/high input model accounts for irrigation installation. Due to there being high rainfall in CHB (approx. 600mm/year) the low input model has accounted for no irrigation installation and a reduction in yield and quality as a result.

9.2 Cost analysis

The profit margin of an almond orchard details the success. To achieve this, particular attention needs to be placed on yield, price and costs in order to improve margins. Many growers place a strong emphasis on reducing costs. In this study the costs are divided into three categories reflecting their nature and effect on profit. The cost categories are labour, annual overheads and variable costs.

9.2.1 Labour costs

Labour costs are mainly calculated on a per tree or per hectare basis and include the time taken to do all tasks such as pruning, harvesting and spraying. Labour has been valued at a standard of $25/hr with an additional allowance for management. Depending on the activity, the labour costs are distributed by a combination of tree canopy fill and production for the year to ensure integrity of the figures. For example, pruning costs in year 3 are a fraction of what they are in year 8 when the tree is at full maturity. The majority of labour costs for tree husbandry practices have been developed from experience observed from existing New Zealand growers. This area is likely to be where NZ almond production varies largely from that seen overseas because of the lack of industrialisation.

9.2.2 Postharvest costs

Postharvest costs are those attributed to the processing of the almonds from shell to kernel. Postharvest costs include reprocessing, drying and shelling, freight and an anticipated industry levy. One of the key areas of difference for the New Zealand almond industry is that most regions around the world are desert climates, and most of the drying needed to keep the nuts from decomposing is carried out naturally in the field. It is likely that in New Zealand conditions the nuts will need some sort of assisted drying to get them to the required moisture content.

9.2.3 Annual overheads

Annual overhead costs are paid to ensure property upkeep and business administration. The costs include lease costs, administration, property charges and crop insurance. The total costs vary with the size of the property, but annual overheads per hectare are not particularly sensitive on a per hectare basis. This study assumes a lease deal rather than including land purchase into the development budget. Lease land is valued at $4000/ha. This is relatively low for high value horticultural land such as the Heretaunga plains, but potentially a good return for sites in the next tiers of soil class or desirability.

9.2.4 Variable cash costs

Variable cash costs are those that are allocated on a per hectare basis included in the gross margin, except the labour costs described above. Variable cash cost include weed and pest control, pollination, fertiliser, orchard sundries, vehicle expenses, fuel, repairs and maintenance and electricity.

9.3 Other indicators

9.3.1 Development budgets

The long-term development costs are vital to the success of a project and allow the development to be viewed from a long-term cash flow basis. Interest costs for borrowed funds are not part of the study. The model builds up a development budget that is typical of a low area almond grower with the ability to mechanically harvest the almonds. The difference between the two models being the exclusion of a bore and headworks installation into the low input model.

9.3.2 Sensitivity analysis

The use of sensitivity analysis enables us to view changes to the IRR when different scenarios for price and yield are given. In a New Zealand context, we are limited to the amount of data we can collect due to the lack of growers and practical experience growing almonds. Thus, the sensitivity analysis gives a broad range of the likely financial result obtained if an investment or project were to take place, based on the model and assumptions made in this study.

10.0 Results of the study

10.1 Business indicators and performance

The data from this study was based experience from existing New Zealand almond growers, as well as the knowledge experienced internationally, with specific relation to the Australian almond industry. The 15 year budgets referred to can be found in Appendix 1.

10.1.1 Total business performance

Yield (Best 3-yr average)

The best consistent figures in New Zealand collected from two known growers in Marlborough and Central Hawkes Bay have been up to 2.7 t/ha of kernel fresh weight. These yields are quoted from mature development in their best season. The level of variability from year to year was low in the orchards studied, therefore the 3-yr average yield is likely to be 2.5-2.7t/ha. The target stands at 3.3 t/ha but due to the secondary nature of the businesses studied this has not been achieved. With more attention to detail in terms of canopy manipulation and fertiliser applications, and the rolling 3-yr yield average of 3.3-3.5t/ha is likely to be achievable.

With a low input system, i.e. no water and minimal attention to detail, it is likely that the yield profile will not exceed approximately 2t/ha on a rolling 3-yr average. Almonds have the tendency to be biennial so for the indicator of yield performance, a 3-year average must be taken into account. With low input you are more than likely going to push the trees into a biennial trend, and therefore the rolling 3-year average is likely to decline.

In a high input scenario where water requirements are met at the right time and growth stage, and pest and disease management is front of mind, it is likely that yield potential will be similar to that of the US and Australia at 3.5-4t/ha. This is based on anecdotal evidence, with no one grower achieving yields to this level in New Zealand. The highest yields achieved that are noted are 2.7t/ha being a low input, low management business.

In comparison, the 2007 Australian average was 2.97t/ha, from mature trees, on good soils, good irrigation systems, usually frost-free and a high level of management skill.

Yield is the primary driver for profitability and in conjunction with price it is the most sensitive indicator of financial performance. It is not hard to believe that blocks which produce higher yields will have excellent gross margins, better and faster cumulative cash flow and better internal rate of returns.

A yield by price sensitivity analysis suggests that for an almond business to be successful in terms of IRR, the minimum yield achieved must be no lower than 2.5t/ha and the return no lower than $20/kg.

Price per kg of kernel

From discussion with NZ growers, they were in a situation where there was no marketing body. Therefore, they processed, marketed and sold the product themselves. In this market where the supply was limited the growers were able to achieve a minimum of $38/kg of kernel for their freshly NZ grown almonds.

This is a scenario where demand is high and supply is very low, therefore price is high. For this feasibility, it is expected that as supply increases, the price will drop and therefore the price per kg used in the modelling is $20/kg class 1 premium and $10/kg for class 2 process grade almonds.

The price per kg of almonds found in the Australian market is NZD$8.48/kg[1]. The difference being the NZ grown almond is a locally grown niche product. Australian almond business models can sustain such low prices because they farm on vast areas with a high degree of mechanisation, and therefore the cost of production per hectare is low. The NZ almond industry does not have the ability to farm on such areas due to land availability and cost, so therefore must base their business model around a niche, locally grown product at a high price.

11.0 Cost analysis

Cost of production per kg kernel

With the New Zealand almond growing experience to date, growers have kept the cost of production very low. The main reason for this is the prioritisation of the almond business being secondary to other sources of income. This will have prevented high potential yield and fruit quality. For the purpose of this study, budgets have been developed for a high (normal/expected quantity input system) and a low input system with key reference around water and how that will influence yield and quality of the crop (Appendix 1).

It is important we do not directly corollate our assumed methods of production to that seen in Australia or USA because of the reasons discussed above. NZ is likely to have higher costs of production per kg of kernel but the ability to sell the fruit at a much higher price.

The cost of production per kg of kernel takes into account all operational and labour expenses. The cost to produce a kg of kernel almond is estimated to be $6.88/kg in an "normal" input system. Alternatively, for a low input system it is estimated to cost $9.14/kg (Table 2). Although this may seem counter intuitive, the major difference is the reduction in yield per hectare and quality of the almonds when taking a low input, no irrigation approach.

Table 2. Cost of production per kg of kernel.

	Cost of production per kg kernel	Assumptions
Normal input	$6.88 kg	Full water access = higher yields and quality
Low input	$9.14 kg	Low water = reduced yields and quality
Australia	$2.01 kg	

1. Source: https://www.selinawamucii.com/

The breakdown of costs will tend to range between property sizes, regions and management strategies. Variable cash costs, which include everything from labour to the cost of fertiliser, make up the greatest cost and are arguably an area where costs can be reduced in an almond operation. Almond growing in a NZ aspect has been lightly explored and the ability to compromise on different costs is unknown. However, it is AgFirst's opinion, with the support of the sensitivity analysis, that if a high price and moderate yield can be maintained, there will be no need to compromise on operational costs in an attempt to make a profit.

Figure 1 and Table 3 below display the cost breakdown for an expected almond orchard. This breakdown does not change for the normal and low input models. Three main variable costs make up 53% of the total. These are wages of management (22%), other wages (16%), and pruning cost (15%). Other wages include miscellaneous jobs such as mowing and mulching and are considered a significant part of the almond operation. Harvest costs in comparison to other horticultural enterprises are low, as the model assumes the almonds are being mechanically harvested which, from NZ experience, comes to $416/ha. All other costs shown in Figure 1 are important to the almond production system and all have a direct or indirect impact on the performance of the orchard.

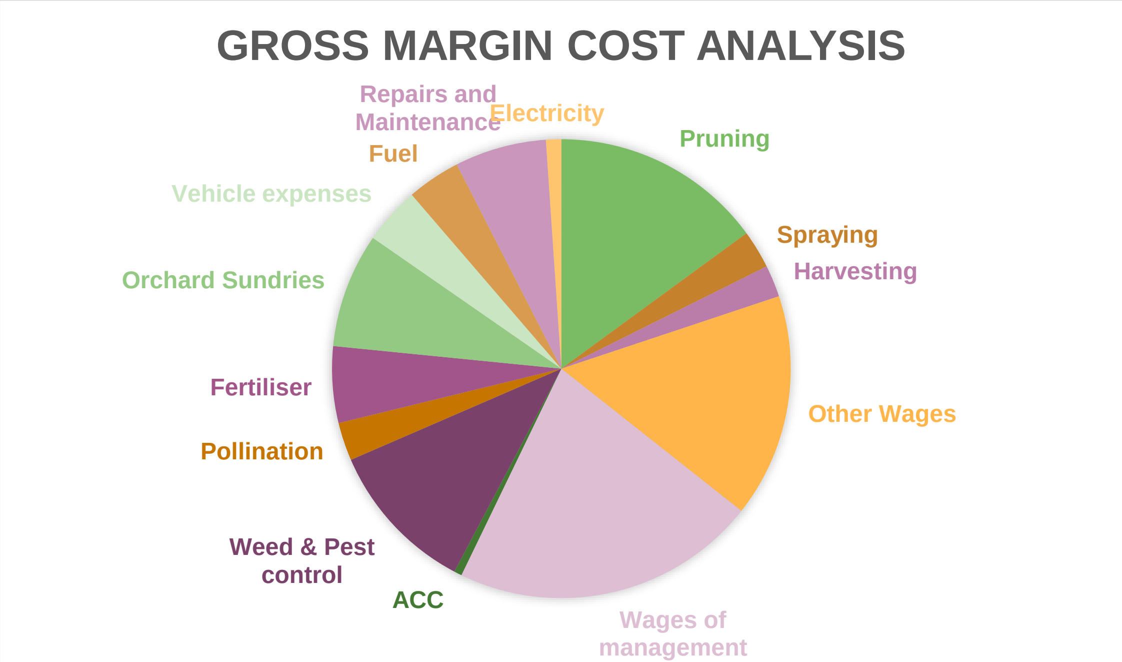

Figure 1. Expected annual cash cost breakdown in Almonds.

Table 3. Expected annual cash cost breakdown by $/ha and % of total costs.

Cost	$/ha	% of costs
Pruning	$4,167	15%
Spraying	$500	3%
Harvesting	$416	2%
Other Wages	$2,925	16%
Wages of management	$4,000	22%
ACC	$115	1%
Weed & Pest control	$2,000	11%
Pollination	$500	3%
Fertiliser	$1,000	5%
Orchard Sundries	$1,500	8%
Vehicle expenses	$750	4%
Fuel	$700	4%
Repairs and Maintenance	$1,200	6%
Electricity	$200	1%

Labour costs

As stated above, labour represents the majority of the costs in an almond operation (as is typical for most permanent horticultural crops). Pruning, harvesting, spraying and other wages make up an estimated 36% of costs. Different management strategies (low input/high input) will have different quantities of labour costs depending on their level of detail. Labour costs on a New Zealand almond orchard are expected to be $6,618/ha, which includes the aspects stated above. A management component of $4,000/ha has been added in addition to the above labour costs to account for all overhead and day-to-day business management needs.

$25/hr was used as a labour rate to account for a range of abilities that might work on the orchard doing a range of tasks from spraying to pruning.

Gross margin

Gross margins will vary depending on yield and the level of input in the production system. Gross margins are based on operating costs and do not include overhead costs. The expected gross margin at full production of a normal input system is expected to be $25,197/ha and $12,270 for a low input system.

Gross margins demonstrate the importance of management efficiencies of any horticultural system. The difference in gross margins between the normal input system vs the low input system in this study is the investment in irrigation during development, which led to an increase in yield by 0.7t/ha and 10% class 1 produce at full maturity. The same goes for factors such as fertiliser. Both of these practices can increase yield, therefore that coupled with practices adopted to substantially reduce the risk to crop loss can increase gross margins significantly.

Cumulative cash flow

Cumulative cash flow is critical to the success of almond investment. Almonds, being a permanent crop, can result in substantial peak debt, hence calculating cumulative cash flow and determining peak debt is important. Cumulative cash flow provides an indication of the year in which peak debt will occur as well as the number of years to a positive cumulative balance, which is the point in time the project has paid for itself. Keep in mind the model has been created assuming a 10ha orchard is being developed.

The normal input model had a peak debt in year 3 of $1,249,759 and a break-even year was year 12. The low input system with limited production and quality due to the lack of irrigation had a peak debt in year 4 of $1,223,472 and a break-even year estimated to be year 17, outside of the 15 year scope of the capital budget (Figure 2).

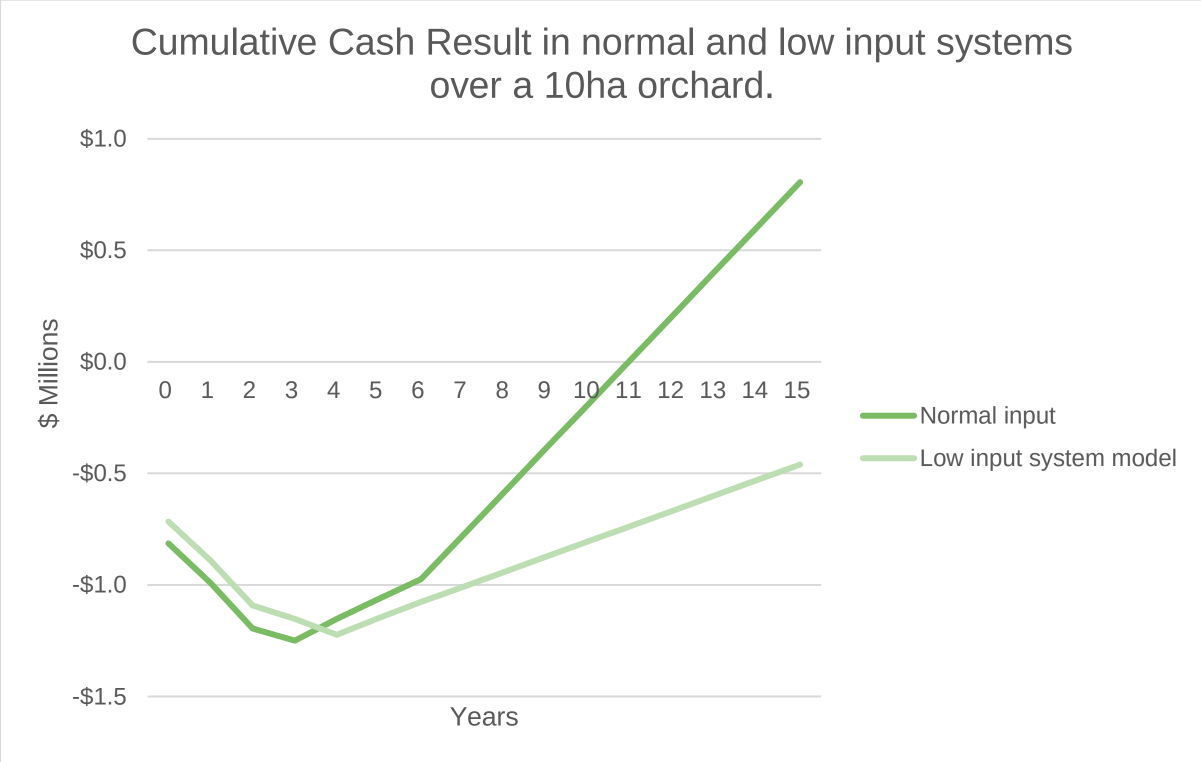

Figure 2. Cumulative cash flow of the normal and low input almond models.

11.1.1 Other indicators

Development budgets

As part of the capital budgeting, a development budget was created using experience from NZ growers as well as the information AgFirst has on orchard establishment and what is required. This cost is required upfront in year 1.

The total development cost for a 10ha orchard came to a total of $717,164 in the normal input system and $620,964 in the low input system. As stated earlier, the difference is the exclusion of a bore and headworks installation in the low input system.

Table 4 shows the breakdown of what is included in the development budget and their relative cost.

Table 4. Development cost breakdown for a 10ha almond Orchard development.

DEVELOPMENT & CAPITAL EXPENSES (10ha Orchard)	**Normal input**	**Low input**
Ground prep	$9,250	$9,250
Drainage	$100,000	$100,000
Shelter establishment	$4,500	$4,500
Irrigation	$15,200	
Plants	$83,333	$83,333
Planting	$6,667	$6,667
Grassing down	$5,000	$5,000
ORCHARD ESTABLISHMENT	**$223,950**	**$208,750**
Bore	$30,000	
Headworks	$50,000	
Implement and spray shed	$50,000	$50,000
Office, Kitchen, Toilets	$25,000	$25,000
Shade sheds, Loading bays, tracks	$50,000	$50,000
Tractor	$65,000	$65,000
Sprayer	$37,500	$37,500
Tractor/harvester	$50,000	$50,000
Mulcher & sweeper	$10,000	$10,000
Fertiliser spreader	$5,000	$5,000
Mower	$9,000	$9,000
Herbicide sprayer	$5,000	$5,000
Frost Fans	$85,714	$85,714
General Orchard Equipment	$20,000	$20,000
INFRASTRUCTURE AND MACHINERY	**$492,214**	**$412,214**
TOTAL DEVELOPMENT COST	**$716,164**	**$620,964**

Sensitivity analysis

The sensitivity tables are based on expected internal rates of return (IRR) of a New Zealand almond operation, as described in the above report. It uses a range of almond prices/kg for a range of given yields. The two models have been used to produce a sensitivity analysis to estimate the impact a normal and low input system has on the feasibility of an almond business in the Central Hawkes Bay.

Table 5. Sensitivity assumptions and results for both models.

	3-yr average production	Class 1 (%)	Class 1 price per kg	IRR (%)
Normal input	2.7 t/ha	70%	$20	5.5%
Low input	2.0 t/ha	60%	$20	-4.9%

Normal input production system

The sensitivity analysis suggests for a normal input system, IRRs after 15 years could range from -19.5% to 32.2%, depending on yield and price performance. With experience from NZ growers, we know that with irrigation and passive management it is possible to achieve 2.5-2.7t/ha. Thus, the likelihood to achieve greater than 2t/ha over a 3-year average is relatively high. We have unknown experience of having a normal input system managed well, therefore the potential optimum yields are largely unknown. However, an orchard with a conducive climate, frost free with good soil and good irrigation, yields of 3—3.5t/ha could be possible, which is the point where IRRs increase significantly.

Price will depend on the market and its potential size in relation to the supply. NZ almond growers were regularly achieving greater than $35/kg for their products however it is of AgFirst's opinion the demand at this price point could be limited and therefore the price will not stay as high.

Table 6. Internal Rate or Return (IRR) at 15 years by yield and weighted price per kg for a normal input system.

5.5%	2.0	2.5	3.0	3.5	4.0
$15.00	-19.5%	-5.0%	1.4%	5.8%	11.2%
$20.00	-3.6%	3.8%	8.6%	12.5%	18.0%
$25.00	3.5%	9.6%	**14.0%**	17.6%	23.5%
$30.00	8.5%	14.2%	18.3%	21.8%	28.1%
$35.00	12.5%	18.0%	22.0%	25.5%	32.2%

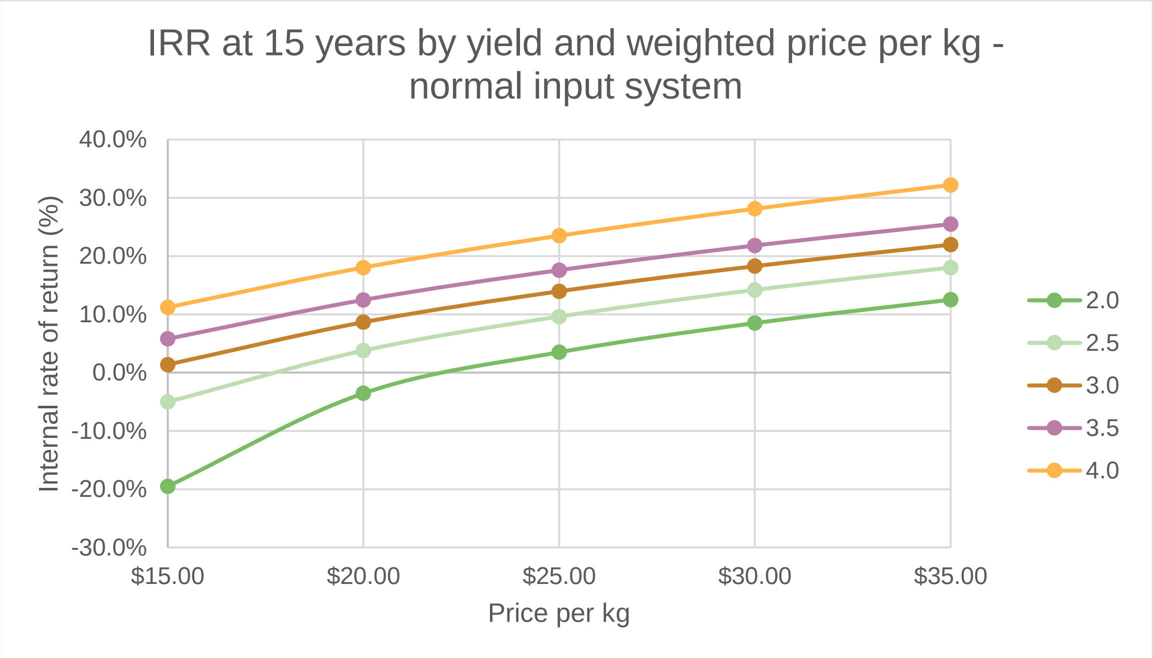

Figure 3. Sensitivity analysis showing IRR at 15 years by yield and price per kg for a normal input system.

Low input production system

The sensitivity analysis of the low input model is significantly different to that of a normal input model. It shows that restricting yields and quality through no irrigation will make the investment in terms of IRR not sustainable. With a maximum of 2.2 t/ha at $35/kg, the IRR is 12.9%. This is okay however, a significant number of factors need to be optimised for this to happen.

Table 7. Internal rate of return (IRR) at 15 years by yield and weighted price per kg for a low input system.

-4.9%	1.4	1.6	1.8	2.0	2.2
$15.00				-22.9%	-12.8%
$20.00			-11.5%	-4.9%	-1.7%
$25.00	-17.8%	-8.8%	**-2.4%**	2.2%	4.5%
$30.00	-6.8%	-2.0%	3.1%	7.2%	9.2%
$35.00	-0.9%	2.7%	7.3%	11.2%	12.9%

Figure 4. IRR at 15 years by yield and weighted price per kg for a low input system.

12.0 Appendices

12.1 Normal input system model

ANNUAL INCOME & EXPENSES			Normal input system														Price/cost per unit at full production		
Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	$/kg		$/HA
INCOME																	GROSS		AREA
Yield - T/ha	0	0	0	1	2	2	2	3	3	3	3	3	3	3	3	3			
- Kg (Gross)	0	0	0	10,000	20,000	20,000	20,000	27,000	27,000	27,000	27,000	27,000	27,000	27,000	27,000	27,000			
Total Income	0	0	0	170,000	340,000	340,000	340,000	459,000	459,000	459,000	459,000	459,000	459,000	459,000	459,000	459,000	$17.00		$45,900
EXPENSES																			
Post Harvest Expenses																			
Reprocessing	0	0	0	2,000	4,000	4,000	4,000	5,400	5,400	5,400	5,400	5,400	5,400	5,400	5,400	5,400	$0.20		$540
Drying	0	0	0	2,100	4,200	4,200	4,200	5,670	5,670	5,670	5,670	5,670	5,670	5,670	5,670	5,670	$0.21		$567
Hulling and Shelling	0	0	0	2,100	4,200	4,200	4,200	5,670	5,670	5,670	5,670	5,670	5,670	5,670	5,670	5,670	$0.21		$567
Freight (orchard to packhouse)	0	0	0	1,000	2,000	2,000	2,000	2,700	2,700	2,700	2,700	2,700	2,700	2,700	2,700	2,700	$0.10		$270
Industry Levy	0	0	0	700	1,400	1,400	1,400	1,890	1,890	1,890	1,890	1,890	1,890	1,890	1,890	1,890	$0.07		$189
Total Post Harvest Expenses	0	0	0	7,900	15,800	15,800	15,800	21,330	21,330	21,330	21,330	21,330	21,330	21,330	21,330	21,330	$0.79		$2,133
Orchard Gate Income	0	0	0	162,100	324,200	324,200	324,200	437,670	437,670	437,670	437,670	437,670	437,670	437,670	437,670	437,670	$16.21		$43,767
Labour Expenses																			
Pruning	6,942	6,942	10,274	13,883	19,437	22,213	24,990	27,767	27,767	27,767	27,767	27,767	27,767	27,767	27,767	27,767	$1.03		$2,777
Spraying	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	$0.19		$500
Harvesting	0	0	0	1,748	2,622	3,284	3,705	4,163	4,163	4,163	4,163	4,163	4,163	4,163	4,163	4,163	$0.15		$416
Other Wages	2,925	5,850	14,625	21,938	26,325	29,250	29,250	29,250	29,250	29,250	29,250	29,250	29,250	29,250	29,250	29,250	$1.08		$2,925
Wages of management	20,000	40,000	40,000	40,000	40,000	40,000	40,000	40,000	40,000	40,000	40,000	40,000	40,000	40,000	40,000	40,000	$1.48		$4,000
ACC	335	555	671	793	896	958	988	1,019	1,019	1,019	1,019	1,019	1,019	1,019	1,019	1,019	$0.04		$102
Operating Expenses																			
Weed & Pest control	2,000	7,000	14,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	$0.74		$2,000
Pollination	0	0	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	$0.19		$500
Fertiliser	10,000	20,000	20,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	$0.37		$1,000
Orchard Sundries	15,000	15,000	15,000	15,000	15,000	15,000	15,000	15,000	15,000	15,000	15,000	15,000	15,000	15,000	15,000	15,000	$0.56		$1,500
Vehicle expenses	750	3,750	5,625	7,500	7,500	7,500	7,500	7,500	7,500	7,500	7,500	7,500	7,500	7,500	7,500	7,500	$0.28		$750
Fuel	700	4,900	5,950	7,000	7,000	7,000	7,000	7,000	7,000	7,000	7,000	7,000	7,000	7,000	7,000	7,000	$0.26		$700
Repairs and Maintenance	0	12,000	12,000	12,000	12,000	12,000	12,000	12,000	12,000	12,000	12,000	12,000	12,000	12,000	12,000	12,000	$0.44		$1,200
Electricity	200	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	$0.07		$200
Total Variable Expenses	63,851	122,996	150,145	161,862	172,781	179,205	182,433	185,698	185,698	185,698	185,698	185,698	185,698	185,698	185,698	185,698	$6.88		$18,570
GROSS MARGIN	(63,851)	(122,996)	(150,145)	238	151,419	144,995	141,767	251,972	251,972	251,972	251,972	251,972	251,972	251,972	251,972	251,972	$9.33		$25,197
less : Orchard overheads																			
Lease cost	20,000	40,000	40,000	40,000	40,000	40,000	40,000	40,000	40,000	40,000	40,000	40,000	40,000	40,000	40,000	40,000	$1.48		$4,000
Administration	7,140	7,140	7,140	7,140	7,140	7,140	7,140	7,140	7,140	7,140	7,140	7,140	7,140	7,140	7,140	7,140	$0.26		$714
Property Charges	7,070	7,070	7,070	7,070	7,070	7,070	7,070	7,070	7,070	7,070	7,070	7,070	7,070	7,070	7,070	7,070	$0.26		$707
Crop insurance	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	$0.00		$0
Subtotal Orchard Overheads	34,210	54,210	54,210	54,210	54,210	54,210	54,210	54,210	54,210	54,210	54,210	54,210	54,210	54,210	54,210	54,210	$2.01		$5,421
CASH ORCHARD SURPLUS (EBITDAR)	(98,061)	(177,206)	(204,355)	(53,972)	97,209	90,785	87,557	197,762	197,762	197,762	197,762	197,762	197,762	197,762	197,762	197,762	$7.32		$19,776
Development Costs	716,164	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
Total Cash Surplus/Deficit	(814,226)	(177,206)	(204,355)	(53,972)	97,209	90,785	87,557	197,762	197,762	197,762	197,762	197,762	197,762	197,762	197,762	197,762			
Cummulative Cash Result	(814,226)	(991,432)	(1,195,787)	(1,249,759)	(1,152,549)	(1,061,764)	(974,207)	(776,446)	(578,684)	(380,923)	(183,161)	14,600	212,362	410,123	607,885	805,646			

Table 8. Normal input system financial result breakdown.

IRR to Year 15	5.5%
IRR to Year 10	-2.2%
NPV (6%) after 15 years	-$50,734
NPV (6%) after 10 years	-$489,571
Cash Surplus at year 15	$805,646
Cash Surplus at Year 10	-$183,161
Breakeven year	12

12.2 Low input system model

ANNUAL INCOME & EXPENSES			Low input system model														*Price/cost per unit at full production*		
Year	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	***$/kg***		***$/HA***
INCOME																	***GROSS***		***AREA***
Yield - T/ha	0	0	0	1	1	2	2	2	2	2	2	2	2	2	2	2			
- Kg (Gross)	0	0	0	10,000	10,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000			
Total Income	0	0	0	160,000	160,000	320,000	320,000	320,000	320,000	320,000	320,000	320,000	320,000	320,000	320,000	320,000	*$16.00*		*$32,000*
EXPENSES																			
Post Harvest Expenses																			
Reprocessing	0	0	0	2,000	2,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	*$0.20*		*$400*
Drying	0	0	0	1,800	1,800	3,600	3,600	3,600	3,600	3,600	3,600	3,600	3,600	3,600	3,600	3,600	*$0.18*		*$360*
Hulling and Shelling	0	0	0	1,800	1,800	3,600	3,600	3,600	3,600	3,600	3,600	3,600	3,600	3,600	3,600	3,600	*$0.18*		*$360*
Freight (orchard to packhouse)	0	0	0	1,000	1,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	*$0.10*		*$200*
Industry Levy	0	0	0	600	600	1,200	1,200	1,200	1,200	1,200	1,200	1,200	1,200	1,200	1,200	1,200	*$0.06*		*$120*
Total Post Harvest Expenses	0	0	0	7,200	7,200	14,400	14,400	14,400	14,400	14,400	14,400	14,400	14,400	14,400	14,400	14,400	*$0.72*		*$1,440*
Orchard Gate Income	0	0	0	152,800	152,800	305,600	305,600	305,600	305,600	305,600	305,600	305,600	305,600	305,600	305,600	305,600	*$15.28*		*$30,560*
Labour Expenses																			
Pruning	4,165	4,165	6,942	11,107	16,660	19,437	22,213	24,990	24,990	24,990	24,990	24,990	24,990	24,990	24,990	24,990	*$1.25*		*$2,499*
Spraying	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	*$0.25*		*$500*
Harvesting	0	0	0	1,748	2,622	3,284	3,705	4,163	4,163	4,163	4,163	4,163	4,163	4,163	4,163	4,163	*$0.21*		*$416*
Other Wages	2,925	5,850	14,625	21,938	26,325	29,250	29,250	29,250	29,250	29,250	29,250	29,250	29,250	29,250	29,250	29,250	*$1.46*		*$2,925*
Wages of management	20,000	40,000	40,000	40,000	40,000	40,000	40,000	40,000	40,000	40,000	40,000	40,000	40,000	40,000	40,000	40,000	*$2.00*		*$4,000*
ACC	308	528	639	766	870	931	962	993	993	993	993	993	993	993	993	993	*$0.05*		*$99*
Operating Expenses																			
Weed & Pest control	2,000	7,000	14,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	*$1.00*		*$2,000*
Pollination	0	0	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	*$0.25*		*$500*
Fertiliser	10,000	20,000	20,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	*$0.50*		*$1,000*
Orchard Sundries	15,000	15,000	15,000	15,000	15,000	15,000	15,000	15,000	15,000	15,000	15,000	15,000	15,000	15,000	15,000	15,000	*$0.75*		*$1,500*
Vehicle expenses	750	3,750	5,625	7,500	7,500	7,500	7,500	7,500	7,500	7,500	7,500	7,500	7,500	7,500	7,500	7,500	*$0.38*		*$750*
Fuel	700	4,900	5,950	7,000	7,000	7,000	7,000	7,000	7,000	7,000	7,000	7,000	7,000	7,000	7,000	7,000	*$0.35*		*$700*
Repairs and Maintenance	0	12,000	12,000	12,000	12,000	12,000	12,000	12,000	12,000	12,000	12,000	12,000	12,000	12,000	12,000	12,000	*$0.60*		*$1,200*
Electricity	200	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	*$0.10*		*$200*
Total Variable Expenses	61,048	120,193	146,781	159,058	169,977	176,402	179,630	182,895	182,895	182,895	182,895	182,895	182,895	182,895	182,895	182,895	*$9.14*		*$18,290*
GROSS MARGIN	(61,048)	(120,193)	(146,781)	(6,258)	(17,177)	129,198	125,970	122,705	122,705	122,705	122,705	122,705	122,705	122,705	122,705	122,705	*$6.14*		*$12,270*
less : Orchard overheads																			
Lease cost	20,000	40,000	40,000	40,000	40,000	40,000	40,000	40,000	40,000	40,000	40,000	40,000	40,000	40,000	40,000	40,000	*$2.00*		*$4,000*
Administration	7,140	7,140	7,140	7,140	7,140	7,140	7,140	7,140	7,140	7,140	7,140	7,140	7,140	7,140	7,140	7,140	*$0.36*		*$714*
Property Charges	7,070	7,070	7,070	7,070	7,070	7,070	7,070	7,070	7,070	7,070	7,070	7,070	7,070	7,070	7,070	7,070	*$0.35*		*$707*
Crop insurance	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	*$0.00*		*$0*
Subtotal Orchard Overheads	34,210	54,210	54,210	54,210	54,210	54,210	54,210	54,210	54,210	54,210	54,210	54,210	54,210	54,210	54,210	54,210	*$2.71*		*$5,421*
CASH ORCHARD SURPLUS (EBITDAR)	(95,258)	(174,403)	(200,991)	(60,468)	(71,387)	74,988	71,760	68,495	68,495	68,495	68,495	68,495	68,495	68,495	68,495	68,495	*$3.42*		*$6,849*
Development Costs	620,964	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
Total Cash Surplus/Deficit	(716,222)	(174,403)	(200,991)	(60,468)	(71,387)	74,988	71,760	68,495	68,495	68,495	68,495	68,495	68,495	68,495	68,495	68,495			
Cummulative Cash Result	(716,222)	(890,625)	(1,091,616)	(1,152,085)	(1,223,472)	(1,148,484)	(1,076,723)	(1,008,228)	(939,734)	(871,239)	(802,744)	(734,249)	(665,754)	(597,259)	(528,765)	(460,270)			

Table 9. Low input system financial result breakdown

IRR to Year 15	-4.9%
IRR to Year 10	-14.7%
NPV (6%) after 15 years	-$690,471
NPV (6%) after 10 years	-$842,462
Cash Surplus at year 15	-$460,270
Cash Surplus at Year 10	-$802,744
Breakeven year	17

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Suitability modelling and life cycle analysis for almond cultivation in Hawke’s Bay and Poverty Bay

Cummins M, Vetharaniam I

July 2022

Confidential report for:

Central Hawke's Bay District Council

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PUBLICATION DATA

Cummins M, Vetharaniam I. July 2022. Suitability modelling and life cycle analysis for almond cultivation in Hawke's Bay and Poverty Bay. A Plant & Food Research report prepared for: Central Hawke's Bay District Council. Milestone No. 94407. Contract No. 40253. Job code: P/442101/01. **PFR SPTS No. 23011**.

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July 2022

Contents

Executive summary

Suitability modelling and life cycle analysis for almond cultivation in Hawke's Bay and Poverty Bay

Cummins M, Vetharaniam I
Plant & Food Research Ruakura

July 2022

We performed suitability modelling to identify locations that would be suitable for growing almonds in Hawke's Bay and Gisborne and carried out climate change impact studies to investigate how suitability for almonds would change in these regions under two greenhouse gas emission pathways. We additionally performed a life cycle assessment (LCA) to evaluate the potential carbon footprint associated with growing almonds. This work is part of a larger effort to investigate the feasibility for establishing a New Zealand almond industry that produces high yields of a premium quality product while using sustainable agronomic practices to minimise environmental impacts.

Suitability modelling

- Suitability modelling was carried out for a number of criteria related to climate, soil and terrain considerations. Climate-related criteria included sufficiency of winter chill accumulation and warmth accumulation for flowering, adequacy of temperatures for pollination, frost risk, moisture-related disease risk, warmth accumulation for crop maturity, risk of rain damage to nuts around harvest, and adequacy of annual rainfall. Soil and terrain criteria included sufficiency of soil depth, sufficiency of drainage, steepness of land, and appropriate land use capability class.
- Continuous suitability models were used, with suitability criteria being assessed on a continuous scale of 0 (unsuitable) to 1 (highly suitable with no limitations). Lower scores indicate more mitigations are required to successfully grow the crop. Suitability scores for different criteria were combined using weighted geometric averaging to obtain an overall cultivation suitability score, with the value of the weights assigned to different criteria reflecting their relative importance. GIS climate and land databases were used to provide inputs to the models, allowing for construction of suitability maps for the Hawke's Bay and Gisborne regions.
- An existing almond phenology model that uses climate data as inputs was modified and parameterised to predict when key phenological stages (flowering, hull split and harvest maturity) occur in relation to potentially inclement weather. Limited New Zealand centric data were available from two Hawke's Bay almond orchards with a combined three years of observations and were used to parameterise the model for New Zealand. More comprehensive data would be needed to obtain a more robust parameterisation.

- The modelling results showed that a diverse suitability landscape for cultivating almonds existed across both Hawke's Bay and Gisborne regions. No locations were identified that would provide optimal conditions for almonds with few limitations to production. However a number of locations were identified that could provide good conditions for growing almonds, although subject to some limitations to achieving maximum production potential.

- Some locations in the Heretaunga Plains, especially around Hastings and Havelock North, were found to have the highest cultivation suitability scores, with a number of locations in Central Hawke's Bay District having slightly lower cultivation suitability scores. A number of locations around Poverty Bay and inland of the Poverty Bay Flats were also identified as having good suitability scores. Although these locations are likely to be subject to more limitations or extra mitigation costs, they are potential sites for successful almond orchards.

- Large areas of Central Hawke's Bay District and areas around Hastings and Napier were identified as having insufficient annual rainfall to obtain maximum yields without irrigation. However growers can choose not to irrigate almonds and accept low yields.

- The climate change impact assessment projected that under RCP 8.5, a high greenhouse gas (GHG) concentration pathway consistent with unabated emissions, cultivation suitability for almond would improve over time, at least to 2070. Under RCP 6.0, a GHG concentration pathway consistent with lower emissions than RCP8.5, cultivation suitability for almond was also projected to improve, but at a slower rate than under RCP 8.5.

Life Cycle Assessment

- A partial Life cycle assessment (LCA) showed that if irrigation were used, almonds at the farm gate would have a potential carbon footprint of 1.83 kg CO_2-eq/kg. For comparison, studies for almond production overseas found the potential carbon footprint to be between 1.6–1.9 kg CO_2-eq/kg.

- Irrigation was highlighted as a potential system hotspot and area of consideration for system improvements accounting for 68% of the total footprint. This is followed by machinery operations (13%) and fertiliser use (9%).

- Sensitivity analysis revealed that a reduction in the applied irrigation could significantly reduce the overall potential footprint. This may, however, have a negative correlation with the overall potential yield.

- Orchard specific data were limited, therefore, a number of assumptions have been made in the design of the LCA model. It is advised that LCA results are considered alongside other information.

- A review of the potential carbon footprint relating to other land uses was completed. However, LCAs are a relative measure and comparisons between land uses and products with different functions should be avoided.

- Future assessments should focus on data quality to improve the reliability and robustness of the current LCA model. Further considerations may include expanding the system boundary or the effect of bi-product utilisation for other processes.

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1 Introduction

This report details the outcomes of a study to perform suitability modelling and life cycle assessment (LCA) for almonds, in order to support the development of a new almond sector in the Hawke's Bay/Poverty Bay regions. This study is part of a larger project to investigate the feasibility for establishing a New Zealand almond industry that produces high yields of a premium quality product while using sustainable agronomic practices to minimise environmental impacts.

Ideal conditions for almonds are Mediterranean-like climates with slightly hot summers and cool winters, coupled with deep, loamy well-drained soils (Ahmed & Verma 2009). The New Zealand Tree Crops Association considers New Zealand climates to be relatively marginal for growing almonds, with the most suitable areas likely to be located in areas of Hawkes' Bay, Nelson, Canterbury and Otago (https://treecrops.org.nz/almond-factsheet/), which is likely reflected by a lack of commercial production, with only a few almond growers in the country. Development of an almond industry would be supported by the identification of promising areas as a first step before on-ground feasibility investigations. New Zealand's primary sector is subject to a number of weather-related risks and is potentially vulnerable to climate change which could bring about declining yields and profitability or alternatively provide new opportunities (Hopkins et al. 2015; Manning et al. 2015; Ausseil et al. 2016; Cradock-Henry et al. 2019). Thus an understanding of potential impacts of climate change is important when establishing a new almond industry.

Some consumers are likely to pay a price premium for sustainably and locally grown almonds (de-Magistris & Gracia 2016). Thus it would be invaluable to understand how New Zealand grown almonds would compare with imported almonds on sustainability issues, as well as with alternative land uses. Life cycle assessment (LCA) is a tool that can be used to assess the potential environmental performance of a production system and LCA methodology is intended to give an indication of the potential footprint along each step of a product's life cycle and highlight hotspots along the production chain. Inputs and associated outputs of a product system can then be quantified to give an indication of their potential environmental burden.

The aim of this study was to:

- Apply a model previously developed by Plant & Food Research (PFR) to evaluate the suitability of almond cultivation, using GIS-based information on soil, terrain, and weather, to identify the most suitable locations in Hawke's Bay and East Coast, and the most suitable almond phenotypes, for the production of sustainably produced almonds.
- Use LCA to evaluate the potential carbon footprint associated with growing almonds in Hawkes Bay, and identify 'hotspots' with the production systems.
- Investigate how climate change could impact the suitability of individual locations under different scenarios of future atmospheric greenhouse gas (GHG) concentrations (and thus different levels of global and regional warming).

1.1 Suitability modelling

The PFR suitability model uses essentially a fuzzy logic approach and calculates a suitability score on a continuous scale from 0 (totally unsuited) to 1 (suitable with no limitations) for each suitability criterion being considered. This approach has been applied to model location suitability for a number of perennial crops (Vetharaniam et al. 2021). Criteria scores are geometrically averaged to get an overall suitability score, with scores weighted to reflect their relative importance.

For modelling suitability with respect to climate-related criteria, the model simulates the temporal development of key phenology stages (e.g. budbreak, flowering period, hull split and maturity) as a function of weather data, in order to assess the timing of weather conditions that could be deleterious to particular phenology stages. For example, frost events or poor pollination conditions during the flowering period, or rainfall from the split hull stage through to harvest.

Thomas & Hayman (2018) noted that phenology-based models provide a means to explore how almonds will perform at new sites and in future climates. Those authors reported the development and evaluation of an almond phenology model driven by chill and heat accumulation, with particular phenological stages (10% and 80% flowering, 1% and 100% hull split, and harvest) dictated at precise amounts of heat and chill accumulation. A similar approach had also been reported by Parker & Abatzoglou (2017) a little earlier.

The PFR model takes a probabilistic approach and simulates the likelihood of a phenological stage having been reached, which can reduce the inconsistencies that occur with hard cut-offs. The model was theoretical for almonds in New Zealand, and has been parameterised based on published data from overseas trials that provided chill and heat accumulation for different phenological stages. Model simulations were formulated separately for three development groups: early, medium and late cultivars. For each phenology stage, the model simulated the percent of cultivars in each development group expected to have reached that stage.

There is a paucity of almond phenology data for New Zealand, and we had access to incomplete datasets for two separate orchard locations in Hawke's Bay, one having observations in two different growing seasons, and the other having observations in only one growing season. However, when testing the initial parameterisation these were sufficient to show that the overseas data were not suitable for modelling the New Zealand situation. This was not unexpected since the cultivars grown here were not represented in the overseas data, and furthermore, chill and heat accumulations for the same cultivar can vary with country.

We adjusted the PFR suitability model to simulate the phenology observations from the Hawke's Bay orchards, and sense checked predictions for phenological stages where data were available. There were insufficient data to parameterise the mode separately for early, medium and late developing cultivars, and so we used one parameterisation set that reflected the variation from early to late developing cultivars.

1.1.1 Interpreting continuous suitability scores

The use of continuous suitability scores is an alternative to using categories with hard cut-offs. A high suitability score (close to 1) for a criterion indicates that crop cultivation will have little or no limitation with respect that criterion. However, the lower the score is below 1, the greater the limitations that can be expected, and more mitigations would be needed to successfully grow the crop, or more losses tolerated. This approach generally does not rule a location as suitable or unsuitable – that becomes a management decision.

1.2 Life cycle assessment

The life cycle of a product may be evaluated from the extraction of raw materials to production, transport, consumer interaction, and recycling (i.e. cradle to grave), or as part of a product system (i.e. cradle to farm gate). Results and interpretation of an LCA can then be integrated with other assessment techniques to improve sustainability outcomes, improve management, or resource use efficiency (Klöpffer 1997; Finnveden et al. 2009; Hauschild et al. 2018).

The LCA framework, as defined by the International Organization for Standardisation (ISO 2006a, 2006b) has four main phases:

- *Goal and scope definition*: this includes the reason for carrying out the study, the intended application and audience. It is also here that the system boundary is defined (i.e. the extent or the cut-off of the production system being assessed) and the functional unit defined (i.e. base reference to compare products).
- *Life cycle inventory (LCI):* LCI is the collection and sum of all the inputs and outputs and associated flows of the product system.
- *Life cycle inventory analysis (LCIA):* aims to describe the environmental consequences of the loads quantified in the LCI, which are translated to potential impacts such as global warming potential (GWP), eutrophication potential or acidification potential.
- *Interpretation:* results from the previous phases are evaluated in relation to the goal and scope in order to reach conclusions and formulate recommendations.

There is increased awareness and concern regarding the potential impacts on society associated with climate change and global warming (Kerr 2007). LCA has been used extensively to assess the potential environmental impact of a variety of products and in more recent times has also been adopted to evaluate the performance of agricultural products (Hayashi et al. 2006; Roy et al. 2009; Caffrey & Veal 2013). Rather than addressing the immediate and most obvious concerns, LCA takes a holistic approach and allows us to evaluate the potential impact of various stages within a product's life cycle. The assessment and definition of environmental impact, when conducting an LCA, is at the discretion of those who are undertaking the study and what has been defined in the goal and scope. When reporting the results from LCAs, in relation to a carbon footprint, units of CO_2-equivalent (CO_2- eq) are often used. The emission of greenhouse gases, which are the result of a number of natural and human driven processes, has varying degrees of global warming potential (GWP) and therefore, CO_2- eq units provide a metric measure that allow us to compare different gaseous emissions on a common scale.

2 Methodology

2.1 Suitability modelling

A number of climate- and soil/land-related suitability criteria were identified by Hall et al. (2018) for a range of temperate tree crops related to climate, soil and terrain considerations, and are applicable to almond cultivation. These include adequacy of winter chill to ensure a sufficient and compact flowering, sufficient warmth during the growing season for the crop to reach maturity, risk to production from frost damage, soil drainage class, soil depth to a root-impermeable layer, and the slope of the land. In addition to these suitability considerations, Vetharaniam et al. (2021) included land use capability (LUC) class descriptors as suitability criteria that could be used for a range of crops, and also developed a generic disease-risk suitability model for pathogens favoured by high moisture availability combined with warm temperatures. We have included all the above as suitability criteria for almonds.

Thomas et al. (2019) listed a number of risk factors of concern identified during workshops with Australian almond growers. Excluding criteria mentioned above, these included rain at harvest, heatwaves, and wind damage, non-synchronised flowering, adequacy of rainfall for growing requirements, temperatures being too cold for pollination, and hail damage. Of these, we have included rain around harvest, adequacy of rainfall and cold temperatures during pollination in our suitability considerations.

There is a lack of quantitative data on the impact of heatwaves, and heatwaves are less likely to be a problem in New Zealand compared with Australia, especially in the current climate, and thus this was a risk that we modelled. The risk of wind damage was not modelled since the historic and simulated future climate data contain average daily wind speeds but not gusts or storm events. We did not have data on historic hail events in our historic climate database, and hail events cannot be projected with any confidence in future climate projection data, and thus hail risk was excluded as a modelled suitability criterion. Non-synchronised flowering between main varieties and pollinator cultivars is related to low chill accumulation, and risks can be reduced by using self-fertile varieties (Thomas et al. 2019). Since we included chill consideration in the modelling, we did not model non-synchronised flowering as a specific criterion.

The temporal development of almonds was modelled in terms of the probabilities that key phenology stages including budbreak, flowering period, hull split and maturity had been reached at different stages of the growing season, with these probabilities expressed as functions of accumulated chill and/or warmth over the course of the growing season. Climate-related suitability scores were calculated with respect to the rate of phenological progression, separately for each year. Scores for individual climate criteria were averaged over a period to get a representative mean score. Overall climate suitability was calculated first on a yearly basis by taking the weighted geometric mean of individual climate criteria scores for each year, and then averaging the yearly climate suitability scores over a period. Land-related suitability scores were calculated separately for each criterion, and then could be geometrically averaged using weights to get an overall suitability score for land-related criteria. The suitability scores for land and for climate could be then geometrically averaged using weights to get an overall suitability score than balanced across all criteria. Weights used in geometric averaging were chosen to reflect the relative importance of individual criteria.

Suitability scores for the contemporary period were calculated using data on historic weather. Suitability scores for future periods required the use of projection data from climate models.

2.1.1 Data

Observed, historic climate data

We used NIWA's VCSN database to provide estimates of historic values of daily climate variables. These data are gridded with a resolution of approximately 5 x 5 km, covering the entire country. The VCSN data are estimates of daily climate variables based on spatial interpolation of actual observations made at climate stations spanning the country (Tait et al. 2006; Tait 2008). We used daily maximum and minimum temperatures, relative humidity (RH) and rainfall data for the period 2001 to early 2021. The maximum temperature for each day is the maximum recorded **from** 9 a.m. of that day; the minimum temperature corresponds to the minimum recorded **to** 9 a.m. of that day; RH is humidity at 9 a.m.

Projected climate data

We used the "SLM RCP" datasets which had been specifically bias and variance adjusted for horticulture-related climate projection by Vetharaniam et al. (2021) and are derived from modelled climate data that were supplied by NIWA for the Sustainable Land Management and Climate Change (SLMACC) project 'Analysis of potential climate change impacts on horticulture's spatial footprint' (#34671).

The NIWA data were derived from NIWA's high resolution Regional Climate Model (RCM), which was run in alternative simulations with boundary conditions that were provided by outputs from six CMIP5 (Coupled Model Intercomparison Project (CMIP) Phase 5) global climate models (GCMs): BCC-CSM1.1, CESM1-CAM5, GFDL-CM3, GISS-EL-R, HadGEM2-ES and NorESM1-M. Simulations were performed under four Representative Concentration Pathways (RCPs) which represent different scenarios of future atmospheric greenhouse gas (GHG) concentrations, and thus four different levels of global and regional warming. The simulations were run for the years 1972 to 2100, and beyond for some GCMs, with a hindcast period of 1872 to 2005. The simulations are described in detail by the Ministry for the Environment (2018).

Of the four RCP pathways, RCP 2.6 and RCP 8.5 are the extremes: RCP 2.6 represents a low greenhouse gas (GHG) concentration pathway consistent with significant emissions reductions, and RCP 8.5 represents a high GHG concentration pathway consistent with unabated emissions. The two intermediate RCP pathways are RCP 4.5 and 6.0 with RCP 4.5 corresponding to more emissions reductions than RCP 6.0.

For projecting climate change impacts, we used RCP 8.5 since it is closest to the current emissions trajectory and additionally we included RCP 6.0.

Land and soil information

We used the FSL and NZLRI databases to get data on the potential rooting depth (PRD, https://lris.scinfo.org.nz/layer/48110-fsl-potential-rooting-depth/) provided by the soil, soil drainage (https://lris.scinfo.org.nz/layer/48104-fsl-soil-drainage-class/), and land use capability (LUC) class (https://lris.scinfo.org.nz/layer/48076-nzlri-land-use-capability/). Slope information was obtained from Land Environments of New Zealand (LENZ, https://lris.scinfo.org.nz/layer/48081-lenz-slope/).

Locations of public conservation areas were obtained from the Department of Conservation (DOC) Public Conservation Areas database (https://koordinates.com/layer/754-doc-public-conservation-areas/). Data on the location of urban areas, quarries, rivers and lakes were available in the NZLRI database. Information from these databases had been extracted and then resampled onto a grid resolution of approximately 1 x 1 km in the SLMACC project 'Analysis of potential climate change impacts on horticulture's spatial footprint' (#34671).

Limitations when using gridded data

There can be significant variation in microclimates and weather variables within the approximately 25 km^2 area represented by each VCSN grid cell. For example Ellenwood (1941) found differences of 1.7 to 2.2°C between locations in neighbouring apple orchards that had no more than a 7.5 m difference in elevation. Such variation is not represented in the VCSN database, which provides a single daily value per grid for each weather variable that it contains. Similar limitations apply to databases for soil and terrain properties. These limitations should be borne in mind when considering outcomes from GIS-based models.

Elevation data

Although we have not used elevation information directly, an elevation map (Figure 5) for the locations being modelled can be useful for sense-checking predictions.

