WORKING DRAFT

South West Western Australia

Drought Resilience Situational Analysis

Cover to come

Australian Government
Department of Agriculture, Water and the Environment

Future Drought Fund

GROWER GROUP ALLIANCE
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South-West WA Drought Resilience Adoption and Innovation Hub

This project received funding from the Australian Government's Future Drought Fund

Working Draft

South West Western Australia

Key messages

- Agricultural 'drought months' (months of extremely low soil moisture) are projected to increase by up to 20% over most of Australia by 2030 and up to 80% in southwest WA by 2070.
- Climate models show high confidence that, across southwest WA, there will be less rainfall in winter and spring and that annual rainfall will continue to decline until the end of the century.
- Compared with 40 years ago, there is now significantly less runoff and streamflow across southwest Western Australia and the region has lost a third of its 10mm and 25mm rainfall events making its natural catchments less effective.
- The fruit, vegetable and about half of the dairy industry rely heavily on irrigation for annual production worth more than a billion dollars across the southwest. Climate projections and competing demands for water will likely place pressure on irrigation supplies.
- Filling farm dams across the southwest will become more difficult in a drying climate and re-engineering of dams to capture more water and reduce evaporation will become increasingly necessary.

Location

The South West NRM region in Western Australia covers 12 local government authorities and runs from Harvey in the north to west of Albany in the south. The region sits west of the 600mm rainfall isohyet. The following report also includes the NRM regions of Perth and Peel (and parts of the Northern Agricultural and South Coast regions) to account for the intensive livestock (pigs, chickens, dairy) and horticulture industries in these areas (Figure 1).

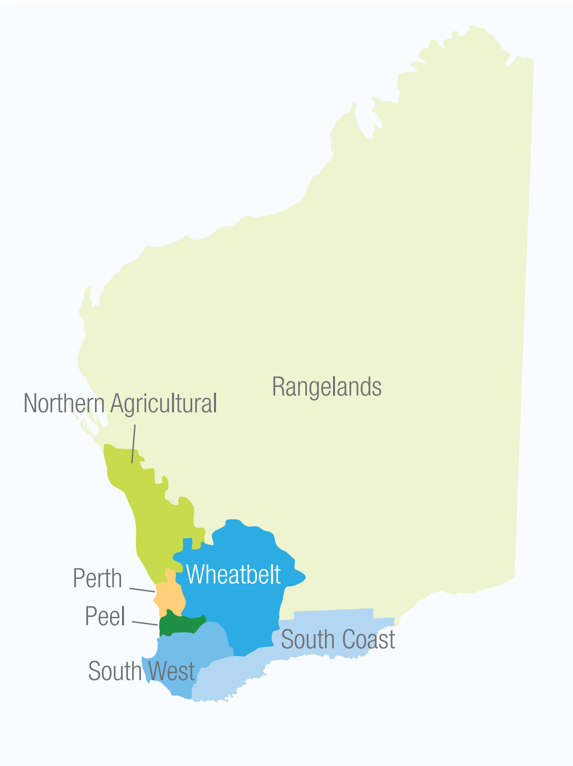


Figure 1: Location of the South West, Perth, Peel, South Coast and Northern Agricultural NRM regions referred to in this report

Industries

There are 10 primary industries across the South West, Perth and Peel NRM regions (Figure 2):

- Sheep – meat and wool
- Dairy
- Beef
- Pigs
- Chicken - meat and eggs
- Perennial fruit
- Vegetables
- Wine grapes
- Honeybee products and services
- Land-based aquaculture.

Collectively, these primary industries contributed about $2.3 billion in gross value of production in 2021 (ABS 2021 Census) (Figure 3).

South West Region

In the South West NRM region, livestock, fruit (including wine grapes) and vegetables contributed about $0.9 billion of production value in 2021 — with most of the remaining production value coming from broadacre crops and hay production ($0.65 billion). Livestock accounted for about $0.6 billion production value with sheep and wool accounting for about half of this ($0.3 billion) followed by milk ($142m), beef ($128m) and pigs ($27m) (Figure 4). Perennial fruit and vegetables accounted for about $0.34 billion of production value with avocadoes and apples dominating fruit value (66%) followed by wine grapes (21%). Potatoes and carrots made up 66% of total vegetable production value ($0.12 billion) (Figure 4).