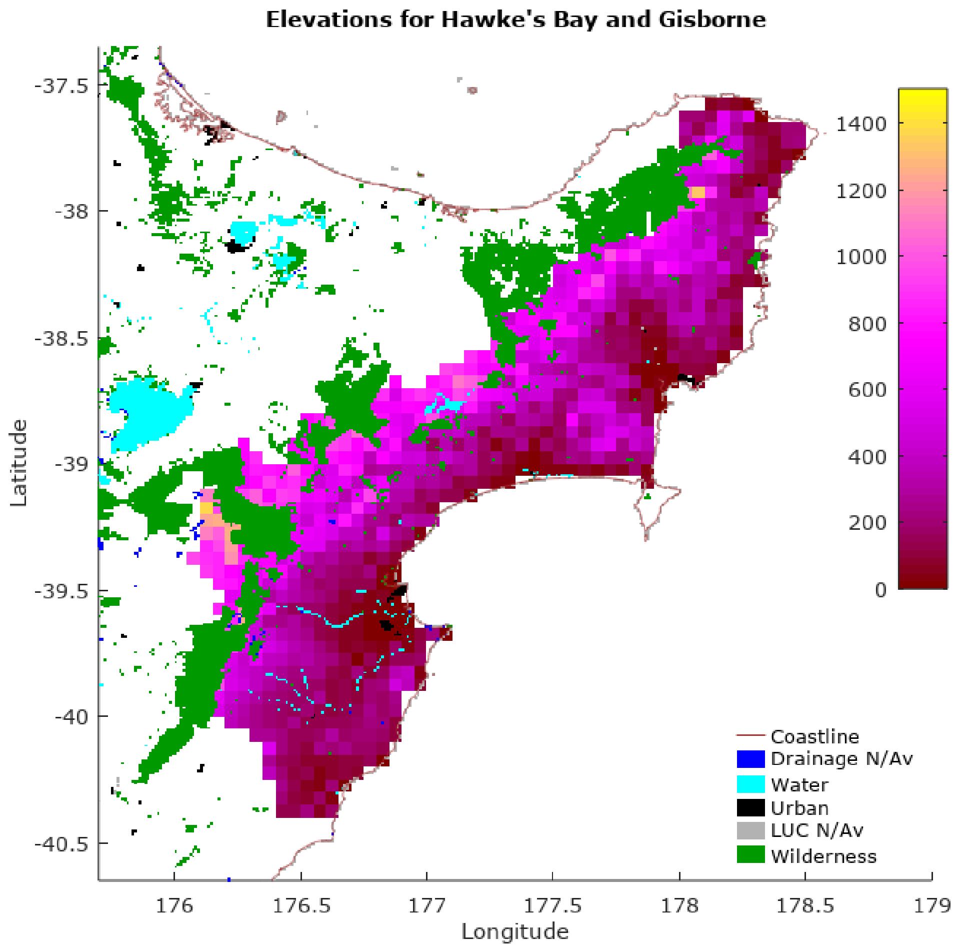


Figure 5. Elevations of locations across the Hawke's Bay and Gisborne Regions, using data provided in the Virtual Climate Station Network (VCSN) database.

2.1.2 Modelling phenological development

Parker & Abatzoglou (2017) described a mechanistic model approach in which key phenology stages (1%, 50% and 100% bloom, 1% and 100% hull split, and harvest maturity) were reached at specified thresholds of chill or warmth accumulations, and associated with different levels of cold hardiness, which was expressed as percent damage below specified threshold temperatures. We adapted this approach by introducing variance into the thresholds for chill and warmth accumulation. We additionally replaced the fixed cold damage thresholds with continuous sigmoidal damage responses as described by Vetharaniam et al. (2021), and this is elaborated on in the section on frost risk below.

Chilling, forcing and flowering

The most common chilling models used for fruit trees are the Utah (or Richardson) Chill Units Model (Richardson et al. 1974), the Dynamic Model (Fishman et al. 1987a, b; Erez et al. 1990) and the simple model of chilling hours between 0 and 7°C. The Utah model has been used in conjunction with growing degree hours (GDH) to predict the transition in almonds from endodormancy to ecodormancy and the time to reach full bloom (opening of 50% of flowers) in several studies (Egea et al. 2003;

Alonso et al. 2005; Alonso et al. 2010). The Dynamic model has also been used to model blooming time in almonds (Gaeta et al. 2018; Thomas & Hayman 2018; Díez-Palet et al. 2019; Thomas et al. 2019). There are contrasting views on which of these two models is better. (Luedeling 2012; Measham et al. 2017) and Covert (2011) found that none of chilling hours, the Utah model or the Dynamic model stood out as better for predicting flowering time.

We used the Utah (Richardson) model together with GDH accumulation, in a "chill-force" model of flowering. This model assumes that chilling is needed for a flower bud to transition from a state of endodormancy to a state of ecodormancy after which its progression to flowering is forced by heat accumulation. The Utah model uses temperature thresholds of 1.5, 2.5, 9.2, 12.5, 16 and 18°C and assigns chill units (CU) of respectively 0.5, 1, 0.5, 0 and -0.5 for each hour that temperature was in the intervals defined by the thresholds. No CU are assigned for temperatures below 1.5°C and -1 CU assigned for each hour above 18°C.

In the Utah model, GDH with respect to a base of 4.5°C are normally calculated by capping hourly temperature at 25°C and then subtracting 4.5 from each hourly temperature above 4.5°C, then summing across the day. However almonds prefer summer temperatures of 30 to 35°C (Ahmed & Verma 2009) and thus 25°C is likely too low for an upper accumulation temperature. Thus we followed Thomas et al. (2019) who used an upper accumulation temperature of 36°C when calculating GDH.

Reported chill and heat accumulation requirements for almonds to transition from endodormancy to full bloom (F50 or 50% of flowers having opened) varied between different studies and between cultivars. Egea et al. (2003) found that 10 cultivars ranged in their chilling and heat requirement from 270 to 1000 CU and 5940 to 7580 GDH respectively. Alonso et al. (2005) found that 44 cultivars had chill requirements ranging from 360 to 480 CU and heat requirement ranging from 5350 to 9350 GDH, while Alonso et al. (2010) found that nine cultivars had a similar range in chill requirement from 330 to 500 CU but a much larger range in heat requirement of 2870 to 10230 GDH.

In a study of three cultivars, Ramírez et al. (2010) found that CU requirements were 35–49% lower but GDH requirements 42– 71% higher than those found by Alonso et al. (2005) for the same cultivars. Similarly comparing results for cultivars common to the studies of Egea et al. (2003) and Alonso et al. (2005), differences in chill requirement were opposite to differences in heat requirement. This may reflect that increased chill could require decreased forcing, or that decreased chill could be compensated for by increased GDH.

To reflect the variability in reported chill requirements, the PFR model uses a function to express the proportion of chill requirement across cultivars that is obtained from a given value of accumulated CU, based on the mean and standard deviation of the published results discussed above. This would for example allow modelling the days by which the 5th, 50th and 95th percentiles of cultivars would have had their chill requirements met and the days by which the 5th, 50th and 95th percentiles of cultivars would have experienced full bloom. To reflect that decreased chill could be compensated by increased GDH accumulation and vice versa, we used a sigmoidal chill function that increased from 0 to 1 as accumulated CU increased, and the daily value of the chill function was used to eight daily GDH when calculating accumulated GDH.

We applied the assumption by Hayman & Thomas (2017) that for almonds in Australia, chill accumulation occurs only from late April, and calculated chill accumulation starting from the last week of April. Calculation of CU requires hourly temperature values, and in order to calculate CU from maximum and minimum temperature, it was assumed that temperature had a sinusoidal variation through the day. The hours spent below a temperature threshold T_{crit} is then given by:

$$\frac{24}{\pi}\left(1 - \mathrm{real}\left(\mathrm{acos}\left(2\frac{T_{\mathrm{crit}} - T_{\mathrm{min}}}{T_{\mathrm{max}} - T_{\mathrm{min}}} - 1\right)\right)\right). \qquad (1)$$

To model the occurrence of the F1 and F100 stages (respectively 1% and 100% bloom) we followed Parker & Abatzoglou (2017) who worked in growing degree days (GDD) base 4.5°C and modelled these stages as occurring when heat accumulation was respectively 80% and 135% of the heat accumulation at F50 (50% bloom). We applied these factors to the probability means and standards for GDH calculated above, allowing us to predict for example the days by which the 5^{th}, 50^{th} and 95^{th} percentiles of cultivars would have experienced the F1 and F100 stages.

Data for testing the models were sparse. We had access to 10 weekly observations recorded from 21 July to 29 September 2021 for two cultivars ('All-In-One' and 'Monovale') from a trial planting near Havelock North. These observations indicated whether budbreak had occurred, and stages of flowering including completion of flowering. We also had observations on flowering from an almond orchard near Waipukurau for the years 2016 and 2021. There were two observations for 2016 (made on 28 August and 10 September) that recorded which of eight cultivars had yet to bloom, had just started to bloom or were in full bloom. For the Waipukurau orchard in 2021, there was a record of when the earliest cultivar had its first flowers (24 July), and a suggestion that the latest variety may have finished flowering 5 weeks later in late August. The grower had some qualitative information on the differences in flowering time between the eight cultivars, but this was not sufficient for quantitative modelling.

The chill-force model was run using an initial parameterisation from the published CU and GDH requirements, and with weather data inputs from the VCSN database that corresponding to the locations of the two orchards providing data and for the growing seasons in which observations were made. This exercise revealed that initial parameterisation predicted a much earlier flowering than was observed. This is unsurprising since the published studies were from overseas trials in continental climates, and used different cultivars from those grown in New Zealand. An adjustment in parameterisation was required to delay model predictions for flowering stages and improve their alignment with observation. The 'All-In-One' and 'Monovale' flowering observations for Havelock North were used as indicators of very early and very late flowering cultivars.

The sigmoidal chill function used to weight daily GDH was specified give values of 0.05 0.5 and 0.95 for accumulations of respectively 28, 400 and 1200 CU. A sigmoidal function predicting the fraction of cultivars reaching the F1 stage was parameterised to give values of 0.05, 0.5 and 0.95 for accumulations of respectively 5000, 5350 and 5700 chill-weighted GDH. Similarly sigmoidal functions were parameterised to give values of 0.05, 0.5 and 0.95 at chill-weighted GDH accumulations of respectively 7488, 8000 and 8512 h°C for the F50 stage and respectively 10295, 11000 and 11705 h°C for the F100 stage.

The logistic curve was used to model sigmoidal curves, and takes the form below, where y is the suitability value, x is the criterion value, and parameter c determines the 0.5 value of x, and k determines the rate at which suitability changes with the criterion variable:

$$y = \frac{1}{1+\exp\left(k(x-c)\right)}. \qquad (2)$$

Ripening and maturity

Two important phenological stages before harvest maturity are the 1% and 100% hull split (HS1 and HS100) stages. Connell et al. (2010) published data on number of days between HS1 and HS100 for different cultivars, and Thomas et al. (2019) used this information to estimate GDD requirements to transition between these phenological stages. The observations of Connell et al. (2010) together with other published observations were similarly used by Parker & Abatzoglou (2017) to estimate GDD requirements from the start of ecodormancy to 1% HS, 100% HS and harvest, providing a continuation to their values for GDD requirements for different stages of bloom.

We had no data on hull split for either the Havelock North or Waipukurau orchards' harvests of 'All-In-One' and 'Monovale' with which to compare model predictions. Harvests of these cultivars were recorded for Havelock North at different times in March and May 2022 (corresponding to the flowering in 2021), but we could not model up to this time period since the VCSN database that we accessed provided information for dates only up to February 2022. However, for the Waipukurau orchard, the maturation of the earliest nuts on the earliest trees was recorded on 2 April 2017 although no further harvest data were available for that year. The grower considered that on average, harvest would occur around mid-April to the end of April. Based on these considerations and the GDH accumulations to these dates in 2017 for that orchard location, we parameterised a sigmoidal function specifying the fraction of cultivars whose crop would have matured to provide values of 0.05, 0.5 and 0.95 for GDH accumulations of respectively 61430, 63450 and 65470 h°C. Applying the ratios between the GDD requirements used by Parker & Abatzoglou (2017) for the HS1, HS100 and harvest stages to our GDH requirements, we then parameterised our hull split functions to give values of 0.05, 0.5 and 0.95 at respectively 42885 44900 46915 h°C for the fraction of cultivars reaching HS1 and at respectively 53385, 55400 and 57415 h°C for the fraction of cultivars reaching HS100.

Simulation of phenology

The New-Zealand-centric observations that were available were not sufficient to model separately early and late cultivars, and one simulation across the spread of cultivar development times was performed. With the new parameterisation for the phenology model, the simulation gave results that were approximately in line with the observations for the two orchards (Figure 6). The VCSN database contained information up to mid-February 2021 and thus while the entire 2016 growing season was simulation, the 2021 growing year was simulated only up to mid-February.

For the Havelock North orchard, the starts of stages F1, F50 and F100 line up with the observations for 'All-In-One' for those stages, and the ends of these stages line up with corresponding observations for 'Monovale' (Figure 6). This is expected since the model parameterisation was designed to achieve this. Similarly the model parameterisation was that for the Waipukurau orchard in 2016, the model predictions for when the earliest and latest cultivars become harvestable coincide with grower observations for the start and end of the harvest period (Figure 6).

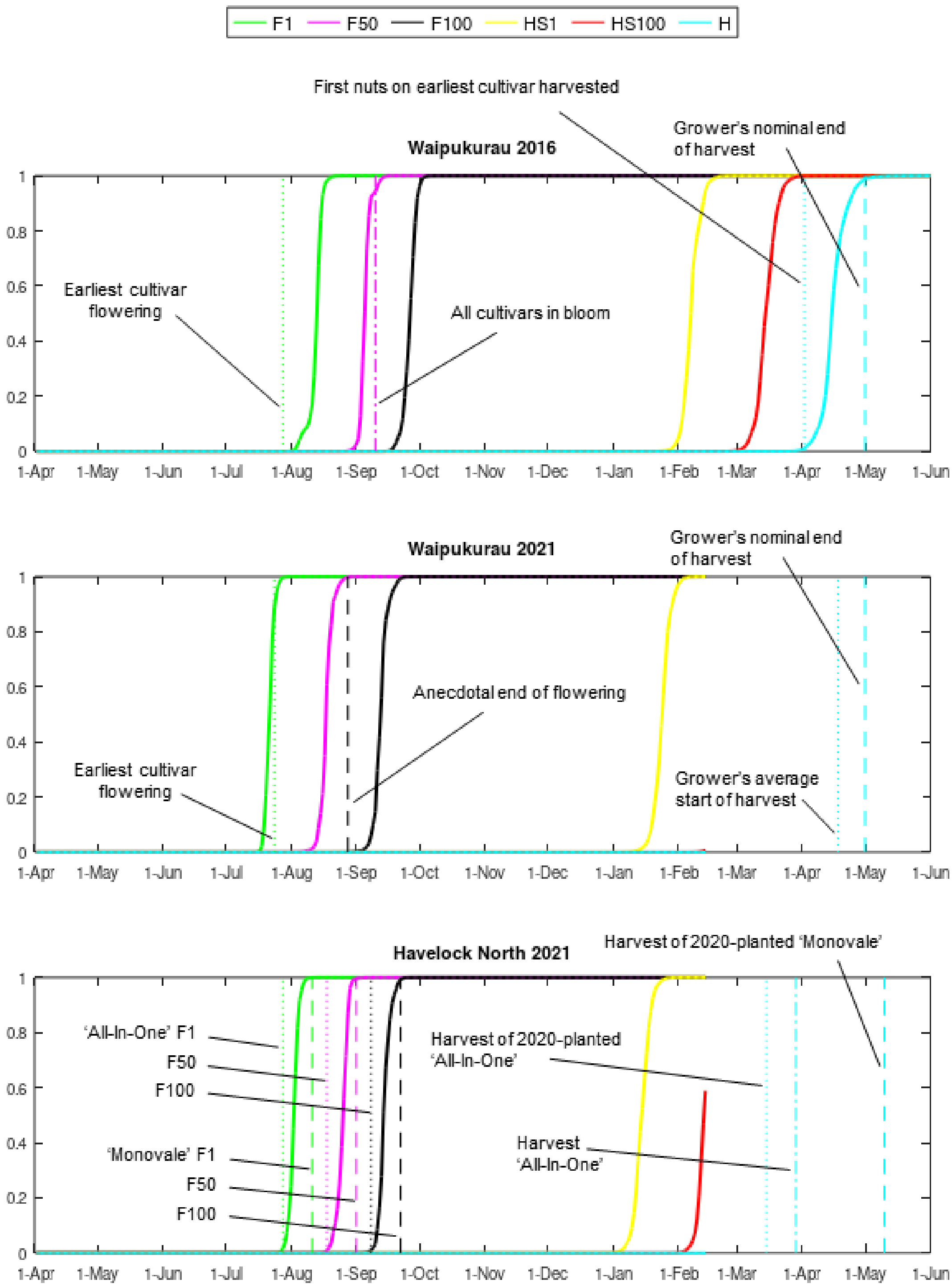


Figure 6. Model predictions of phenological stages of almonds for Waipukurau and Havelock North orchards. Solid curves show the fraction of cultivars predicted to have reached the 1%, 50% and 100% bloom stage (respectively F1, F50 and F100), the 1% and 100% hull split stage (respectively HS1 and HS100) and harvestable stage (H). Vertical lines indicate grower observations. Simulations used the Virtual Climate Station Network (VCSN data) and were run only to mid-February 2022 because weather data were not available after that time.

For the Waipukurau orchard, the model prediction for the start of the F1 period in 2016 occurred a few days before the earliest flowering observation, while for 2021 the model predicted that most cultivars would have reached F1 by the time the first flowers of the earliest cultivar were observed (Figure 6). Possible reasons for this discrepancy include that the parameterisation of the model lacks robustness due to insufficiency of data, or that the orchard is in a microclimate not represented by the VCSN weather data for that grid. No observations were made for the 2016 F100 stage for the Waipukurau orchard. While the end of flowering observation for 2021 occurred earlier than predicted (Figure 6), that observation was anecdotal and corresponds to a far more compact flowering period that occurred in 2016. Thus it is difficult to gauge the degree of model discrepancy from this F100 comparison.

There were no observations from the Waipukurau or Havelock North orchards to compare with the model predictions for the HS1 and HS100 stages. However in Australian observations, HS1 was found to occur from the very end of December to very early February and HS100 from the last week of January to the mid-March (Thomas & Hayman 2018). The model predictions do not significantly depart from this, and suggest that HS1 and HS100 would occur slightly later for the New Zealand orchards (Figure 6).

The model was parameterised to predict that for 2016, the earliest almonds would reach harvest maturity on the day that the Waipukurau grower first harvested nuts, and to predict that for 2016 all almonds would have reached harvest maturity on the nominal last day of harvest. We note however that the day of harvest does not necessarily coincide with the days almonds reach maturity. The harvest of 'All-In-One' at Havelock North at the end of March 2021 is earlier than predicted for Waipukurau, and this is consistent with prediction of hull split occurring earlier at Havelock North (Figure 6). The earlier harvest of 'All-In-One' from trees planted in 2020 and the very late harvest of 'Monovale' from trees also planted in 2020 (Figure 6) can be regarded as atypical since the phenology of young trees can be quite different from mature trees, according to the grower.

The phenology model was run for all locations across Hawke's Bay and Gisborne for the growing years 2001–2002 through to 2020–2021, using weather data from the VCSN database.

2.1.3 Suitability modelling

Chill-force suitability score

The cut-off by which flowering should have been completed was 30 September. For each location, the fraction of cultivars having completed flowering on any day during a growing year is given by the F100 value for that day and location. Thus we used the F100 value for 30 September as a "chill-force" suitability score to indicate how well almond requirements for flowering were met by the combination of chilling and warmth at each GIS location in the VCSN database.

Pollination suitability score

Honey bee colonies tend to have small populations during the late winter/early spring period that almonds flower, and this can make pollination challenging, as can inclement weather (Danka et al. 2006). Almond nectar secretion rate is likely to be a primary driver for foraging activity, and honey bees evaluate the profitability of nectar rewards against environmental conditions (Alqarni 2015). In very cold winters, almond nectar secretion may be too low to be attractive to honey bees (Farkas & Zajácz 2007). Honey bees will forage for water at temperatures as low as 5°C (Kovac et al. 2010) and for a range of resources at temperatures up to as high as 43°C, (Abou-Shaara et al. 2017) .

Covert (2011) considered that for good pollination of almonds, wind speeds should be under 24 km/h and temperatures between 15 and 38°C, with an absence of both rain and cloudy weather. However, Szabo (1980) found that RH and wind speed had little effect on flight activity of honey bees and that ambient temperature and solar radiation were the most important factors. Similarly, Clarke & Robert (2018) found that variation in temperature and solar radiation together explained 78% of egress rate of honey bees from their hives.

Although high temperatures can reduce the effective pollination period of almonds by reducing stigma receptivity, this is countered by a longer effective pollination period in almonds compared with other fruit trees (Ortega et al. 2004), and high temperatures are unlikely to be a concern when almonds flower in New Zealand.

Flight activity in *Apis mellifera* was found to increase 10-fold when temperatures increased from 10°C to 12°C. Based on a four-hour foraging window (10 am to 2 pm) for almond (Danka et al. 2006), we calculated the proportion of time that temperature in this period was above 12°C for each day.

The pollination suitability score was then calculated as the weighted mean of this proportion, where the weight used was the probability that the almonds were in flower. This probability was calculated as the proportion of cultivars having reached the 1% bloom stage minus the proportion having reached the 100% bloom stage.

Frost suitability score

Thomas et al. (2019) considered frost risk to almonds in terms of the number of nights colder than 2°C, these being considered prone to frost. The PFR model uses a different approach to frost risk and calculates expected damage as a function of minimum temperature, following the approach described by Vetharaniam et al. (2021). This requires knowledge of damage versus temperature at different phenological stages.

Connell & Snyder (1996) found that the small nut stage was the most vulnerable to frost damage, with a 100% damage rate at -3.3°C but negligible damage at -1.1°C, with a lethal cold temperature (LCT) for 50% kill between -2.2 and -2.8°C. The full bloom stage was the second most vulnerable to frost with reported damage rates ranging from 1 to 5% at -2.2°C, from 70 to 100% at -3.3°C and from 80 to 100% at -3.9°C (Connell & Snyder 1996). This contrasts with a 20% damage rate at -3.9°C and 75% damage rate at -5.6 °C given by Parker & Abatzoglou (2017). For the pink bud stage, reported damage rates averaged 52% at -3.9°C (20 to 70% damage). Based on a sparse amount of data from two cultivars, the green bud stage appeared much hardier with average losses of 5, 5 and 7.5% at temperatures of -3.9, -5.6 and -6.7°C (Connell & Snyder 1996). Dormant shoots are hardier still, with an LCT for 50% kill in the range -18.0 to -24.5 °C.

We assumed temperatures would rarely be cold enough to cause significant damage to the green bud stage or earlier, and used the frost susceptibility values for the full bloom stage as an approximate average of susceptibilities across the pink, full bloom and nut stage. We constructed a sigmoidal frost-damage function with damage rates of 5%, 50% and 95% at temperatures of -2.2, -3.0 and -3.8°C (Figure 7), to simulate the susceptibility of almonds to frost from the pink bud stage onwards.

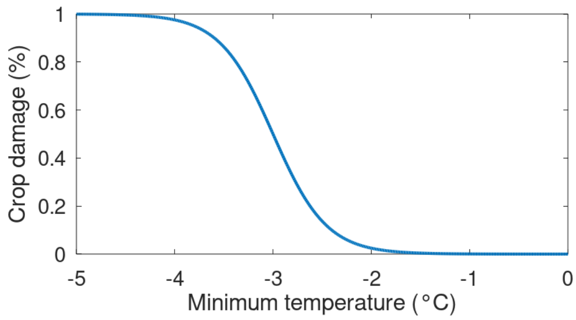


Figure 7. Curve used to model crop damage as function of minimum temperature.

We did not model the occurrence of the pink bud stage, and so used the F1 curve as an indicator or a switch from low frost susceptibility to high frost susceptibility. The harvestable stage curve was used as an indicator of when there was no longer a frost risk. Daily expected losses were calculated from the frost-damage function using minimum daily temperature as an input, and were then weighted by the daily difference between the F1 curve and the harvest stage curve. Weighted losses were accumulated over the growing season and the portion of crop surviving was expressed as a fraction to give the frost suitability score.

Sufficiently warm growing season

A nominal cut-off date of 30 April was taken for nuts to ripen to maturity and be harvestable. For each location, the fraction of cultivars having reached the harvestable stage is given by the harvest maturity curve value for that day and location. Thus we used the value for the harvest maturity curve on 30 April as a GDH suitability.

Rain damage to nuts

Almond growers in Australia identified rain at harvest as their primary concern (Thomas et al. 2019). Under wet conditions *Salmonella* can migrate from soil through the hull and shell of shaken almonds lying on the ground to the almond kernel (Danyluk et al. 2008) and the risk of high concentrations of this pathogen is increased (Uesugi & Harris 2006). Harvesting onto a cover would reduce this risk. *Aspergillus* infection can occur during hull split, especially if there is high humidity (or insect injury) and has the potential to contaminate almonds by producing aflatoxins (Picot et al. 2017). Rain at harvest can also prevent harvesting operations, impose additional costs to dry wet fruit, or cause loss in the harvest year by causing hull rot or, in subsequent years, by causing the death of spurs (Thomas et al. 2019). We found no information that quantified crop damage as a function of rainfall. Therefore we constructed a harvest-rain suitability score function relative to 50mm of rain falling in the period between hull split and harvestable stage, to which we assigned a suitability value of 0.5. A weighted risk window for rain damage to fruit was calculated for each location as the proportion of cultivars having reached the 100% split hull stage subtracted from the proportion having reached the harvest stage. For each grid location, daily rainfall data were multiplied by the daily risk window weightings and summed to obtain a "risk-weighted rainfall" value for each year. We assigned a harvest-rain suitability curve having values of 0.95, 0.5 and 0.05 for 25, 50 and 75 mm of risk-weighted rainfall.

Disease risk

There is a large variation between different plant pathogens in their optimal environments, and their requirements factors such as temperature and moisture (DeLucia et al. 2012; Juroszek & von Tiedemann 2015). Thomas et al. (2019) indicated that almond pathogens are favoured by high moisture conditions (e.g. rainfall or high RH). Certainly the majority of plant pathogens are favoured by high-moisture conditions (Velásquez et al. 2018). Different pathogens have different optimal growing temperatures and thus there will be a microbial threat across a band of temperatures (see Vetharaniam et al. 2021). Those authors calculated a generic disease suitability score as a function of both temperature and RH, and assumed pathogens risk would be a threat only within a temperature band. However for this project we have not considered temperature as a limiting factor to disease, and modelled disease risk in terms moisture alone. Some studies have found that RH was a more reliable indicator of disease risk than rainfall (Creasy 1980), and RH has been used as an predictor in some models of disease threat (e.g. Wilks & Shen 1991; Beresford et al. 2016). Thus we used a sigmoidal suitability score for disease risk that was a function of RH alone, taking values of 0.05, 0.5 and 0.95 at RH values of respectively 77, 85 and 93%.

The risk of root disease resulting from waterlogging is reflected in suitability considerations around soil drainage.

Annual rainfall deficit

Although almonds are considered among the more drought tolerant of perennial tree crops, there is a variation between cultivars in the sensitivity of yield to water deficit stress (Ghrab et al. 2002; Gutiérrez-Gordillo et al. 2020). Estimated evapotranspiration (ET) for almond orchards was 1100–1350 mm for California (Goldhamer & Fereres 2017) and 1450 mm for the south-east of Australia (Stevens et al. 2012). Tree density and the nature and density of ground vegetation will have an impact on crop ET.

In regions averaging 118 mm of rain per year, almond yield was maximised (3900 kg/ha) when 1250 mm of water was applied, while yields of 3250 kg/ha were obtained for 1000 mm of applied water. By contrast, in the Waipukurau orchard with no irrigation, very low inputs and an average annual rainfall of about 750 mm, yields obtained were much lower; we estimated yield was in the order of 500 kg/ha based on discussions with the grower on nuts harvested per tree. Differences in yield can be affected by differences in cultivars, management practices and intensity of fertiliser use, as well as by rainfall deficits.

Based on published ET values above, we worked with an average annual ET for almonds of 1300 mm, and based on the yield to water response found by Goldhamer & Fereres (2017), we constructed a sigmoidal annual rainfall suitability score function that gave suitability values of 0.18, 0.83 and 1.0 for annual rainfalls of respectively 750, 1000 and 1300 mm.

Potential rooting depth

The depth of soil to an impermeable layer, referred to as the potential rooting depth (PRD), is an important criterion identified by Hall et al. (2018), since this determines the ability of the tree to develop a strong vigorous root structure, and trees in deeper soil can have more tolerance of drought than trees in shallow soil.

The depth of almond roots can be affected by irrigation and the type of irrigation (Ben-Asher et al. 1994). Romero et al. (2004) found that subsurface irrigation stimulated deeper root development (40–80 cm) compared with surface irrigation (0–40 cm), and that that root density below 80 cm was almost nil, with 75% of fine roots in the upper 70 cm of soil, although in that trial the soil properties below 80 cm may have presented a barrier to deeper root penetration. Young, trickle-irrigated almond rootstocks had root depths down to one metre, but the majority of roots occurred in the top 60 cm of soil (Franco & Abrisqueta 1997). Ben-Asher et al. (1994) found that almond roots may exceed 1.5 to 2 m in depth, even with trickle irrigation.

For constructing a suitability score, we noted that Long & Kaiser (2013) considered that soil depths of 3 to 5 feet (0.9 to 1.5 m) are required for semi-dwarfing root stocks of cherry, and thus almonds will likely require at least a similar root depth. Thus we assigned a suitability curve with values of 0.05, 0.5, 0.95 and 1 for potential rooting depths of 0.2, 0.5, 0.95 and 1.5 m.

Slope

For many crops, considerations of slope of the land from the viewpoints of erosion risk or suitability for machinery give 30° as generally being an upper limit (Rowland et al. 2016). However, since harvesting almonds involves shaking fruit from the tree and gathering from the ground, a flat surface would pose significant advantages. However, almond orchards have been established on steeply sloping land, though tree vigour decreased with increased slope (García et al. 2010). We assigned a continuous sigmoidal suitability function that had a value of 1.0, 0.97, 0.5 and 0.0 for slopes of respectively 0, 5, 10 and 20°.

Drainage

Many almonds and almond × peach hybrids used for rootstocks have a low tolerance to asphyxia caused by waterlogging (Felipe 2009). In New Zealand, 'Golden Queen' peach is often used as a rootstock, and also prefers well-drained conditions. Moist soil conditions can increase susceptibility to a number of diseases such as crown gall (*Agrobacterium tumefaciens*), oak root fungus (*Armillaria mellea*) and attacks by a number of *Phytophthora* species (Gradziel 2009).

Drainage information for individual locations was available in terms of classifications that took into account a number of factors, including soil structure, depth, and permeability, and water table depth. These classifications had the following qualitative descriptors: well, moderately, imperfectly, poorly and very poorly drained. Reflecting the requirement that good drainage is essential for almonds, we assigned suitability scores of respectively 1.0, 0.9, 0.3 0.1 and 0 to these drainage categories.

Land use capability class

Land Use Capability (LUC) class descriptors are divided into eight main categories (numbered 1 to 8), with 1 indicating land classes with virtually no limitations for arable use and 8 indicating land classes with very severe limitations or hazards that make it unsuitable for agriculture or forestry. Following Vetharaniam et al. (2021) we used LUC class as a suitability criterion, despite some overlap between LUC class descriptors and other land information such as slope, PRD and drainage, since LUC class also contains extra information on soil. We assigned suitability scores to LUC classes to develop a graduated scale, with Classes 1 to 8 assigned scores of 1, 0.95, 0.9, 0.8, 0.65, 0.5, 0.05 and 0.

Calculation procedures for suitability scores

Climate related suitability scores for calculated for each growing year for the growing years 2001–2002 through to 2020–2021, using data from the VCNS database. A representative score for each climate-related criterion was obtained taking the arithmetic mean of yearly scores calculated for the 20-year period.

Overall climate suitability

Scores for individual climate criteria were combined for each year by taking their weighted geometric means provide an overall climate suitability score for that year. A higher weight reflects a higher significance placed on that factor. We chose weights of 2.0 for the chill-force, GDH, frost and pollination suitability scores, and a weight of 1.0 for harvest rain suitability and a weight of 0.5 for the disease suitability score. The early climate suitability scores were averaged over a period of years using arithmetic means to provide a climate suitability score for the period.

The annual rainfall suitability score was kept separate from the overall climate suitability since this was developed from the perspective of maximising yield, whereas a grower may prefer a low input system with lower yields as part of a niche industry.

Overall cultivation suitability

Climate suitability and soil criteria suitability were combined by weighted geometric averaging to give an overall cultivation suitability map. The weightings used were, respectively, the sum of the climate criteria weights and the soil criteria weights.

2.1.4 Projecting suitability changes in future climates

The SLM RCP datasets were used to project suitability scores for two two-decade periods: 2031 to 2050 and 2051 to 2070. Although the projection data extend to 2100, uncertainty increases with increased projection date, and the projection period that we have used will easily encompass the productive lifetime of an almond orchard.

For each of the RCP datasets (6.0 and 8.5) that we used in the climate projection dataset, the suitability models were run separately for the corresponding six SLM RCP datasets (corresponding to forcing by six GCMs). This gave six alternative values for each suitability criterion score at each GIS location, for each RCP. The six alternatives scores were averaged and standard deviation calculated for each suitability score, separately for each RCP. This procedure was carried out for each of the two future periods.

SLM RCP data for the period 1971–2005 are considered to be historical simulations and are referred to as 'SLM RCP Past', and for each CMIP5 model, all RCP datasets share the same RCP Past dataset. To provide a reference from which to gauge projected change, the suitability models were run separately for the six SLM RCP Past datasets, for the period 1981 to 2000. Means were calculated from the six suitability calculations for use as a reference.

2.2 Life cycle analysis

From a New Zealand context, LCA methodology has been used to evaluate a number of land use systems. Barber et al. (2011) found that potential carbon emissions associated with a selection of crops from New Zealand's arable sector, specifically wheat, maize silage, maize grain, ryegrass seed, were 340, 125, 190 and 1325 kg CO_2-eq/tonne, respectively. Results from the assessment showed that emissions associated with the manufacture and application of synthetic fertilisers were the biggest contributors to the overall potential emissions. Milà i Canals et al. (2006) found that the environmental impacts associated with commercial apple production in Hawke's Bay and Central Otago ranged from 40 to almost 100 kg CO_2-eq/tonne of grade 1 and 2 apples. The majority of the associated emissions where due to mechanisation, activities such as spraying, irrigation, frost protection and harvesting, and also to the application of fertilisers. Overall emissions where found to be higher for apple production in central Otago than that of Hawke's Bay due to the greater energy demand associated with frost protection and fertiliser use.

Basset-Mens et al. (2005), found that emissions associated with dairy production in New Zealand were 50–80% lower than that in Europe, with an estimated 718 g CO_2-eq/kg milk produced in New Zealand. Emissions of methane, from on farm pasture digestion, and production of feed, accounted for 46 and 40% of the total emissions respectively. The authors noted that the lower results of New Zealand's dairy production compared to that of Europe was likely due to New Zealand's high-producing perennial pastures and all-year grazing, compared with the supplementary feeding systems of Europe. Ledgard et al. (2016) found that emissions associated with dairy production in the Waikato increased with stocking rate intensification. However, the total emissions between the low-, medium-, and high-intensity systems were not too dissimilar, ranging from 0.75–0.8 kg CO_2-eq/kg of fat and protein corrected milk for the low-, medium-, and high-intensity systems. In a study comparing beef production in New Zealand and Uruguay, López et al. (2013) found that New Zealand beef production had a potential carbon footprint of 8–10 kg CO_2-eq/kg of live weight compared to 18–21 kg CO_2-eq/kg of live weight in Uruguay. However, on a per hectare basis, New Zealand's potential footprint was much higher than Uruguay, these being 3013–6683 kg CO2eq/ha/year and 1895–2226 kg CO2eq/ha/year, respectively. The greater amount of emissions was attributed to the more intense stocking rates found here in New Zealand.

In a recent review of the potential carbon footprint of commercial kiwifruit production, McLaren et al. (2021) found that the carbon footprint of kiwifruit delivered to a retailer in Germany was 1.24 kg CO_2-eq/kg. This was found to be a 24% decrease compared to those results of Mithraratne et al. (2010) who attributed 1.64 kg CO_2-eq/kg of kiwifruit delivered to a retailer in Germany. Shipping and pack house operations were found to be the greatest contributors to the overall emissions, while at the orchard phase of kiwifruit production, the majority of the total emissions were found to be attributed to the production and application of lime and fertilisers, and energy consumption from diesel and electricity.

While LCAs have not been undertaken for almonds within New Zealand, previous LCA studies of almond production, specifically in the USA, have indicated potential carbon emissions in the range of 1.76 kg CO_2-eq/kg, 1.6 kg CO_2-eq/kg, 1.92 kg CO_2-eq/kg (Marvinney et al. 2014; Kendall et al. 2015; Volpe et al. 2015). Nutrient management and energy consumption related to irrigation were highlighted as the main hotspots and greatest contributors to the overall total emissions within the production system.

2.2.1 Goal and scope

The main objective of this study was to evaluate the potential environmental impact associated with growing almonds in the Hawke's Bay, focusing on the potential carbon footprint. To assess the potential footprint, we conducted a partial LCA compliant with the framework defined by the International Organization for Standardisation (ISO 2006a, 2006b). GaBi Professional software (https://www.thinkstep-anz.com/) and its associated databases where utilised to assist with the modelling of the almond production system.

In the wider context, this research set out to investigate the feasibility for the establishment of a New Zealand almond industry and to assess the potential hotspots (i.e. areas with the greatest contribution to the overall impact) within the almond production system using internationally recognised methodology. The intended use of the LCA results is to help inform future decisions on management strategies to improve environmental performance and strive towards a premium product.

Under the LCA framework, the system boundary defines the processes, inputs, and outputs of the production system. Here, this was considered to be from the cradle to the farm gate. This included, where data were available, processes relating to the extraction of raw materials, production and transport of goods from overseas (i.e. fertilisers, pesticides), through to the cultivation and harvest of the final product. The final product in this context also defines our functional unit, which was chosen to be 1kg of shelled and hulled raw almond kernel.

Lack of New Zealand specific data relating to almond production meant we did not have sufficient information to conduct a satisfactory LCA. Hence, due to the hypothetical nature of the study, information used for modelling purposes relied solely on data obtained from literature and personal communications. The LCA model was designed to represent a "typical" orchard with conventional practices. To compare the effects of management practices and inputs into the orchard system, a sensitivity analysis was performed on areas within the production chain that were identified as potential hotspots. Further details of the orchard system are given below.

2.2.2 Model Design

The LCA model of the conventional system has been designed to represent a typical almond orchard according information obtained from literature. Much of the data used were specific to the production of almonds but in some instances the data have been adapted or modified, where appropriate, to provide the best estimate or approximation. Where information or data required to model a particular process were not available, the software package GaBi Professional and its associated databases have been used. The following key assumptions have been made regarding the design of the almond orchard:

- The model represents the inputs and potential environmental impact over a typical growing season.
- The orchard is a mature orchard (7+ years) so is expected to be in full production.
- Machinery, i.e. harvesters, mowers, sprayers etc., are considered to be an asset already present at the orchard.
- Irrigation is required to maximise productivity and is assumed to already be established.
- Pesticides and synthetic fertilisers are used as standard management practice, some of which are derived from overseas.
- Total yield is based on 2.5 t/ha of raw almond kernel.

2.2.3 Life Cycle Inventory (LCI)

Life cycle inventory (LCI) is the collection and sum of all the inputs, outputs and associated flows of a product system Inputs to the orchard system and sub system. Model inputs and data sources are summarised in Appendix 1, pages 59–60.

2.2.4 Pesticide Production and Transport:

Herbicides, fungicides, and insecticides are typically used for growing almonds under conventional settings (Gradziel 2017). Specific LCI data were not available for the production and formulation for the majority of pesticides considered in this study and were therefore modelled using a generic database from GaBi Professional as a proxy. Due to the lack of supply chain information, it was assumed that these pesticides where produced in the EU (Germany) and imported through Australia to New Zealand, following Müller et al. (2011). GaBi Professional databases where used for train, truck, and shipping for transport inputs. However, emissions associated with the production, formulation and transport of glyphosate to New Zealand have been calculated (Müller et al. 2011) and have been included in the model.

2.2.5 Fertiliser production and transport

The production of each fertiliser was modelled using databases from GaBi Professional. For transport of the final product, it was assumed that the urea fertiliser was made in Kapanui, Taranaki, New Zealand and then transported to Napier via truck. For the production and shipment of potassium chloride (KCL), it was assumed that the product was shipped directly from Hamburg, Germany, to Napier, New Zealand. Databases for transport (i.e. trucks, trains, ships) were modelled as described above for pesticides.

2.2.6 Orchard management

Orchard management includes inputs and activities that occur during the growing season and at harvest. This includes, for example, the application of pesticides and fertilisers, operation of machinery and application of irrigation. No data were found regarding the use of diesel for specific machinery tasks but was given as a total input. Therefore, it was assumed that this total amount included all operations relating to machinery throughout the growing season and during harvest. Databases for diesel and gas production where used from GaBi Professional. Similarly no specific data were available regarding the energy requirements and operation of irrigation systems. This was also modelled using a database available in GaBi Professional.

2.2.7 Estimation of field emissions relating to fertiliser use

Nitrous oxide emissions from soil are associated with both direct and indirect sources, including volatilisation and leaching of synthetic fertiliser through the soil profile. Total emissions associated with the use of synthetic fertiliser applications were calculated according to IPCC guidelines (IPCC 2006) and following Barber et al. (2011). The IPCC approach assumes that a proportion ($Frac_{LEACH}$) of anthropogenic N applied as synthetic fertiliser (N_{FERT}) to soils is leached or runs off (N_{LEACH}). The IPCC default value of $Frac_{LEACH}$ is 0.3, and New Zealand's country-specific $Frac_{LEACH}$ value is 0.07 (Ministry for the Environment 2017a). We use the IPCC default value $Frac_{LEACH}$ of 0.3 in the main analysis of the total emissions from fertilisers. Emissions associated with the use and combustion of diesel and gas during orchard activities where calculated using the emission factors provided by the Ministry for the Environment (Ministry for the Environment 2017b).

2.2.8 Components excluded from the system boundary

All processes beyond the farm gate were excluded in this LCA. For example, the transport of the harvested goods to processing facilities as well as all processing of the crops, such as drying, were not considered. Farm capital including machinery, trucks, tractors, sheds, and equipment such as irrigation infrastructure were already considered to be an asset within the orchard.

It was assumed that ground cover and crop residue was kept to a minimum through regular mowing and herbicide applications. Therefore potential emissions associated with crop residues have been excluded. Similarly, the effects of carbon sequestration associated with soils have also been excluded within the LCA model. In general, soils can act as a source and a sink of greenhouse gasses (Oertel et al. 2016), and it was assumed that the carbon content would remain relatively stable over the time frame considered for the LCA.

3 Results

3.1 Suitability score modelling for Hawke's Bay and Gisborne

3.1.1 Chill-force suitability score

The model calculates that large areas of Hawke's Bay and Gisborne away from mountain areas currently have very high levels of chill-force suitability, and there should be no issue with regard to flowering of all cultivars in these locations (Figure 8). In particular, in Hawke's Bay chill-force suitability was very high from north of the Heretaunga Plains through to the Takapau Plains, and in some coastal regions. In Gisborne, suitability was very high in the Poverty Bay area as well as further north through to East Cape.

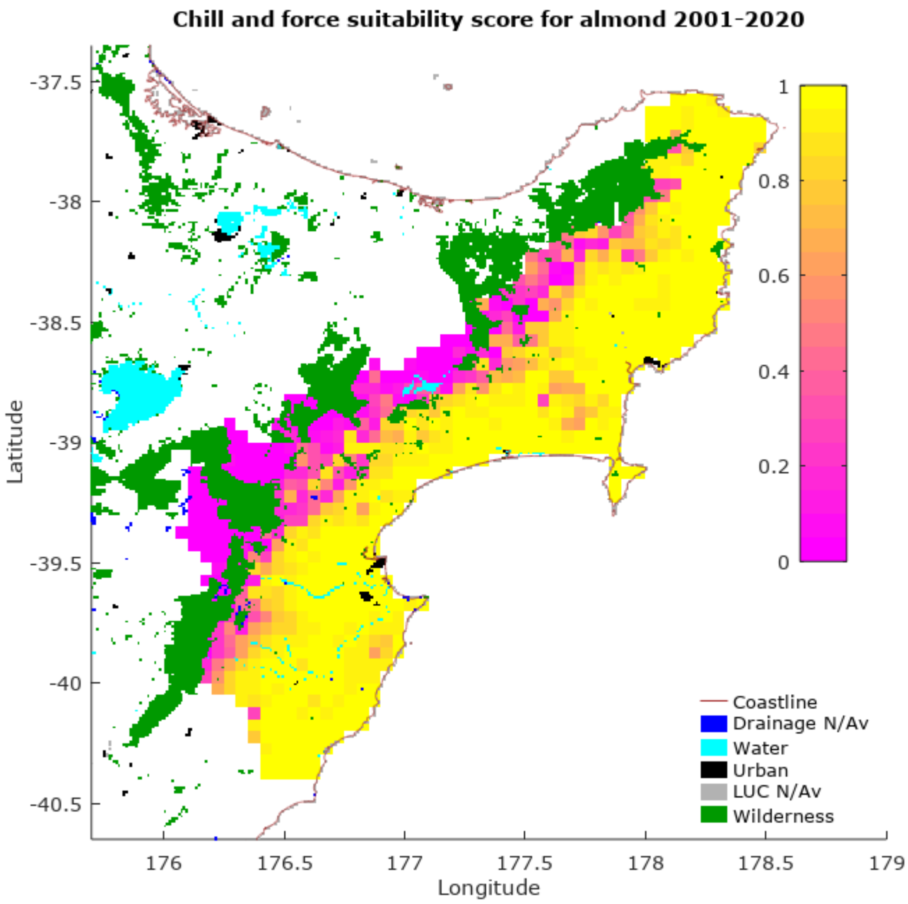


Figure 8. Adequacy of winter chill to progress flower buds to ecodormancy and subsequent warmth to force flowering, expressed as a suitability score from 0 to 1 and mapped for locations across the Hawke's Bay and Gisborne regions, for growing years 2001 to 2020. Suitability scores were calculated using Virtual Climate Station Network (VCSN) data.

3.1.2 Pollination suitability score

Pollination suitability was found to be generally low in many mountainous locations, and moderate in most other locations, with for example scores in the Poverty Bay area being in the order of about 0.7 and scores in the Heretaunga Plains being about 0.6 or less (Figure 9). The highest scores were for some locations around East Cape. This result suggests that in many locations of Hawke's Bay and Gisborne, the winter climate during almond flowering periods would allow pollination to occur but would not be sufficiently warm for very high honey bee activity on almond flowers. This may result in an incomplete pollination of flowers and a reduced yield in many locations. However, microclimates that are not captured by the VCSN data may provide more clement pollination weather.

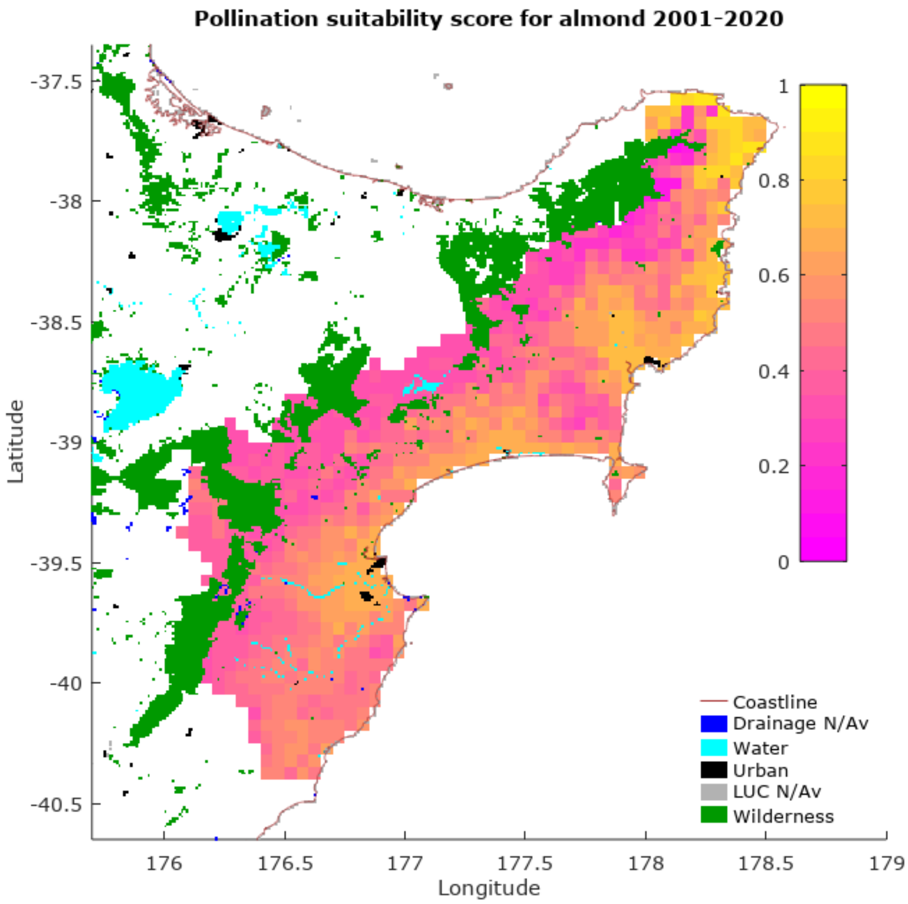


Figure 9. Adequacy of temperatures during flowering for the pollination of almonds by honey bees, expressed as a suitability score from 0 to 1 and mapped for locations across the Hawke's Bay and Gisborne regions, for growing years 2001 to 2020. Suitability scores were calculated using Virtual Climate Station Network (VCSN) data.

3.1.3 Frost suitability score

Frost was found not to be a significant threat areas for locations from Tangoio through to East Cape excluding mountainous locations to the west (Figure 10). The Heretaunga Plains around Napier were also found to have high frost suitability, with the risk of frost damage increasing further inland, northward up to Tangoio and south of Hastings (Figure 10). Frost protection methods such as with irrigation may be beneficial in the latter areas.

The locations with better frost suitability have a degree of correlation with locations with better pollination suitability scores (comparing Figure 10 with Figure 9).

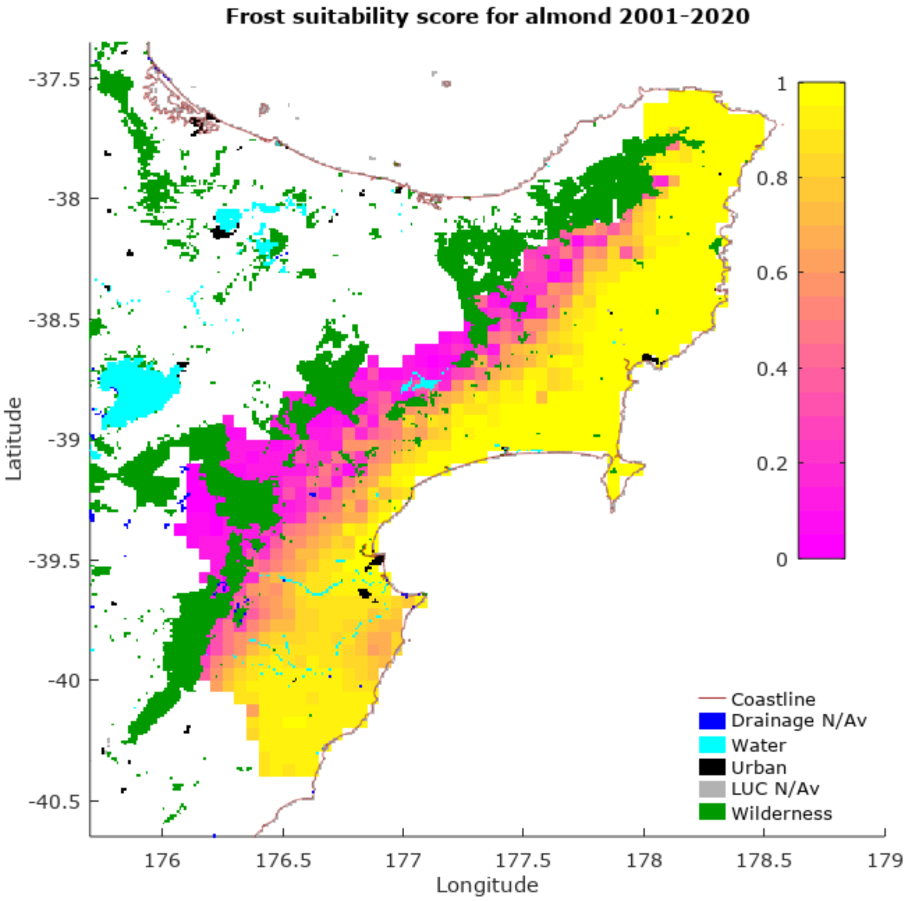


Figure 10. Risk of crop damage from frost expressed as a suitability score from 0 to 1 and mapped for locations across the Hawke's Bay and Gisborne regions, for growing years 2001 to 2020. Suitability scores were calculated using Virtual Climate Station Network (VCSN) data.

3.1.4 Sufficiently warm growing season

For most locations apart from those in mountainous areas, GDH suitability was found to be very high (Figure 10). A high GDH suitability score requires high enough accumulation of GDH to ensure that all cultivars have reached harvest maturity by the end of April. Since GDH accumulation within the model first requires that adequate winter chill has been achieved, some locations that are too warm to provide adequate winter chill may receive a low GDH suitability score, despite being warm locations.

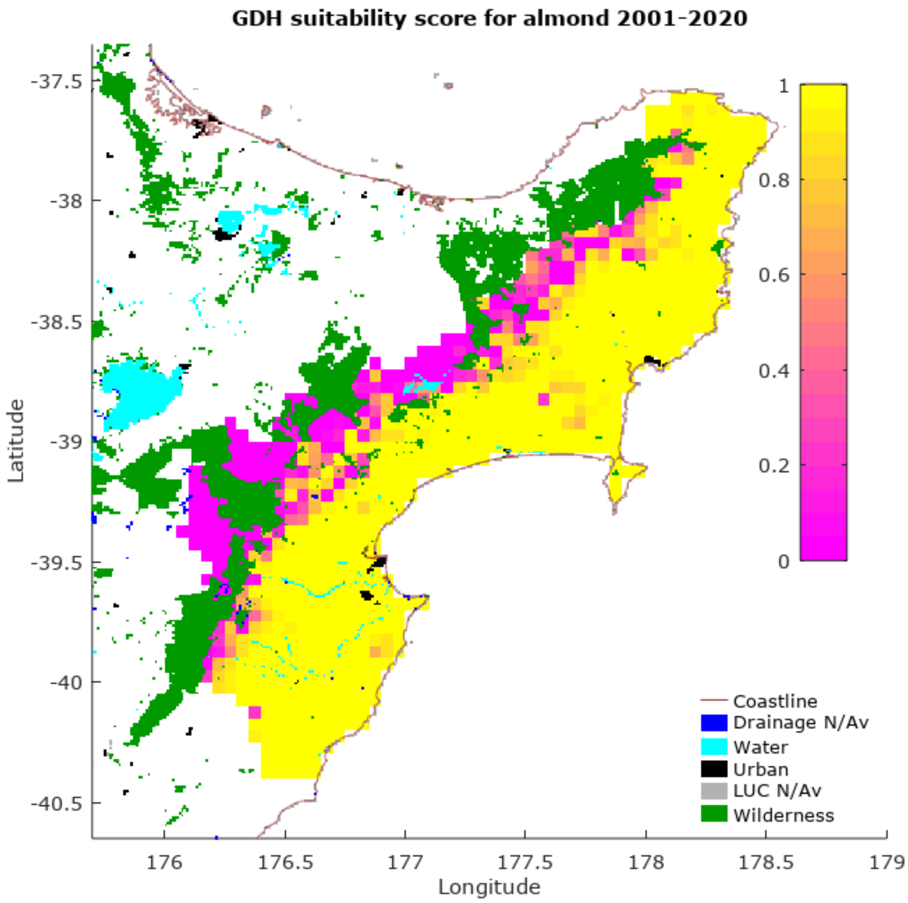


Figure 11. Adequacy of growing-season warmth, calculated as a growing degree hour (GDH) suitability score from 0 to 1 and mapped for locations across the Hawke's Bay and Gisborne regions, for growing years 2001 to 2020. Suitability scores were calculated using Virtual Climate Station Network (VCSN) data.

3.1.5 Disease risk

All locations modelled were found to have a degree of general disease risk from pathogens favoured by moist conditions occurring throughout the year. This excludes the specific risks caused by rain at harvest time, which has its own score. General disease risk scores varying from about 0.5 to about 0.8, with suitability tending to be lower in more mountainous areas (Figure 12). Since this suitability score is generic and does not address specific pathogens, it can be interpreted as illustrative of variation in potential risk between locations.

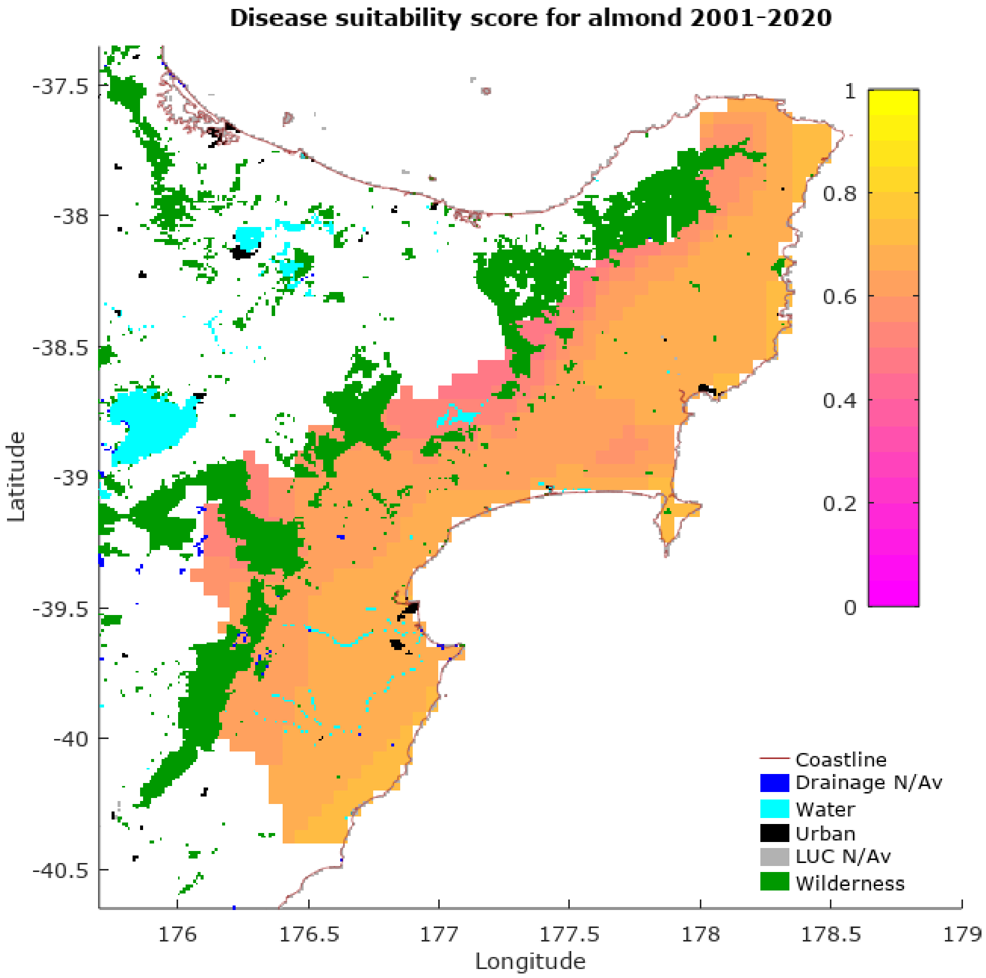


Figure 12. Risk to almonds from pathogens favoured by high moisture availability, expressed as a disease suitability score from 0 to 1 and mapped for locations across the Hawke's Bay and Gisborne regions, for growing years 2001 to 2020. Suitability scores were calculated using Virtual Climate Station Network (VCSN) data.

3.1.6 Harvest rain suitability

Many areas that scored highly in suitability scores for winter chill and forcing, frost risk, and GDH during the growing season were found to have low to very low harvest rain suitability, indicating a high risk of rain damage from between hull split and harvest, while anomalously some areas that had scored very low for winter chill and forcing, frost risk and GDH were found to have very high suitability (Figure 13). The explanation for the anomalous high harvest rain suitability is that those locations would be too cold for hull split or harvest to occur. The Poverty Bay area is indicated as one where rain around harvest could be a problem, while for locations from around the Heretaunga Plains to the locations around Waipukurau, the problem of harvest rain would be less severe, but likely to impose some yield losses or additional costs on growers.

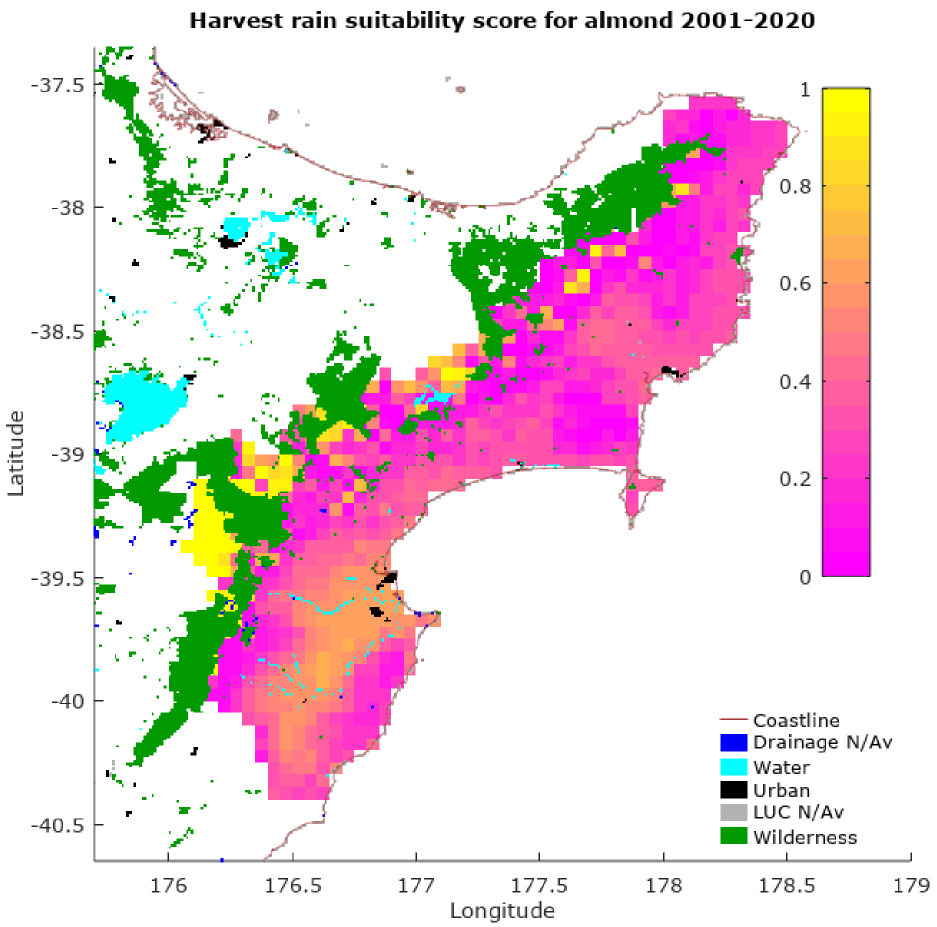


Figure 13. Risk to nuts from rain occurring between hull split and harvest, expressed as a harvest rain suitability score from 0 to 1 and mapped for locations across the Hawke's Bay and Gisborne regions, for growing years 2001 to 2020. Suitability scores were calculated using Virtual Climate Station Network (VCSN) data.

3.1.7 Annual rainfall deficit suitability

Annual rainfall suitability was identified as being high to very high for the majority locations, with the notable exception of locations from the Heretaunga Plains through to and around Waipukurau and to a lesser extent in the Poverty Bay area (Figure 14). With the exception of the anomalous areas in Figure 13 discussed above, Figure 13 and Figure 14 are close to mirror opposites, reflecting the trade-off between two criteria that are both dependent in different ways on rain.

Growers in a location of low annual rainfall suitability would have the option of mitigating the deficit in rainfall by irrigation, or could manage their orchards without irrigation and accept lower yields, as one grower has done. Therefore annual rainfall suitability was not included in the criteria used to calculate an overall climate suitability score, and is intended to be used stand-alone as an indicator of potential irrigation requirements.

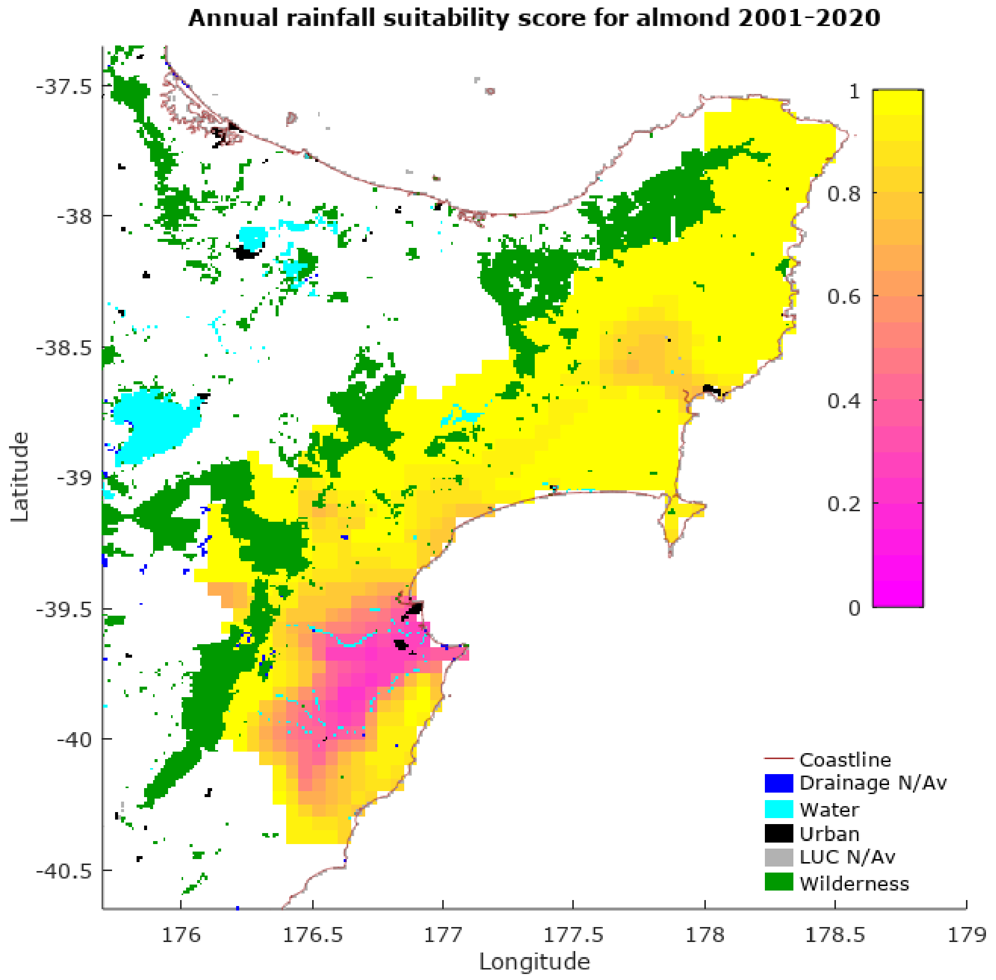


Figure 14. Adequacy of annual rainfall to meet the growing needs of almonds, expressed as an annual rainfall suitability score from 0 to 1 and mapped for locations across the Hawke's Bay and Gisborne regions, for growing years 2001 to 2020. Suitability scores were calculated using Virtual Climate Station Network (VCSN) data.

3.1.8 Overall climate suitability

Combing individual climate criteria by taking year-by-year weighted geometric means before arithmetic averaging over the 20-year period of the simulation provides an overall climate suitability score for that year (Figure 15). The chill-force, GDH, frost and pollination suitability scores were given weights of 2 reflecting a (subjectively) greater importance placed on them compared with the harvest rain suitability score which had a weight of 1. A weight of 0.5 was used for the disease suitability score because of the generic nature of the risk it calculated.

Annual rainfall suitability was excluded from the overall climate suitability, since it was intended that annual rainfall suitability be used as an indicator of irrigation requirements rather than as a determiner of location suitability.

Locations around and peripheral to Hastings are indicated as being among the more suitable locations in the Hawke's Bay and Gisborne regions. Some locations between Hastings and Waipukurau are indicated as having similar suitability to locations around Hastings, while some locations in Poverty Bay are indicated as posing only slightly more climate limitations for almond than the best sites (Figure 15).

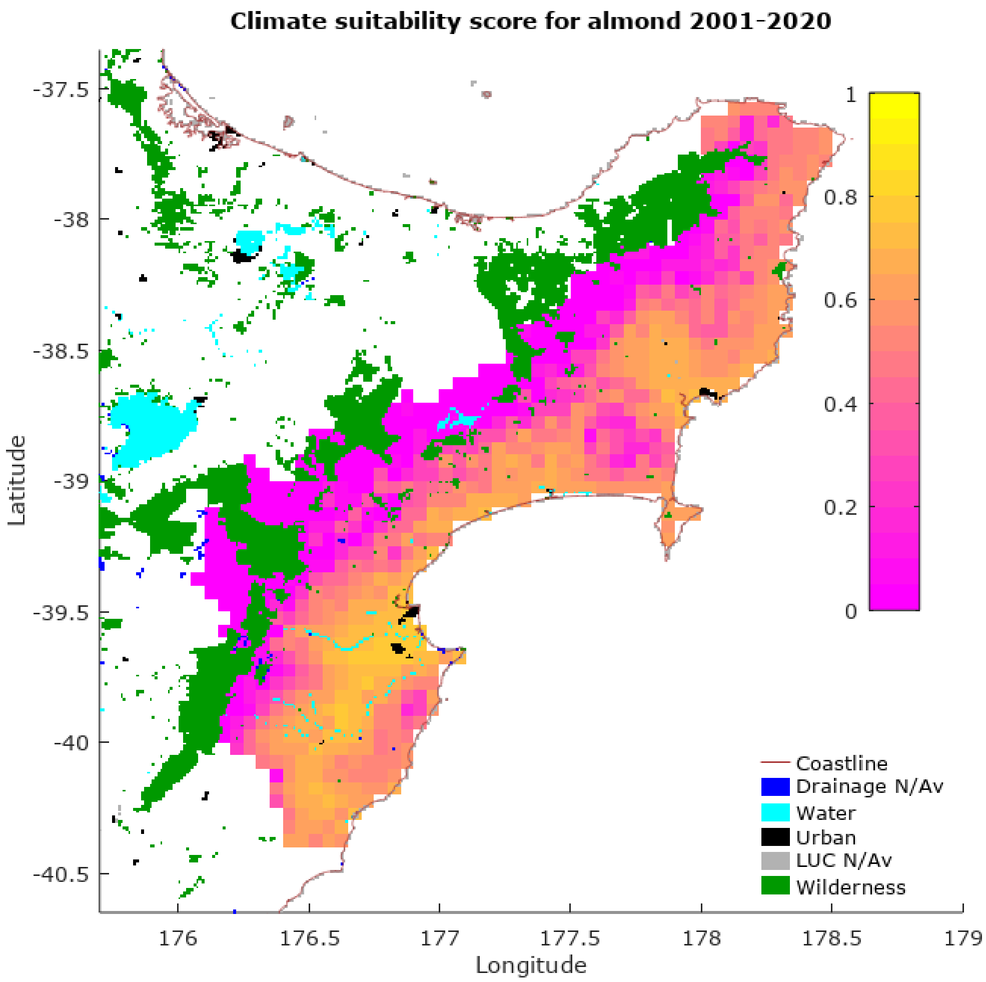


Figure 15. Overall climate suitability score from 0 to 1 that balances multiple climate-related criteria and mapped to show how well locations across the Hawke's Bay and Gisborne regions meet the climate requirements for almond. Scores were calculated for the growing years 2001 to 2020, using Virtual Climate Station Network (VCSN) data.

3.1.9 Potential rooting depth

Most areas of the Gisborne region were identified as having high suitability for PRD, although some locations in or around the Poverty Bay Flats area were identified as having shallow soils and thus low PRD suitability (Figure 16). Significant areas of land around Napier and to the west and north were found to have PRDs of low suitability for almonds, although with scattered areas of high suitability, while a large area around Hastings was found to have high suitability. Further south, large areas of Central Hawke's Bay were found to have low PRD suitability scores, but with significant areas of high

PRD suitability around the Takapau Plains and in the south-east (Figure 16). A low PRD can increase susceptibility to drought, and could be mitigated by irrigation or mounding.

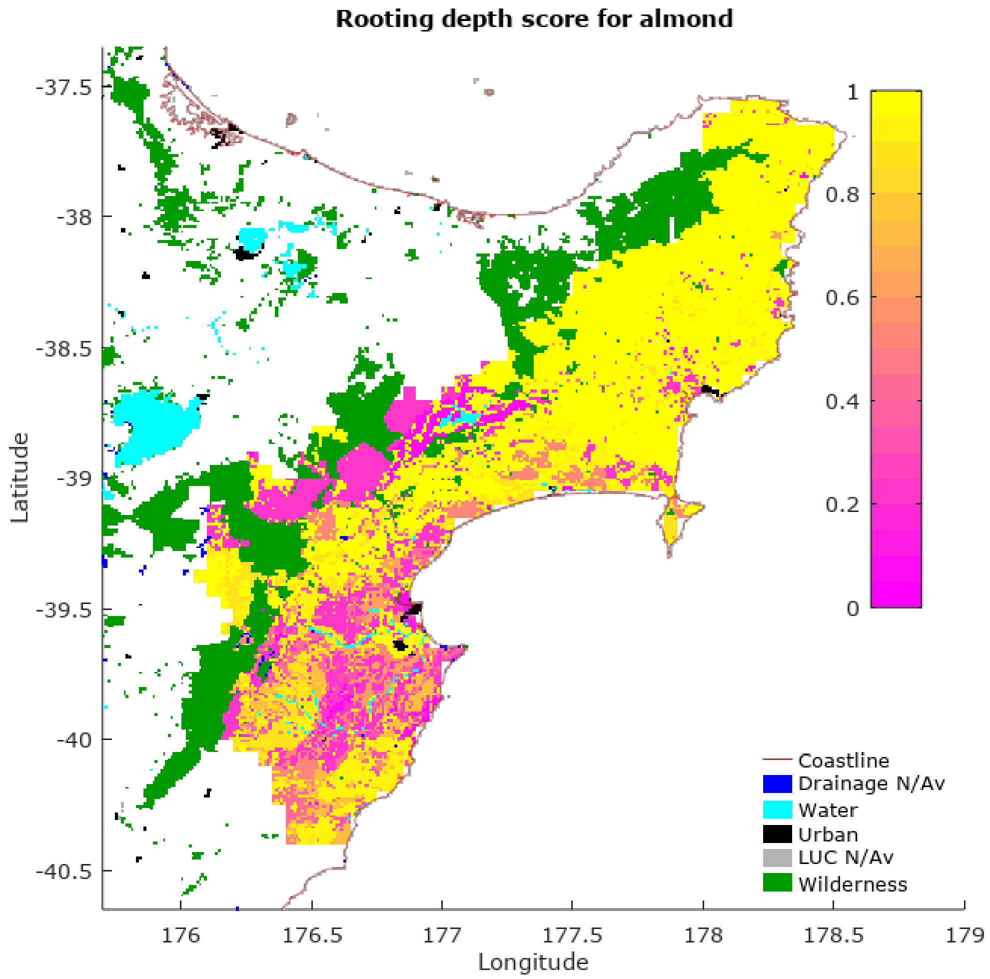


Figure 16. Rooting depth suitability scores for locations across the Hawke's Bay and Gisborne regions indicating the suitability of soil depth for growing almond.

3.1.10 Slope suitability

The majority of locations in Gisborne and the area of Hawke's Bay north of Napier were found to have very low slope suitability, although there are still a large number of high slope suitability locations scattered in this area, and a large contiguous area of highly suitable land in the Poverty Bay Flats extending inland (Figure 17). South of Napier the majority of locations have high slope suitability, with a number of low suitability areas in Central Hawke's Bay (Figure 17). Land with low slope scores corresponds to steeper slopes which may not be conducive to machine shaking to harvest almonds. However, manual shaking of almonds is possible (and carried out by the Waipukurau grower), and would be a possible mitigation in locations with low slope suitability.

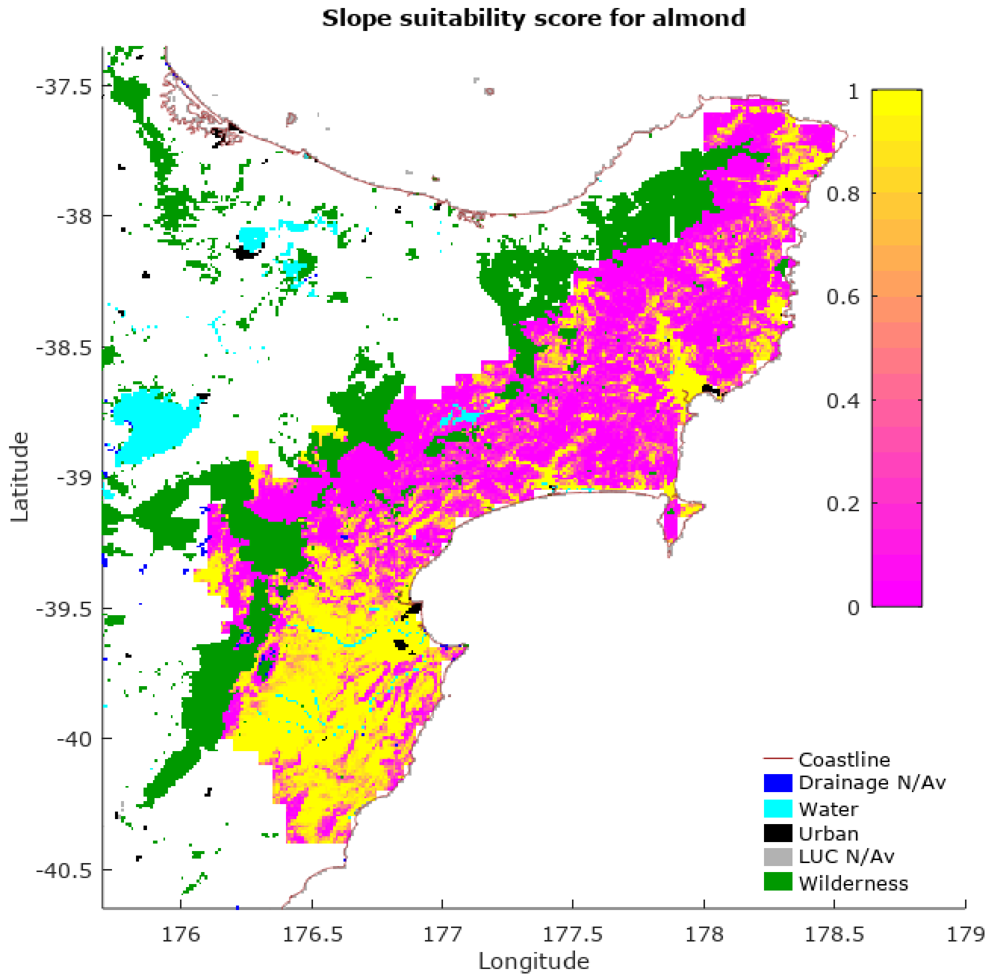


Figure 17. Slope suitability scores for locations across the Hawke's Bay and Gisborne regions indicating the suitability of slopes for almond, in particular with consideration of machine harvesting.

3.1.11 Drainage

Drainage suitability was generally high for most locations in Gisborne, although large parts of the Poverty Bay Flats and surrounding areas were found to have drainage of low suitability for almonds (Figure 18). Much of Hawke's Bay north of the Napier region was found to have high drainage suitability, with some areas of poor drainage located in some coastal and peri-coastal areas, and from Napier South to Waipukurau, the suitability maps shows a mosaic of high- and low-suitability areas (Figure 18).

It might still be possible to grow almonds in locations with low drainage suitability, but this would require extra costs and effort to improve soil drainage, for example by mounding, subsurface ploughing, or installing drainage systems.

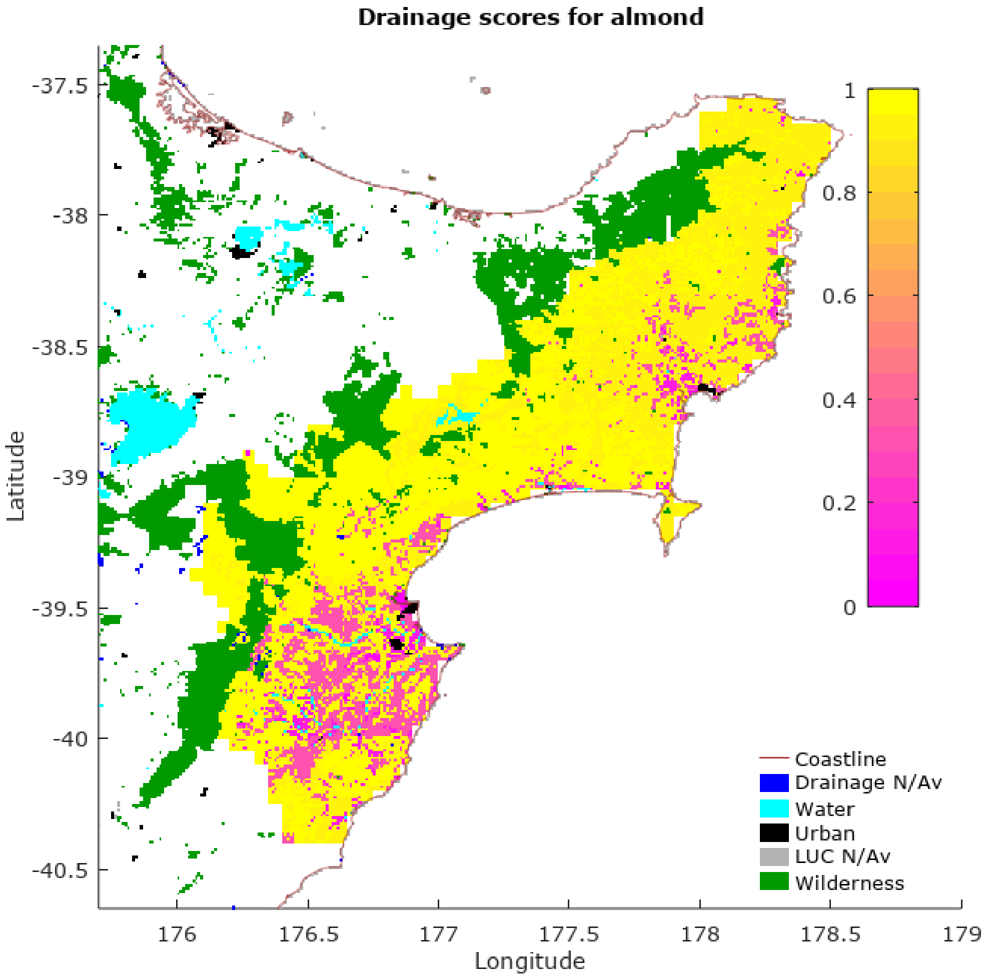


Figure 18. Drainage suitability scores for locations across the Hawke's Bay and Gisborne regions for growing almond.

3.1.12 Land use capability class

LUC classifications provide a generic assessment of land suitability for different uses, and thus there is some overlap between LUC class descriptors and slope, PRD and drainage information. However, LUC class also contains extra information regarding the soil properties and thus provides a useful suitability criterion. We found that most areas of the Hawke's Bay and Gisborne regions scored lowly in LUC suitability score, with notable exceptions being in and around the Poverty Bay Flats, the Heretaunga Plains, and around Waipukurau and the Takapau Plains (Figure 19).

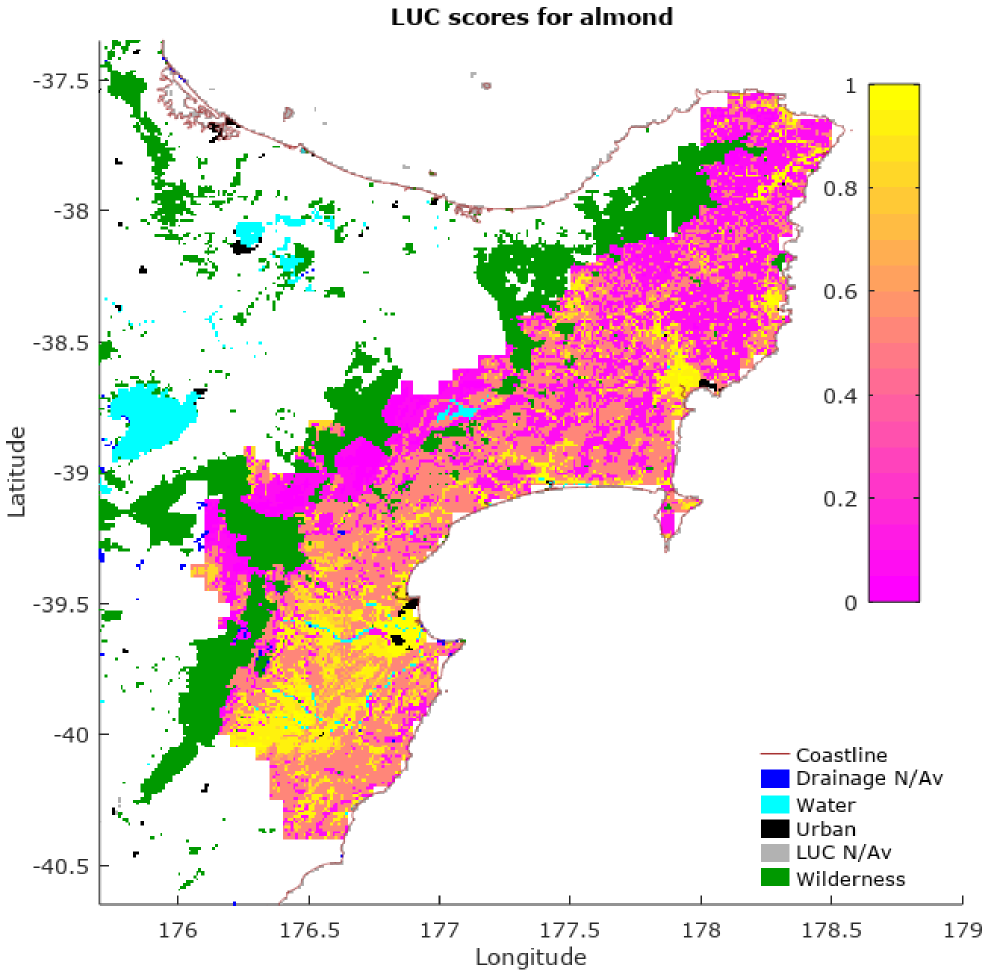


Figure 19. Land use capability (LUC) class suitability scores for locations across the Hawke's Bay and Gisborne for growing almond.

3.1.13 Cultivation suitability

The cultivation suitability score combines the climate suitability score with the land-related suitability scores using weighted geometric averaging. The weight for the climate suitability score was 9.5, which is the sum of the weights for the individual climate-related suitability scores used when calculating it (Section 3.1.8). A weight of 3 was used for slope suitability, a weight of 2 for drainage suitability and weights of 1 for PRD suitability and LUC suitability. Slope suitability was given the highest weight since it would be harder to mitigate if a commercial grower required harvesting machinery.

The cultivation suitability map shows a diverse suitability landscape across both the Hawke's Bay and Gisborne regions, with some locations in the Heretaunga Plains, especially around Hastings and Havelock North, having the highest cultivation suitability scores. A number of locations in Central Hawke's Bay have slightly lower cultivation suitability scores, and although these locations are likely to be subject to more limitations or extra mitigation costs, these could be potential sites for successful almond orchards. A number of locations around Poverty Bay and inland of the Flats are identified as potential areas for almonds, but also likely to experience limitations to production or require extra establishment and on-going costs, compared with highly suitable locations.

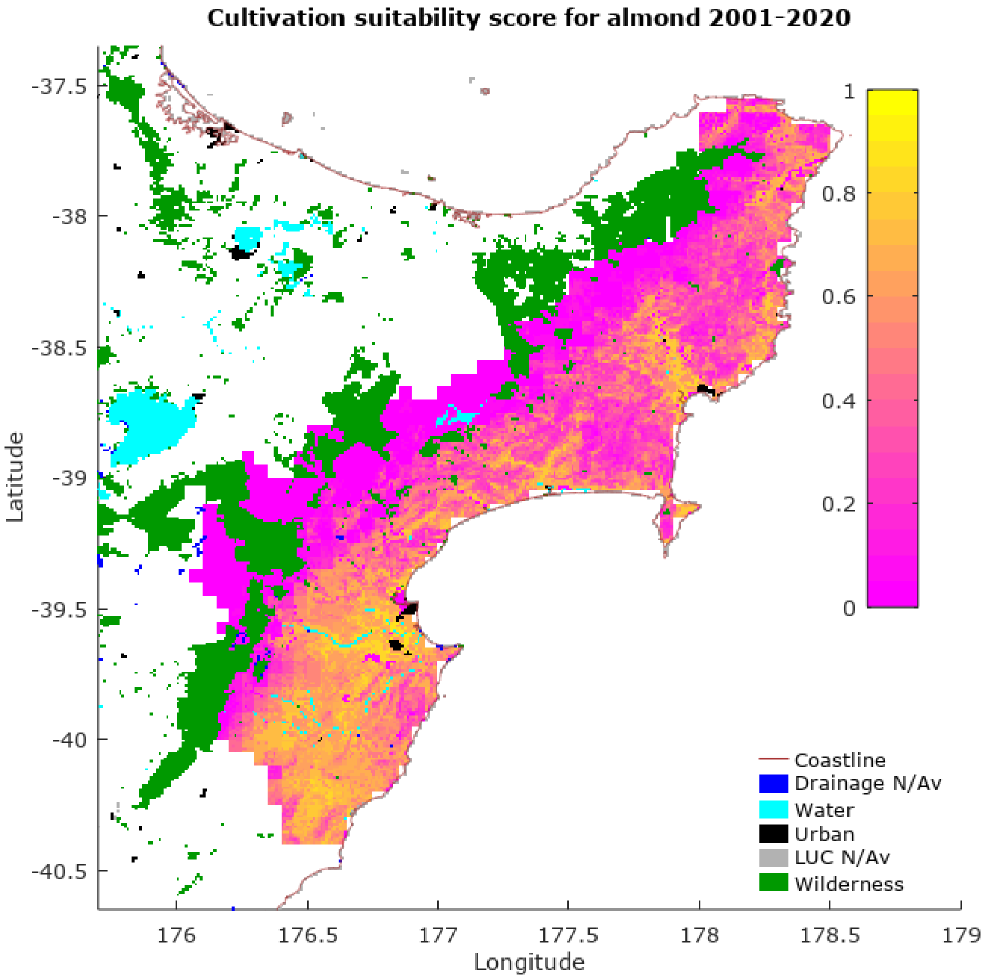


Figure 20. Cultivation suitability scores showing overall suitability for locations across the Hawke's Bay and Gisborne for growing almond by providing weighted average of individual climate-related and soil-related suitability scores.

3.2 Projecting climate change impacts on suitability

Within each RCP, the simulation datasets from the six different GCMs provide six alternative versions of future weather patterns. The approach is to use each of the six datasets to perform suitability calculations, and then to take the mean as the projected future suitability for the RCP. The standard deviation of the six alternative suitability calculations is often used to indicate the uncertainty in the mean projection.

The VCSN-based suitability maps show suitability of the current climate for almonds. However potential climate change impacts on suitability should be estimated by comparing suitability scores calculated from climate model projection data for a future period with suitability scores calculated from climate model data for the hindcast (RCP Past) period. We calculated projected suitability scores for the future periods 2031–2050 and 2051–2070 using the SLM RCP datasets, and to estimate climate change impacts, calculated suitability scores for the period 1981–2000 using the SLM RCP Past datasets. The projected changes are useful for indicating the direction of change for different locations, and the relative magnitudes of change between locations.

Projected suitability for individual criteria and combined criteria were mapped for the two future periods for both RCP 8.5 and 6.0, and are presented in Appendix 2 (page 61), along with maps of the standard deviations of suitability score projections and of change in suitability with respect to the 1981–2000 hindcast period (page 61).

RPC 8.5, which is consistent with unabated GHG emissions, is likely the closest to the current emissions trajectory, and we discuss the projection results in this section. For brevity, we present only maps for overall cultivation suitability and maps for projected change in climate suitability.

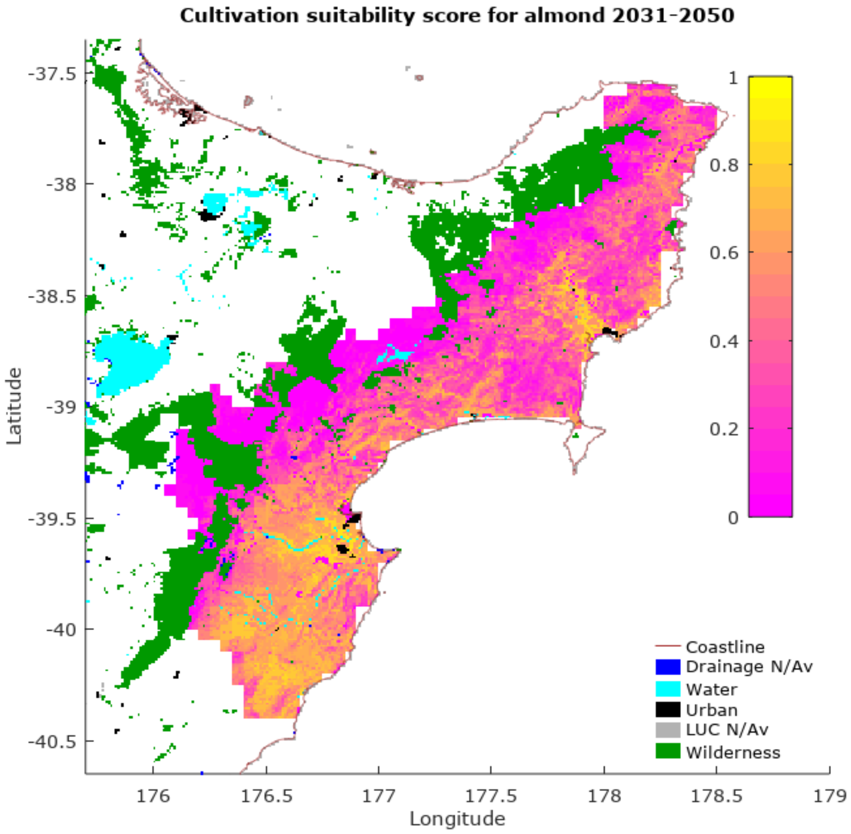
3.2.1 Climate change impact under RCP 8.5

Cultivation suitability 2031 to 2050 period

The projected cultivation suitability map for 2031 to 2050 under RCP 8.5 (left panel of Figure 21) is similar to the cultivation suitability map for the 2001–2020 (Figure 20), which represents current suitability. The projected change in climate suitability (right panel of Figure 21) shows the trend in climate suitability under RCP 8.5 and indicates a generally positive impact on overall climate suitability.

Note that projected changes for cultivation suitability will have smaller magnitudes than projected changes for climate suitability. This is because when climate suitability and land suitability scores are combined by geometric averaging, the climate contribution is diluted. Note also that the change in projection is calculated for a time difference of 50 years, while the time difference between the contemporary and future periods is 30 years. Thus projected changes should be interpreted as only indicators of the direction of change.

Examining the maps for projected changes in individual suitability which are presented in Appendix 2, there were a very few locations of historically high chill-force suitability that had significant decreases in chill-force suitability. This can be linked directly to a decrease in CU accumulations. However, there were generally only very small decreases in chill-force suitability in areas that historically were very high, and these areas remained of high suitability. Small decreases in CU can be compensated for by increased GDH accumulation. There were large improvements in some areas of historically low chill-force suitability that substantially improved their scores. These areas were historically too cold to accumulate sufficient GDH for timely flowering, and under the climate projection, improved their GDH accumulation while still maintaining adequate chill.



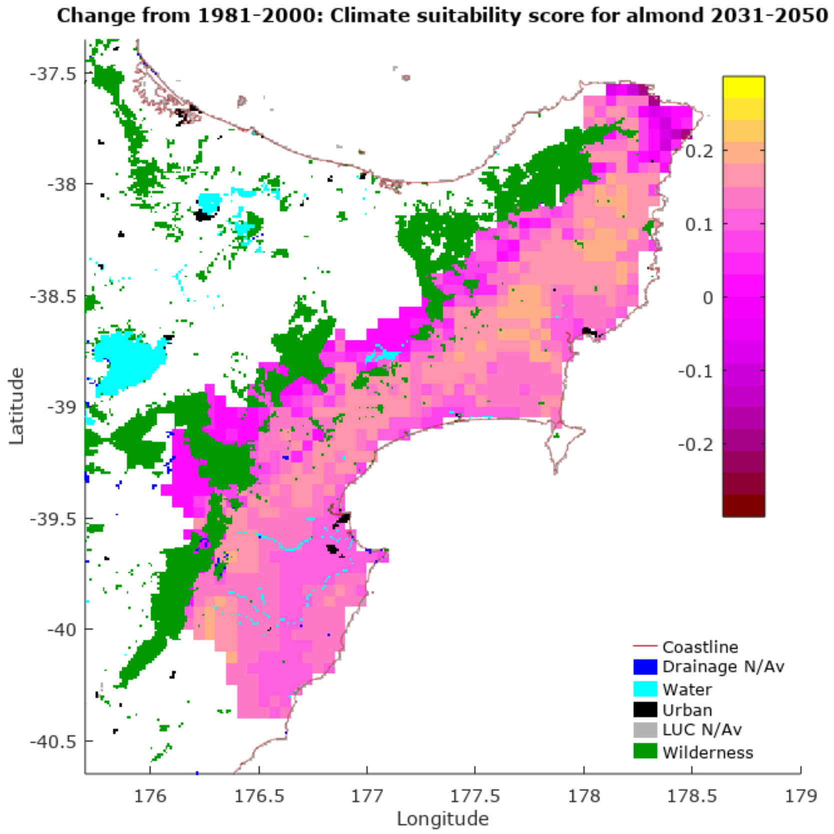


Figure 21. Projected cultivation suitability scores for 2031–2050 under RCP 8.5 (left) showing overall suitability of locations across the Hawke's Bay and Gisborne regions for growing almond, and projected change in cultivation suitability scores for 2031–2050 compared with 1981–2000 under RCP 8.5 (right) showing the direction of suitability change.

There was generally little change in GDH suitability for areas with historically high suitability since these already had sufficient heat accumulation, and larger increases in some locations that historically had low GDH that closely matched increases in the areas of historically low chill-forcing suitability (Appendix 2). This correlation is not unexpected since GDH accumulation in the model was contingent on adequate CU being accumulated.

There was little projected change in harvest rain suitability, except for big deceases in suitability for some areas that, for the contemporary period, were calculated as having high suitability because they were too cold to produce a crop (Appendix 2). These areas had warmed sufficiently under the climate projection to produce a crop in some year, and subsequently rain at harvest would become an issue. Pollination suitability was generally projected to increase, especially in areas of historically higher suitability, and frost suitability was also projected to increase in most locations, with other locations tending to have only small declines (Appendix 2). Declines in frost suitability can occur when warmer climates bring forward flowering into a frost risk period.

Projected changes to the generic disease risk suitability score were minor, as were projected changes to the annual rainfall suitability score (See Appendix 2). With respect to the latter, although annual rainfall was not projected to change significantly for Hawke's Bay or Gisborne, the rainfall patterns may well do, but the rainfall model is not sensitive to this.

Cultivation suitability 2051 to 2070 period

The projected cultivation suitability map for 2031 to 2050 under RCP 8.5 (left panel of Figure 22) is similar to the cultivation suitability map for the 2001–2020 (Figure 20) but indicates slightly higher cultivation suitability in Central Hawke's Bay and also parts of the Heretaunga Plains, with little suitability change indicated for around the Poverty Bay area. The projected change in climate suitability (right panel of Figure 22) shows the trend in climate suitability under RCP 8.5 and indicates a generally positive impact on overall climate suitability with suitability changes having up to twice the magnitude compared with the projected changes to 2031–2050 period. The largest changes were decreases in suitability around the East Cape area, in the order of 0.4.

A slight decline in suitability in many historically high chill-force locations was projected, with a continued improvement of colder locations with historically insufficient GDH accumulation for forcing (See Appendix 2). Projections indicate little change in GDH suitability for areas with historically high suitability and larger increases in some locations with historically low GDH accumulation, following the projected changes discussed above for the 2031–2050 period (See Appendix 2).

For most areas, very slight to small increases in harvest rain suitability were projected, but large decreases in suitability were projected for some locations. These latter locations included the same locations that were projected to have big decreases in harvest rain suitability by 2031–2050, but the projected declines are much larger (See Appendix 2). These locations which were historically too cold to produce a crop and thus were calculated as having low harvest rain risk, have continued to warm and fruit successfully in more years, and thus have more years in which rain at harvest is a risk.

Frost risk suitability was projected to increase in almost all locations across the two regions, with very high frost suitability scores for most areas other than in some higher altitude locations. Pollination suitability was projected to improve across the two regions, with bigger suitability increases in lower-elevation locations, resulting in a much improved pollination suitability map for 2051–2070 than for the contemporary period. As was the case for 2031–2050, projected changes to the generic disease risk suitability and annual rain suitability scores were minor (Appendix 2).

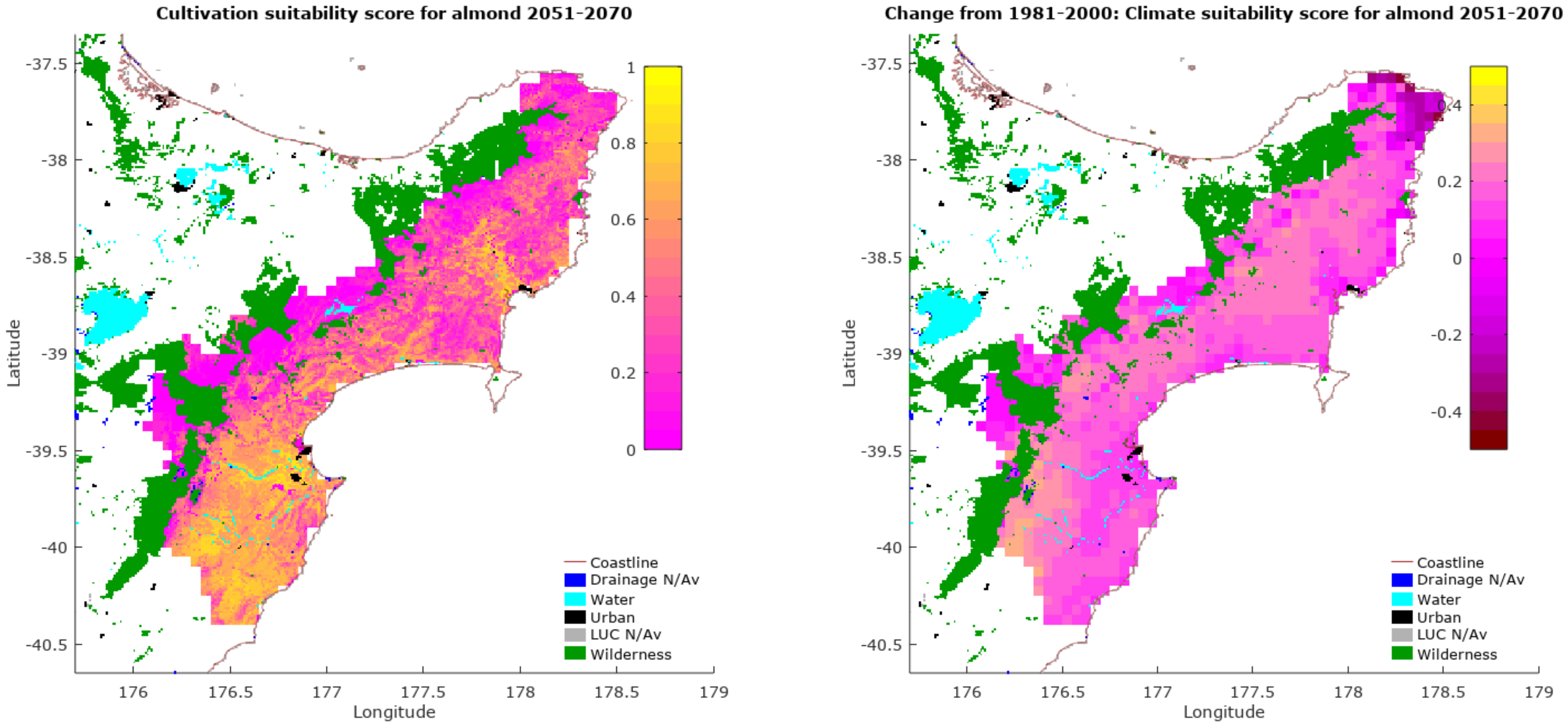


Figure 22. Projected cultivation suitability scores for 2051–2070 under RCP 8.5 (left) showing overall suitability of locations across the Hawke's Bay and Gisborne for growing almond, and projected change in cultivation suitability scores for 2051–2070 compared with 1981–2000 under RCP 8.5 (right) showing the direction of suitability change.

The trends in the projected changes in suitability scores under RCP 6.0 are similar in direction to those under RPC 8.5, but the magnitudes of projected change are smaller – i.e. the rate of change over time is slower. Graphs showing projected means, standard deviations of projected mean, and projected change under RCP 6.0 are presented in Appendix 2.

3.3 Life cycle assessment

3.3.1 Life Cycle Impact Assessment

Life cycle impact assessment (LCIA) translates emissions and resource extractions into a set of environmental impact scores using characterisation factors (ISO 2006a, 2006b). In this study, the LCIA method ReCiPe 2016 (Huijbregts et al. 2017) and the most recent GWP100 metrics (IPCC 2014) were applied to calculate the potential carbon footprint of harvested almonds, reported here as kg of carbon dioxide equivalents per kg of raw almonds (kg CO_2-eq/kg). Results have been aggregated into groups to make them easier to interoperate. For example, glyphosate, pesticide, and fertiliser production includes the emissions associated with the production of the product, transport and shipping. Similarly machinery operations represent all the emissions associated with machinery activities within the orchard.

Based on the inputs to the orchard system outlined above, Results indicate that there is potential carbon footprint of 1.83 kg CO_2-eq/kg of almonds associated with the life cycle of almond production to the farm gate. Overall, irrigation has the greatest contribution to the system (1.24 CO_2-eq/kg) accounting for 68% of the associated footprint; this is followed by machinery operations (0.23 CO_2-eq/kg) and fertiliser applications (0.17 CO_2-eq/kg). Table 10 and Figure 23 and Figure 24 provide a summary of the results based on the orchard activities.

Table 10. Potential carbon footprint associated with almond production.

Activity/input	kg CO_2-eq/kg
Glyphosate Production	0.02
Pesticide Production	0.06
Urea Production	0.06
KCl Production	0.05
Machinery Operation	0.23
Fertiliser Applications	0.17
Irrigation	1.24
Total	1.83

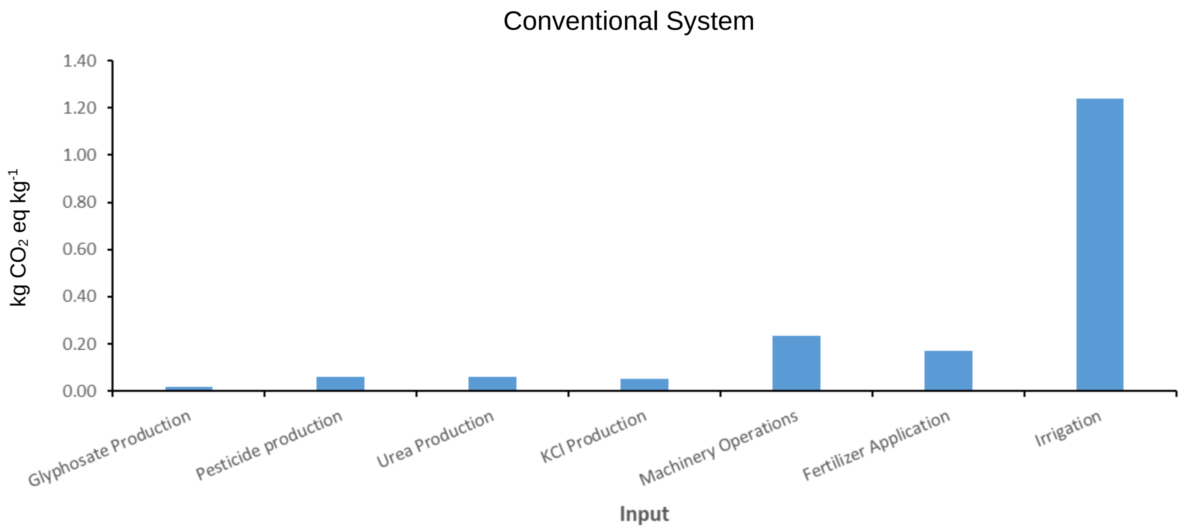


Figure 23. Potential emissions from each input of the conventional system.

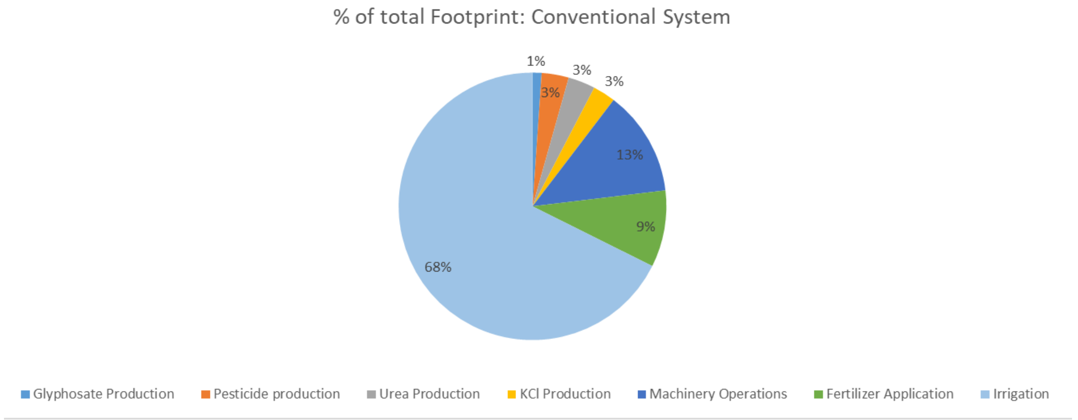


Figure 24. Percentage contribution of each input of the conventional system to the total potential carbon footprint.

3.3.2 Sensitivity Analysis

From the LCIA, irrigation was identified as a major hotspot within the almond life cycle accounting for 68% of the overall potential footprint. Here, adjustments were made to the total amount of irrigation to assess what influence this may have on the overall results. The essence of the adjusted LCA model, and its inputs, was kept the same as per the conventional system with only the total volume of irrigation adjusted. As there are no current New Zealand specific data relating to irrigation inputs and yield response of almonds, adjustments to the amount of irrigation applied where based on work by Moldero et al. (2021) and used only as a guide. The total inputs to irrigation were taken as a percentage of the total used in the conventional scenario (i.e. 12 ML). Adjustments were as follows: 65% and 30% of total irrigation and zero irrigation. Table 11 and Figure 25, Figure 26, Figure 28, Figure 27, Figure 29, Figure 30 summarise the results of the adjusted inputs.

Table 11. Adjusted carbon footprint based on reduced irrigation inputs.

% of irrigation from conventional input	Total kg CO_2-eq/kg	Total kg CO_2-eq/kg contributed from Irrigation	% reduction of total kg CO_2-eq
100	1.83	1.24	0
65	1.40	0.81	23
30	0.96	0.37	48
0	0.59	0	68

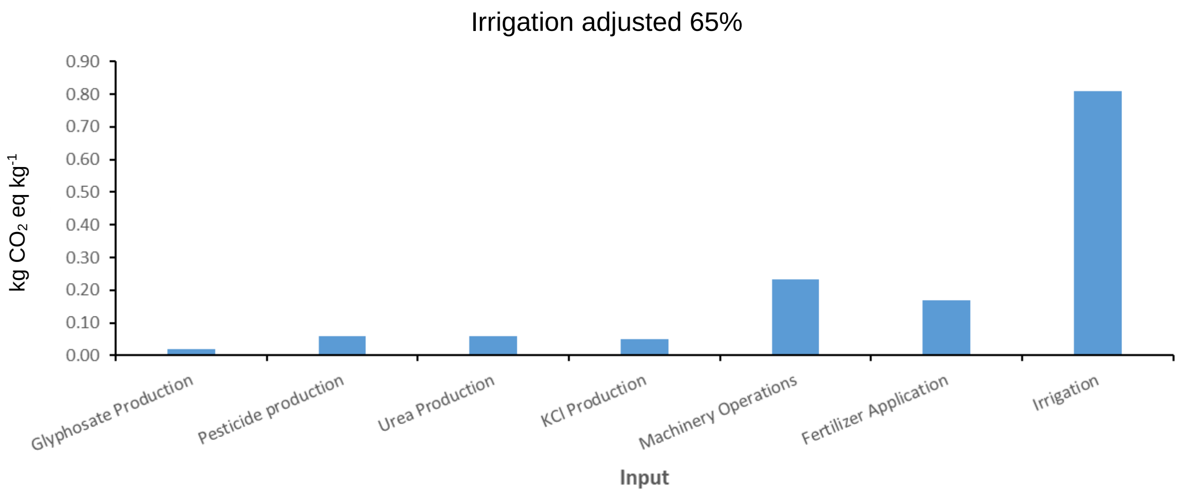


Figure 25. Potential emissions associated with each input and assuming 65% of total irrigation from conventional system.

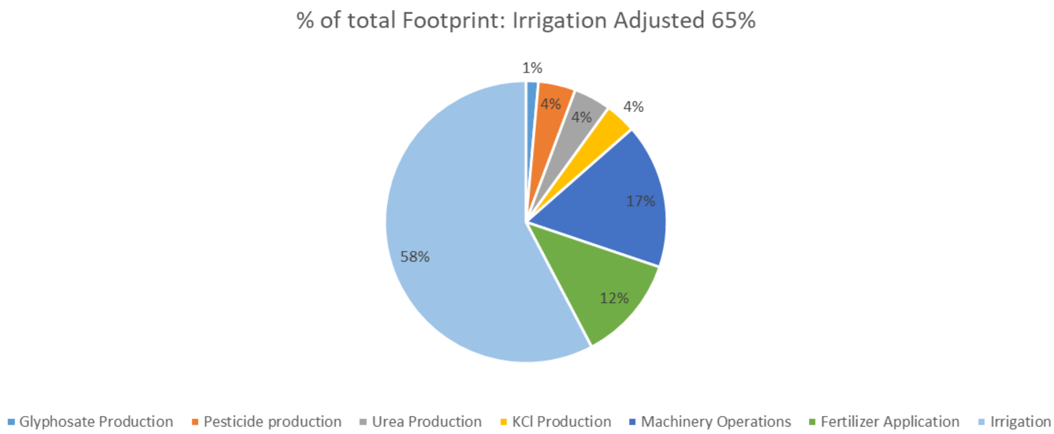


Figure 26. Percentage contribution of each input to the total potential carbon footprint, assuming 65% of total irrigation.

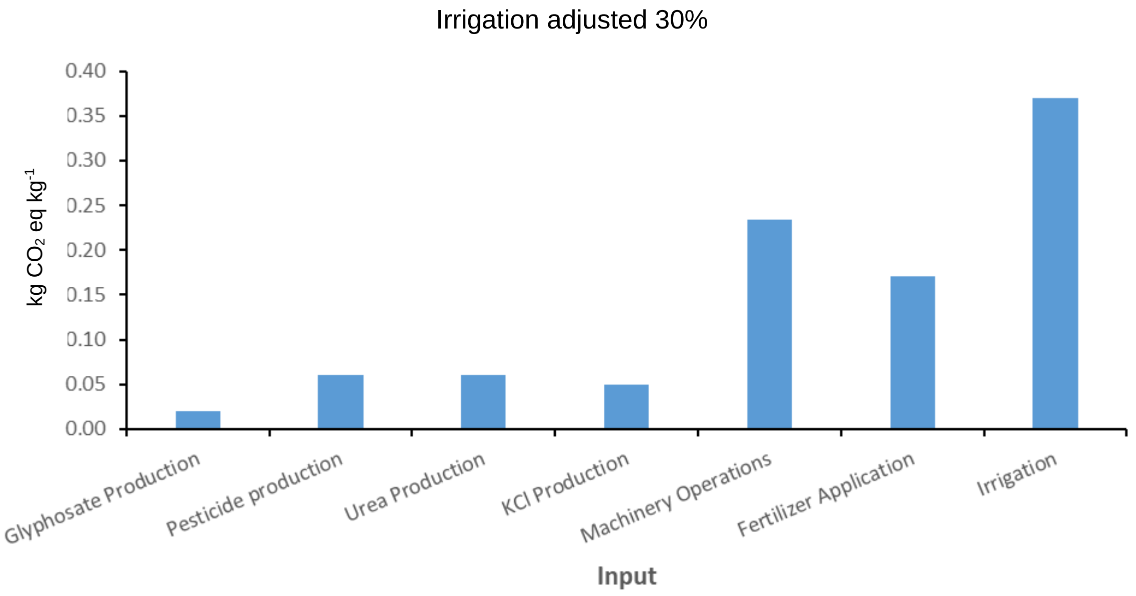


Figure 27. Percentage breakdown of carbon footprint associated with each input and assuming 30% of total irrigation of conventional system.

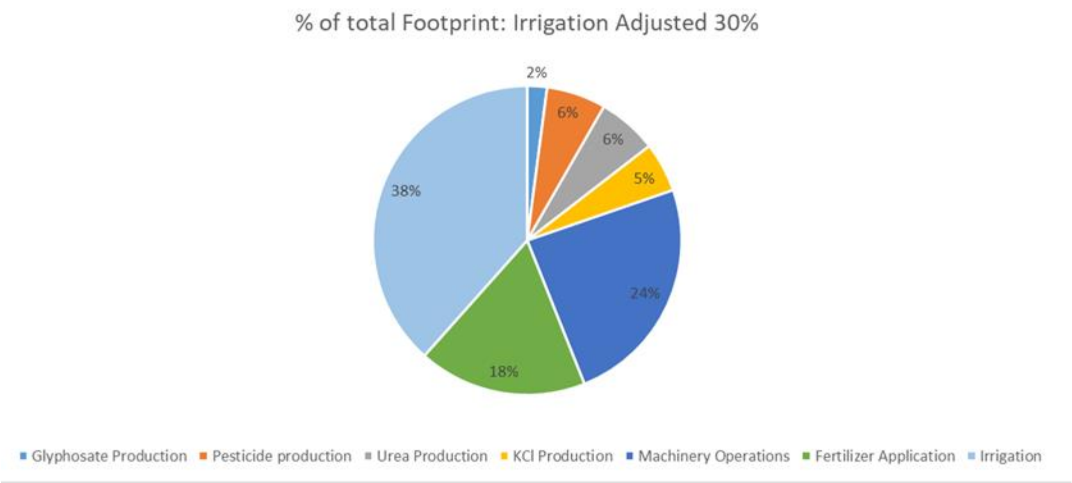


Figure 28. Potential emissions associated with each input and assuming 30% of total irrigation from conventional system.

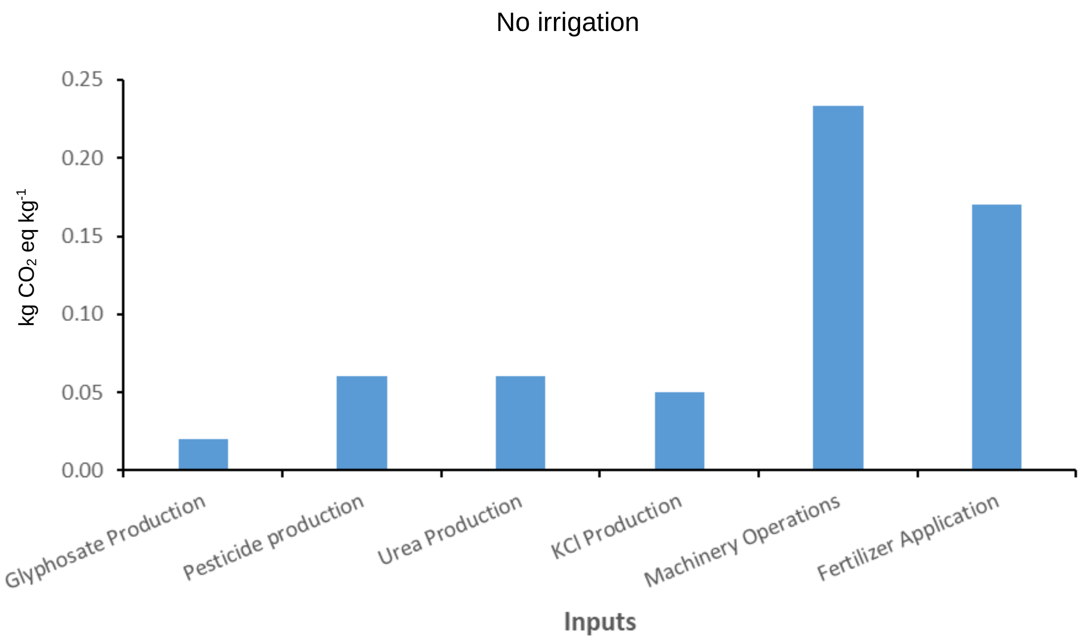


Figure 29. Potential emissions associated with each input and assuming no irrigation.

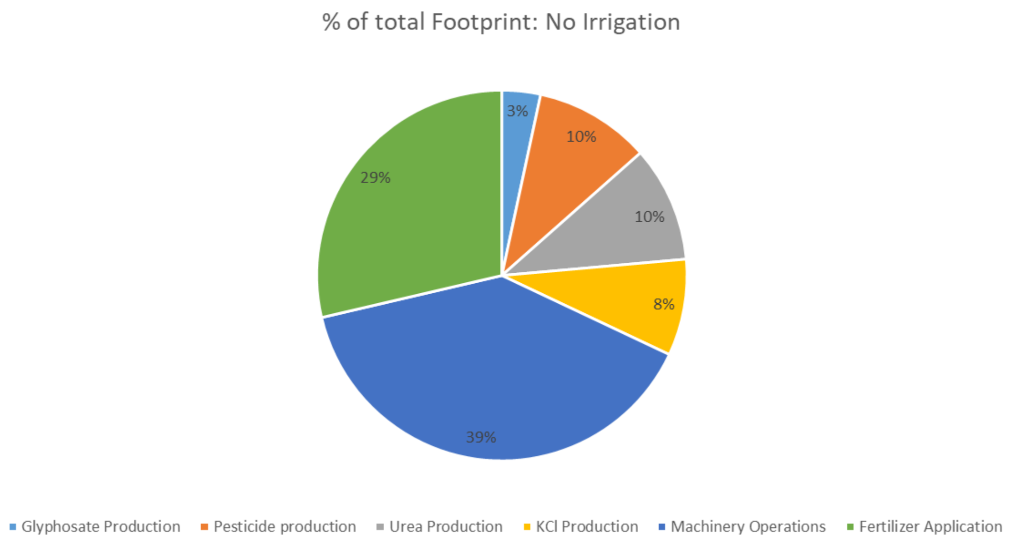


Figure 30. Percentage breakdown of carbon footprint associated with each input and assuming no irrigation.

4 Discussion and conclusion

4.1 Suitability modelling

Suitability models

The continuous suitability models provides a more flexible assessment than commonly used binary (suitable/unsuitable) models or categorical models (e.g. poor vs fair vs good vs very good) that require the stipulation of cut-off values for indicator variables. The use of cut-offs can result in artificial distinctions of two similar locations, or class two dissimilar sites into one category. Continuous suitability modelling not only allows optimal locations to be identified and ranked on merit, it also allows the study of gradual shifts in suitability under climate change, which cannot be done when one is dealing with categories. Continuous suitability modelling is useful also when appropriate data on crop or cultivar requirements are sparse or unavailable.

Many of the climate-related risks to almonds are dependent on the phenological stage of the tree, such as frost risk, rain at harvest or poor pollination weather. Thus modelling phenological stages over time was a key component of the suitability modelling, allowing the severity of a risk to be gauged on the basis of the probability of the tree being at a phenological stage vulnerable to that risk.

Going into the project, the phenology component of the PFR suitability model had an initial parameterisation that was theoretical, being based on published data from overseas studies that were not aligned with New Zealand climates or with the cultivars grown here. There was a lack of New Zealand almond phenology data with which to test our phenology model, but it was evident that the requirements for heat and chill accumulation published for almonds are largely not relevant for the New Zealand situation.

Our re-parameterisation of the phenology model was based on incomplete data from two sites taken over one or two years, and thus cannot be considered robust. This should be borne in mind when considering results, although the behaviour of the phenology model appeared sensible.

The weighted geometric averaging of continuous suitability scores for individual criteria to get overall soil, climate and cultivation suitability scores provides a means to aggregate considerations of multiple requirements and criteria in a way that reflects their relative importance (as reflected by their weighting). The selection of weights is subjective, and can vary among growers. For example, we gave the slope the highest weighting on the grounds that highly sloped land is less conducive to machine harvesting, and cannot be readily mitigated if a prospective grower intended to use machine harvesting. However a small-scale grower who is happy to harvest manually may consider that slope suitability should have a lower weight.

Suitability of locations for growing almonds

The suitability study was aimed at identifying suitable locations for growing almonds in the Poverty Bay area as well as the Hawke's Bay region, and thus we included Gisborne in our study. Our suitability models identified no locations with very high cultivation suitability scores (i.e. close to 1). Such locations would allow cultivation of almonds with few or no limitations from the climate, soil properties or the terrain.

However, a number of locations with suitability scores with "moderate" values in the order of 0.6 to 0.8, with some locations in the Heretaunga Plains in the vicinity of Hastings were identified as the most suitable. These locations of moderate cultivation suitability were found to be distributed across many areas of the Hawke's Bay region, with a large density in the Central Hawke's Bay District, and in some parts of the Gisborne region, including Poverty Bay – in the Flats and surrounding area.

Such locations would allow the successful cultivation of almonds, albeit with limitations that could result in decreased yields or require additional costs to mitigate. For reference, the Waipukurau and Te Puke orchards had calculated cultivation suitability scores of 0.69 and 0.62 respectively, climate suitability scores of 0.61 and 0.73 respectively, and soil suitability scores of 0.81 and 0.53 respectively. Due diligence is recommended before establishing large-scale establishment of almond orchards in these locations.

Annual rain suitability

The annual rainfall suitability score reflected the beneficial effect of rain towards maintaining crop evapotranspiration, as opposed to its damaging effect at harvest. Annual rainfall was not included in the calculation of overall cultivation suitability but intended to be used separately as a guide on irrigation requirements.

Projected impacts under climate change

The projected impact of climate change under RCP 8.5 was a slight improvement in cultivation suitability, due to such factors as decreased frost and disease risks, and increased GDH accumulation. The trend in improvement continued from the 2031–2050 period through to the 2051–2070 period. Projected changes in suitability scores under RCP 6.0 were qualitatively similar to those under RCP 8.5, but occurring at a slower pace.

An important difference between this study and previous climate change studies is on the issue of winter chill and flowering. For example, Vetharaniam et al. (2021) found that increased temperatures under RCP8.5 could lead to a lack of winter chill and lack of flowering. In that study, the chill models were either based on mean winter temperature or purely accumulation of chill. In this study, we have used a chill-force model in which chill accumulation is required for buds to reach ecodormancy and then heat accumulation is required to force buds to the flowering stage. In the chill-force model, decreased chill can be partially compensated for by increased GDH, and this would essentially mitigate increasing temperatures, but only up to a point.

4.2 Life cycle analysis

The main objective of this study was to evaluate the potential carbon footprint associated with growing almonds in Hawke Bay and to highlight hotspots within the almond production system. Using inputs previously outlined, a typical almond system under conventional management has a potential footprint of 1.83 kg CO_2-eq/kg associated with almond production. Previous studies which have also assessed the environmental impact associated with almonds, indicated a potential carbon footprint of 1.92 kg CO_2-eq/kg of almonds (Volpe et al. 2015) while work by Marvinney et al. (2014) Kendall et al. (2015) found a potential carbon footprint of 1.76 kg CO_2-eq/kg and 1.6 kg CO_2-eq/kg, respectively. In this study, irrigation has been highlighted as the greatest potential hotspot within the life cycle, accounting for 68% of the total associated footprint and an area within the production system which may provide opportunity for environmental improvement. This was followed by machinery operations (13%) and fertiliser applications (9%). Orchard operations and nutrient management were also highlighted as large contributors to the overall potential emissions associated with almond production in California. This was attributed to the energy-intensive process associated with fertiliser manufacture and the large quantities applied during the growing season, and also the energy required for operations such as irrigation and harvesting (Kendall et al. 2015)

Sensitivity analysis revealed that by applying 65% less irrigation than the conventional system, the potential footprint was reduced by 23%, while applying only 30% of the total irrigation or no irrigation at all resulted in a potential footprint reduction of 48% and 68%, respectively. Noting that as the overall impact contributed by irrigation decreased, the relative proportion of other inputs, in terms of their overall impact, gradually increased, although their overall magnitude remained the same. While irrigation has been identified as a system hotspot, data used here are based on intensive almond production systems in California (Duncan et al. 2019) and not related to site-specific information here in New Zealand. Furthermore, the total energy demand to operate a specific irrigation system was not known and the database used to provide the irrigation inputs in GaBi professional were used only as a proxy and may not be representative of a typical orchard operation.

Water availability can be a limiting factor in crop production and can potentially have a negative correlation with total kernel total yield (Moldero et al. 2021). Improving the environmental performance may not be as simple as reducing irrigation inputs without first considering other influences to the system. It is recommended that any decisions regarding irrigation requirements should first be considered with other site-specific data such as evapotranspiration rates, soil characteristics, local climate and planting density. Under the reduced irrigation scenarios, emissions associated with nutrient management and machinery operations contributed to a larger overall percentage to the total footprint.

Operation of machinery during the growing season and harvesting can be an energy-intensive process, and harvesting in particular is also associated with other negative environmental impacts in the form of pollution via air-borne particulate matter (Faulkner 2013). While reducing the reliance of machinery, especially during harvest, may be considered as a potential mitigation strategy for reducing environmental footprints, this may affect the overall efficiency of crop recovery, harvesting time, and result in increased costs required for manual labour (Pascuzzi & Santoro 2017). Based on the data available, we cannot say with confidence what the energy requirements and emissions would be for each mechanisation process, but assume that the total contribution from machinery operation will still remain significant to the overall potential footprint.

Emissions associated with fertilisers will vary over space and time, and will also be dependent on other factors such as, the type of fertiliser applied, soil and climate, and the emission factors used (Oertel et al. 2016; Wu et al. 2021). For example, if the New Zealand specific soil emission factor for leaching was used (0.07) it would result in 0.14 kg CO2-eq/kg potential emissions from fertiliser in contrast to 0.17 kg CO2-eq/kg using the emission factor from the IPCC (0.3). This adjustment would bring the total emissions from 1.83 kg CO2-eq/kg to 1.80 kg CO2-eq/kg. If we assumed that the same amount of fertiliser was applied (i.e. 165kg) as calcium ammonium nitrate (CAN) which has an N content of 27%, then the overall emissions associated with fertilisers would be reduced further to 0.08 kg CO2-eq/kg. But, as per the recommendations for irrigation, it is advised that fertiliser inputs be considered with other site-specific information as nutrient requirements will be crop dependent.

In the context of this study, there have been a number of assumptions and approximations made due to the lack of data availability. To help improve the robustness of the LCA model and provide greater confidence in the results, there are a number of recommendations for future assessments:

- A focus on accurate data collection relating to orchard inputs and management practices, and perhaps over a longer time scale. Irrigation, nutrient management, and machinery operations have already been identified as areas that may have the greatest potential impact, but more extensive data will allow more detailed analysis and interpretation. This may reveal hotspots in other areas of the life cycle or reduced impacts from those areas already identified.
- More in-depth sensitivity analysis will allow us to determine how multiple scenarios will influence the results, especially if the limitations of the orchard system are known.
- Looking beyond the farm gate and extending the system boundary to include processing, packaging, distribution etc. may also significantly alter the results. For example Milà i Canals et al. (2007) noted that one of the biggest contributing factors in the apple production life cycle can be related to shipping and transport. This was also true for the kiwifruit supply chain where shipping was one of the greatest impact stages (Mithraratne et al. 2010).
- Considering the utilisation of harvest by-products, i.e. husks and hulls, for use in other process such as feed supplement or for power generation, this could help reduce the overall impact by reducing inputs from other stages. Kendall et al. (2015) found that by using almond by-products, i.e. shell and husks, for the generation of power or as supplementary feed, the overall potential carbon footprint of almond production was reduced from 1.6 to 0.9 kg CO_2-eq/kg.

LCA studies should be used as a tool to make more informed decisions regarding environmental performance. The interpretation of LCA results should be considered alongside other information and environmental metrics, keeping the goal, scope, and functional unit in mind. Where data are unavailable, assumptions about model inputs must be made. This may lead to uncertainties regarding the reliability of the LCA model (Björklund 2002; Bicalho et al. 2017). Furthermore, LCAs do not provide an absolute value in terms of the total environmental impact associated with

LCA Conclusion

Life cycle assessment has been used to evaluate the potential environmental footprint associated with growing almonds in Hawke's Bay and to highlight system hotspots within almond production to the farm gate. Results from this initial assessment found a potential footprint of 1.83 kg CO_2-eq/kg associated with almond production. There is potential to reduce the overall environmental impact of the system but to really understand and determine where they can be made, future assessments should consider accurate data collection of inputs and management practices to provide more confidence in the overall results. Any input changes that are considered should be done so in respect to other inputs to the system and what effects they may have on yield and crop quality. As is the case when considering environmental improvements, there is often a trade-off between one area and another.

5 Acknowledgments

We thank NIWA for providing us access to the VCSN climate database for use in this project. We thank Graham Farnell, Tony Kuklinski and Tessa Leitch for sharing experiences with growing almonds and providing data and other information, and Grant Thorp for helpful discussions.

Funding was provided by Central Hawke's Bay District Council, Hastings District Council, Hawke's Bay Regional Council, Wairoa District Council, and Picot Productions and Tony Kuklinski.

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Appendix 1. LCA model inputs and data

Pesticide production data

a) Data relating to production and transport taken from Müller et al. (2011); b) RoW refers to "rest of world" database in GaBi Professional and is based on global average for production; c) product was assumed to be formulated in Europe and shipped to New Zealand via Australia.

Pesticide (a, b, c, d)	Active ingredient	Function
Roundup® (a)	Glyphosate	Herbicide
Goal 2XL® (b, c)	Oxyfluorfen	Herbicide
Matrix® SG (b, c)	Rimsulfuron	Herbicide
Vanguard® WG (b, c)	Cyprodinil	Fungicide
Pristine® (b, c)	Pyraclostobin	Fungicide
Bravo-Weatherstik® (b, c)	Chlorothalonil	Fungicide
Abamectin® 0.15 EC (b, c)	Abamectin	Insecticide
Intrepid 2F® (b, c)	methoxyfenozide	Insecticide
Clinch® 9 (b, c)	Abamectin	Insecticide

Pesticide transport data.

Location, transport and distances considered for pesticide production (excluding glyphosate).

Location	Transport	Distance (km)
Leverkusen – Hamburg	Rail	346
Hamburg – Brisbane	Ship	12224
Brisbane Port to Factory	Truck	25
Brisbane – Sydney	Ship	952
Sydney – Auckland	Ship	2359
Auckland – Napier	Truck	414

Fertiliser production data

Reference to fertiliser database used for fertiliser production.

Fertiliser	LCI data base
Potassium Chloride (KCL)	EU-28: Potassium Chloride (GaBi Professional)
Urea (46%)	EU-28: Urea (46%) (GaBi Professional)

Fertiliser transport data

Location, transport and distances considered for fertiliser production.

Product	Location	Transport	Distance (km)
KCl	Hamburg – Napier	Ship	13550
Urea (46%)	Kapuni (Taranaki) – Napier	Truck	372

Orchard inputs

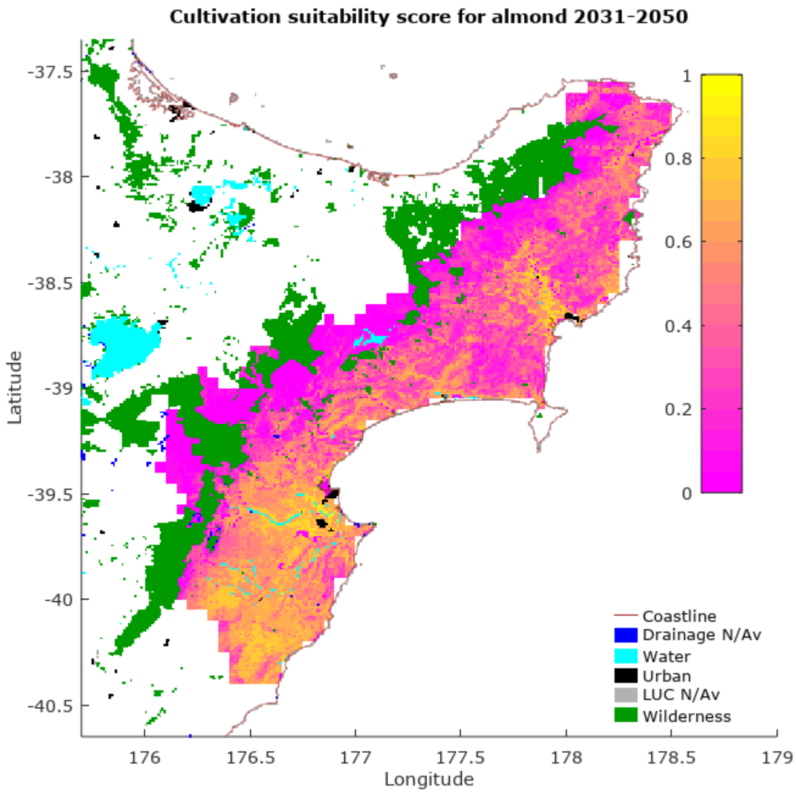
Orchard inputs used for LCA model; a) information taken from (Duncan et al. 2019); b) data base used to model irrigation inputs (CH irrigation); c) database used for gas inputs (AU Natural gas Mix); d) database used for diesel inputs (AU diesel mix at refinery).

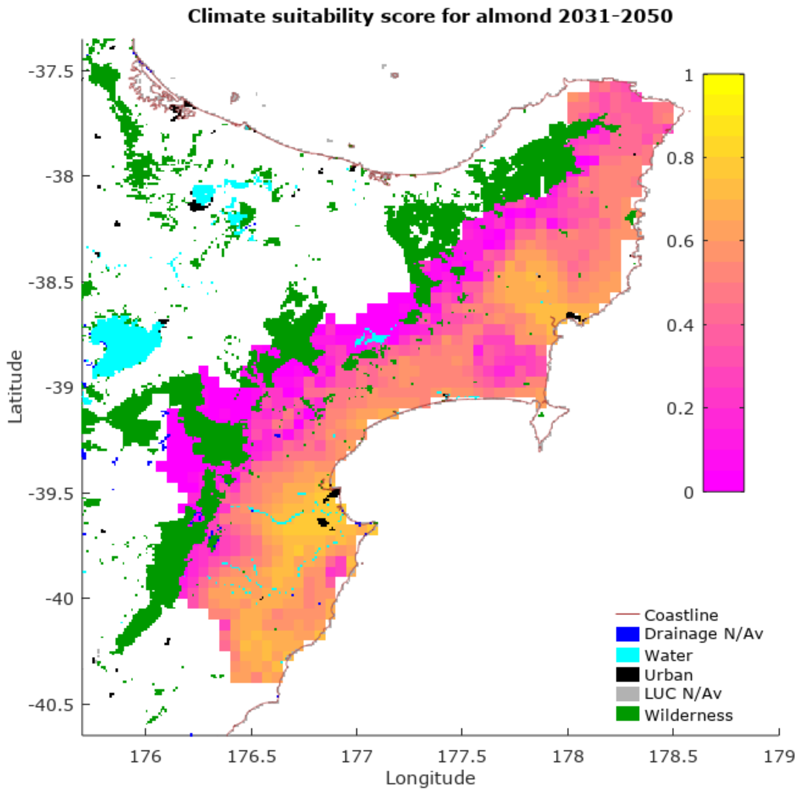
Orchard Operation (a, b, c, d)	Input	Amount	Unit
Spraying (a)	Roundup®	3.45	L/ha
Spraying (a)	Goal®	1.11	L/ha
Spraying (a)	Matrix SG®	0.27	kg/ha
Spraying (a)	Vanguard WG®	0.34	kg/ha
Spraying (a)	Pristine®	0.58	L/ha
Spraying (a)	Bravo Weatherstik®	3.5	L/ha
Spraying (a)	Abamectin®	0.36	L/ha
Spraying (a)	Intrepid 2F®	3.36	kg/ha
Spraying (a)	Clinch®	0.55	kg/ha
Fertiliser (a)	Urea	165	kg/ha
Fertiliser (a)	KCL	392	kg/ha
Irrigation (a, b)	water	12	ML/ha
Gas for Machinery (a, c)	Natural Gas	25	L/ha
Diesel for Machinery (a, d)	Diesel	166	L/ha

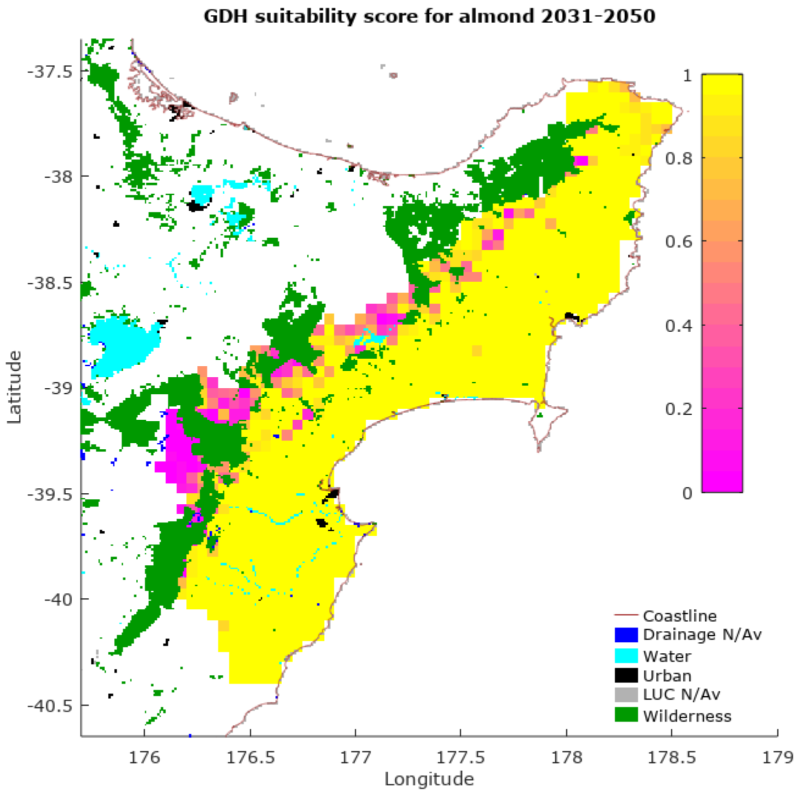
Appendix 2. Climate projection maps

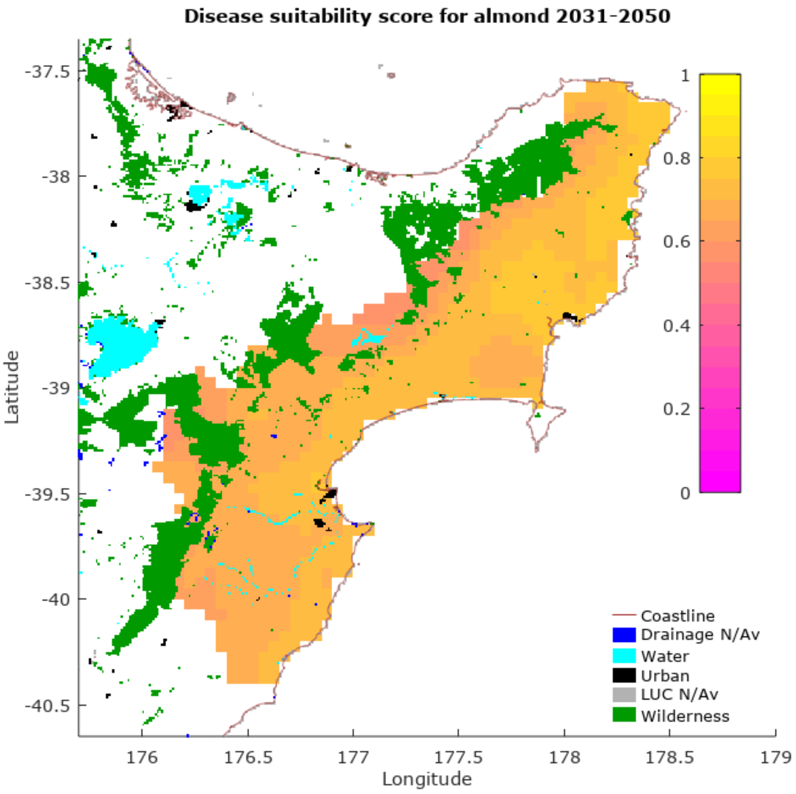
RCP 8.5 2031 to 2050

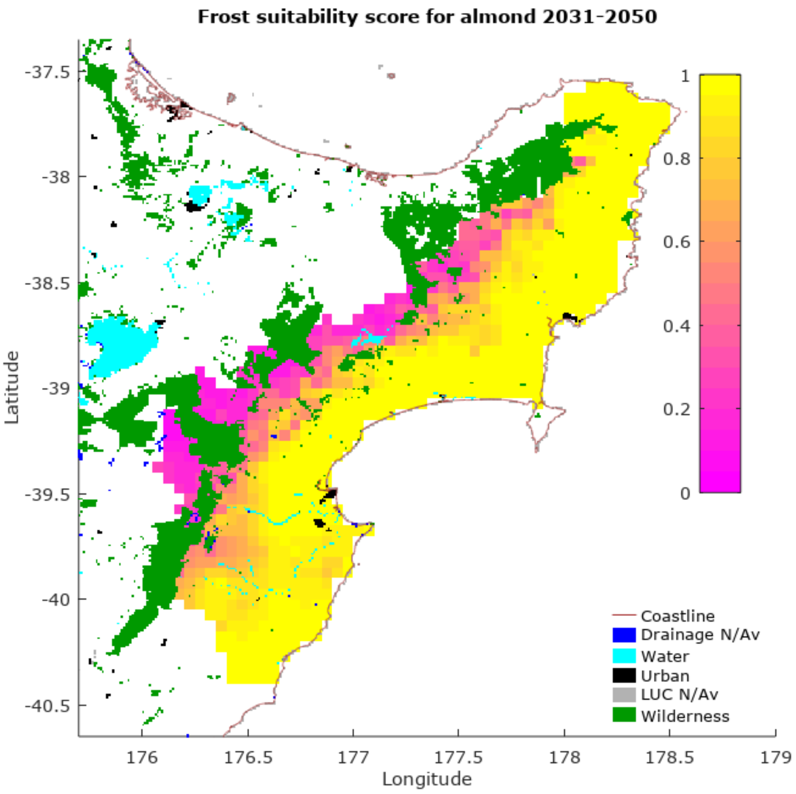
Climate suitability projections




Climate suitability score for almond 2031-2050
-37.5
-38
-38.5
-39
-39.5
-40
-40.5
Latitude
176
176.5
177
177.5
178
178.5
179
Longitude
1
0.8
0.6
0.4
0.2
0
Coastline
Drainage N/Av
Water
Urban
LUC N/Av
Wilderness


GDH suitability score for almond 2031-2050
-37.5
-38
-38.5
-39
-39.5
-40
-40.5
Latitude
176
176.5
177
177.5
178
178.5
179
Longitude
1
0.8
0.6
0.4
0.2
0
Coastline
Drainage N/Av
Water
Urban
LUC N/Av
Wilderness


Disease suitability score for almond 2031-2050
Latitude
Longitude
-37.5
-38
-38.5
-39
-39.5
-40
-40.5
176
176.5
177
177.5
178
178.5
179
1
0.8
0.6
0.4
0.2
0
Coastline
Drainage N/Av
Water
Urban
LUC N/Av
Wilderness


Frost suitability score for almond 2031-2050
Latitude
Longitude
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-38
-38.5
-39
-39.5
-40
-40.5
176
176.5
177
177.5
178
178.5
179
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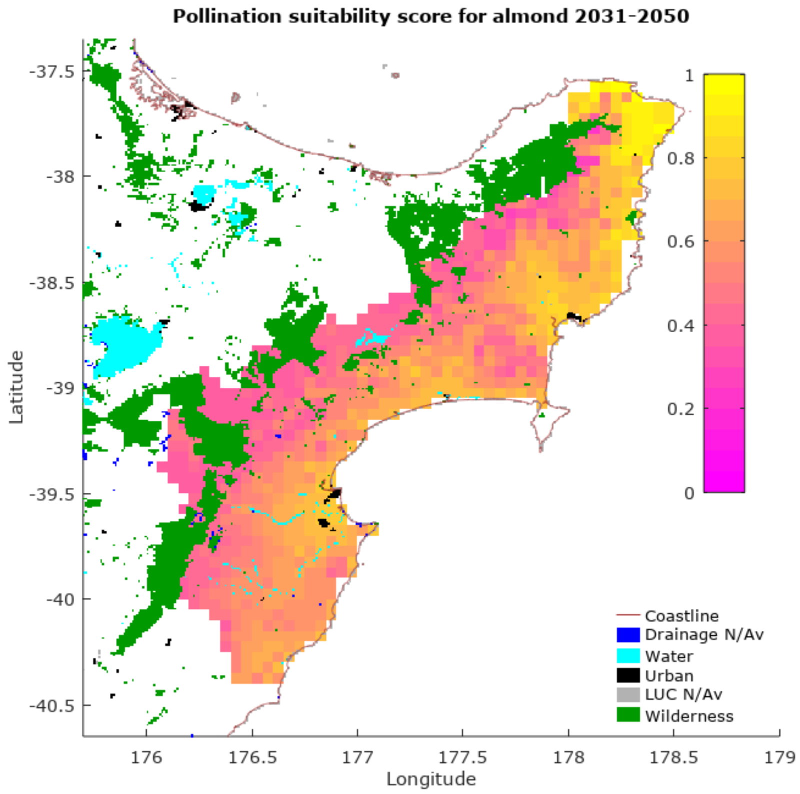
0.6
0.4
0.2
0
Coastline
Drainage N/Av
Water
Urban
LUC N/Av
Wilderness


Pollination suitability score for almond 2031-2050
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-38
-38.5
-39
-39.5
-40
-40.5
Latitude
176
176.5
177
177.5
178
178.5
179
Longitude
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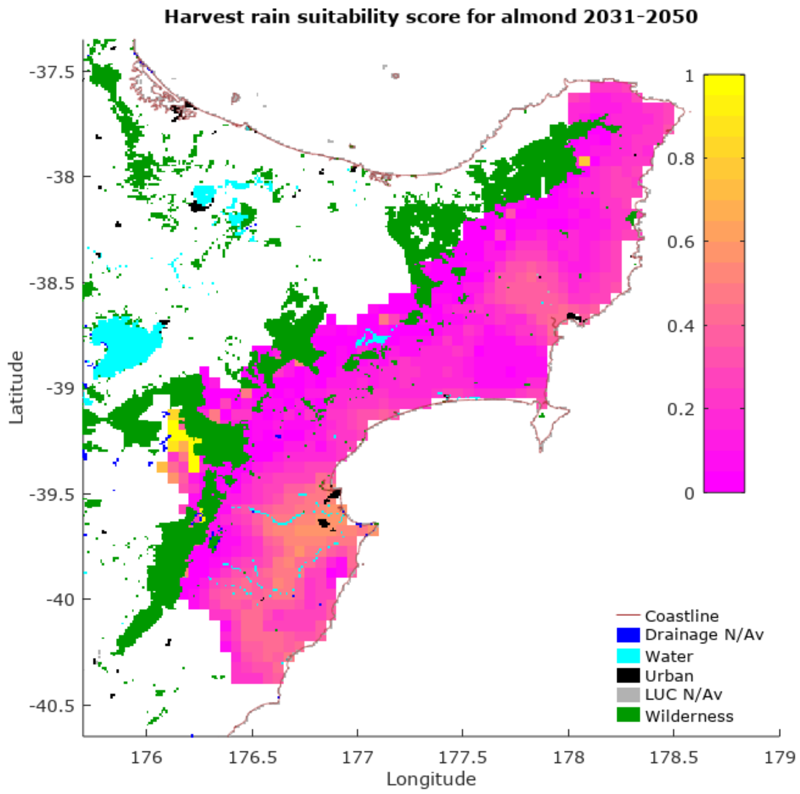
0.6
0.4
0.2
0
Coastline
Drainage N/Av
Water
Urban
LUC N/Av
Wilderness


Harvest rain suitability score for almond 2031-2050
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-38.5
-39
-39.5
-40
-40.5
Latitude
176
176.5
177
177.5
178
178.5
179
Longitude
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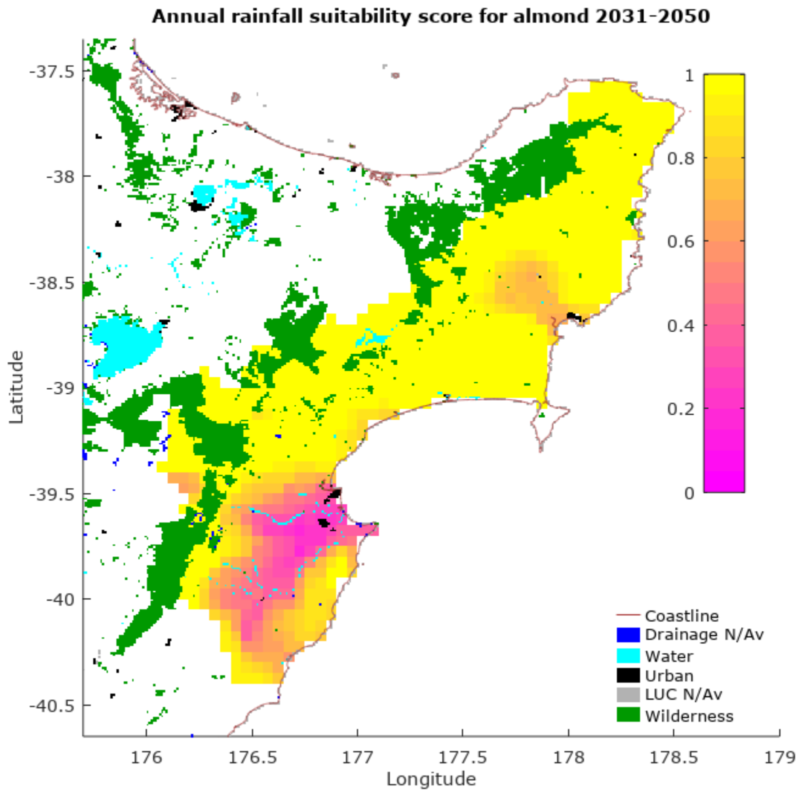
0.6
0.4
0.2
0
Coastline
Drainage N/Av
Water
Urban
LUC N/Av
Wilderness


Annual rainfall suitability score for almond 2031-2050
Latitude
Longitude
-37.5
-38
-38.5
-39
-39.5
-40
-40.5
176
176.5
177
177.5
178
178.5
179
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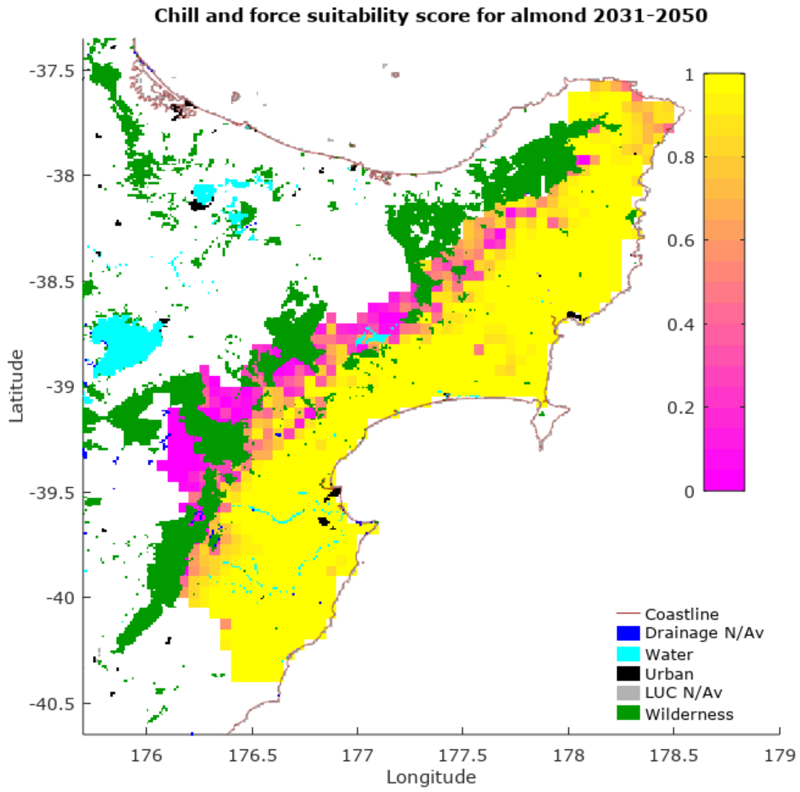
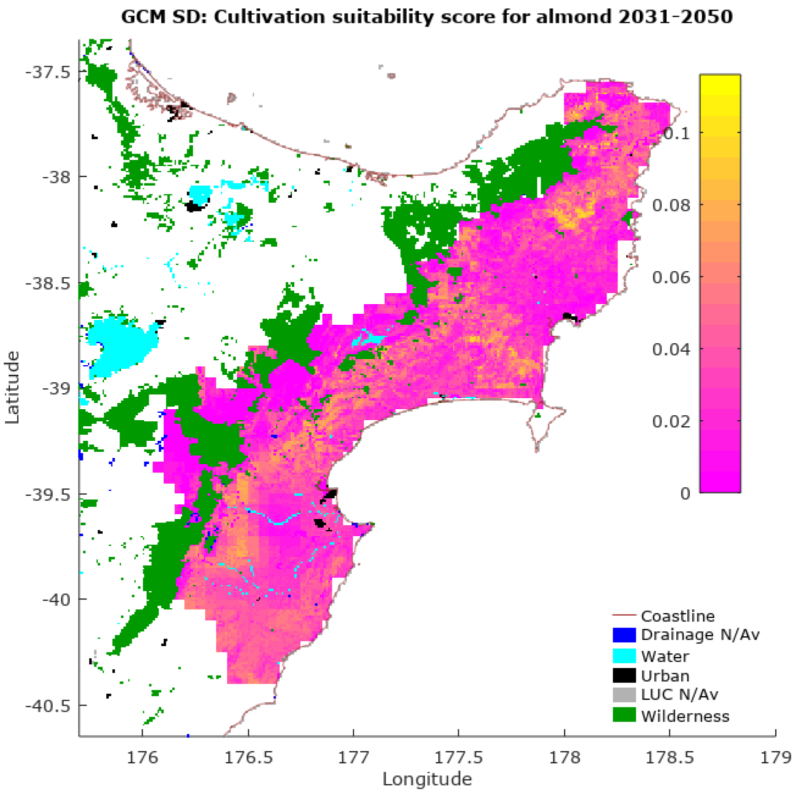
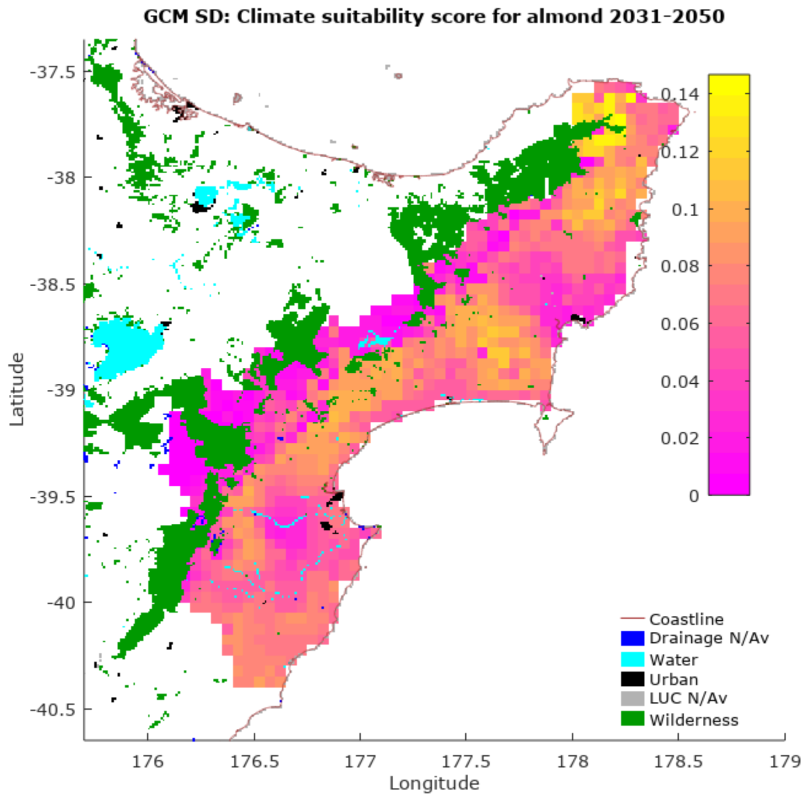
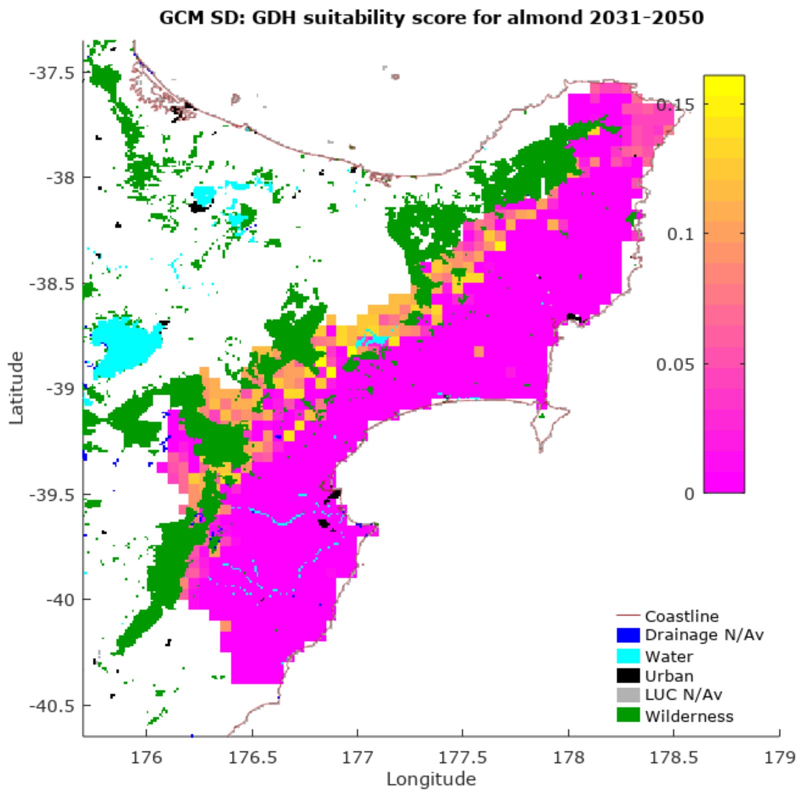
0.6
0.4
0.2
0
Coastline
Drainage N/Av
Water
Urban
LUC N/Av
Wilderness


Chill and force suitability score for almond 2031-2050
Latitude
Longitude
-37.5
-38
-38.5
-39
-39.5
-40
-40.5
176
176.5
177
177.5
178
178.5
179
1
0.8
0.6
0.4
0.2
0
Coastline
Drainage N/Av
Water
Urban
LUC N/Av
Wilderness

Standard deviation (SD) of projections




GCM SD: Climate suitability score for almond 2031-2050
Latitude
-37.5
-38
-38.5
-39
-39.5
-40
-40.5
Longitude
176
176.5
177
177.5
178
178.5
179
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Coastline
Drainage N/Av
Water
Urban
LUC N/Av
Wilderness


GCM SD: GDH suitability score for almond 2031-2050
Latitude
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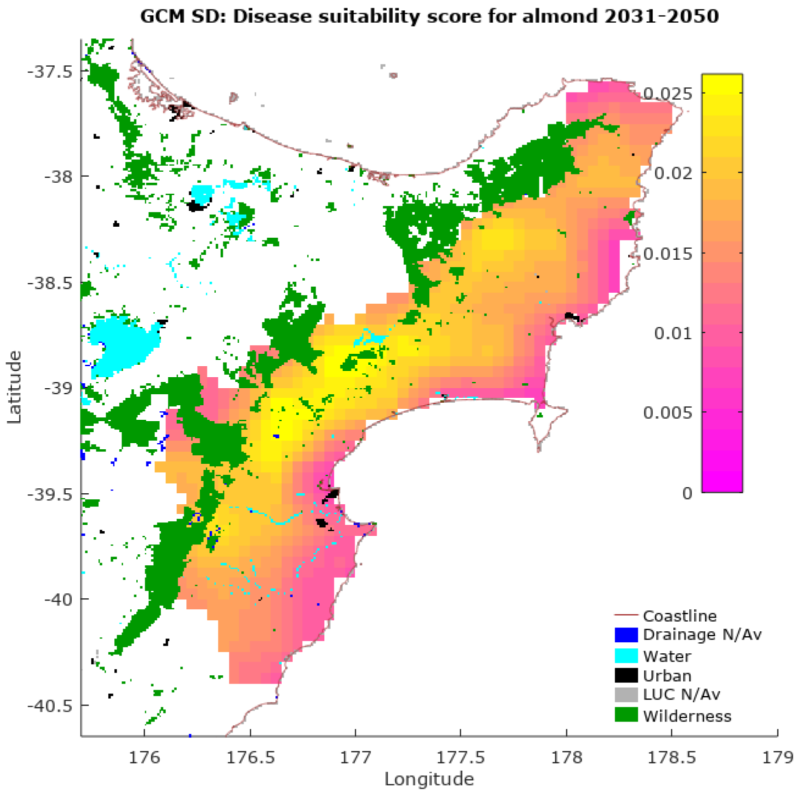
-38
-38.5
-39
-39.5
-40
-40.5
Longitude
176
176.5
177
177.5
178
178.5
179
0.15
0.1
0.05
0
Coastline
Drainage N/Av
Water
Urban
LUC N/Av
Wilderness


GCM SD: Disease suitability score for almond 2031-2050
Latitude
Longitude
-37.5
-38
-38.5
-39
-39.5
-40
-40.5
176
176.5
177
177.5
178
178.5
179
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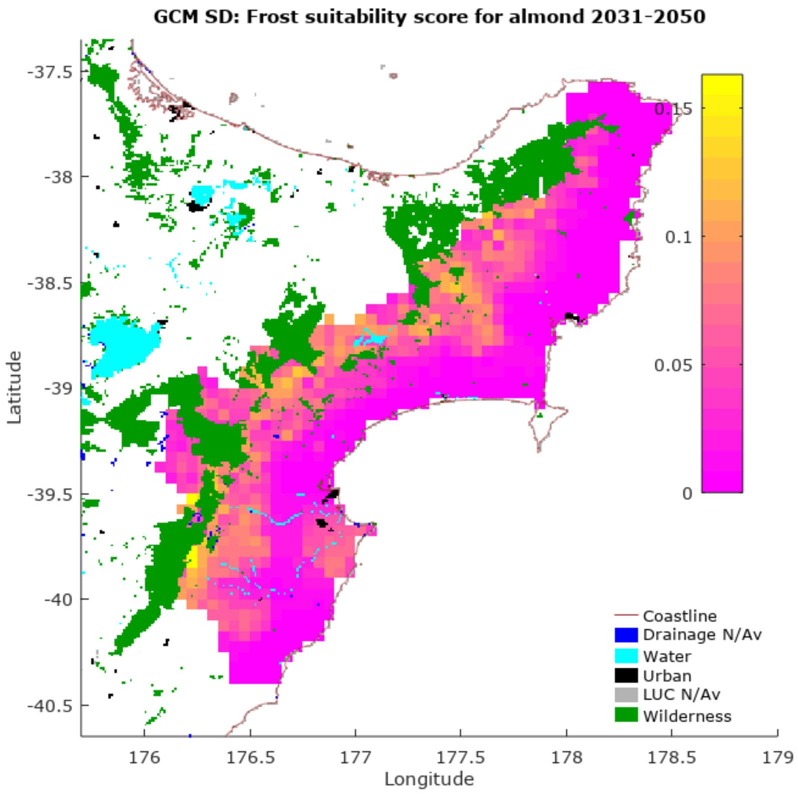
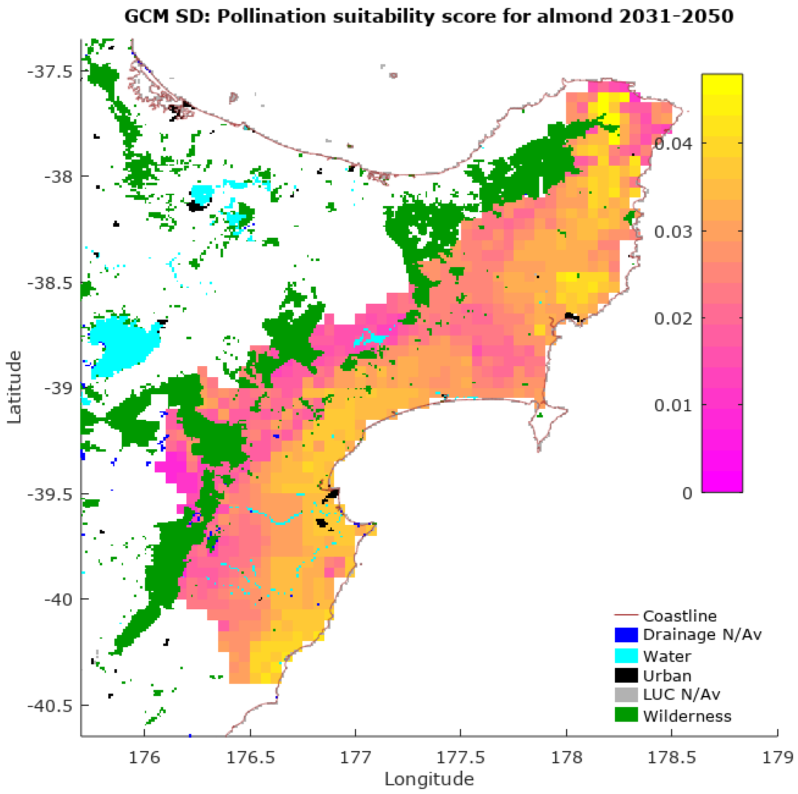
0.02
0.015
0.01
0.005
0
Coastline
Drainage N/Av
Water
Urban
LUC N/Av
Wilderness


GCM SD: Frost suitability score for almond 2031-2050
Latitude
Longitude
-37.5
-38
-38.5
-39
-39.5
-40
-40.5
176
176.5
177
177.5
178
178.5
179
0.15
0.1
0.05
0
Coastline
Drainage N/Av
Water
Urban
LUC N/Av
Wilderness


GCM SD: Pollination suitability score for almond 2031-2050
Latitude
Longitude
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-38
-38.5
-39
-39.5
-40
-40.5
176
176.5
177
177.5
178
178.5
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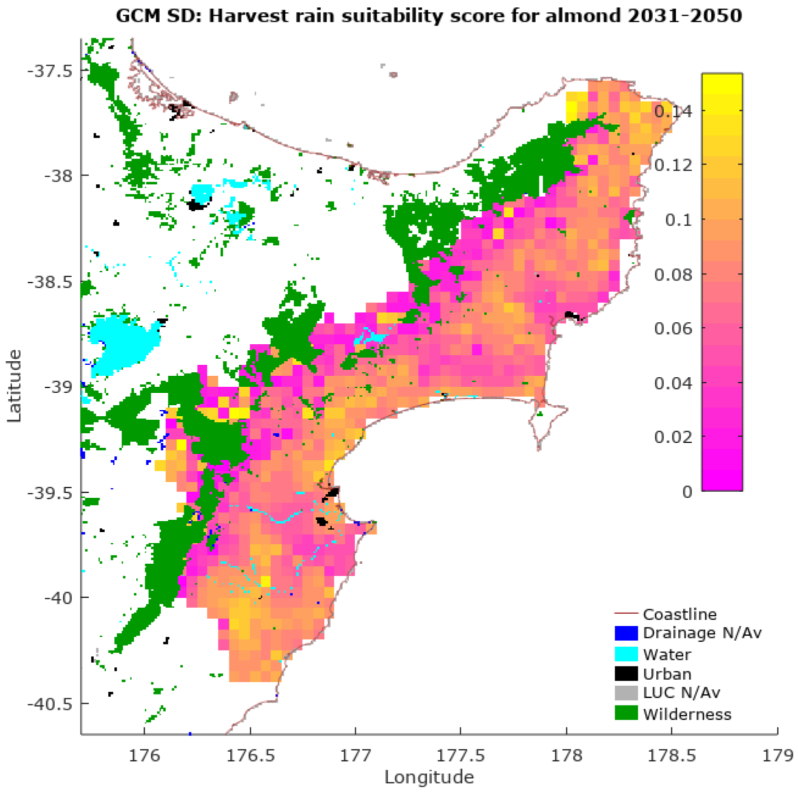
Drainage N/Av
Water
Urban
LUC N/Av
Wilderness


GCM SD: Harvest rain suitability score for almond 2031-2050
Latitude
Longitude
-37.5
-38
-38.5
-39
-39.5
-40
-40.5
176
176.5
177
177.5
178
178.5
179
0.14
0.12
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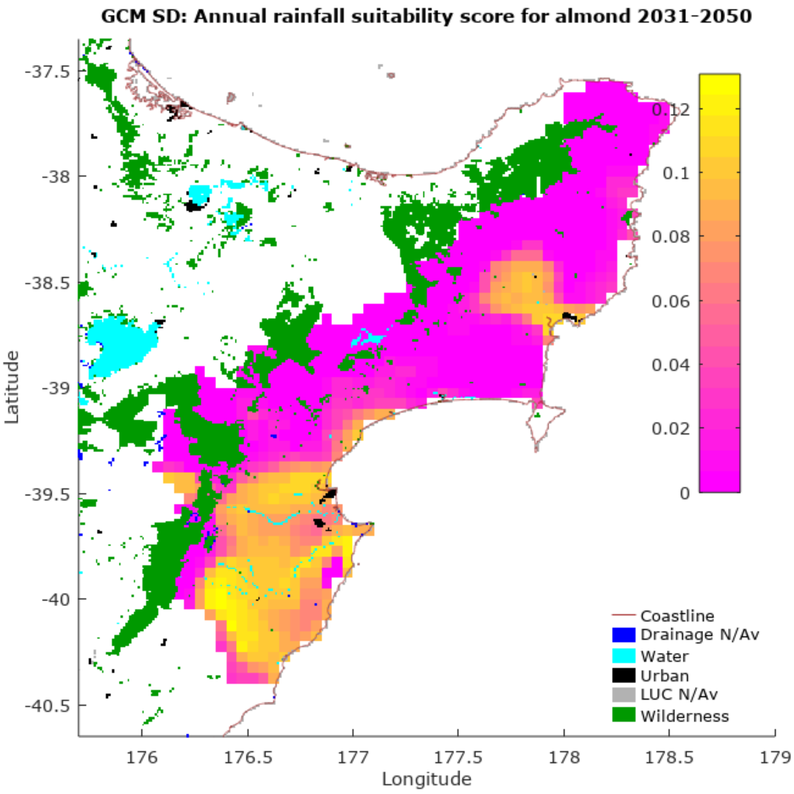
0.04
0.02
0
Coastline
Drainage N/Av
Water
Urban
LUC N/Av
Wilderness


GCM SD: Annual rainfall suitability score for almond 2031-2050
-37.5
-38
-38.5
-39
-39.5
-40
-40.5
Latitude
176
176.5
177
177.5
178
178.5
179
Longitude
0.12
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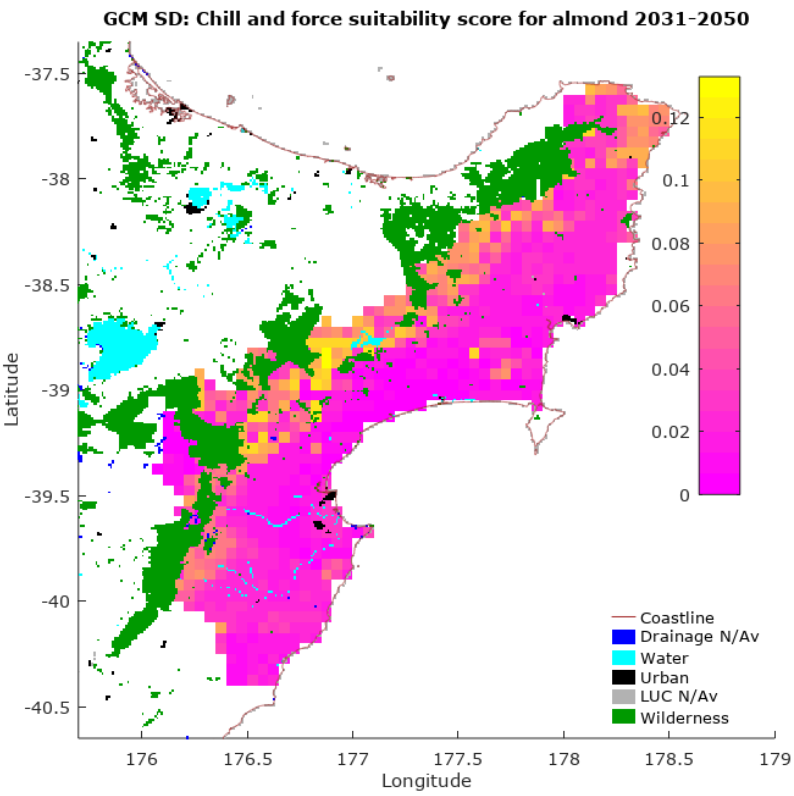
Coastline
Drainage N/Av
Water
Urban
LUC N/Av
Wilderness


GCM SD: Chill and force suitability score for almond 2031-2050
-37.5
-38
-38.5
-39
-39.5
-40
-40.5
Latitude
176
176.5
177
177.5
178
178.5
179
Longitude
0.12
0.1
0.08
0.06
0.04
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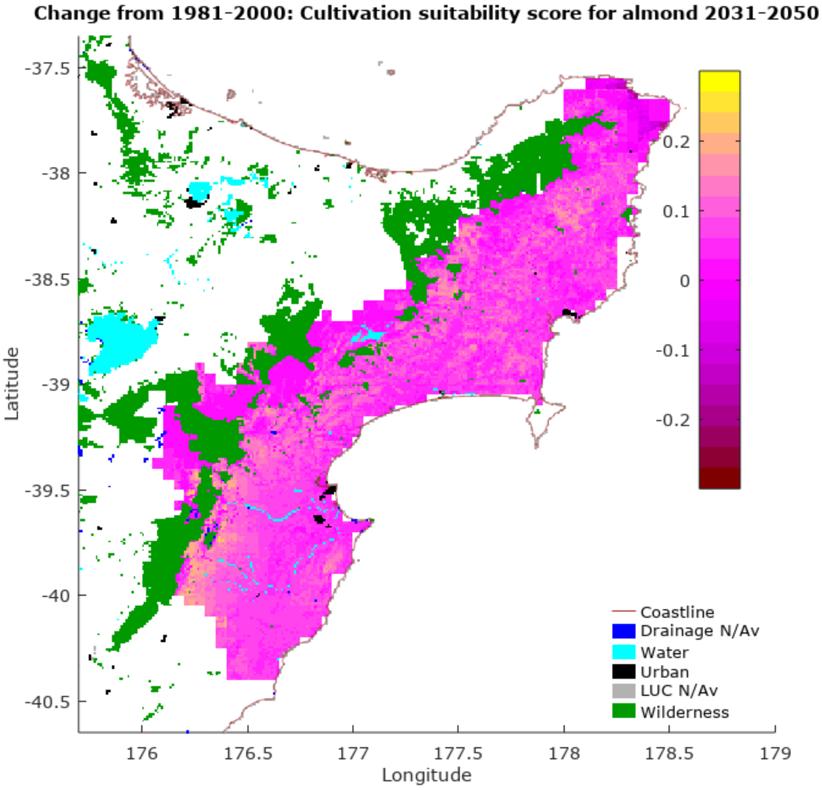
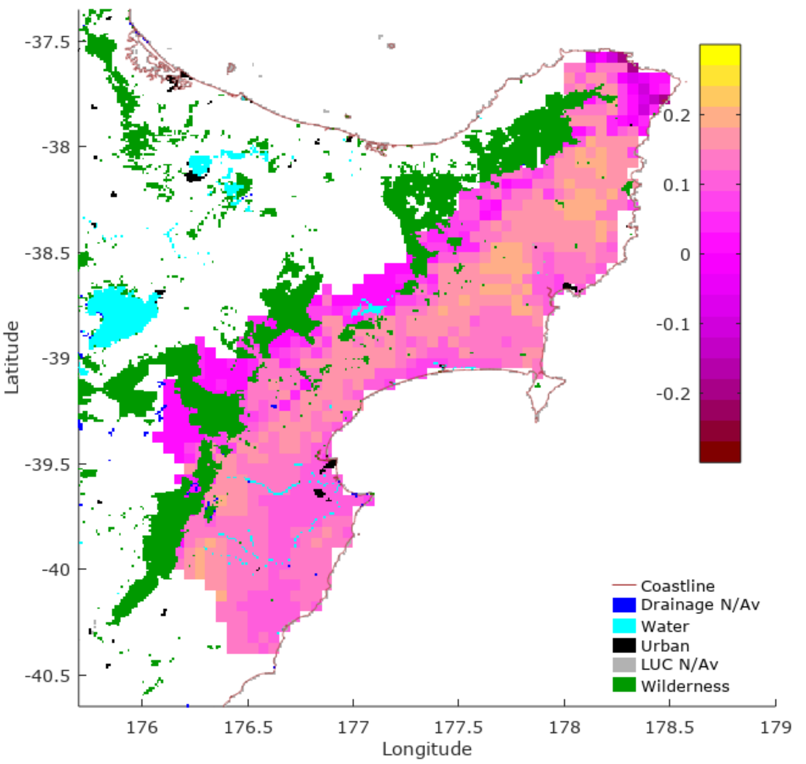
0
Coastline
Drainage N/Av
Water
Urban
LUC N/Av
Wilderness

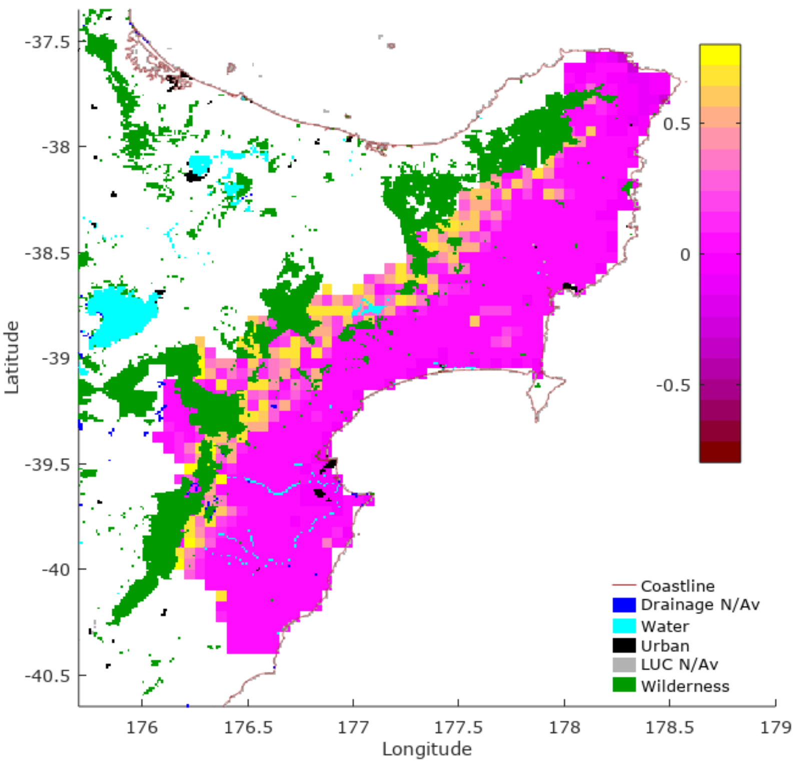
Projected change from 1981–2000 (RCP Past period)

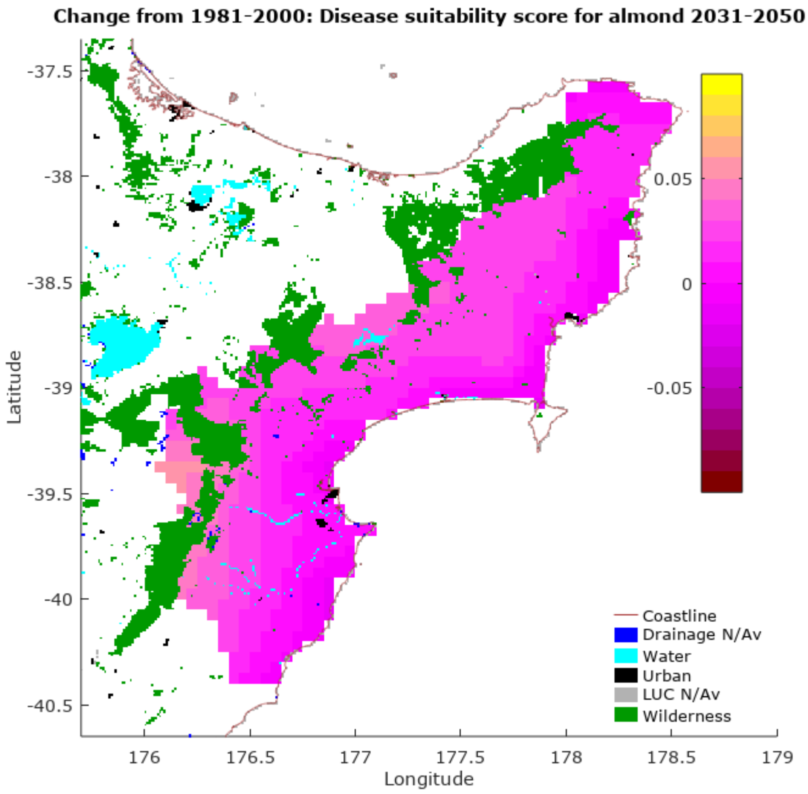


Change from 1981-2000: Climate suitability score for almond 2031-2050

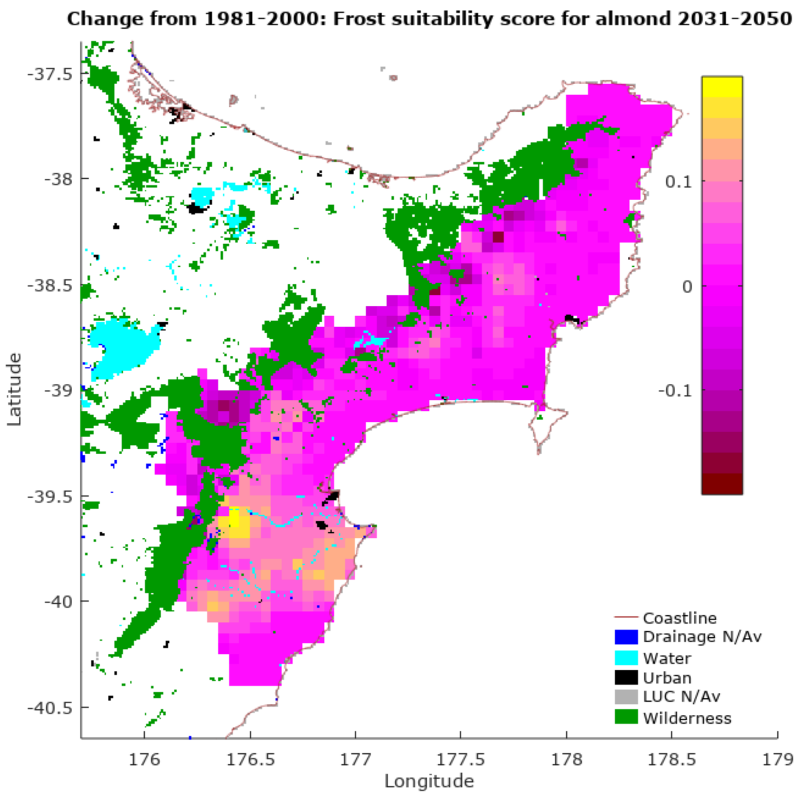


Change from 1981-2000: GDH suitability score for almond 2031-2050





Change from 1981-2000: Disease suitability score for almond 2031-2050
-37.5
-38
-38.5
-39
-39.5
-40
-40.5
Latitude
176
176.5
177
177.5
178
178.5
179
Longitude
0.05
0
-0.05
Coastline
Drainage N/Av
Water
Urban
LUC N/Av
Wilderness



Change from 1981-2000: Frost suitability score for almond 2031-2050
-37.5
-38
-38.5
-39
-39.5
-40
-40.5
Latitude
176
176.5
177
177.5
178
178.5
179
Longitude
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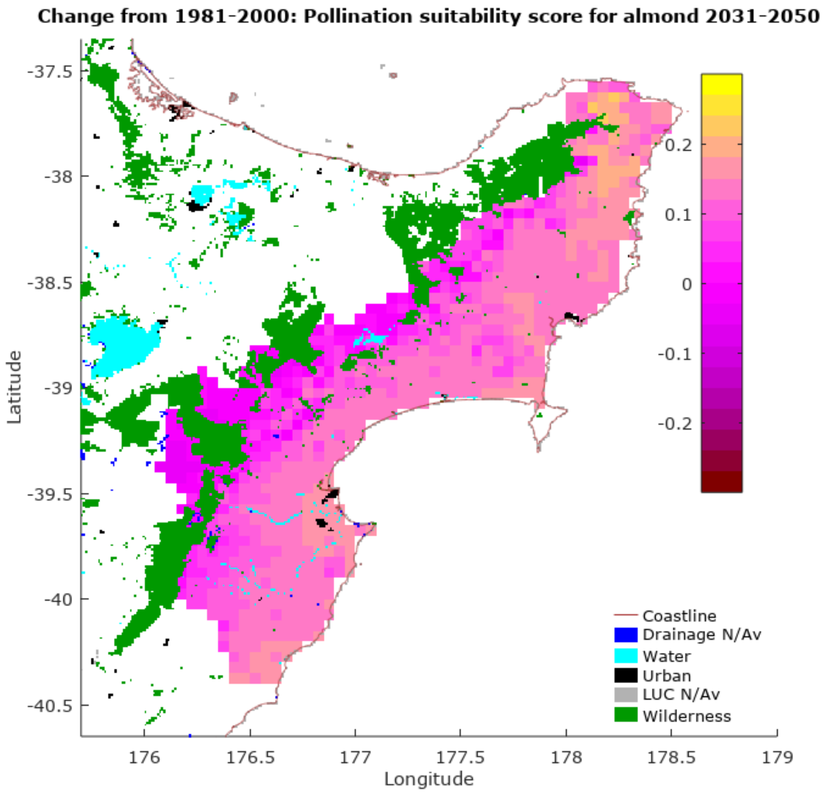
0
-0.1
Coastline
Drainage N/Av
Water
Urban
LUC N/Av
Wilderness


Change from 1981-2000: Pollination suitability score for almond 2031-2050
Latitude
-37.5
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-38.5
-39
-39.5
-40
-40.5
Longitude
176
176.5
177
177.5
178
178.5
179
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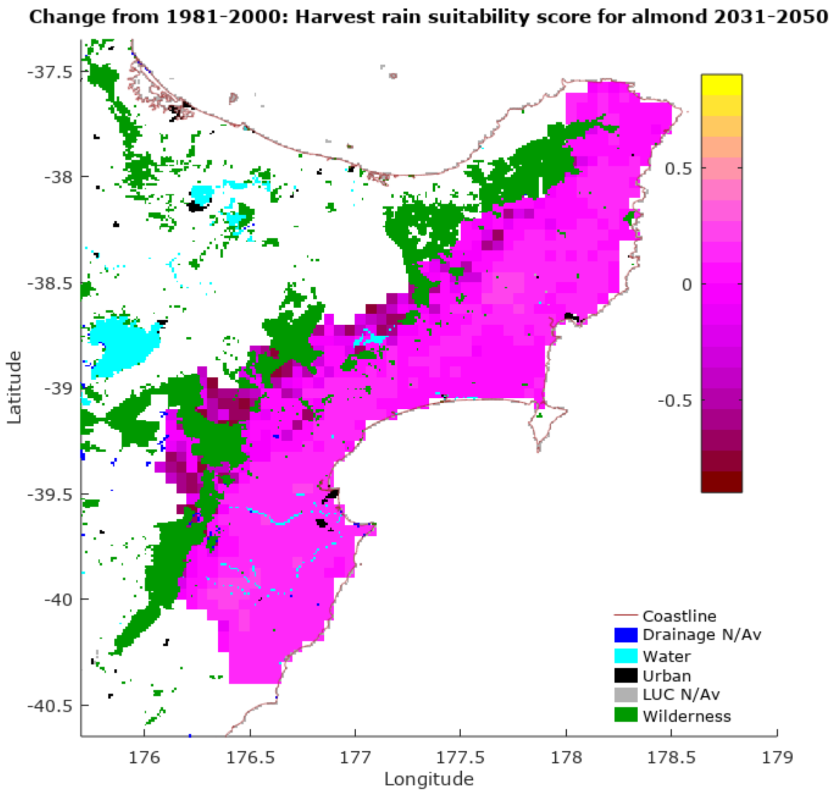
0
-0.1
-0.2
Coastline
Drainage N/Av
Water
Urban
LUC N/Av
Wilderness


Change from 1981-2000: Harvest rain suitability score for almond 2031-2050
Latitude
-37.5
-38
-38.5
-39
-39.5
-40
-40.5
Longitude
176
176.5
177
177.5
178
178.5
179
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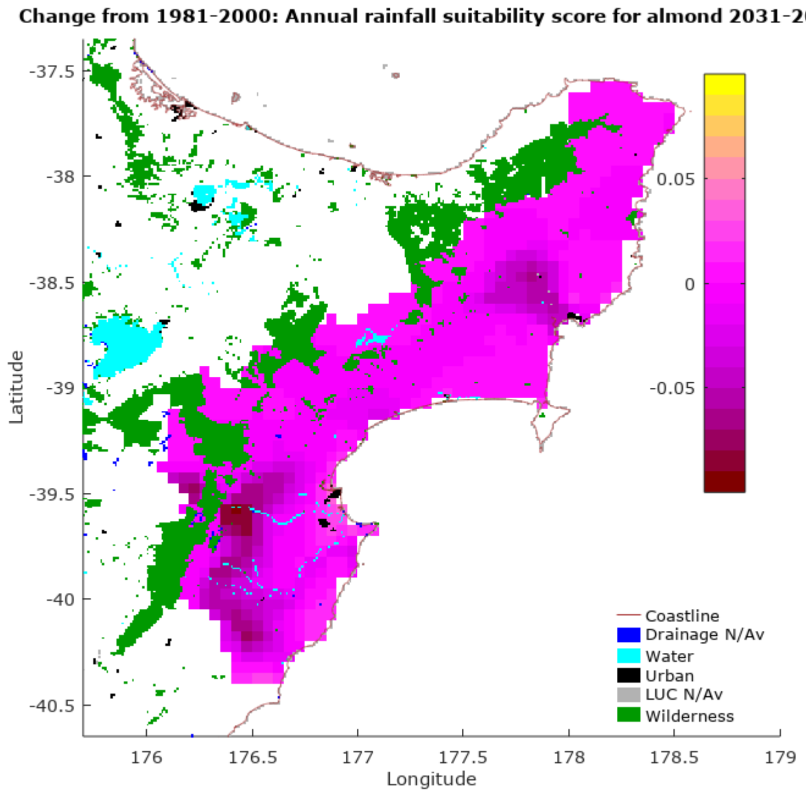
0
-0.5
Coastline
Drainage N/Av
Water
Urban
LUC N/Av
Wilderness


Change from 1981-2000: Annual rainfall suitability score for almond 2031-2050
Latitude
Longitude
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-38
-38.5
-39
-39.5
-40
-40.5
176
176.5
177
177.5
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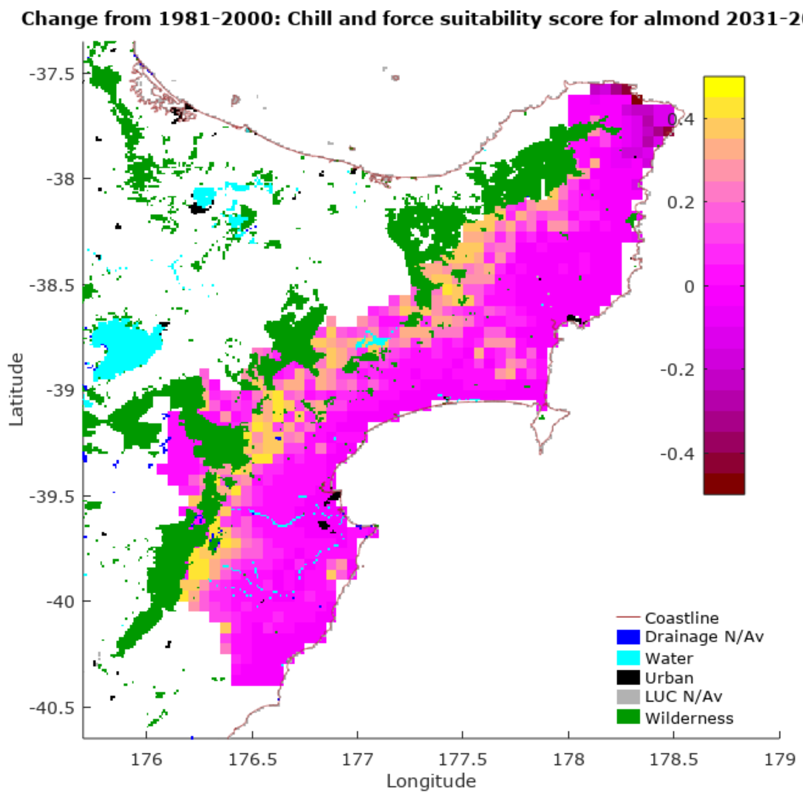
-0.05
Coastline
Drainage N/Av
Water
Urban
LUC N/Av
Wilderness


Change from 1981-2000: Chill and force suitability score for almond 2031-2050
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Longitude
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-38.5
-39
-39.5
-40
-40.5
176
176.5
177
177.5
178
178.5
179
0.4
0.2
0
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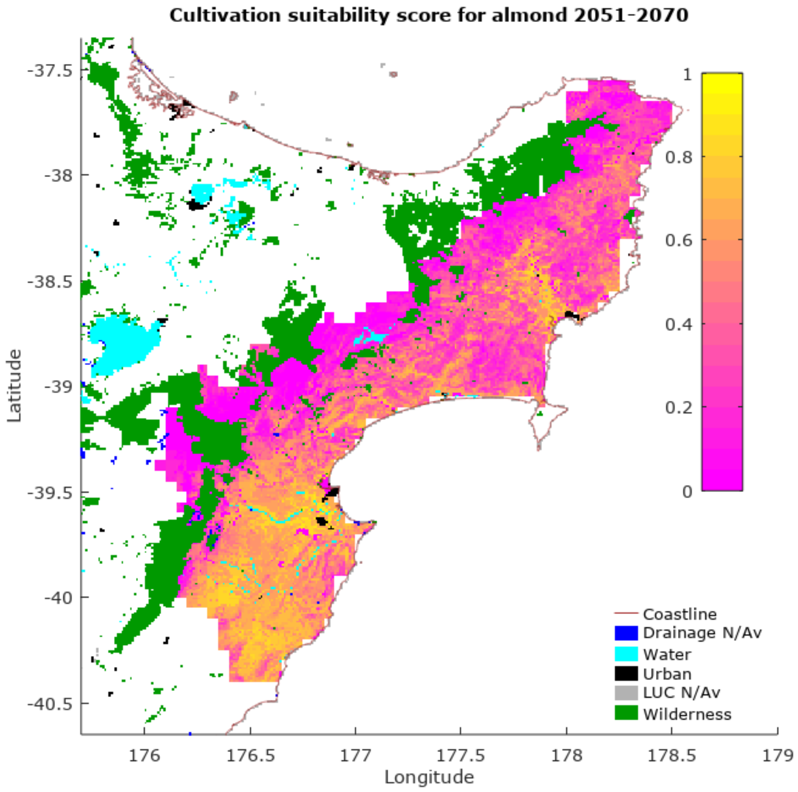
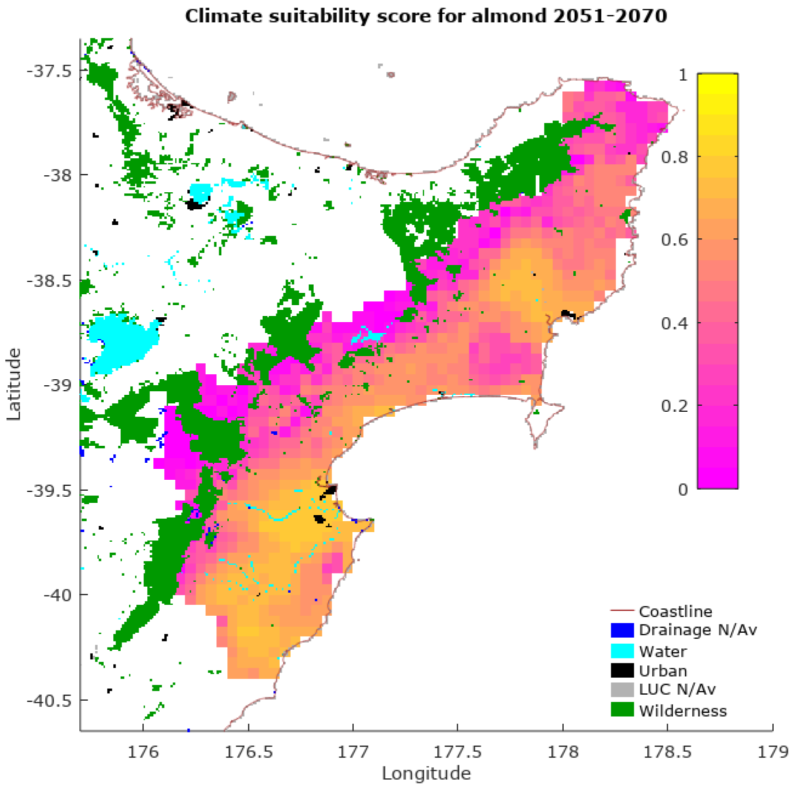
-0.4
Coastline
Drainage N/Av
Water
Urban
LUC N/Av
Wilderness

RCP 8.5 2051 to 2070

Climate suitability projections




Climate suitability score for almond 2051-2070
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Longitude
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-38.5
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-39.5
-40
-40.5
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176.5
177
177.5
178
178.5
179
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0.8
0.6
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0.2
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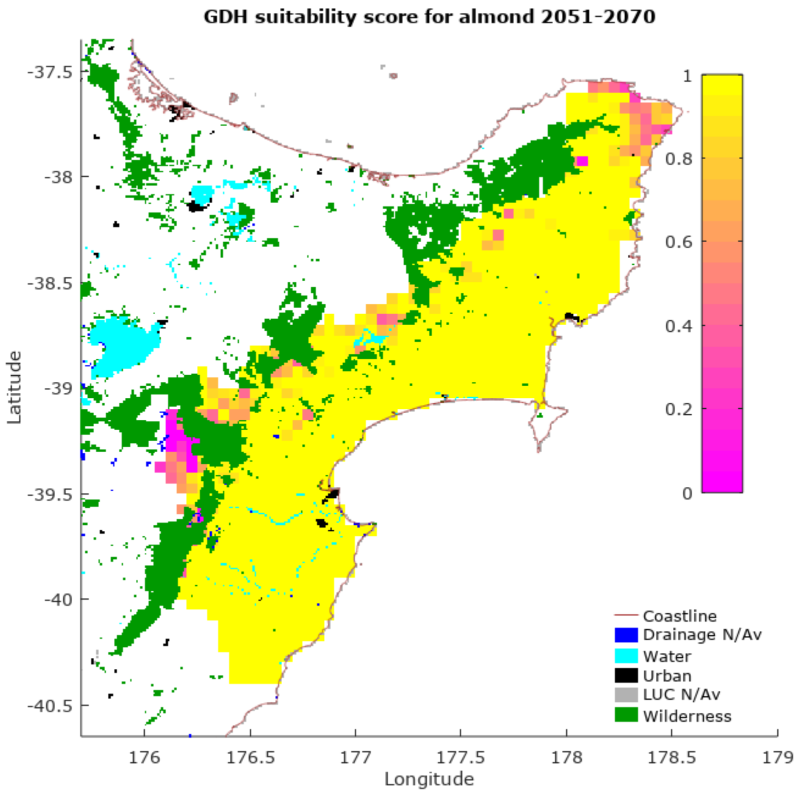
Coastline
Drainage N/Av
Water
Urban
LUC N/Av
Wilderness


GDH suitability score for almond 2051-2070
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Longitude
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-38.5
-39
-39.5
-40
-40.5
176
176.5
177
177.5
178
178.5
179
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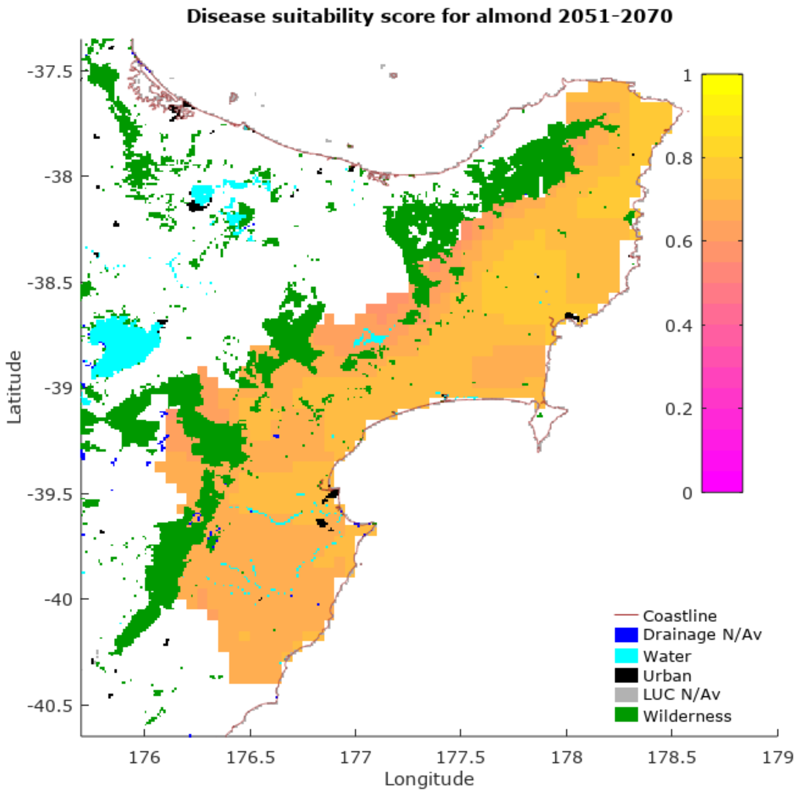
0.8
0.6
0.4
0.2
0
Coastline
Drainage N/Av
Water
Urban
LUC N/Av
Wilderness


Disease suitability score for almond 2051-2070
Latitude
Longitude
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-38.5
-39
-39.5
-40
-40.5
176
176.5
177
177.5
178
178.5
179
1
0.8
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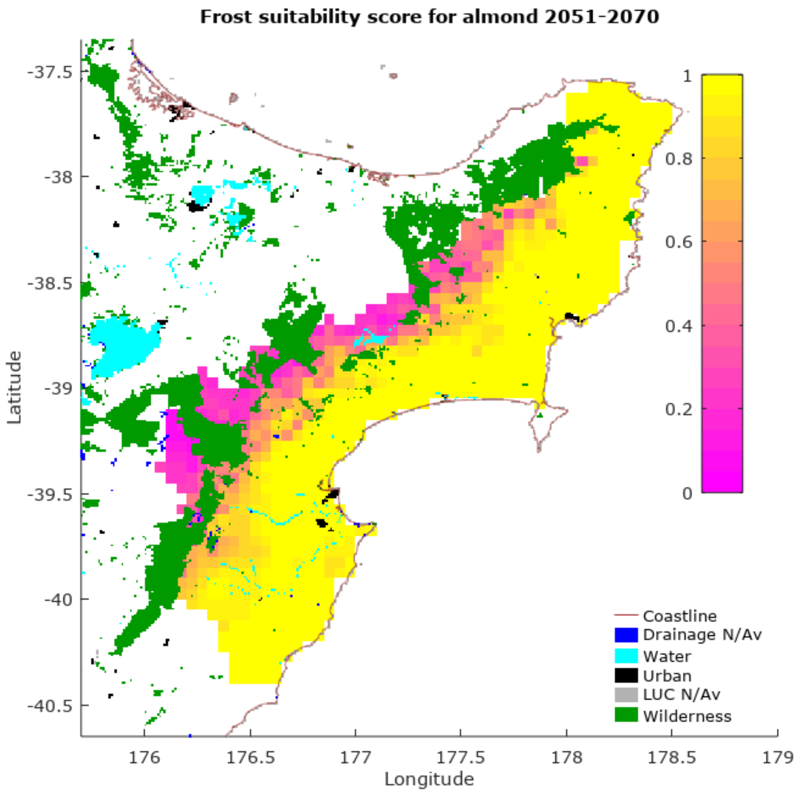
0
Coastline
Drainage N/Av
Water
Urban
LUC N/Av
Wilderness


Frost suitability score for almond 2051-2070
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Longitude
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-39
-39.5
-40
-40.5
176
176.5
177
177.5
178
178.5
179
1
0.8
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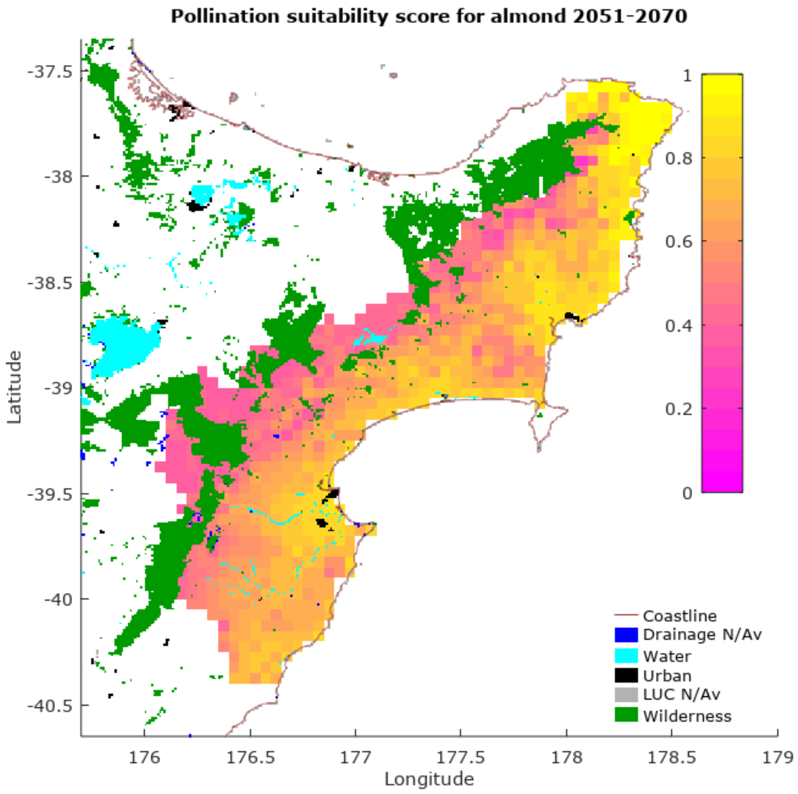
0.2
0
Coastline
Drainage N/Av
Water
Urban
LUC N/Av
Wilderness


Pollination suitability score for almond 2051-2070
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Longitude
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-40
-40.5
176
176.5
177
177.5
178
178.5
179
1
0.8
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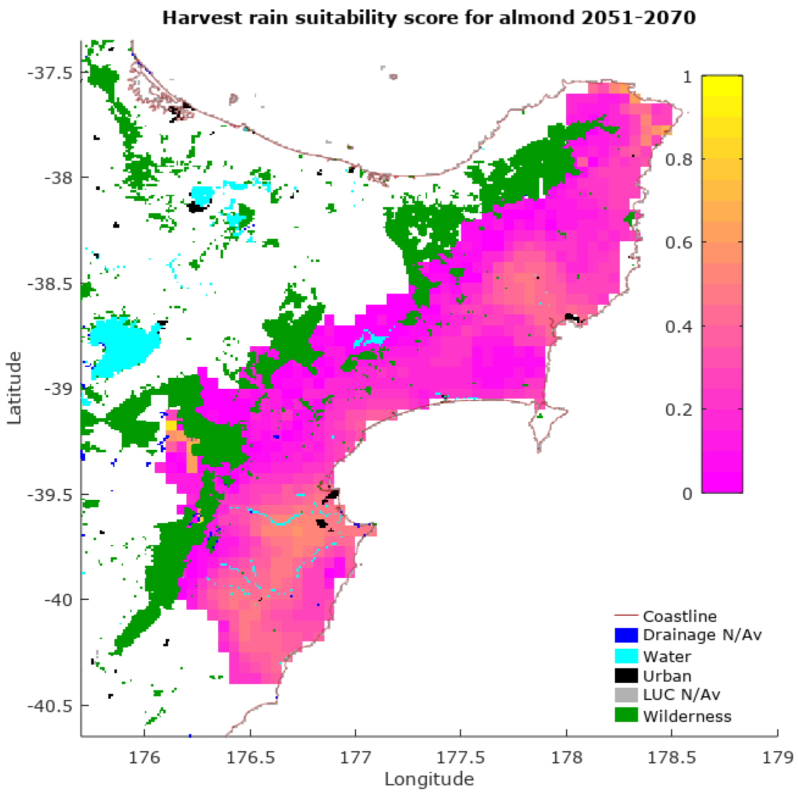
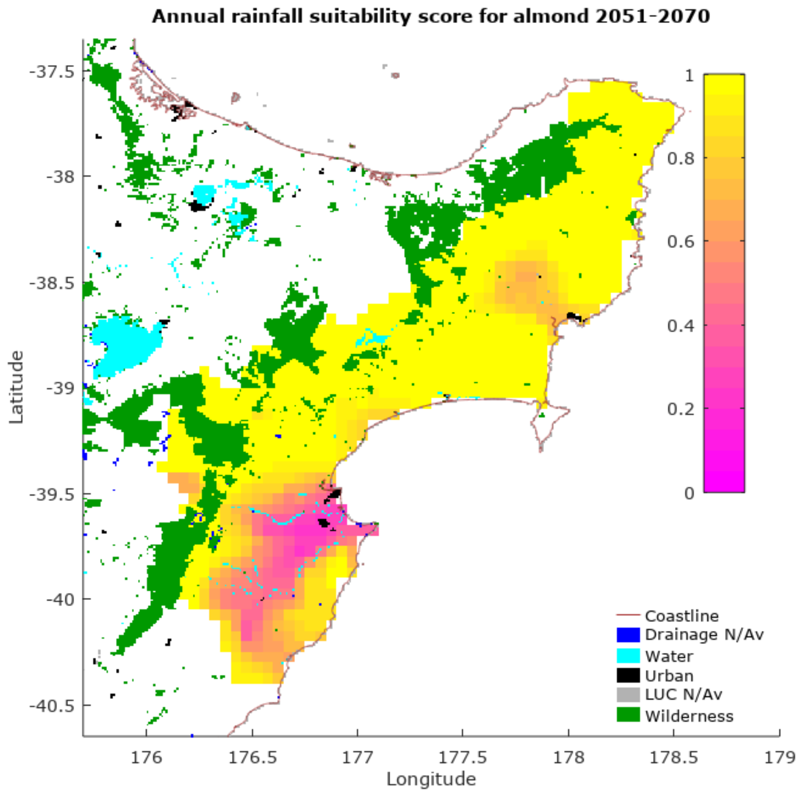
0.4
0.2
0
Coastline
Drainage N/Av
Water
Urban
LUC N/Av
Wilderness


Harvest rain suitability score for almond 2051-2070
Latitude
Longitude
-37.5
-38
-38.5
-39
-39.5
-40
-40.5
176
176.5
177
177.5
178
178.5
179
1
0.8
0.6
0.4
0.2
0
Coastline
Drainage N/Av
Water
Urban
LUC N/Av
Wilderness


Annual rainfall suitability score for almond 2051-2070
Latitude
Longitude
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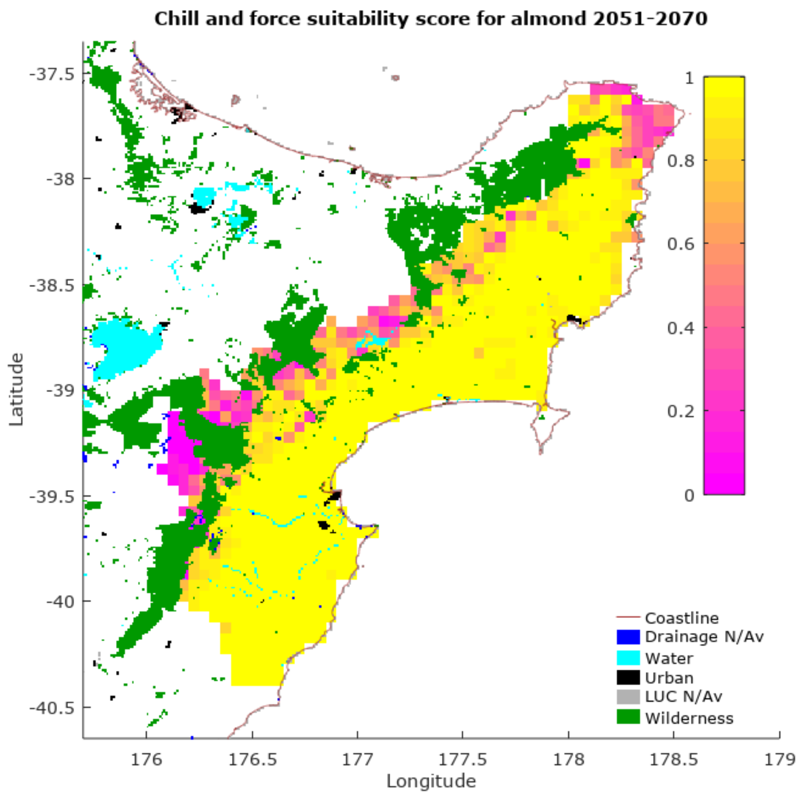
-38
-38.5
-39
-39.5
-40
-40.5
176
176.5
177
177.5
178
178.5
179
1
0.8
0.6
0.4
0.2
0
Coastline
Drainage N/Av
Water
Urban
LUC N/Av
Wilderness


Chill and force suitability score for almond 2051-2070
Latitude
Longitude
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-38
-38.5
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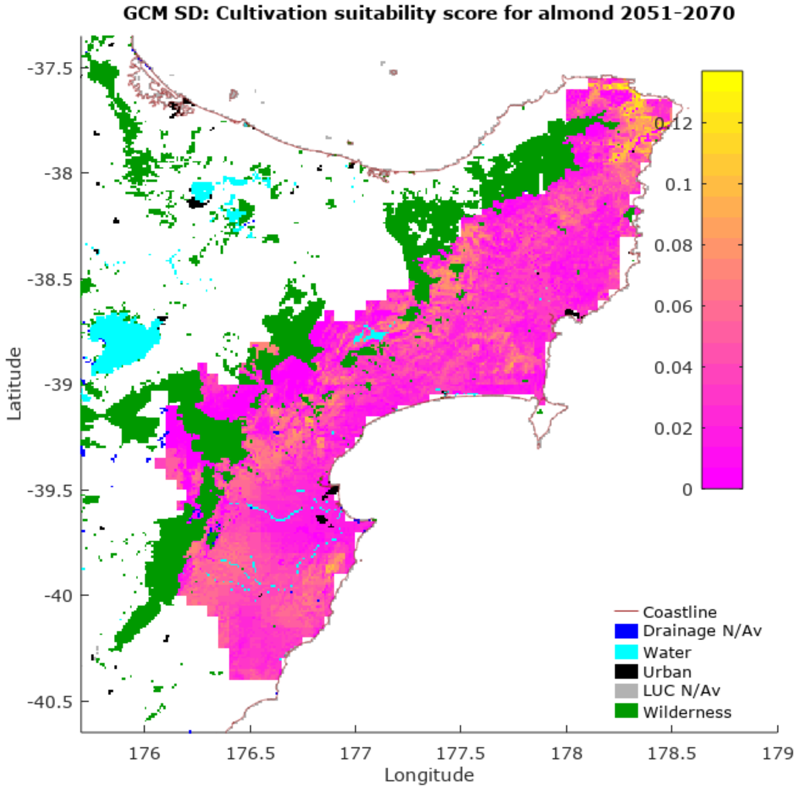
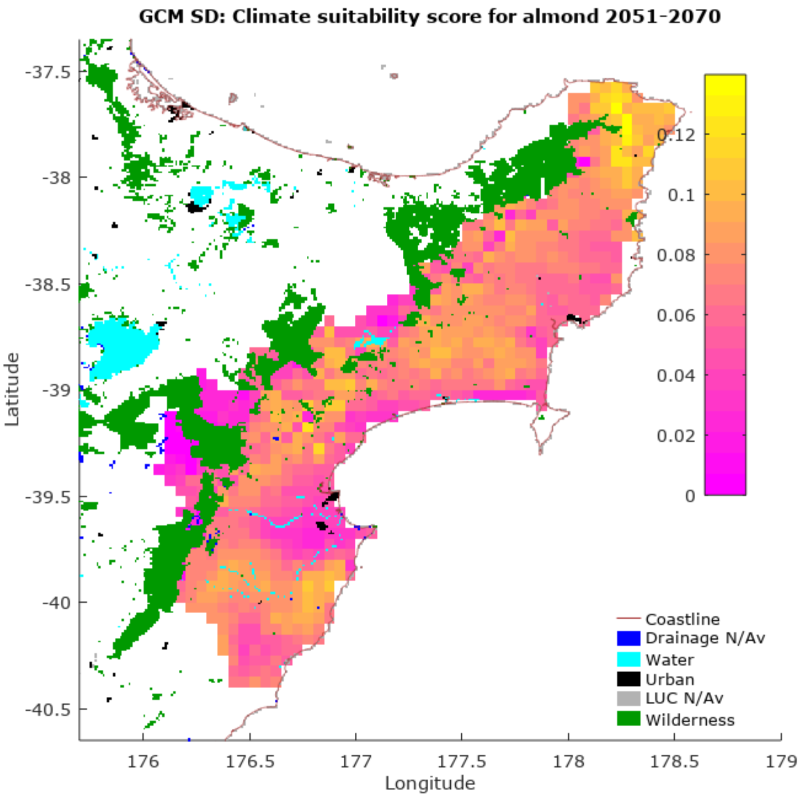
-39.5
-40
-40.5
176
176.5
177
177.5
178
178.5
179
1
0.8
0.6
0.4
0.2
0
Coastline
Drainage N/Av
Water
Urban
LUC N/Av
Wilderness

Standard deviation (SD) of projections




GCM SD: Climate suitability score for almond 2051-2070
Latitude
Longitude
-37.5
-38
-38.5
-39
-39.5
-40
-40.5
176
176.5
177
177.5
178
178.5
179
0.12
0.1
0.08
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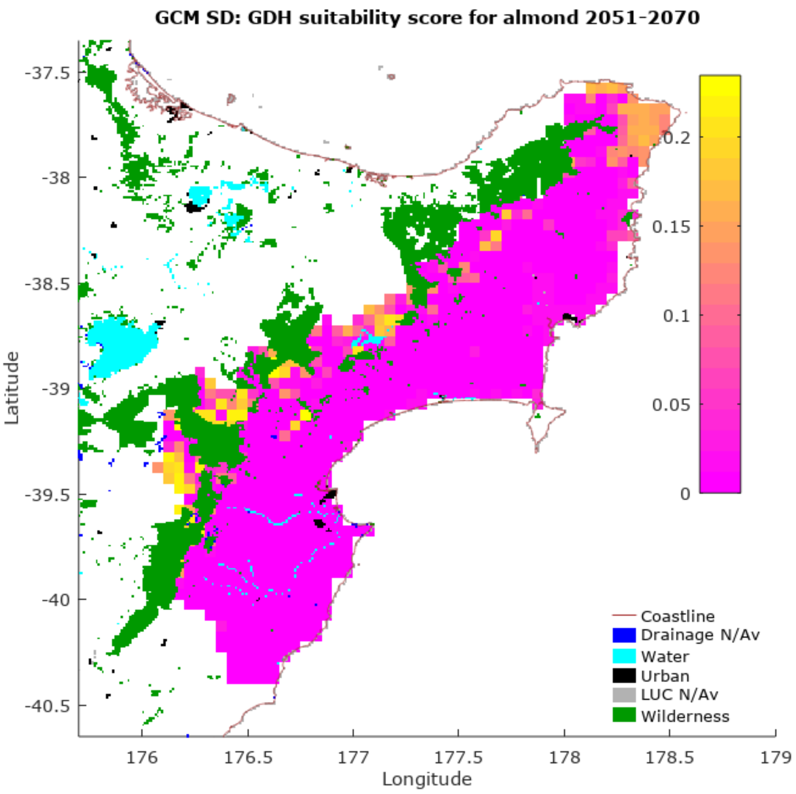
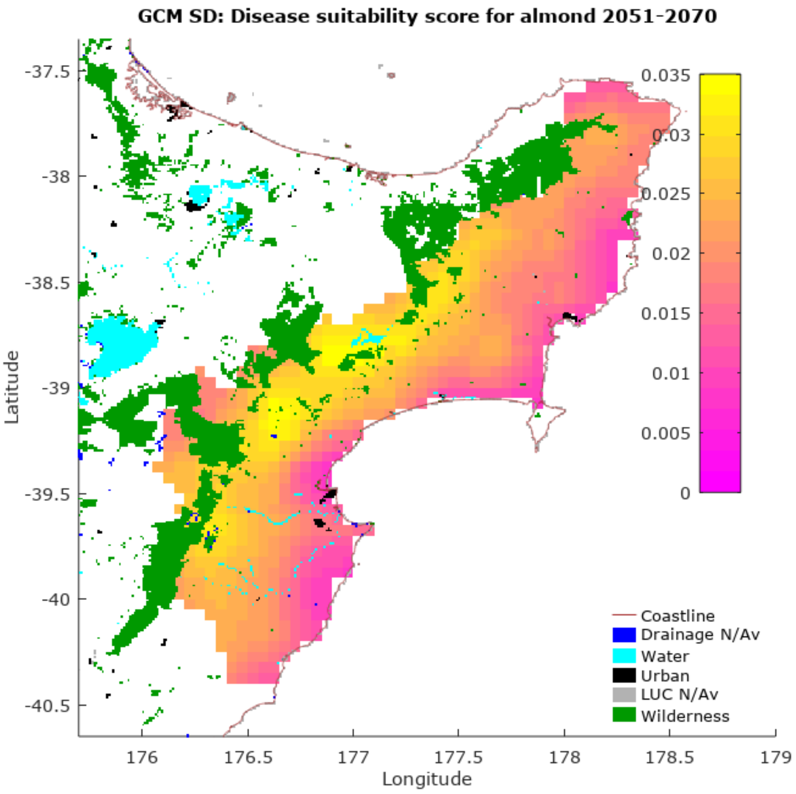
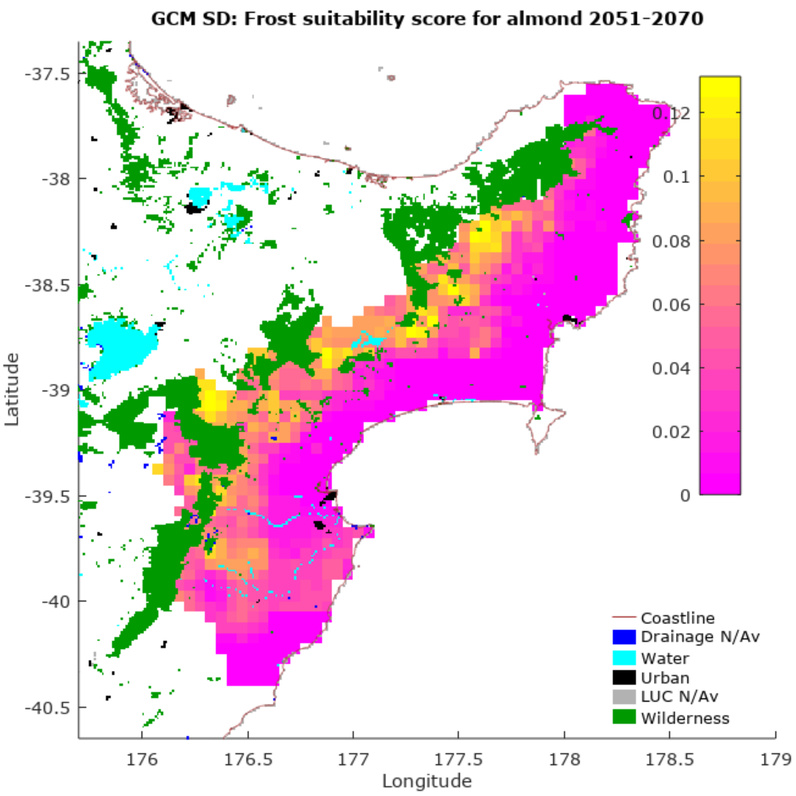
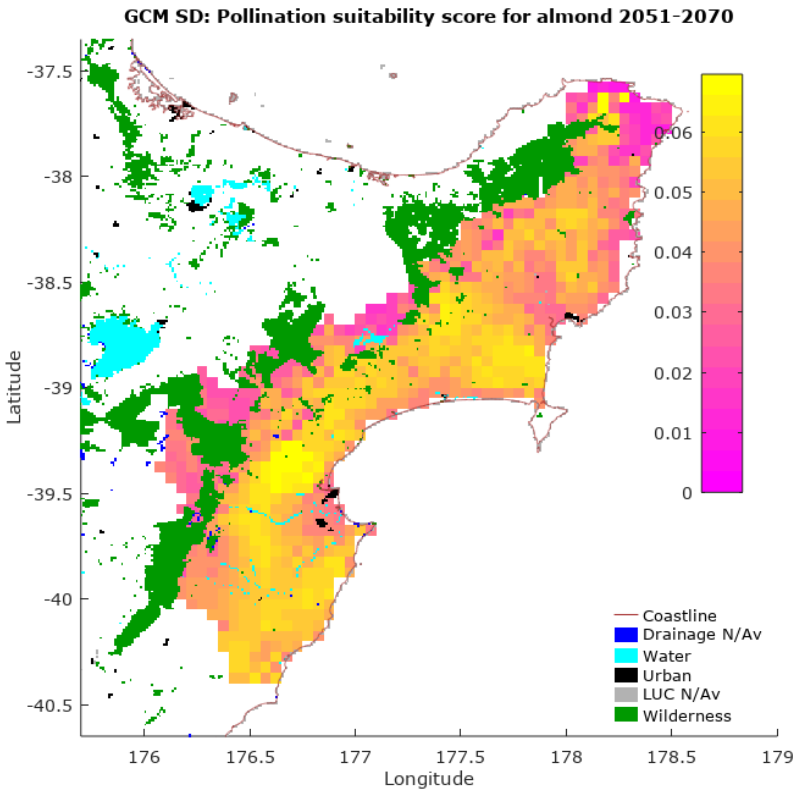
0.04
0.02
0
Coastline
Drainage N/Av
Water
Urban
LUC N/Av
Wilderness


GCM SD: GDH suitability score for almond 2051-2070
Latitude
Longitude
-37.5
-38
-38.5
-39
-39.5
-40
-40.5
176
176.5
177
177.5
178
178.5
179
0.2
0.15
0.1
0.05
0
Coastline
Drainage N/Av
Water
Urban
LUC N/Av
Wilderness


GCM SD: Disease suitability score for almond 2051-2070
Latitude
Longitude
-37.5
-38
-38.5
-39
-39.5
-40
-40.5
176
176.5
177
177.5
178
178.5
179
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
Coastline
Drainage N/Av
Water
Urban
LUC N/Av
Wilderness


GCM SD: Frost suitability score for almond 2051-2070
Latitude
Longitude
-37.5
-38
-38.5
-39
-39.5
-40
-40.5
176
176.5
177
177.5
178
178.5
179
0.12
0.1
0.08
0.06
0.04
0.02
0
Coastline
Drainage N/Av
Water
Urban
LUC N/Av
Wilderness


GCM SD: Pollination suitability score for almond 2051-2070
Latitude
-37.5
-38
-38.5
-39
-39.5
-40
-40.5
Longitude
176
176.5
177
177.5
178
178.5
179
0.06
0.05
0.04
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0.02
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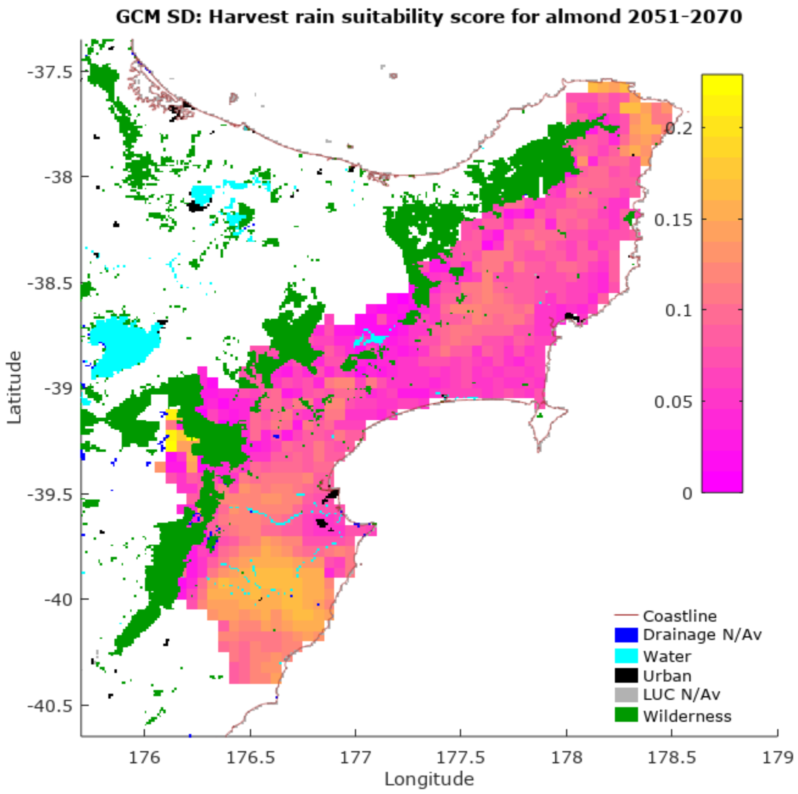
Coastline
Drainage N/Av
Water
Urban
LUC N/Av
Wilderness


GCM SD: Harvest rain suitability score for almond 2051-2070
Latitude
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-38.5
-39
-39.5
-40
-40.5
Longitude
176
176.5
177
177.5
178
178.5
179
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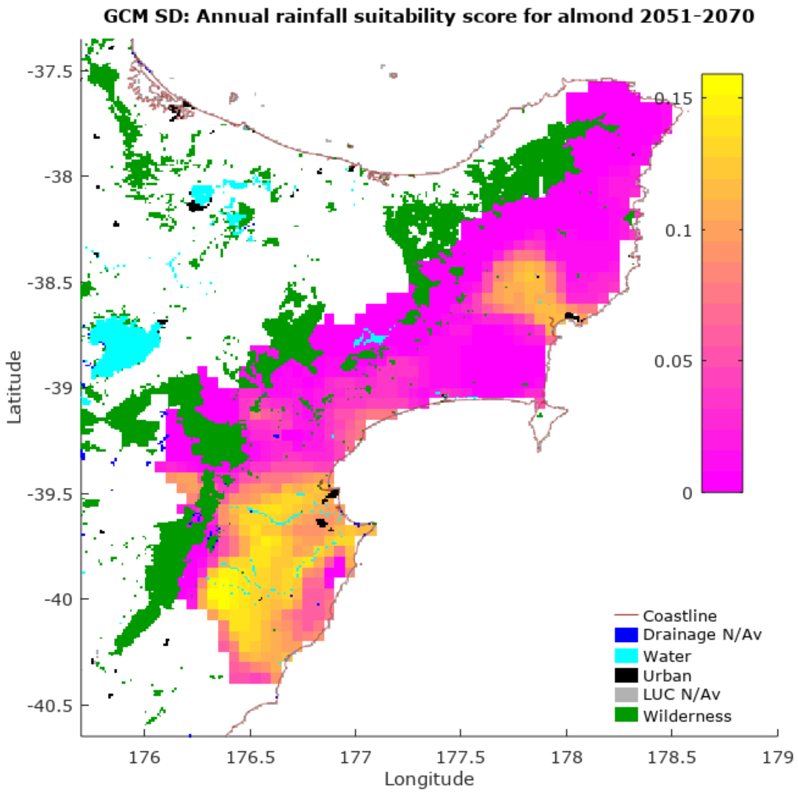
0.1
0.05
0
Coastline
Drainage N/Av
Water
Urban
LUC N/Av
Wilderness


GCM SD: Annual rainfall suitability score for almond 2051-2070
Latitude
Longitude
-37.5
-38
-38.5
-39
-39.5
-40
-40.5
176
176.5
177
177.5
178
178.5
179
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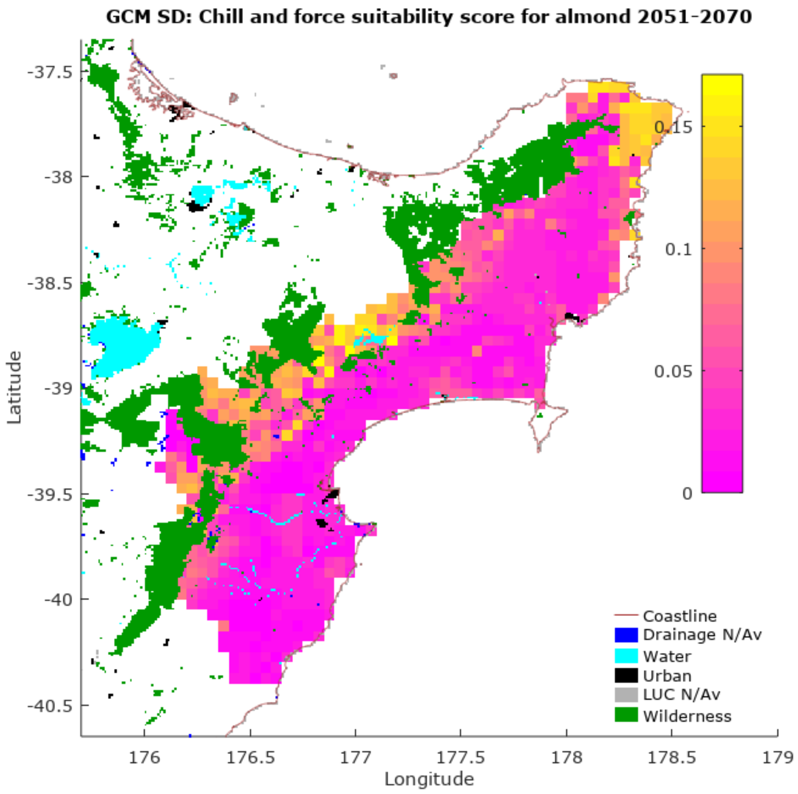
0.1
0.05
0
Coastline
Drainage N/Av
Water
Urban
LUC N/Av
Wilderness


GCM SD: Chill and force suitability score for almond 2051-2070
Latitude
Longitude
-37.5
-38
-38.5
-39
-39.5
-40
-40.5
176
176.5
177
177.5
178
178.5
179
0.15
0.1
0.05
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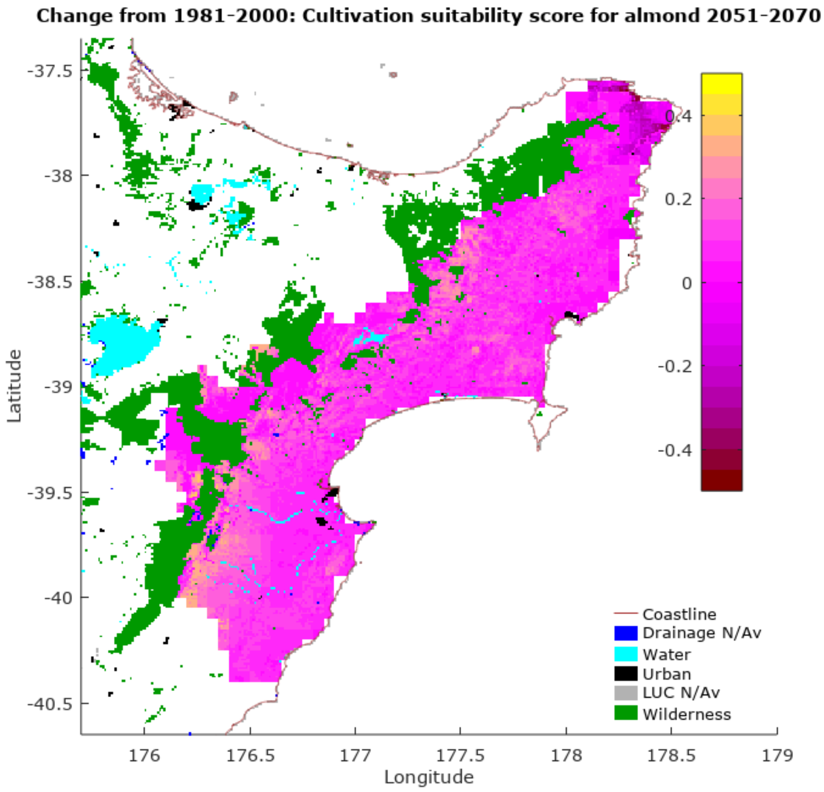
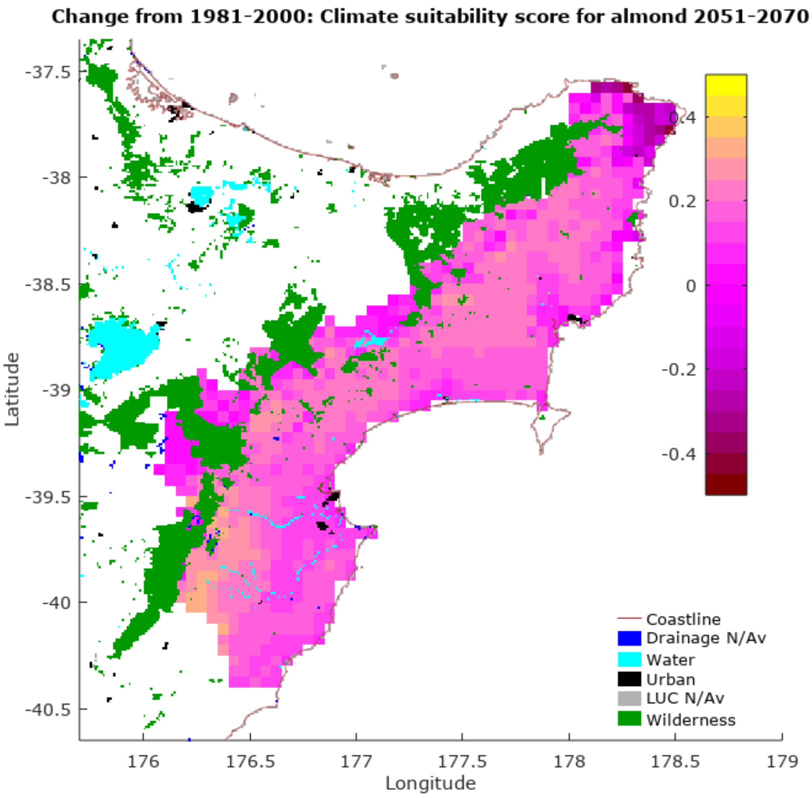
Coastline
Drainage N/Av
Water
Urban
LUC N/Av
Wilderness

Projected change from 1981–2000 (RCP Past period)




Change from 1981-2000: Climate suitability score for almond 2051-2070
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-38
-38.5
-39
-39.5
-40
-40.5
Latitude
176
176.5
177
177.5
178
178.5
179
Longitude
0.4
0.2
0
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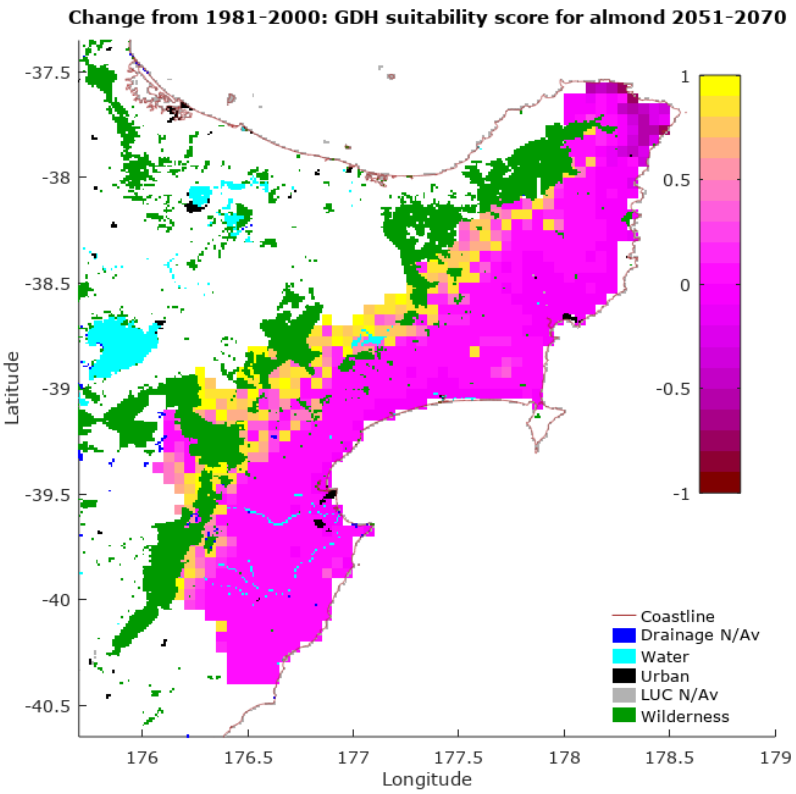
-0.4
Coastline
Drainage N/Av
Water
Urban
LUC N/Av
Wilderness


Change from 1981-2000: GDH suitability score for almond 2051-2070
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-38.5
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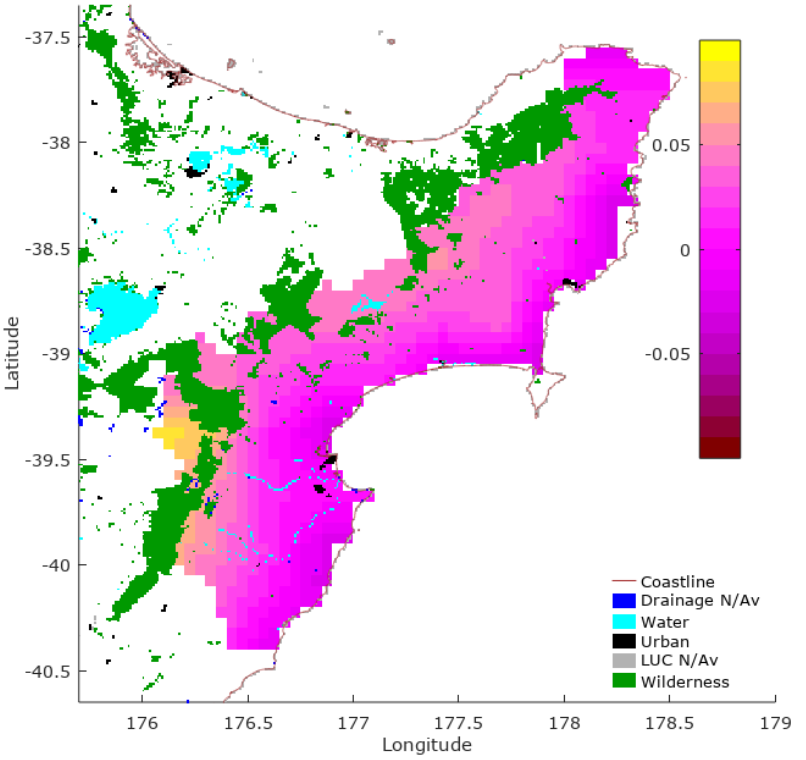
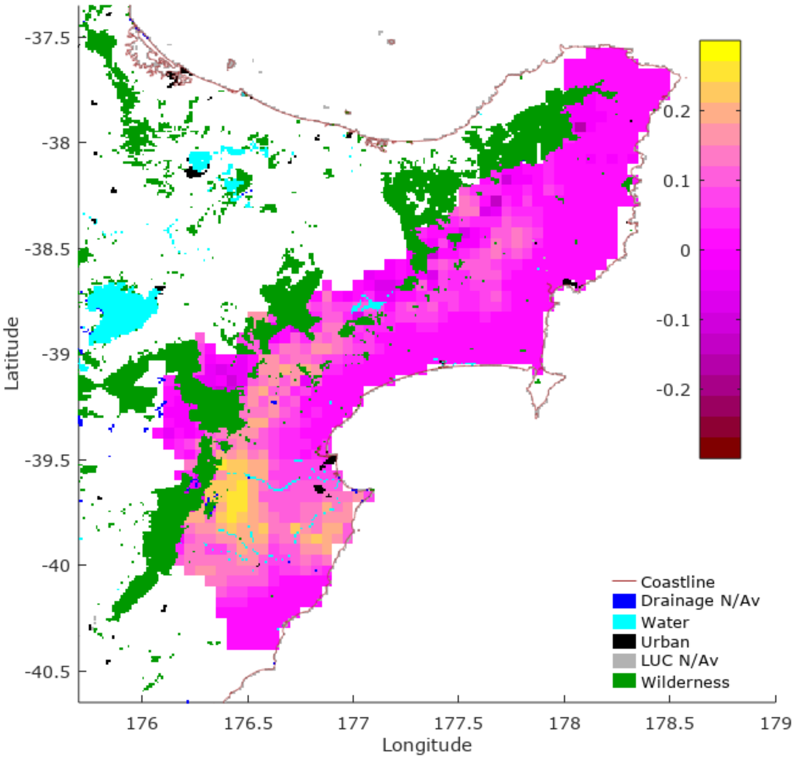
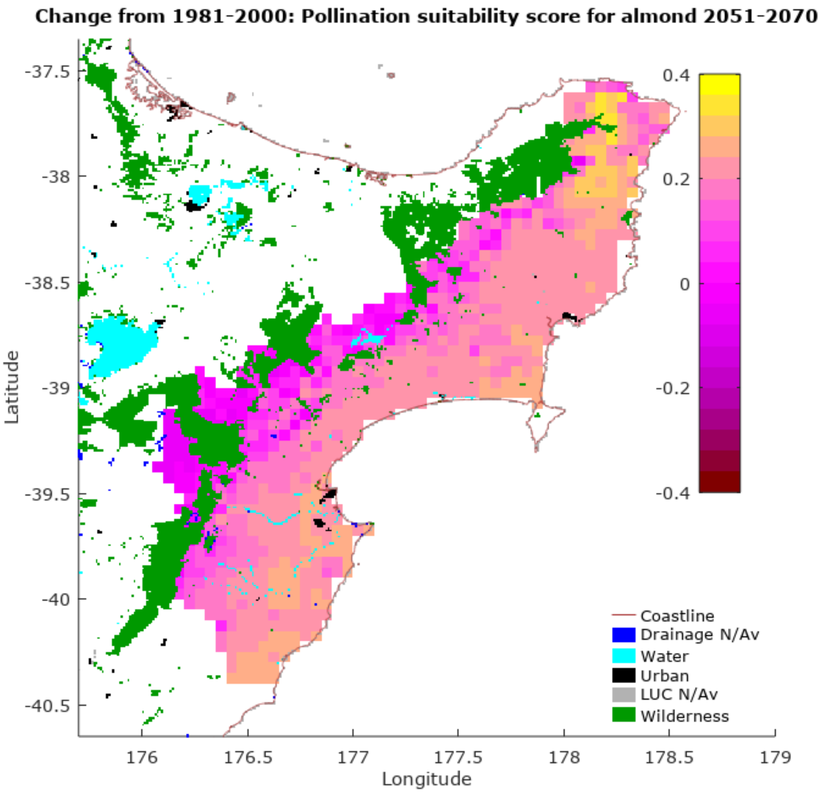
-40
-40.5
Latitude
176
176.5
177
177.5
178
178.5
179
Longitude
1
0.5
0
-0.5
-1
Coastline
Drainage N/Av
Water
Urban
LUC N/Av
Wilderness

Change from 1981-2000: Disease suitability score for almond 2051-2070



Change from 1981-2000: Frost suitability score for almond 2051-2070




Change from 1981-2000: Pollination suitability score for almond 2051-2070
Latitude
Longitude
-37.5
-38
-38.5
-39
-39.5
-40
-40.5
176
176.5
177
177.5
178
178.5
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0
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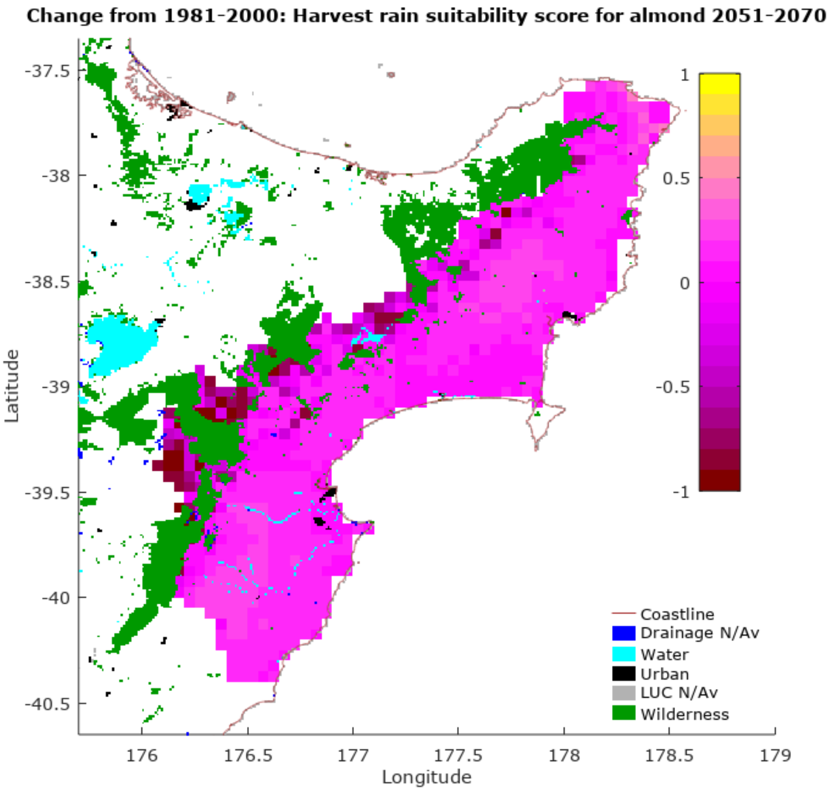
-0.4
Coastline
Drainage N/Av
Water
Urban
LUC N/Av
Wilderness


Change from 1981-2000: Harvest rain suitability score for almond 2051-2070
Latitude
Longitude
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-38
-38.5
-39
-39.5
-40
-40.5
176
176.5
177
177.5
178
178.5
179
1
0.5
0
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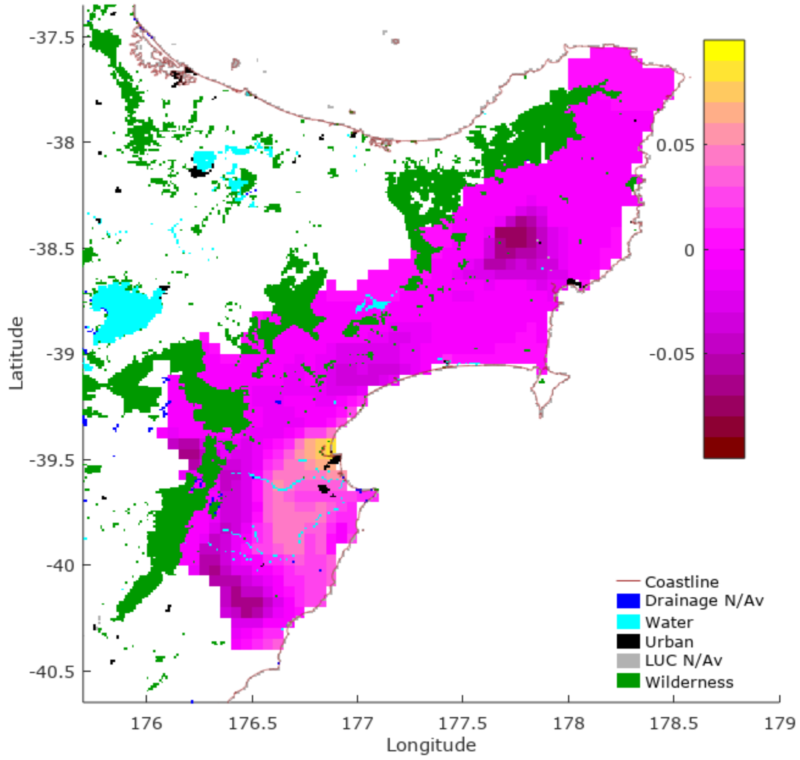
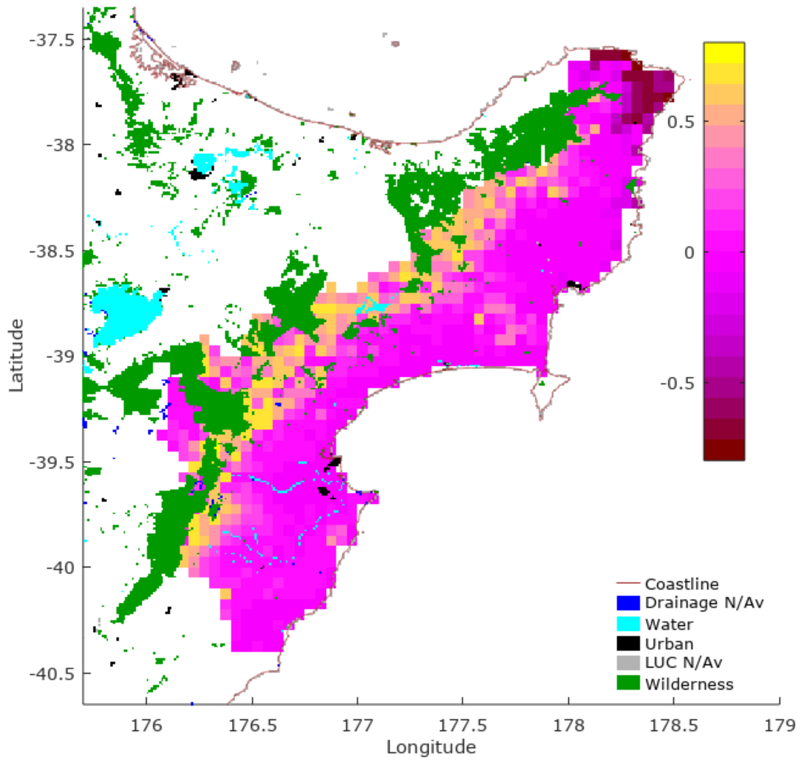
-1
Coastline
Drainage N/Av
Water
Urban
LUC N/Av
Wilderness

Change from 1981-2000: Annual rainfall suitability score for almond 2051-2070

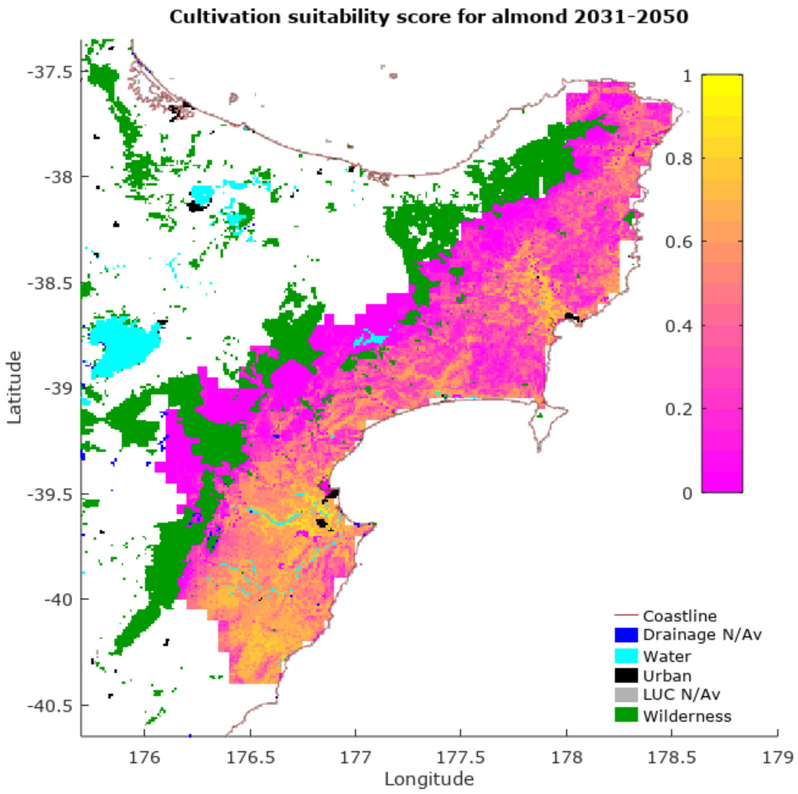


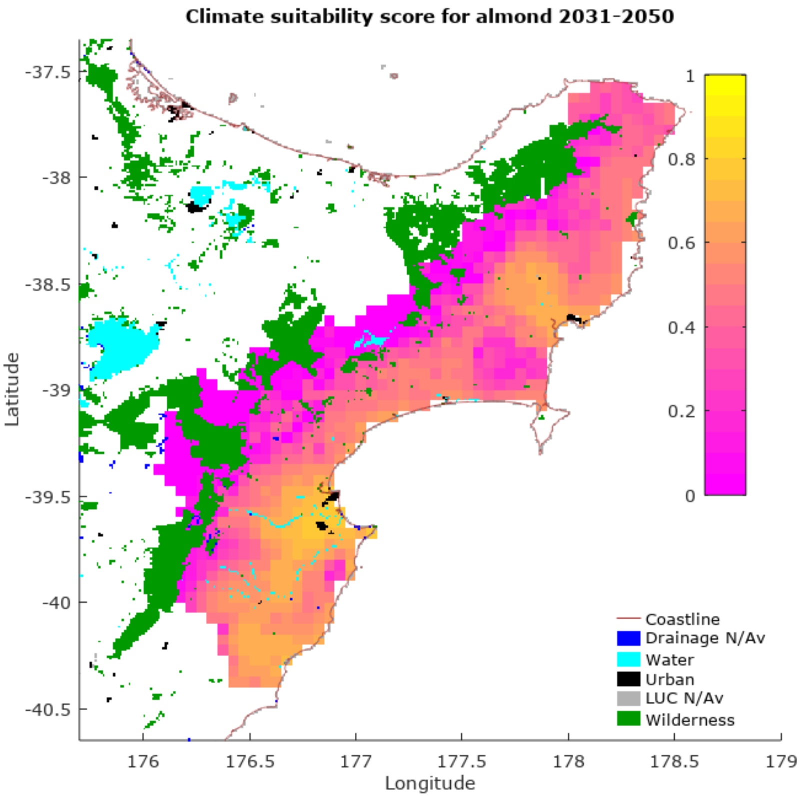
Change from 1981-2000: Chill and force suitability score for almond 2051-2070



RCP 6.0 2031 to 2050

Climate suitability projections




Climate suitability score for almond 2031-2050
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-38
-38.5
-39
-39.5
-40
-40.5
Latitude
176
176.5
177
177.5
178
178.5
179
Longitude
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0.4
0.2
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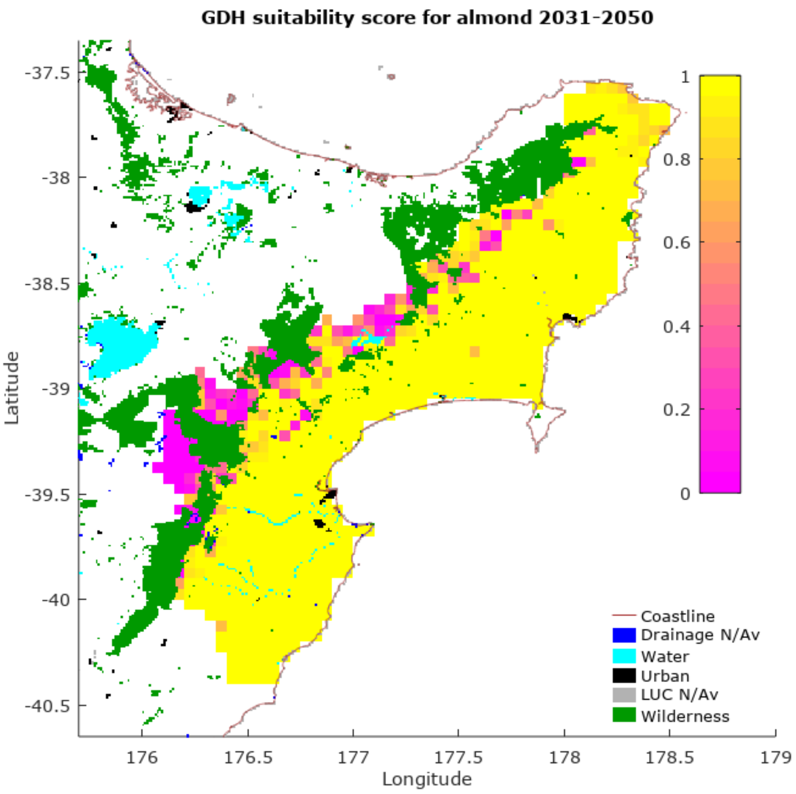
Coastline
Drainage N/Av
Water
Urban
LUC N/Av
Wilderness


GDH suitability score for almond 2031-2050
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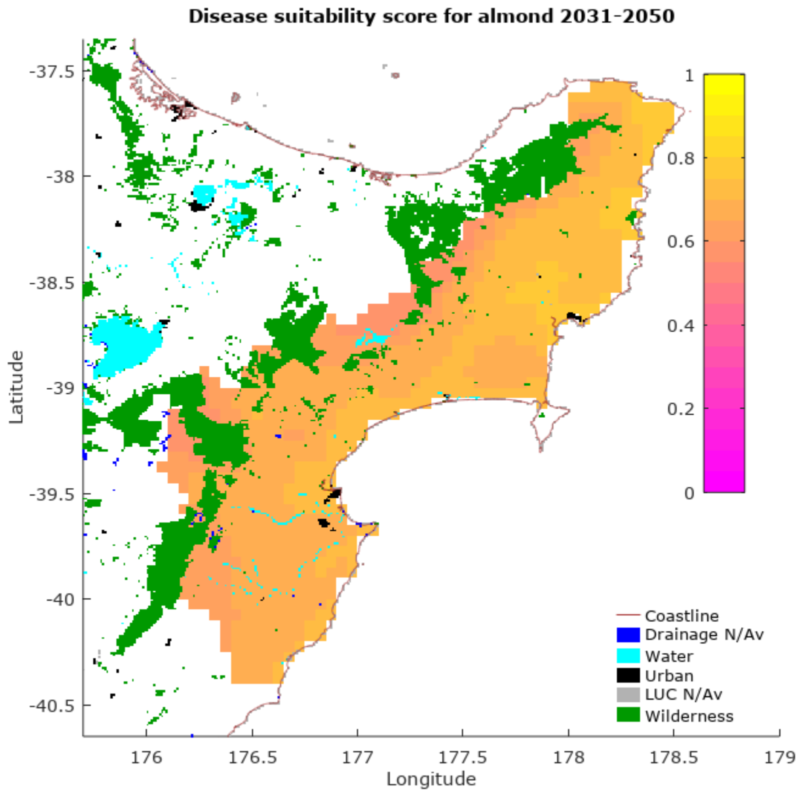
-38
-38.5
-39
-39.5
-40
-40.5
Latitude
176
176.5
177
177.5
178
178.5
179
Longitude
1
0.8
0.6
0.4
0.2
0
Coastline
Drainage N/Av
Water
Urban
LUC N/Av
Wilderness


Disease suitability score for almond 2031-2050
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Longitude
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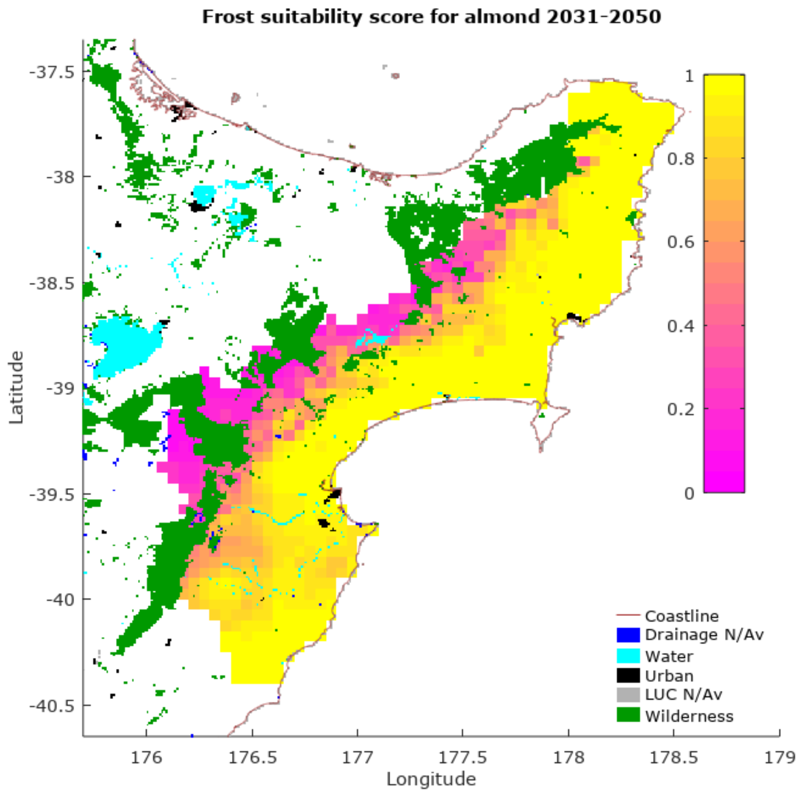
-38.5
-39
-39.5
-40
-40.5
176
176.5
177
177.5
178
178.5
179
1
0.8
0.6
0.4
0.2
0
Coastline
Drainage N/Av
Water
Urban
LUC N/Av
Wilderness


Frost suitability score for almond 2031-2050
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Longitude
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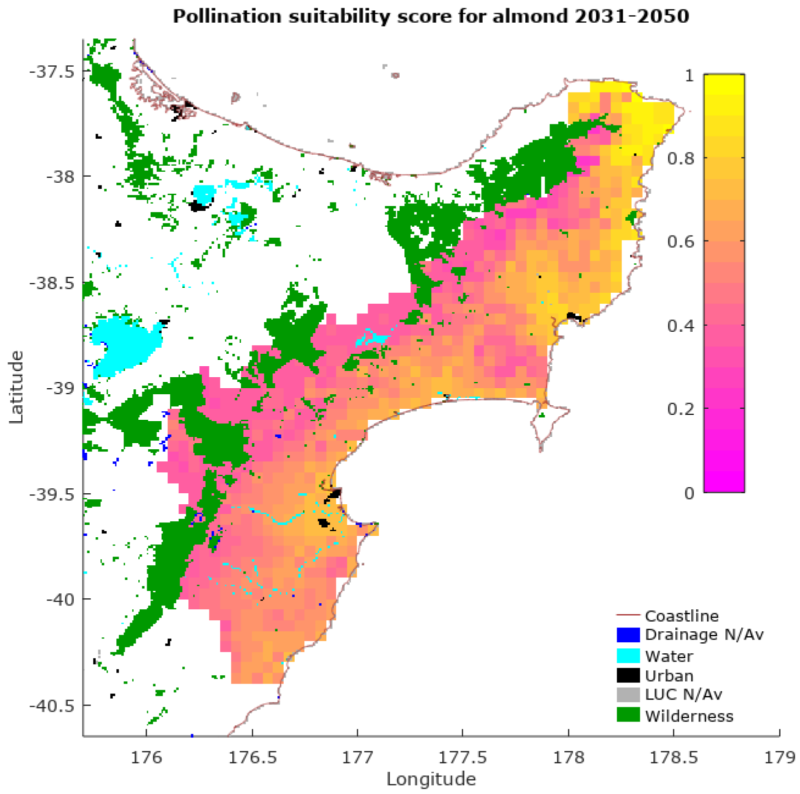
-38.5
-39
-39.5
-40
-40.5
176
176.5
177
177.5
178
178.5
179
1
0.8
0.6
0.4
0.2
0
Coastline
Drainage N/Av
Water
Urban
LUC N/Av
Wilderness


Pollination suitability score for almond 2031-2050
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-38.5
-39
-39.5
-40
-40.5
Latitude
176
176.5
177
177.5
178
178.5
179
Longitude
1
0.8
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0.4
0.2
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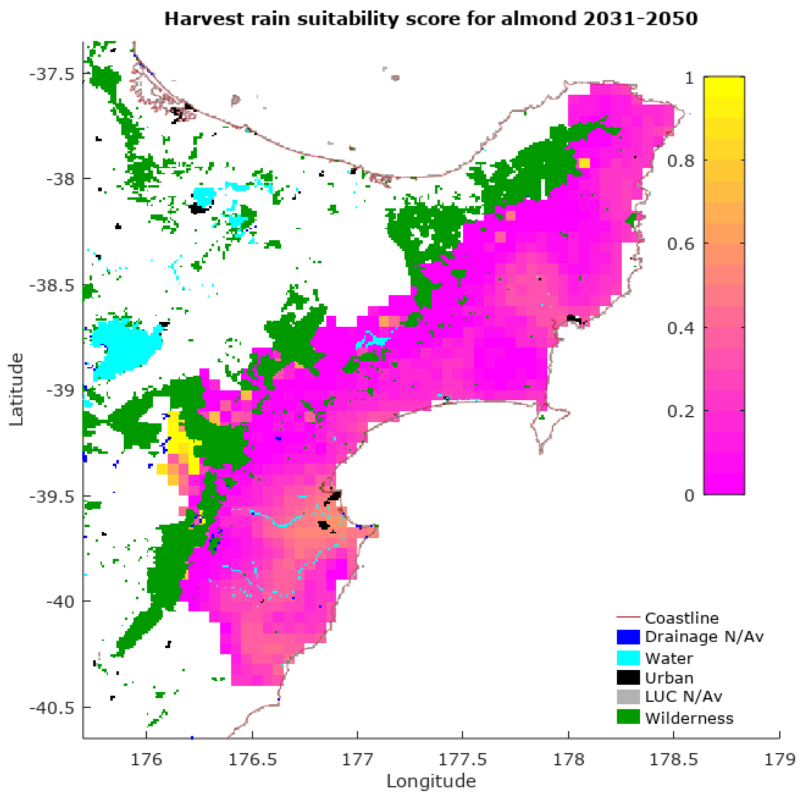
Coastline
Drainage N/Av
Water
Urban
LUC N/Av
Wilderness


Harvest rain suitability score for almond 2031-2050
-37.5
-38
-38.5
-39
-39.5
-40
-40.5
Latitude
176
176.5
177
177.5
178
178.5
179
Longitude
1
0.8
0.6
0.4
0.2
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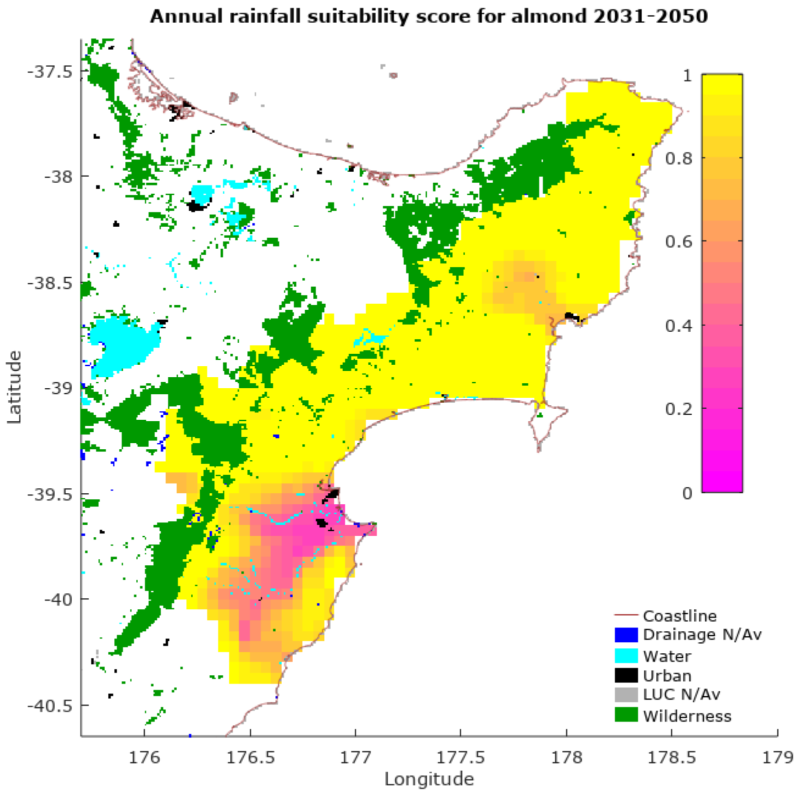
Coastline
Drainage N/Av
Water
Urban
LUC N/Av
Wilderness


Annual rainfall suitability score for almond 2031-2050
Latitude
Longitude
-37.5
-38
-38.5
-39
-39.5
-40
-40.5
176
176.5
177
177.5
178
178.5
179
1
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0.6
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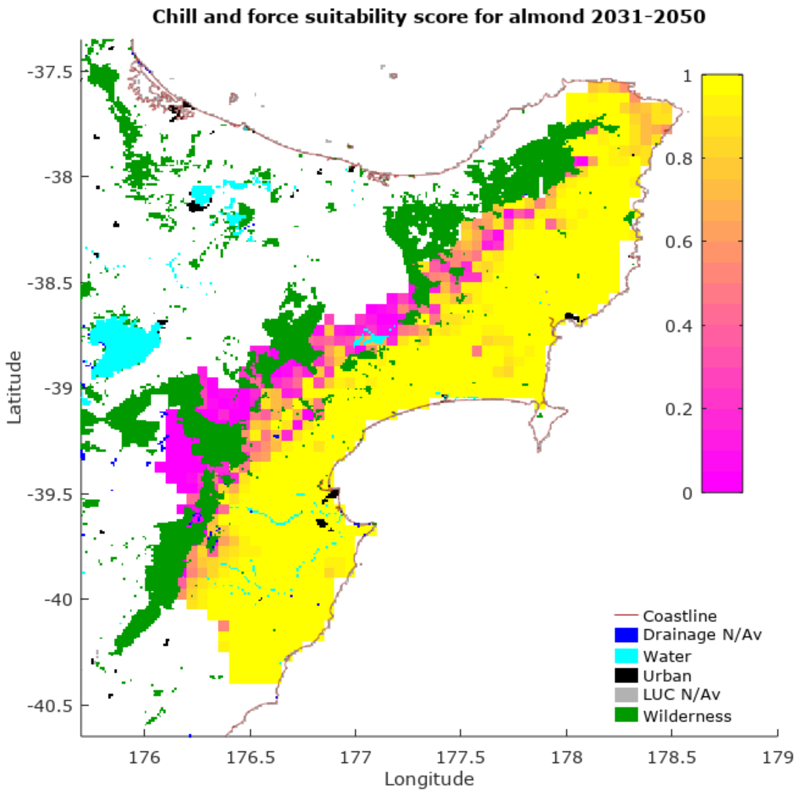
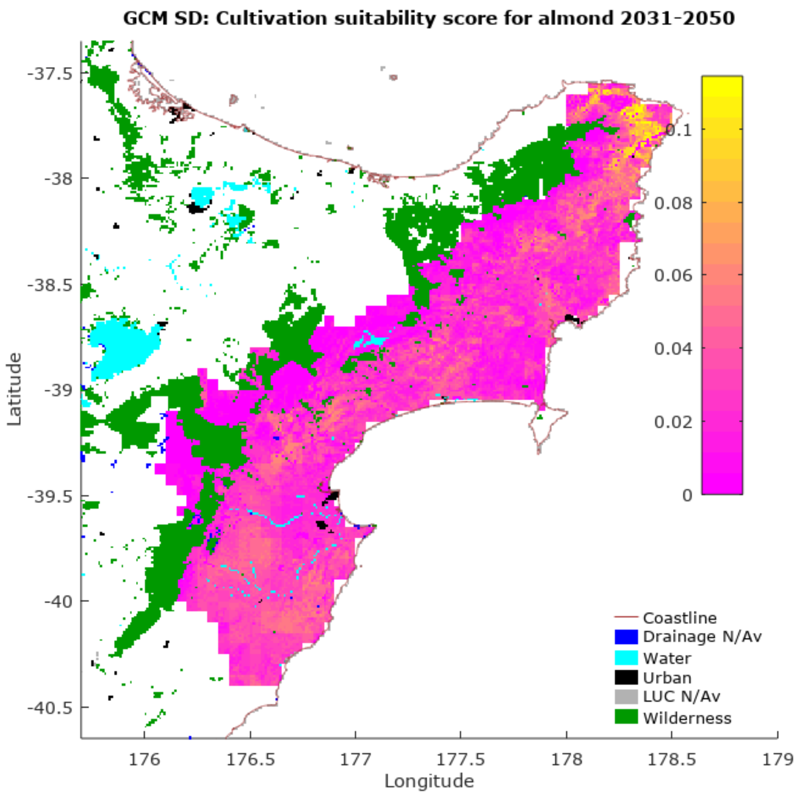
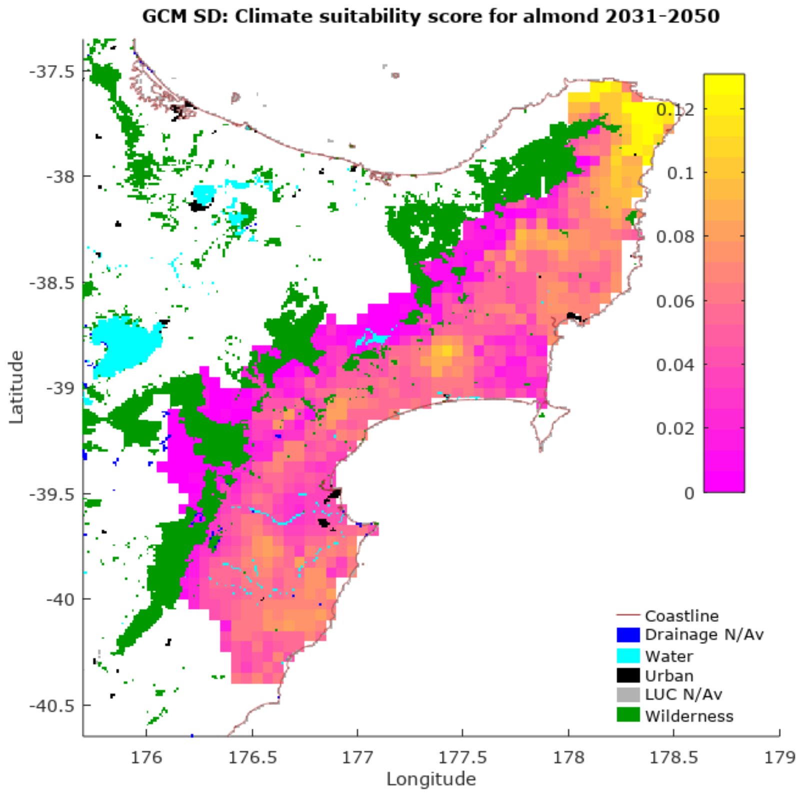
Coastline
Drainage N/Av
Water
Urban
LUC N/Av
Wilderness


Chill and force suitability score for almond 2031-2050
Latitude
Longitude
-37.5
-38
-38.5
-39
-39.5
-40
-40.5
176
176.5
177
177.5
178
178.5
179
1
0.8
0.6
0.4
0.2
0
Coastline
Drainage N/Av
Water
Urban
LUC N/Av
Wilderness

Standard deviation (SD) of projections




GCM SD: Climate suitability score for almond 2031-2050
Latitude
Longitude
-37.5
-38
-38.5
-39
-39.5
-40
-40.5
176
176.5
177
177.5
178
178.5
179
0.12
0.1
0.08
0.06
0.04
0.02
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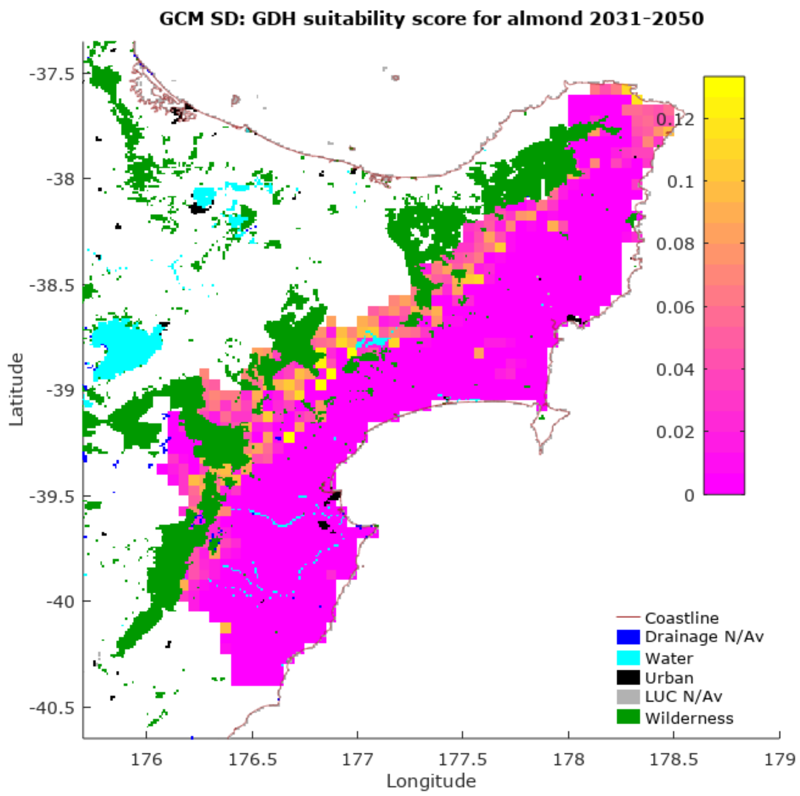
Coastline
Drainage N/Av
Water
Urban
LUC N/Av
Wilderness


GCM SD: GDH suitability score for almond 2031-2050
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Longitude
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-38.5
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-39.5
-40
-40.5
176
176.5
177
177.5
178
178.5
179
0.12
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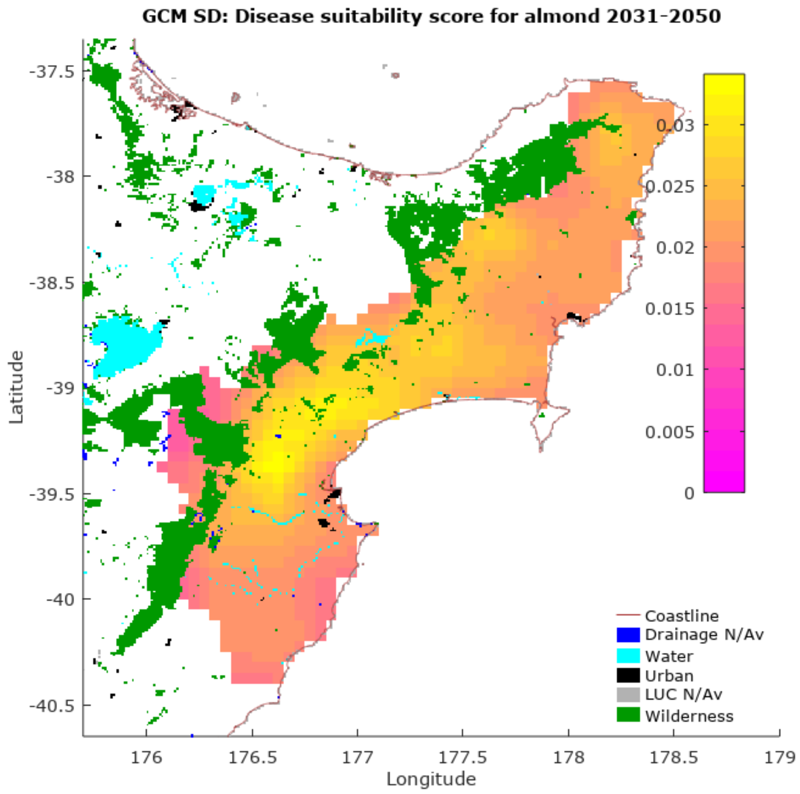
Coastline
Drainage N/Av
Water
Urban
LUC N/Av
Wilderness


GCM SD: Disease suitability score for almond 2031-2050
Latitude
Longitude
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-39.5
-40
-40.5
176
176.5
177
177.5
178
178.5
179
0.03
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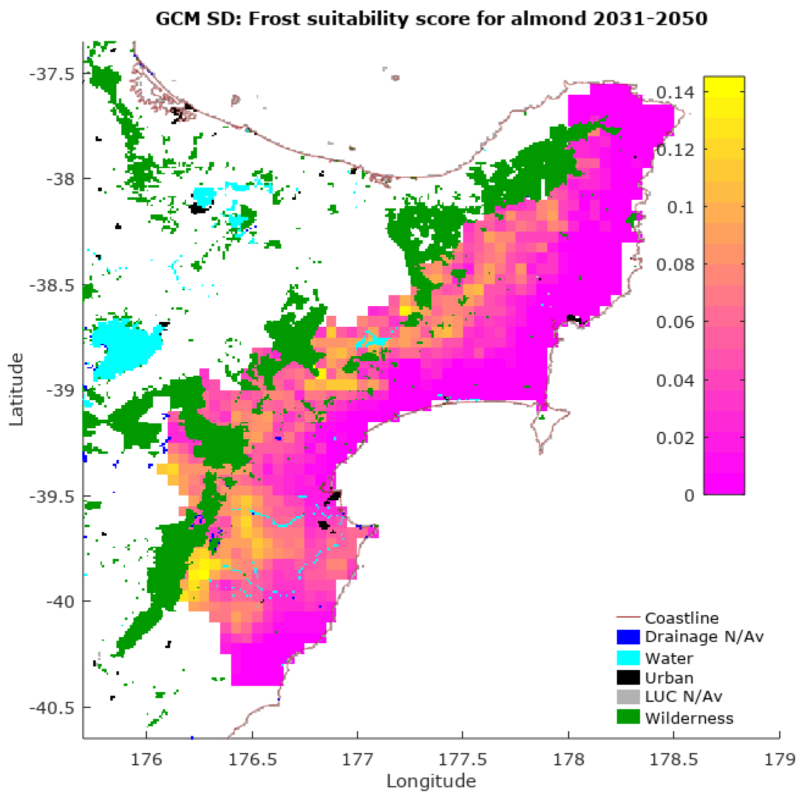
Coastline
Drainage N/Av
Water
Urban
LUC N/Av
Wilderness


GCM SD: Frost suitability score for almond 2031-2050
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Longitude
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-38.5
-39
-39.5
-40
-40.5
176
176.5
177
177.5
178
178.5
179
0.14
0.12
0.1
0.08
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0.04
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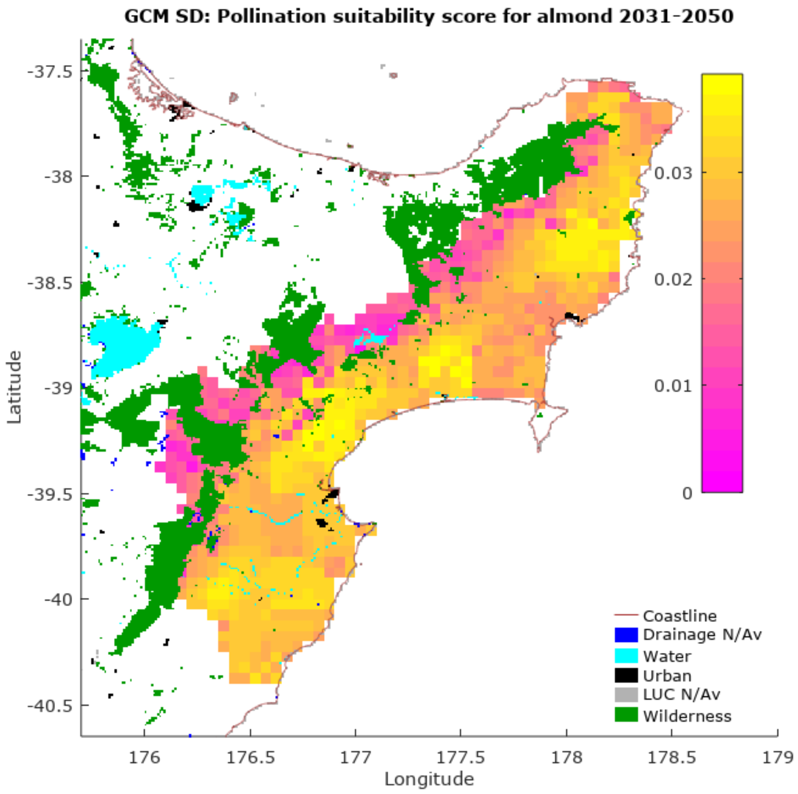
Coastline
Drainage N/Av
Water
Urban
LUC N/Av
Wilderness


GCM SD: Pollination suitability score for almond 2031-2050
Latitude
Longitude
-37.5
-38
-38.5
-39
-39.5
-40
-40.5
176
176.5
177
177.5
178
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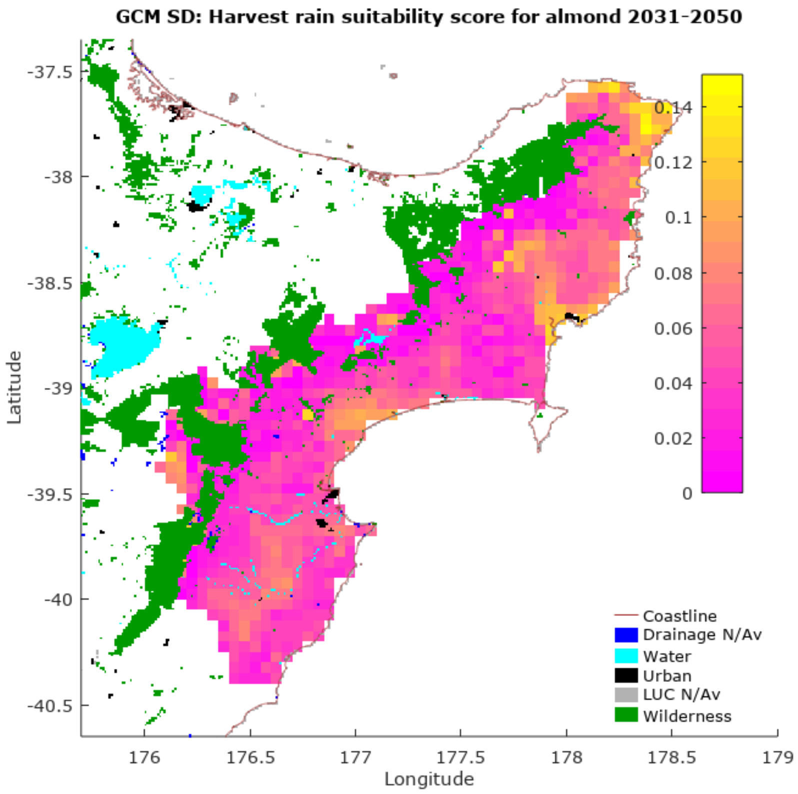
Coastline
Drainage N/Av
Water
Urban
LUC N/Av
Wilderness


GCM SD: Harvest rain suitability score for almond 2031-2050
Latitude
Longitude
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-38
-38.5
-39
-39.5
-40
-40.5
176
176.5
177
177.5
178
178.5
179
0.14
0.12
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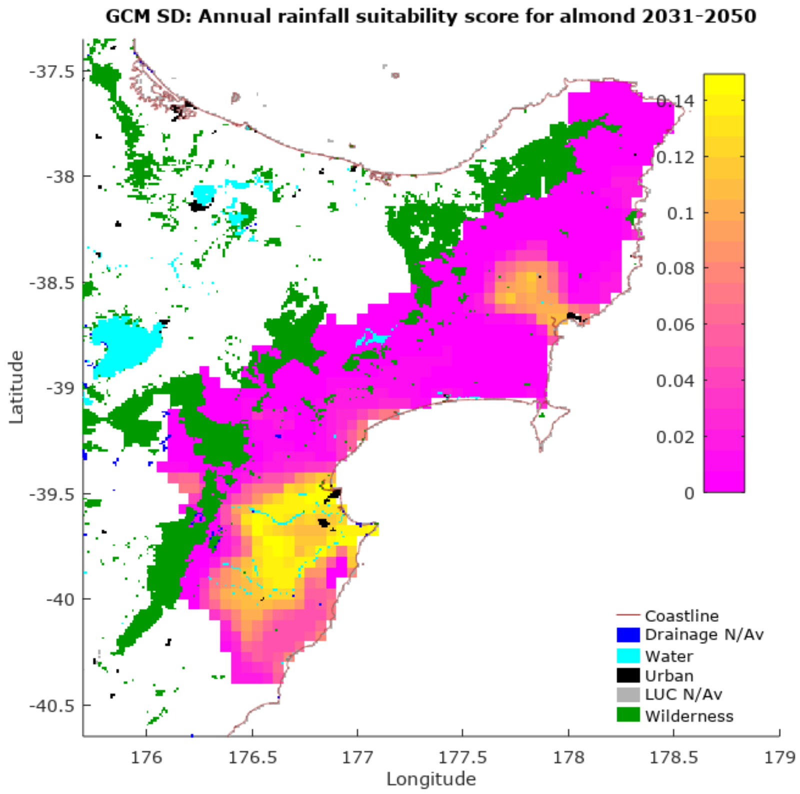
Coastline
Drainage N/Av
Water
Urban
LUC N/Av
Wilderness


GCM SD: Annual rainfall suitability score for almond 2031-2050
Latitude
Longitude
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-38.5
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-39.5
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-40.5
176
176.5
177
177.5
178
178.5
179
0.14
0.12
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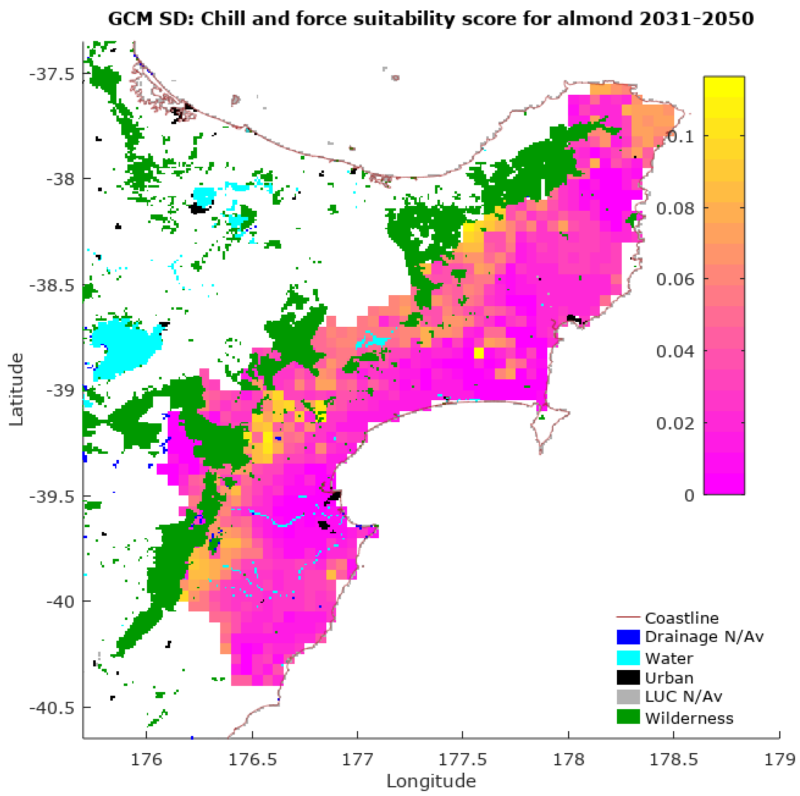
Coastline
Drainage N/Av
Water
Urban
LUC N/Av
Wilderness


GCM SD: Chill and force suitability score for almond 2031-2050
Latitude
Longitude
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-38
-38.5
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-39.5
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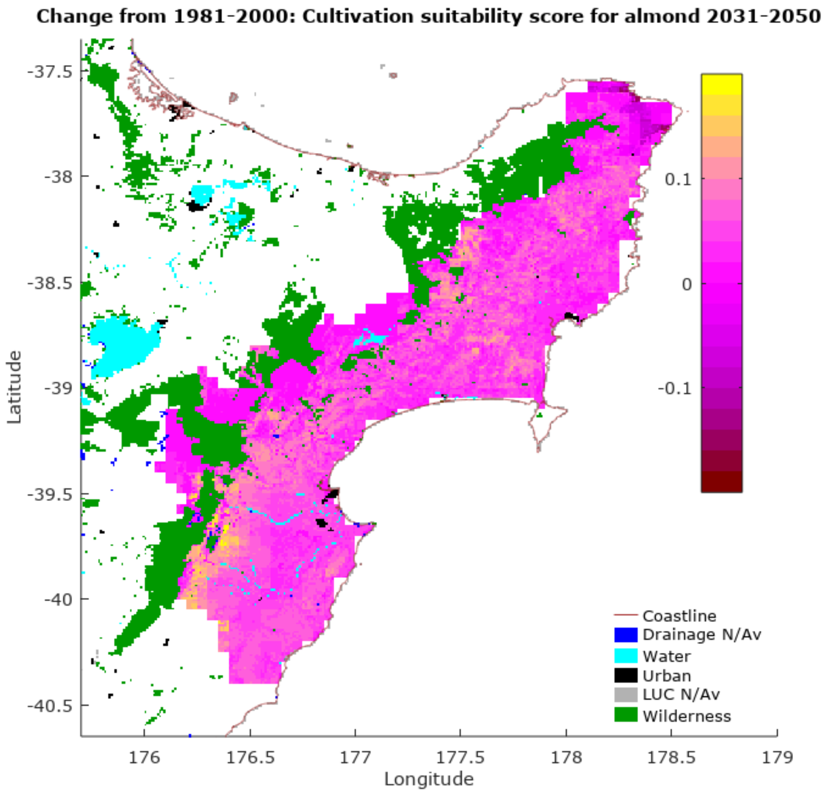
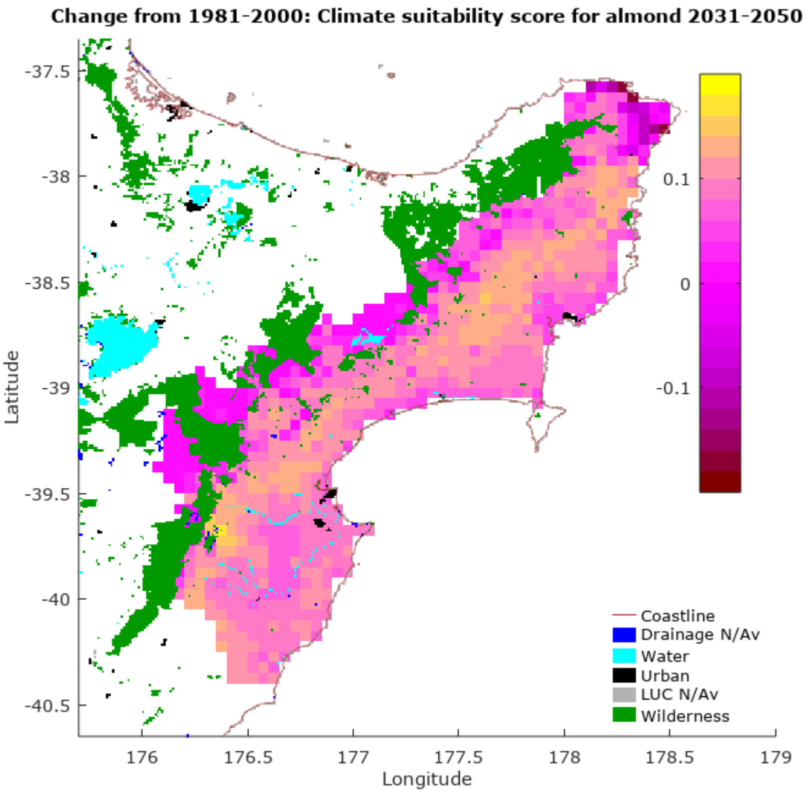
-40.5
176
176.5
177
177.5
178
178.5
179
0.1
0.08
0.06
0.04
0.02
0
Coastline
Drainage N/Av
Water
Urban
LUC N/Av
Wilderness

Projected change from 1981–2000 (RCP Past period)




Change from 1981-2000: Climate suitability score for almond 2031-2050
Latitude
Longitude
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-40
-40.5
176
176.5
177
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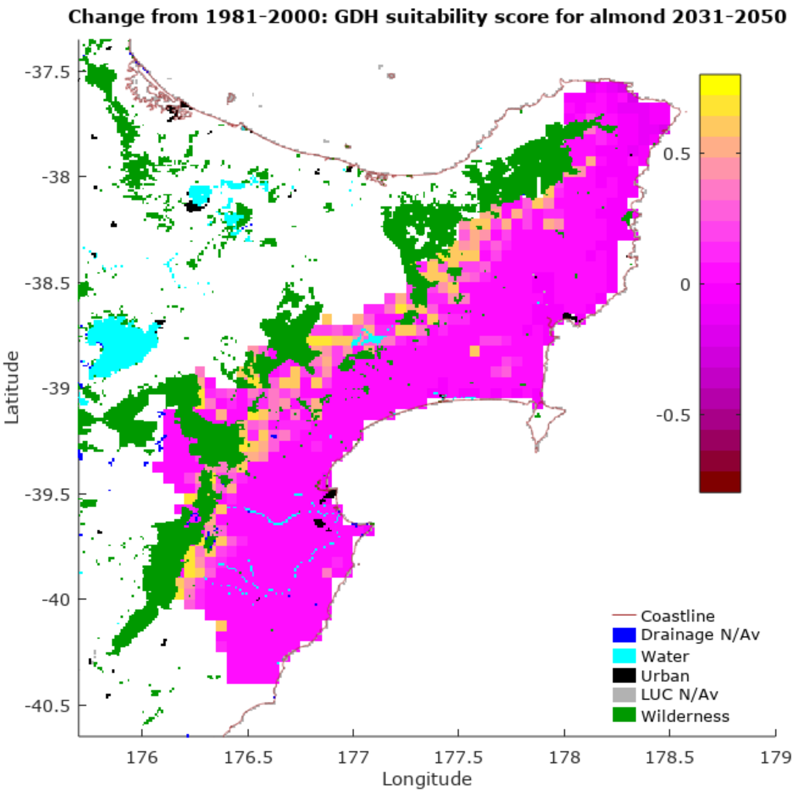
0
-0.1
Coastline
Drainage N/Av
Water
Urban
LUC N/Av
Wilderness


Change from 1981-2000: GDH suitability score for almond 2031-2050
Latitude
Longitude
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-39.5
-40
-40.5
176
176.5
177
177.5
178
178.5
179
0.5
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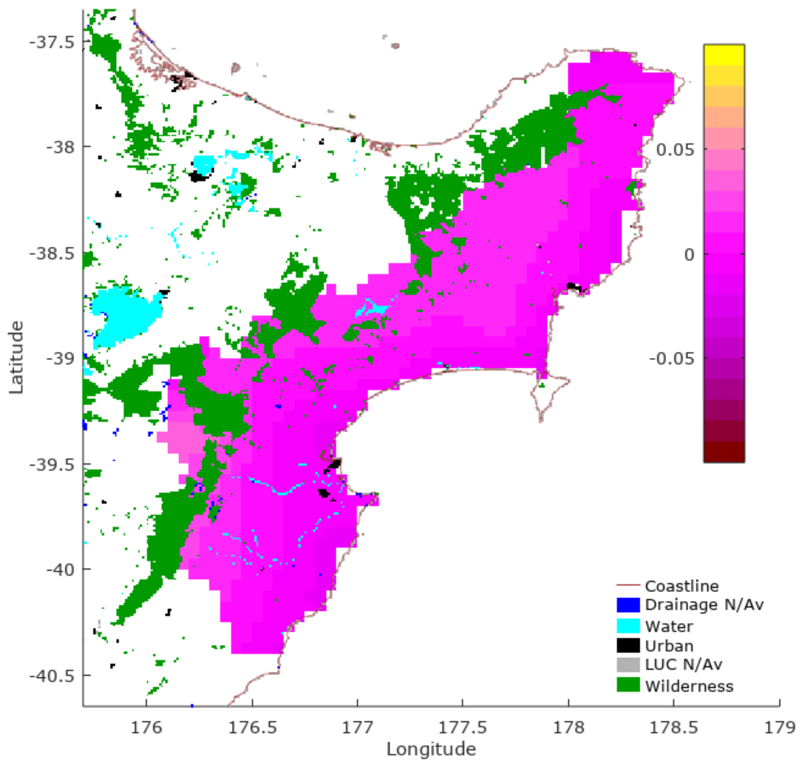
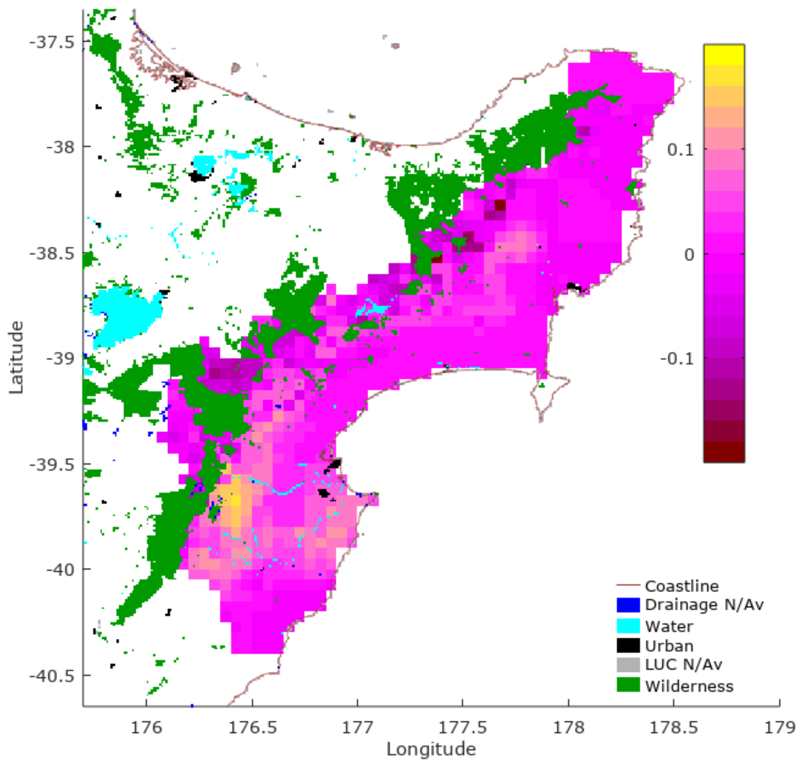
Coastline
Drainage N/Av
Water
Urban
LUC N/Av
Wilderness

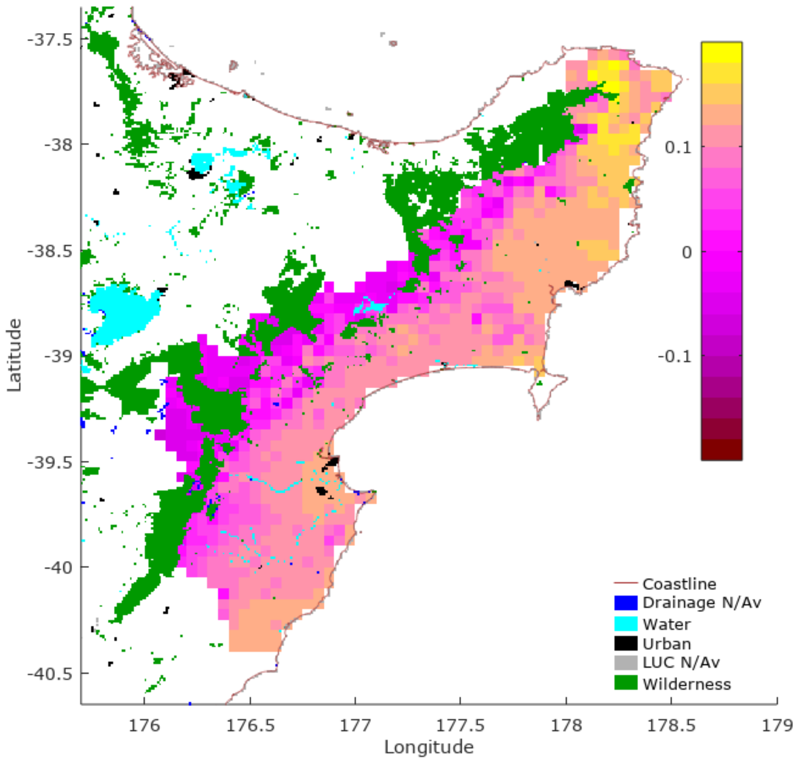
Change from 1981-2000: Disease suitability score for almond 2031-2050



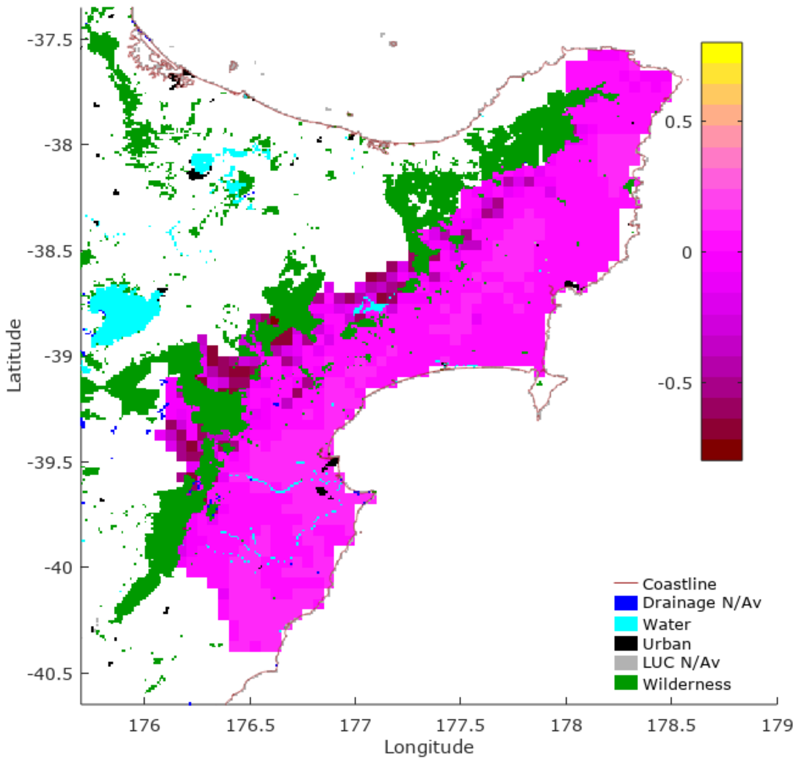
Change from 1981-2000: Frost suitability score for almond 2031-2050



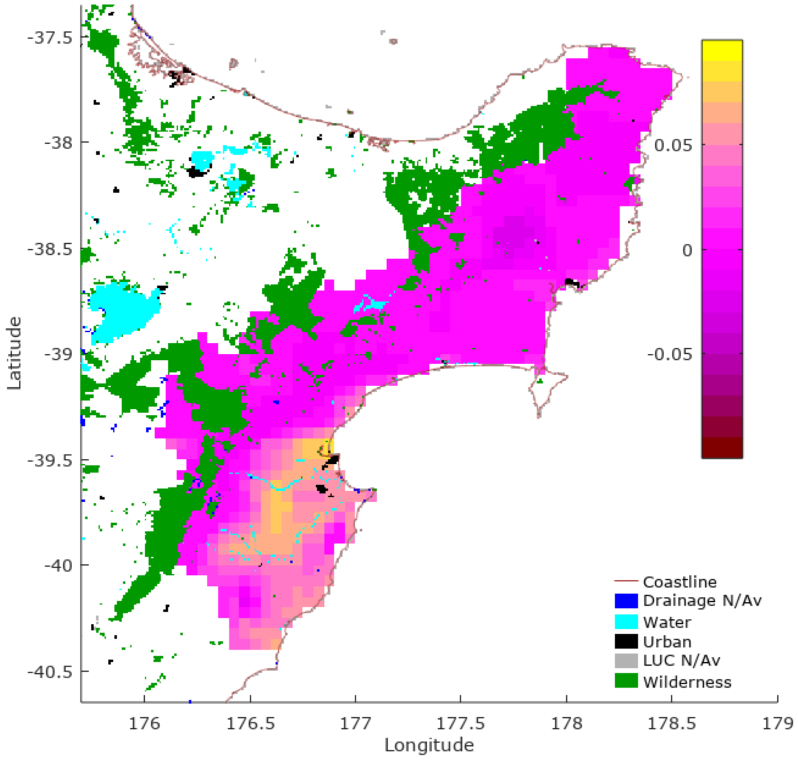
Change from 1981-2000: Pollination suitability score for almond 2031-2050



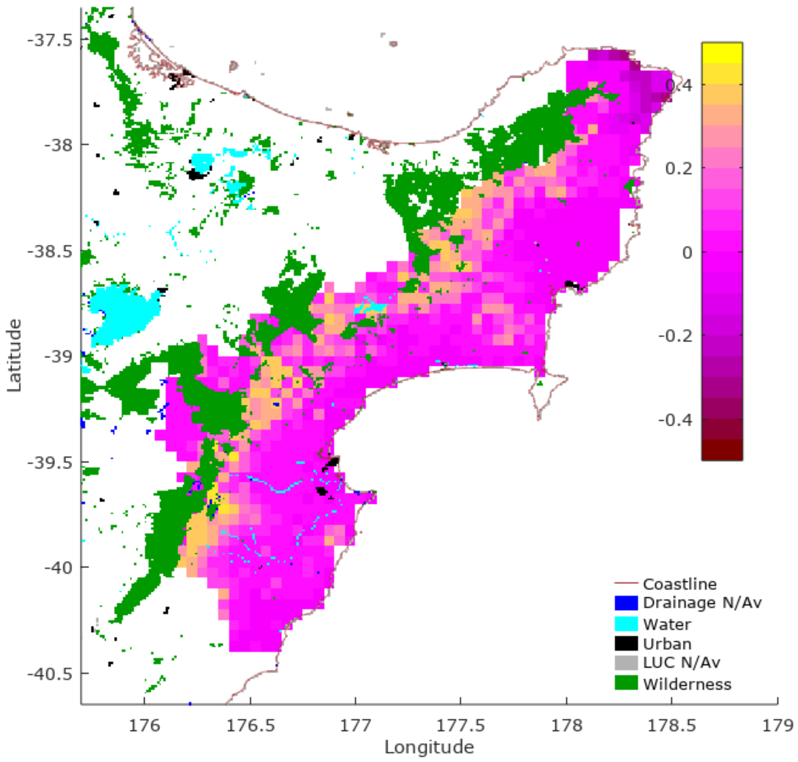
Change from 1981-2000: Harvest rain suitability score for almond 2031-2050



Change from 1981-2000: Annual rainfall suitability score for almond 2031-2050

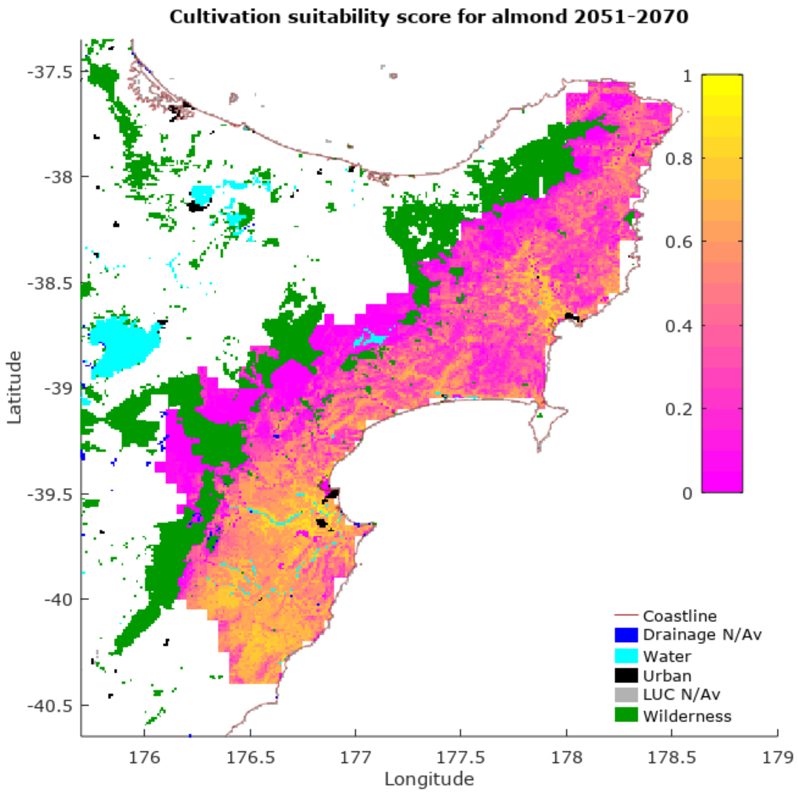


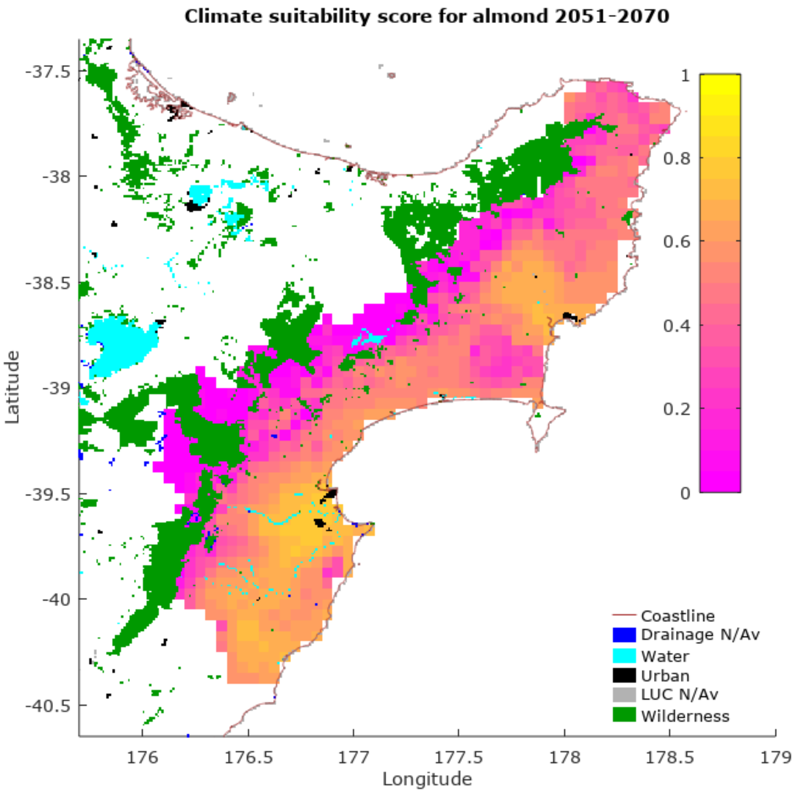
Change from 1981-2000: Chill and force suitability score for almond 2031-2050

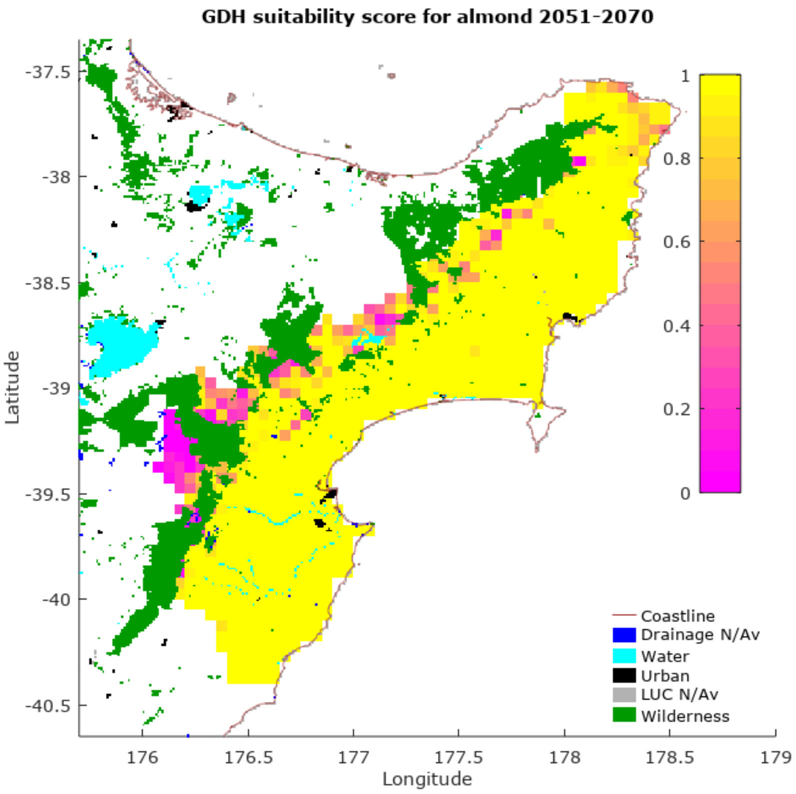


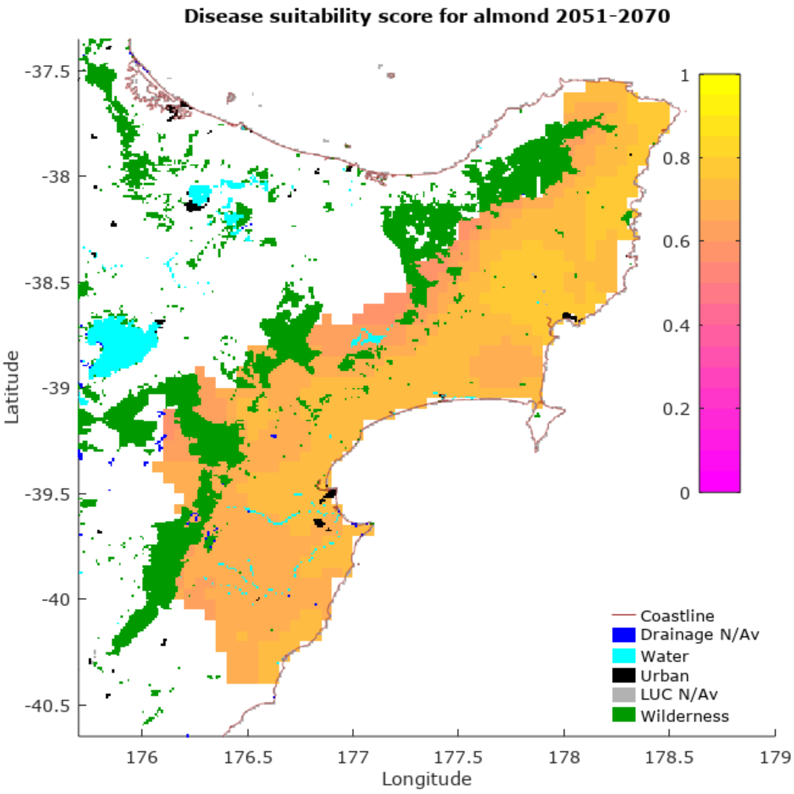
RCP 6.0 2051 to 2070

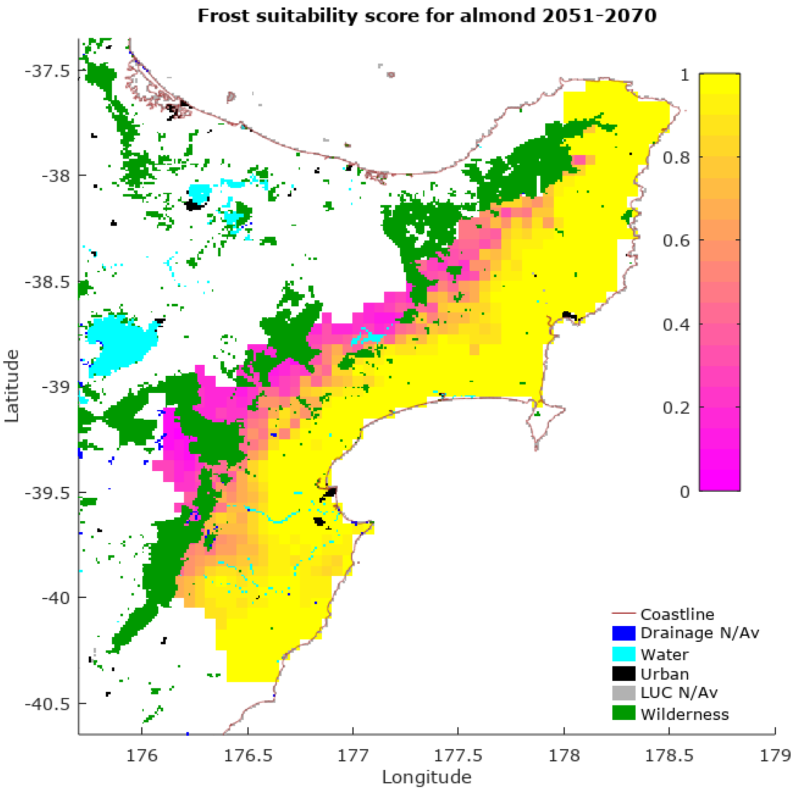
Climate suitability projections

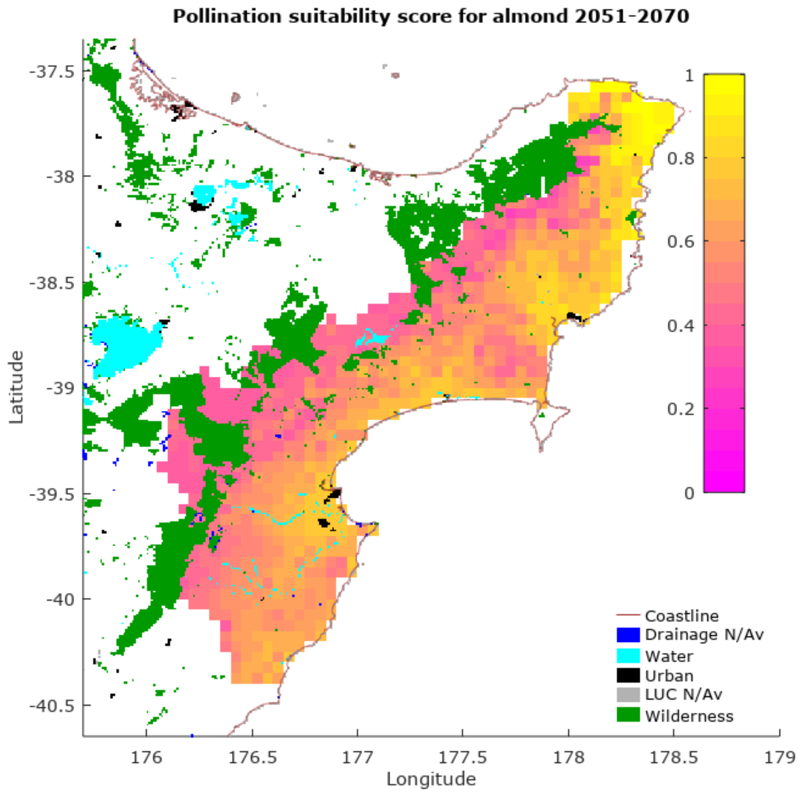


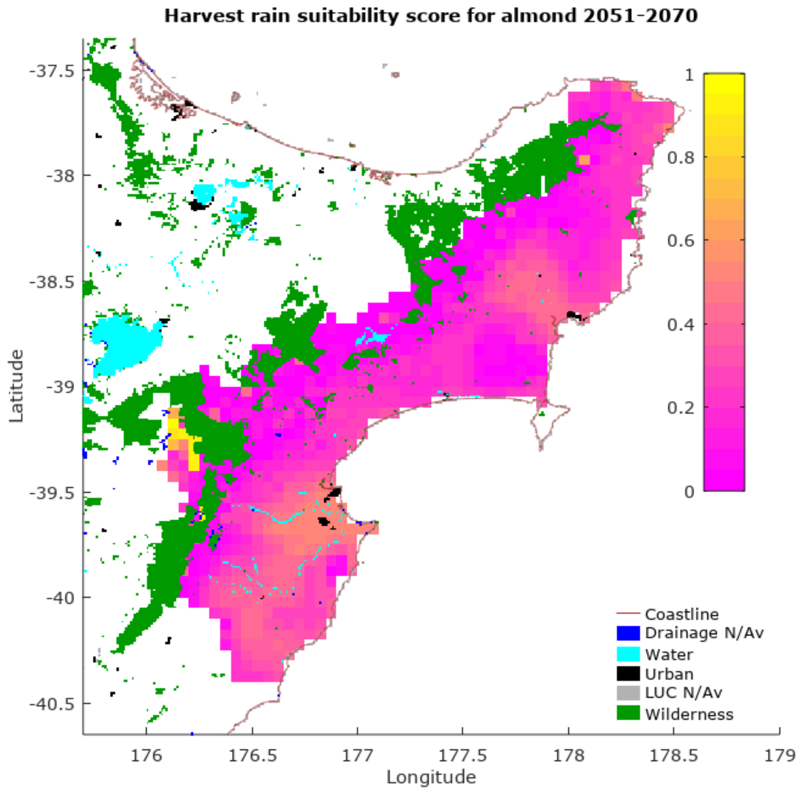

Climate suitability score for almond 2051-2070
Latitude
Longitude
-37.5
-38
-38.5
-39
-39.5
-40
-40.5
176
176.5
177
177.5
178
178.5
179
1
0.8
0.6
0.4
0.2
0
Coastline
Drainage N/Av
Water
Urban
LUC N/Av
Wilderness

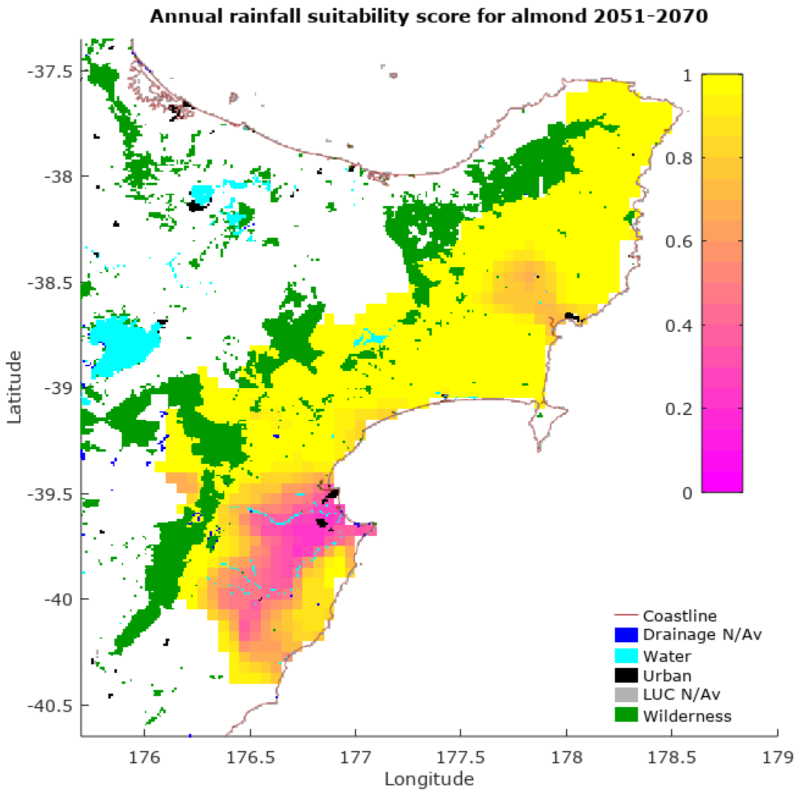

GDH suitability score for almond 2051-2070
Latitude
Longitude
-37.5
-38
-38.5
-39
-39.5
-40
-40.5
176
176.5
177
177.5
178
178.5
179
1
0.8
0.6
0.4
0.2
0
Coastline
Drainage N/Av
Water
Urban
LUC N/Av
Wilderness


Disease suitability score for almond 2051-2070
-37.5
-38
-38.5
-39
-39.5
-40
-40.5
Latitude
176
176.5
177
177.5
178
178.5
179
Longitude
1
0.8
0.6
0.4
0.2
0
Coastline
Drainage N/Av
Water
Urban
LUC N/Av
Wilderness

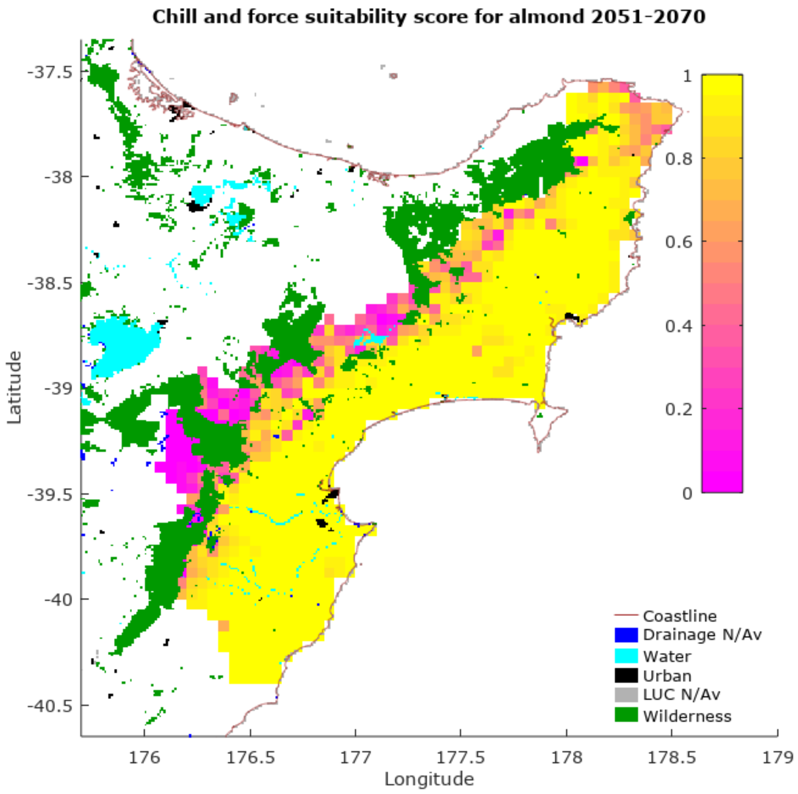

Frost suitability score for almond 2051-2070
-37.5
-38
-38.5
-39
-39.5
-40
-40.5
Latitude
176
176.5
177
177.5
178
178.5
179
Longitude
1
0.8
0.6
0.4
0.2
0
Coastline
Drainage N/Av
Water
Urban
LUC N/Av
Wilderness


Pollination suitability score for almond 2051-2070
Latitude
-37.5
-38
-38.5
-39
-39.5
-40
-40.5
Longitude
176
176.5
177
177.5
178
178.5
179
1
0.8
0.6
0.4
0.2
0
Coastline
Drainage N/Av
Water
Urban
LUC N/Av
Wilderness


Harvest rain suitability score for almond 2051-2070
Latitude
-37.5
-38
-38.5
-39
-39.5
-40
-40.5
Longitude
176
176.5
177
177.5
178
178.5
179
1
0.8
0.6
0.4
0.2
0
Coastline
Drainage N/Av
Water
Urban
LUC N/Av
Wilderness

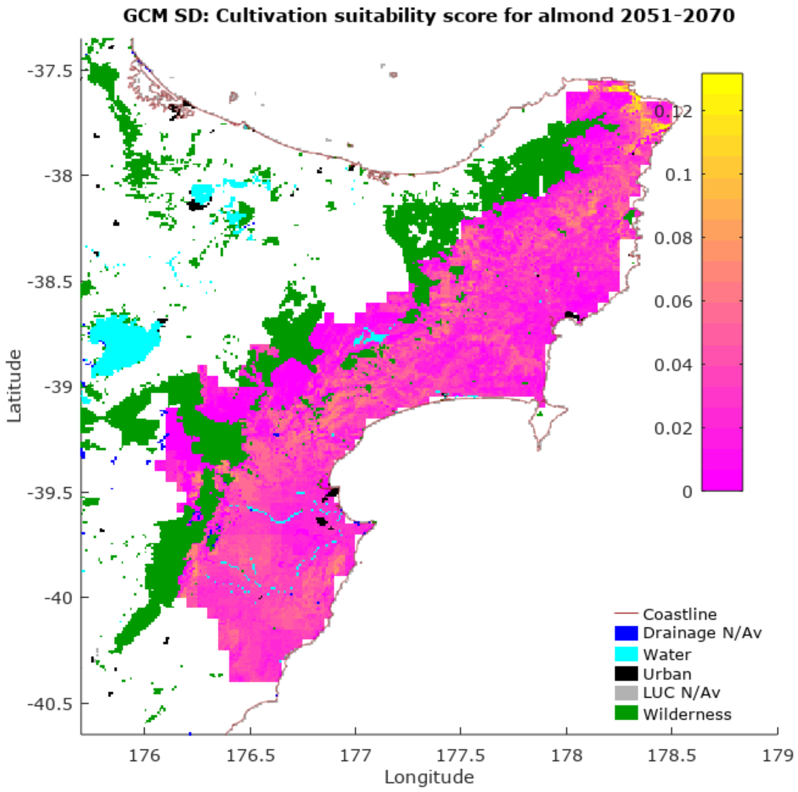


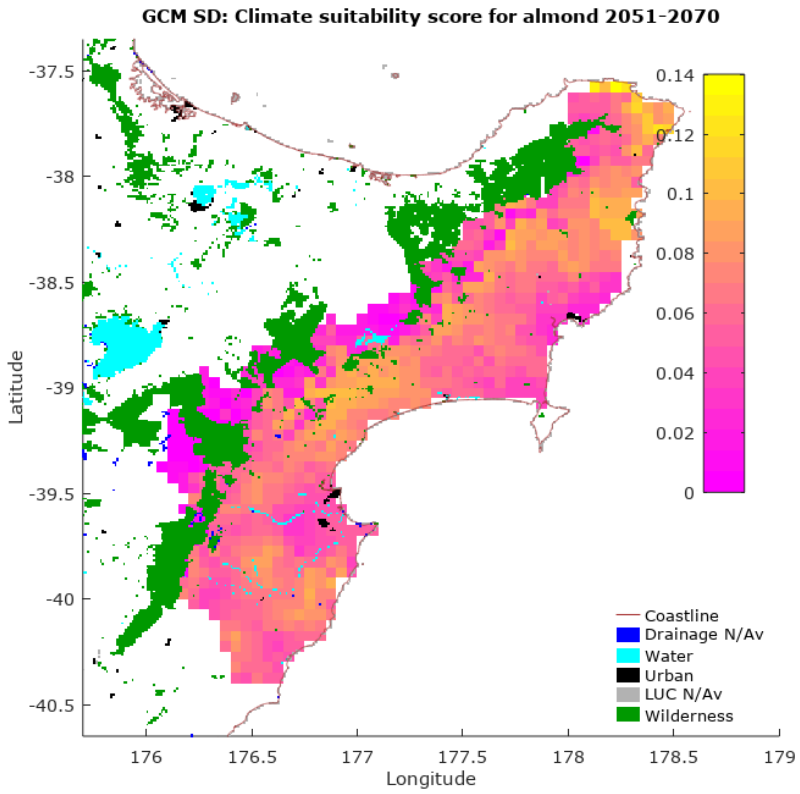
Annual rainfall suitability score for almond 2051-2070
Latitude
Longitude
-37.5
-38
-38.5
-39
-39.5
-40
-40.5
176
176.5
177
177.5
178
178.5
179
1
0.8
0.6
0.4
0.2
0
Coastline
Drainage N/Av
Water
Urban
LUC N/Av
Wilderness

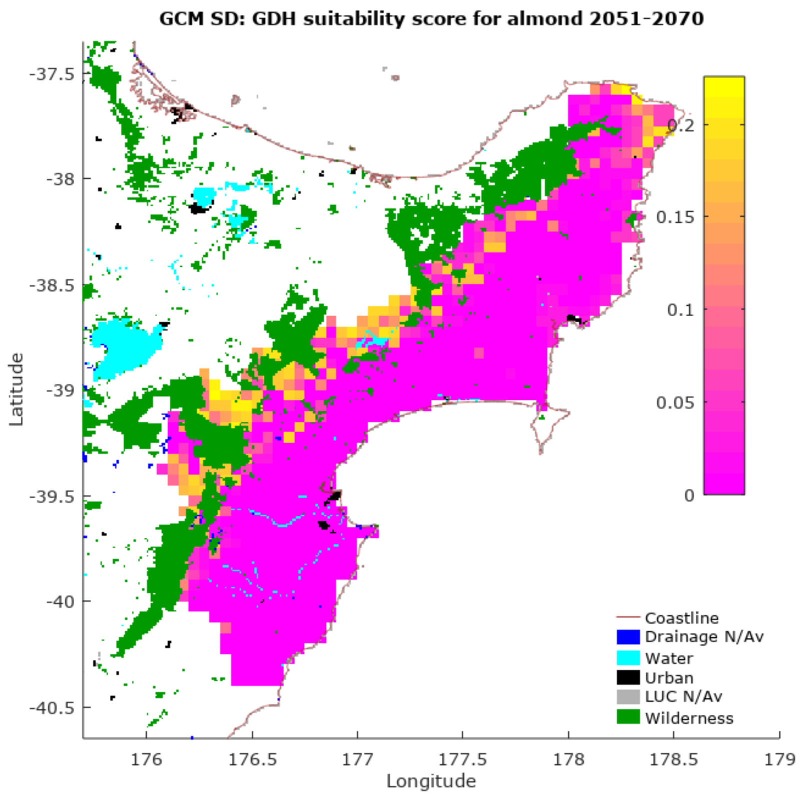


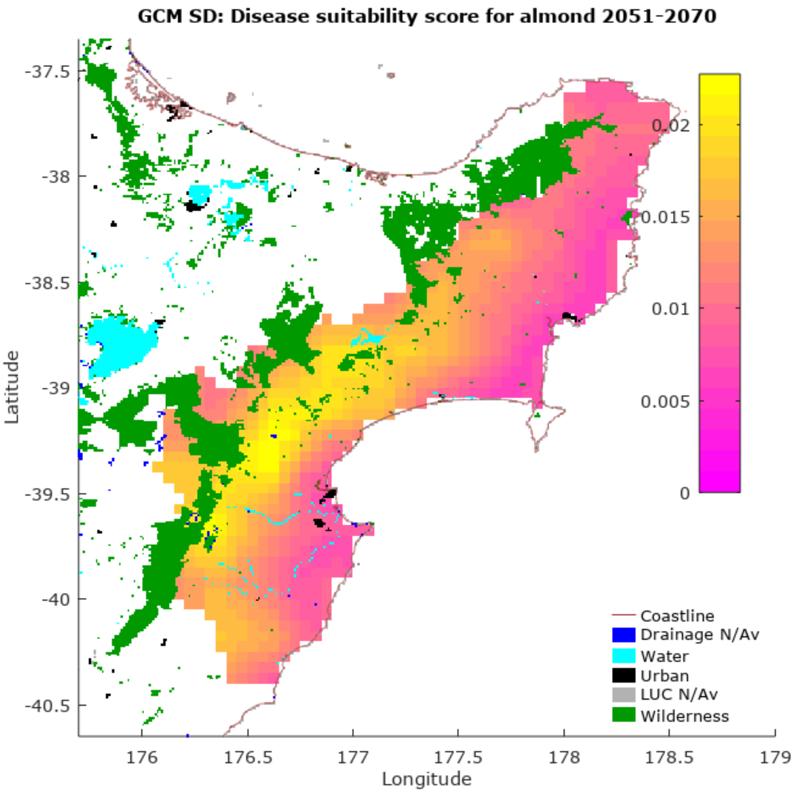
Chill and force suitability score for almond 2051-2070
Latitude
Longitude
-37.5
-38
-38.5
-39
-39.5
-40
-40.5
176
176.5
177
177.5
178
178.5
179
1
0.8
0.6
0.4
0.2
0
Coastline
Drainage N/Av
Water
Urban
LUC N/Av
Wilderness

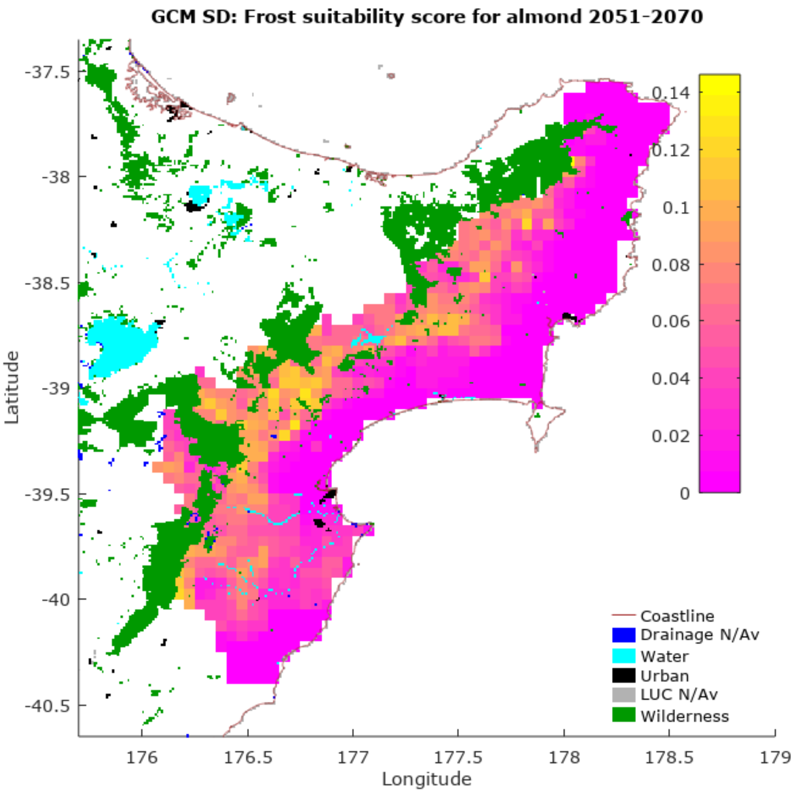
Standard deviation (SD) of projections

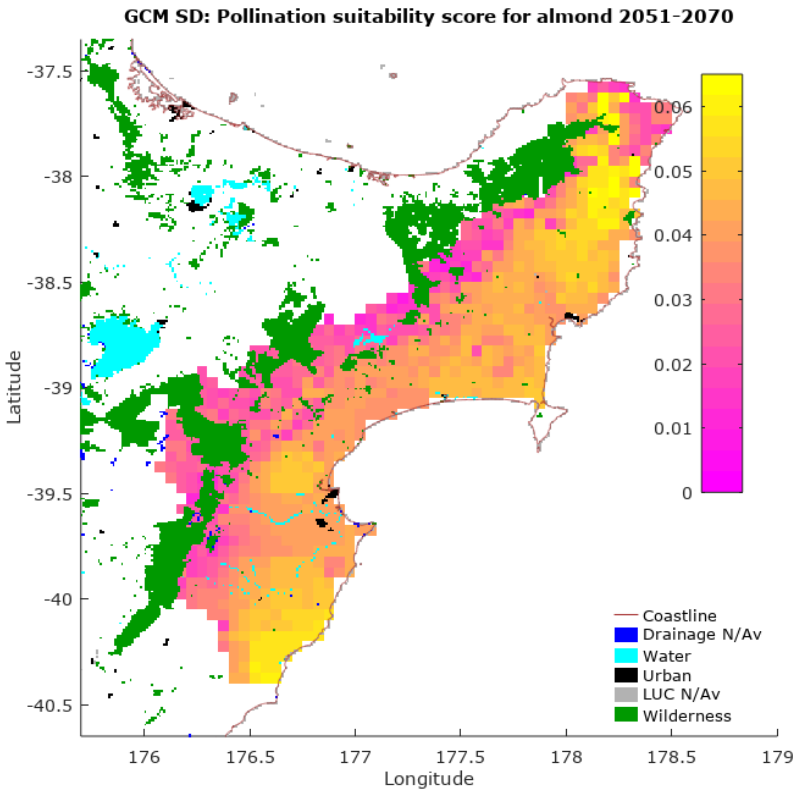


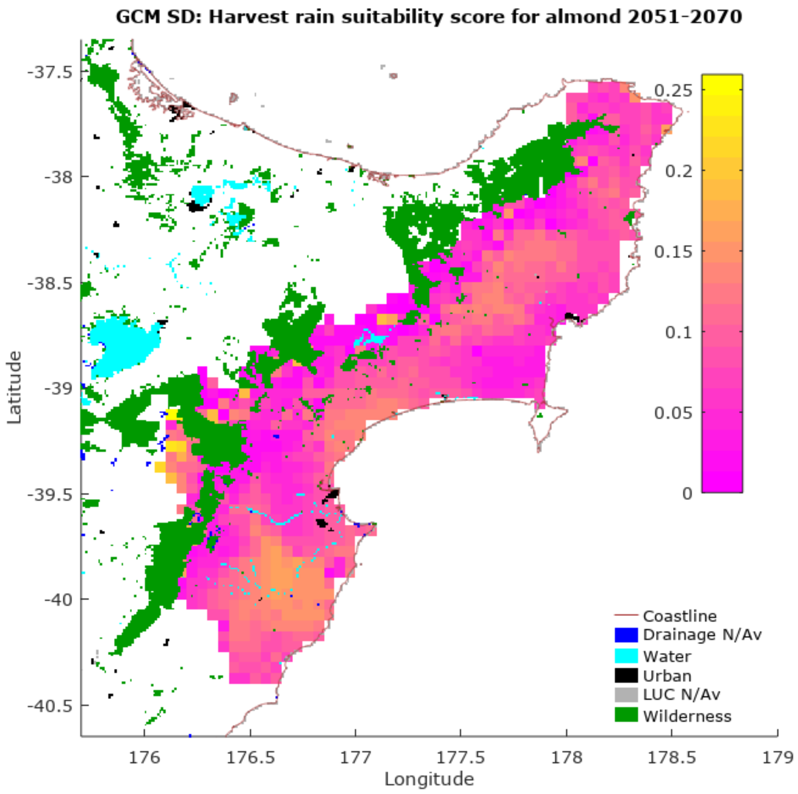

GCM SD: Climate suitability score for almond 2051-2070
Latitude
Longitude
-37.5
-38
-38.5
-39
-39.5
-40
-40.5
176
176.5
177
177.5
178
178.5
179
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Coastline
Drainage N/Av
Water
Urban
LUC N/Av
Wilderness


GCM SD: GDH suitability score for almond 2051-2070
Latitude
Longitude
-37.5
-38
-38.5
-39
-39.5
-40
-40.5
176
176.5
177
177.5
178
178.5
179
0.2
0.15
0.1
0.05
0
Coastline
Drainage N/Av
Water
Urban
LUC N/Av
Wilderness


GCM SD: Disease suitability score for almond 2051-2070
Latitude
-37.5
-38
-38.5
-39
-39.5
-40
-40.5
Longitude
176
176.5
177
177.5
178
178.5
179
0.02
0.015
0.01
0.005
0
Coastline
Drainage N/Av
Water
Urban
LUC N/Av
Wilderness


GCM SD: Frost suitability score for almond 2051-2070
Latitude
-37.5
-38
-38.5
-39
-39.5
-40
-40.5
Longitude
176
176.5
177
177.5
178
178.5
179
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Coastline
Drainage N/Av
Water
Urban
LUC N/Av
Wilderness


GCM SD: Pollination suitability score for almond 2051-2070
Latitude
Longitude
-37.5
-38
-38.5
-39
-39.5
-40
-40.5
176
176.5
177
177.5
178
178.5
179
0.06
0.05
0.04
0.03
0.02
0.01
0
Coastline
Drainage N/Av
Water
Urban
LUC N/Av
Wilderness


GCM SD: Harvest rain suitability score for almond 2051-2070
Latitude
Longitude
-37.5
-38
-38.5
-39
-39.5
-40
-40.5
176
176.5
177
177.5
178
178.5
179
0.25
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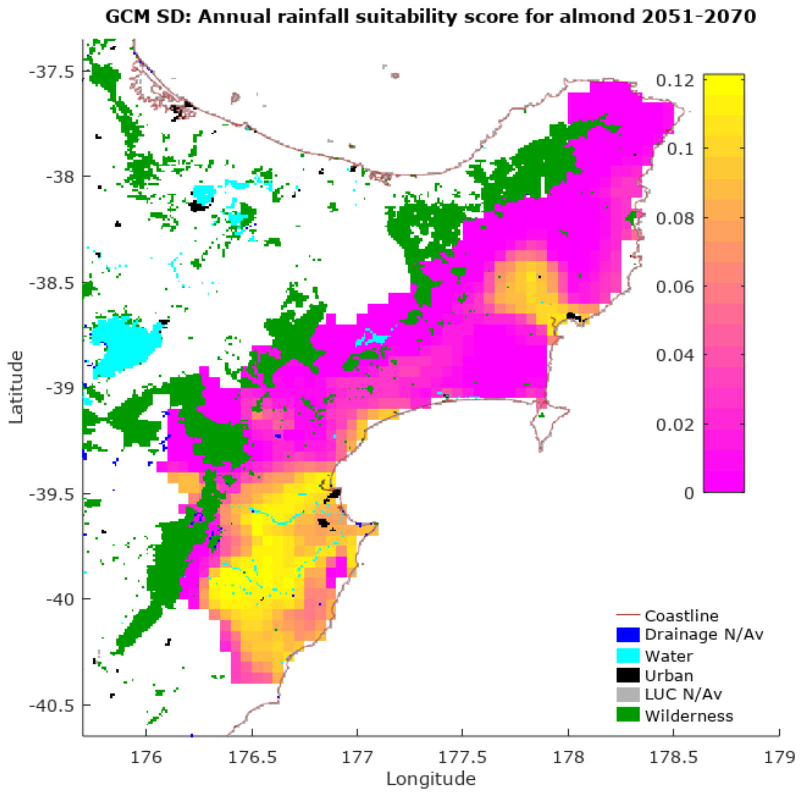
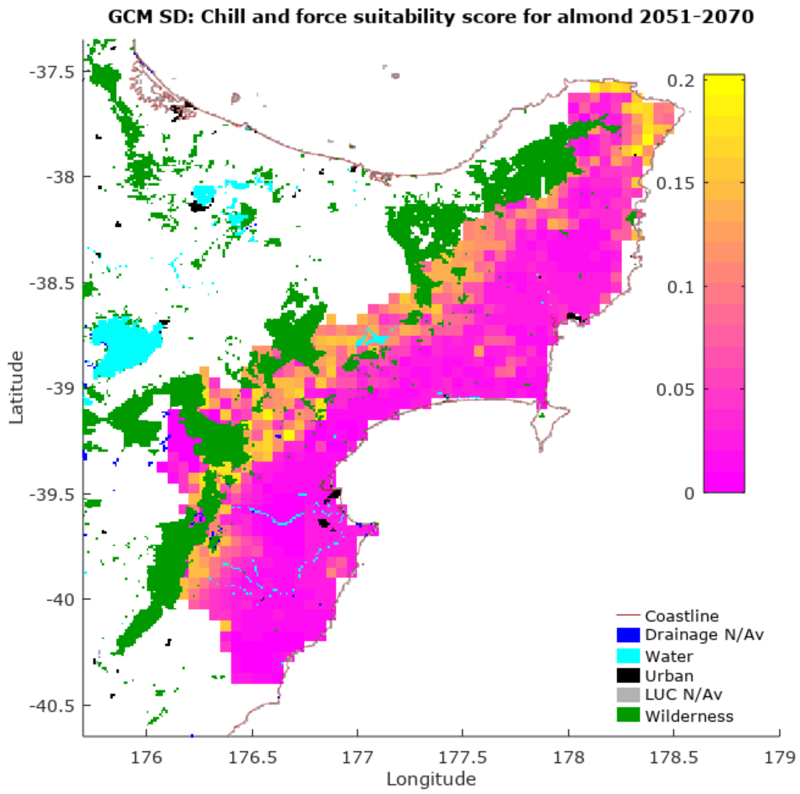
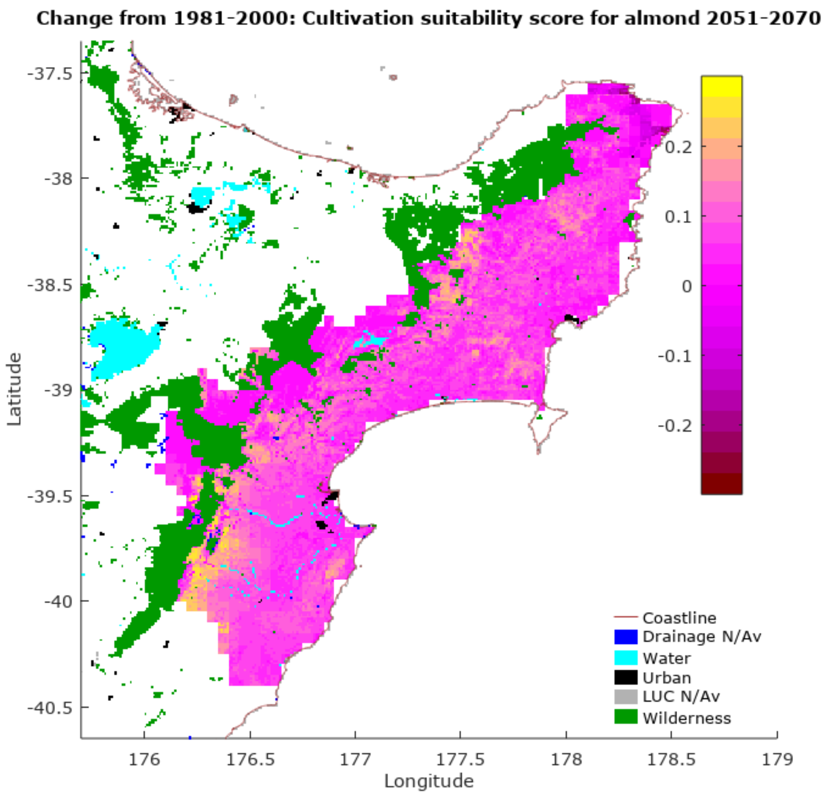
0.15
0.1
0.05
0
Coastline
Drainage N/Av
Water
Urban
LUC N/Av
Wilderness

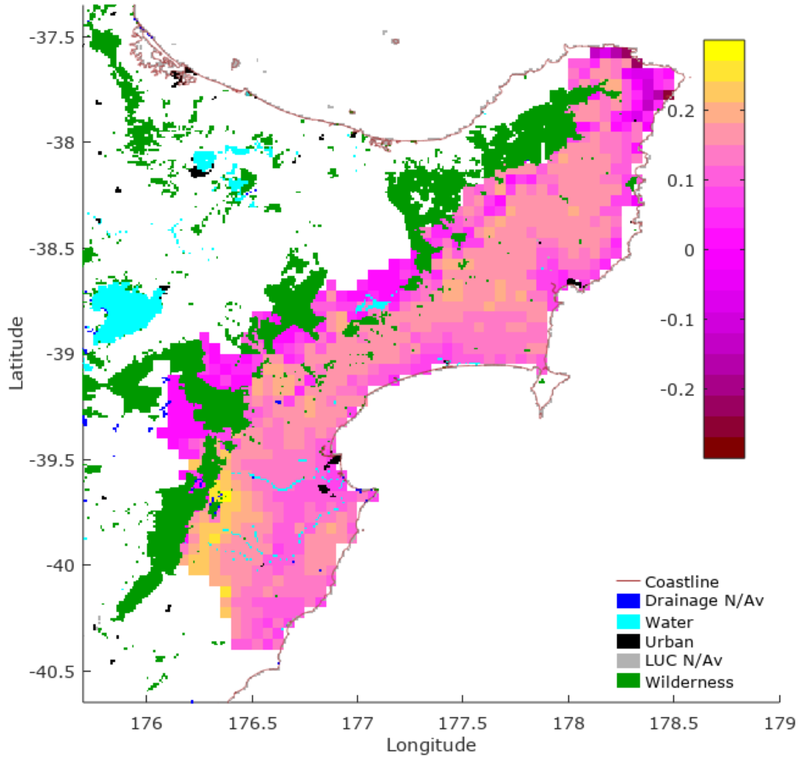

GCM SD: Annual rainfall suitability score for almond 2051-2070
Latitude
Longitude
-37.5
-38
-38.5
-39
-39.5
-40
-40.5
176
176.5
177
177.5
178
178.5
179
0.12
0.1
0.08
0.06
0.04
0.02
0
Coastline
Drainage N/Av
Water
Urban
LUC N/Av
Wilderness


GCM SD: Chill and force suitability score for almond 2051-2070
Latitude
Longitude
-37.5
-38
-38.5
-39
-39.5
-40
-40.5
176
176.5
177
177.5
178
178.5
179
0.2
0.15
0.1
0.05
0
Coastline
Drainage N/Av
Water
Urban
LUC N/Av
Wilderness

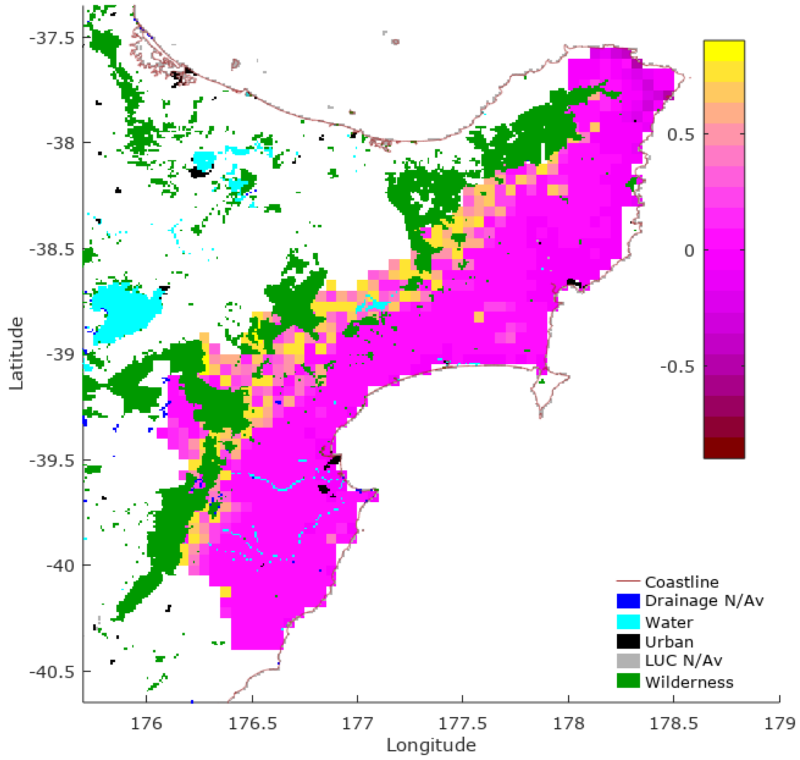
Projected change from 1981–2000 (RCP Past period)

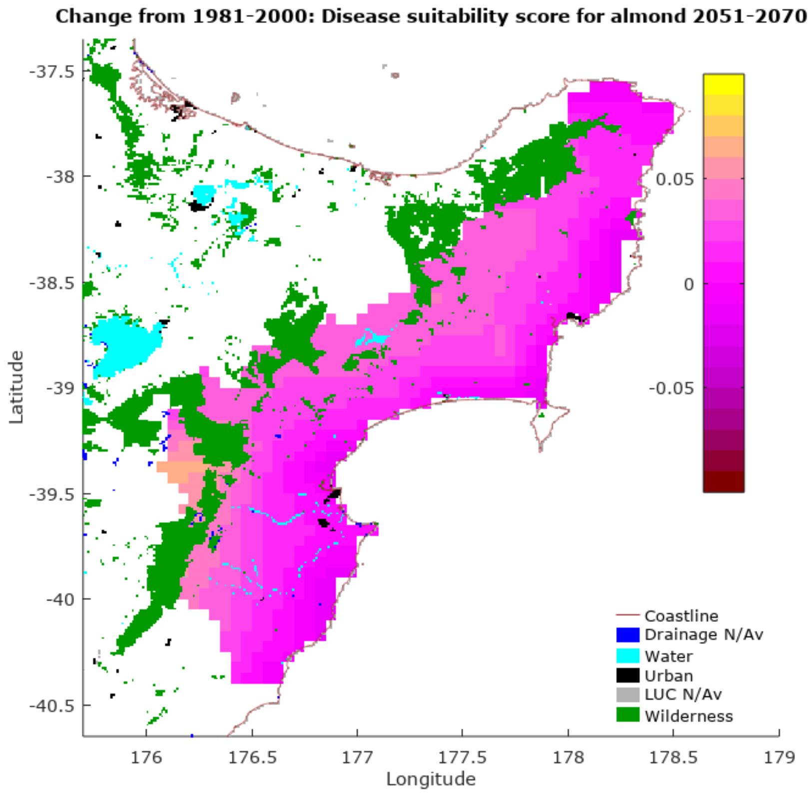


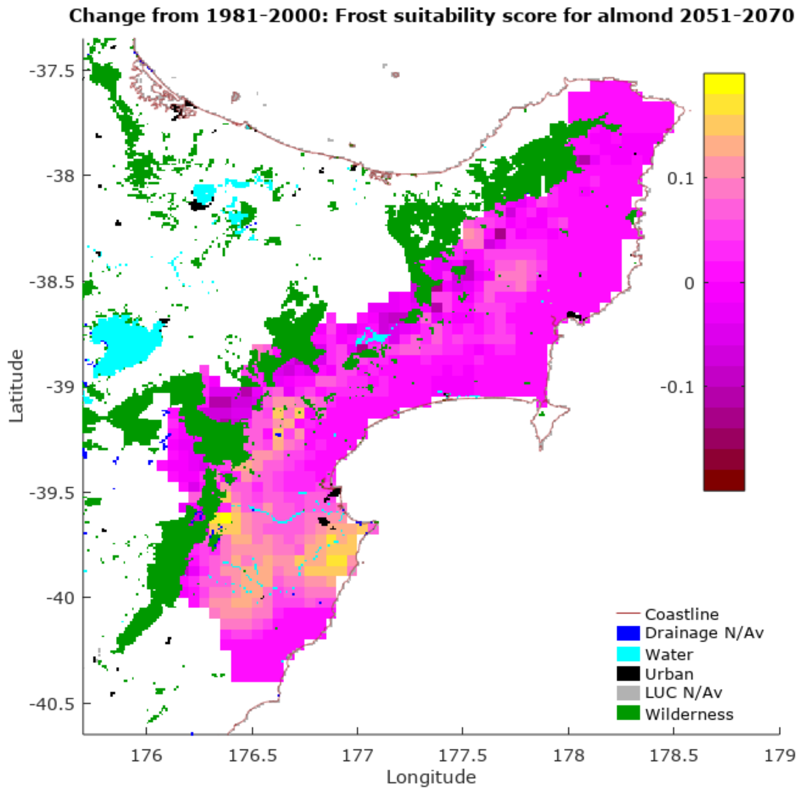
Change from 1981-2000: Climate suitability score for almond 2051-2070

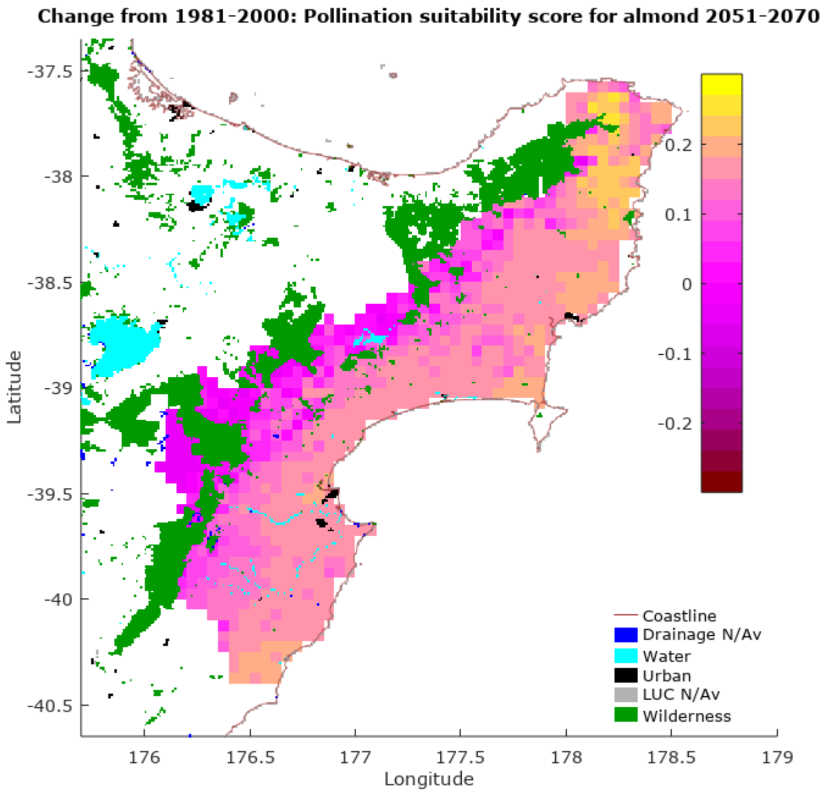


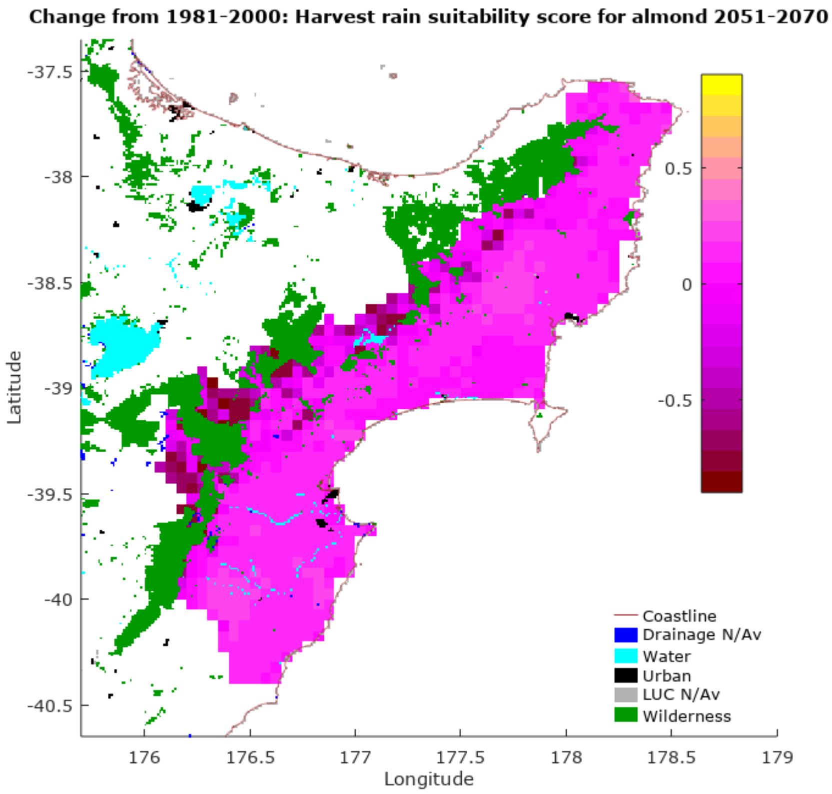
Change from 1981-2000: GDH suitability score for almond 2051-2070



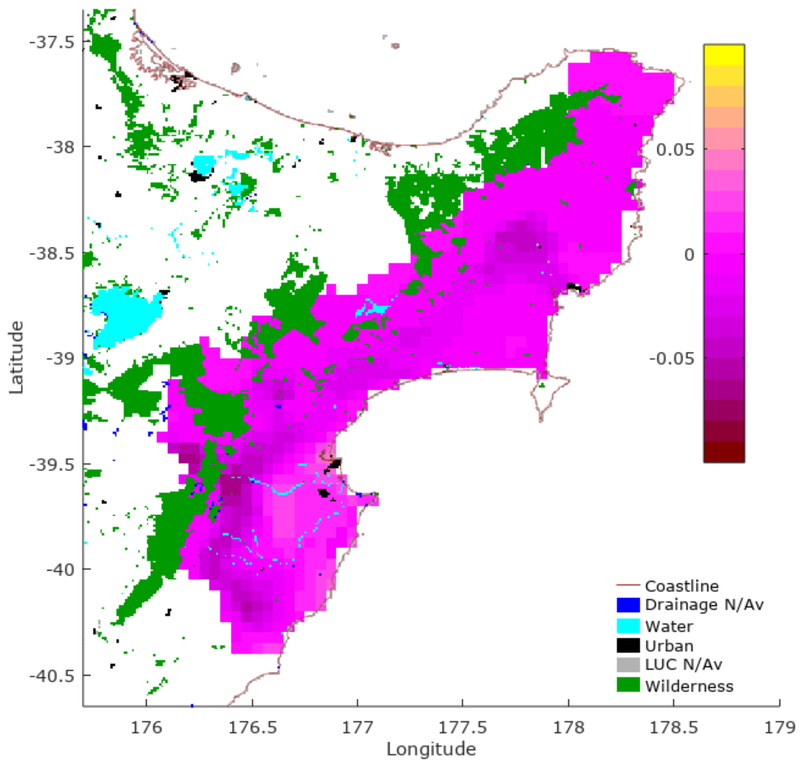

Change from 1981-2000: Disease suitability score for almond 2051-2070
Latitude
Longitude
-37.5
-38
-38.5
-39
-39.5
-40
-40.5
176
176.5
177
177.5
178
178.5
179
0.05
0
-0.05
Coastline
Drainage N/Av
Water
Urban
LUC N/Av
Wilderness


Change from 1981-2000: Frost suitability score for almond 2051-2070
Latitude
Longitude
-37.5
-38
-38.5
-39
-39.5
-40
-40.5
176
176.5
177
177.5
178
178.5
179
0.1
0
-0.1
Coastline
Drainage N/Av
Water
Urban
LUC N/Av
Wilderness

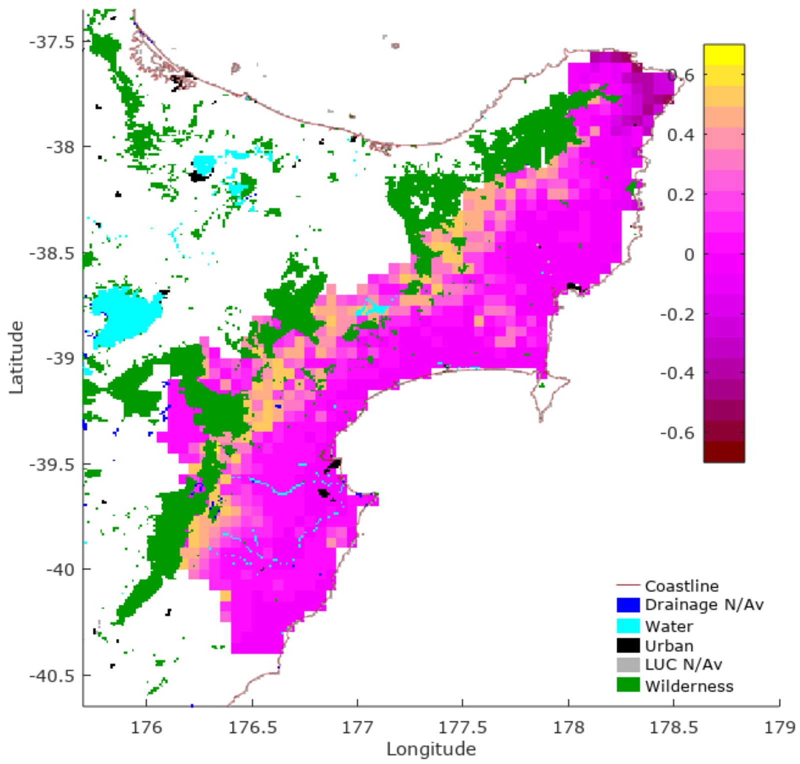

Change from 1981-2000: Pollination suitability score for almond 2051-2070
-37.5
-38
-38.5
-39
-39.5
-40
-40.5
Latitude
176
176.5
177
177.5
178
178.5
179
Longitude
0.2
0.1
0
-0.1
-0.2
Coastline
Drainage N/Av
Water
Urban
LUC N/Av
Wilderness


Change from 1981-2000: Harvest rain suitability score for almond 2051-2070
-37.5
-38
-38.5
-39
-39.5
-40
-40.5
Latitude
176
176.5
177
177.5
178
178.5
179
Longitude
0.5
0
-0.5
Coastline
Drainage N/Av
Water
Urban
LUC N/Av
Wilderness

Change from 1981-2000: Annual rainfall suitability score for almond 2051-2070



Change from 1981-2000: Chill and force suitability score for almond 2051-2070



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