Figure 2. Location of Perth, Peel and South West NRM regions across southwest WA

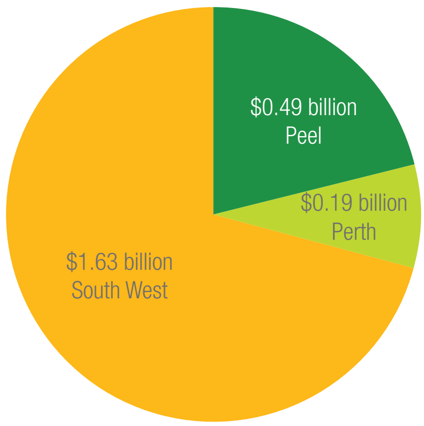


Figure 3. Gross value of agricultural production in the South West, Perth and Peel NRM regions in 2021
Source: ABS 2021 Census

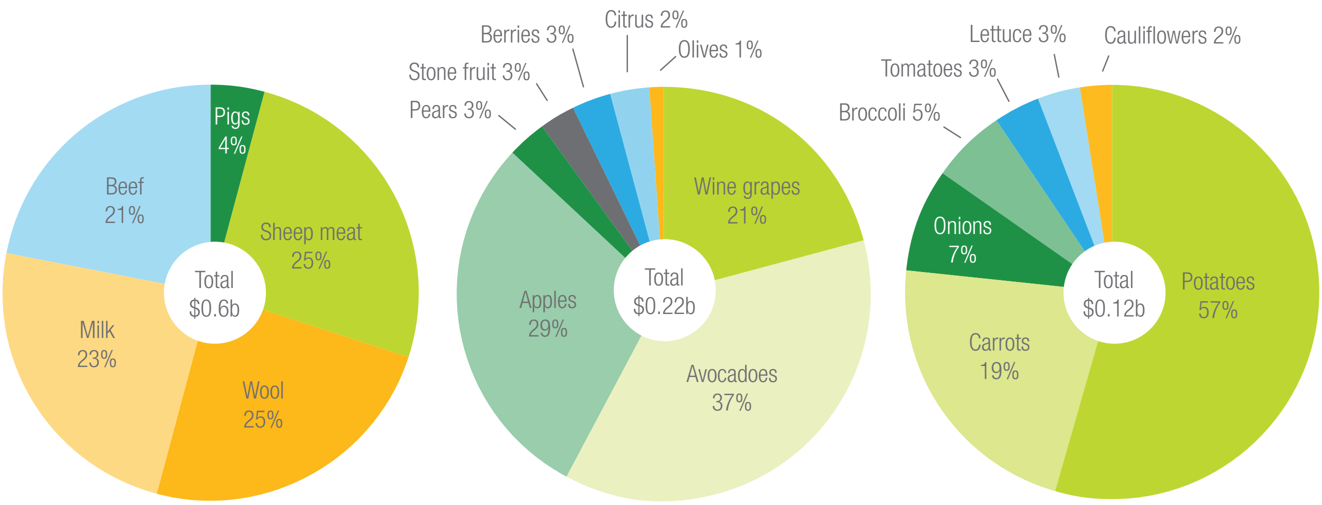


Figure 4. Relative production value of the livestock, perennial fruit and vegetable industries across the South West NRM region of Western Australia in 2021. Source: ABS 2021 Census

Primary industries across WA's South West, Perth and Peel regions contributed about $2.3 billion in gross value of production in 2021. Livestock industries (dairy, beef, sheep, pigs and chickens) accounted for $0.8 billion while fruit, wine grapes and vegetables accounted for $0.6 billion.

Total industry value

The South Coast NRM region and the Gingin/ Dandaragan shires (Northern Agricultural NRM region) also contribute significant production value to the intensive livestock (pigs/dairy/chicken meat + eggs) and horticultural industries across southwest WA and have therefore been included in the industry summaries below (Table 1).

In 2021, the South West, Peel and Perth NRM regions collectively generated 72% of the fruit and vegetable value across southwest WA. The Northern Agricultural NRM region (predominantly Gingin/ Dandaragan) generated most of the remaining fruit and vegetable value (about 24%) (Table 1).

Nearly 90% of WA's milk production occurs in the South West and Peel regions – with the South Coast region producing the remainder (Table 1).

Gingin and Dandaragan (Northern Agricultural region) generate about 60% of the state's pig production value – followed by the South West (23%), Peel (10%), Wheatbelt (4%) and South Coast (2%) (Table 1).

Gingin and Dandaragan also generate the majority of chicken egg value (93%) while chicken meat production is focussed largely in the Perth and Peel regions near processing plants (71% of total meat chicken numbers) (Table 1).

Table 1. Production value ($m) of fruit, vegetables, milk, pigs and eggs + meat chicken numbers across southwest NRM regions of WA and percentage (%) contribution to industry value by each region (2021)

NRM Region	Fruit (%)	Vegetables (%)	Milk (%)	Pigs (%)	Eggs (%)	Meat Chickens (#s)** (%)
South West	53	29	74	23	1	0
Peel	7	17	14	10	1	31
Perth	12	26	0	0	5	40
South Coast[1]	6	1	12	2*	1	17
Northern Agricultural[2]	21	27	0	61	93	11
Total value ($m)	411,552,541	408,284,655	192,783,965	119,145,953^	59,772,403	6,002,369

Source: (ABS 2021 Census)

1 South Coast NRM region contains the Great Southern region.

2 Northern Agricultural includes Gingin/Dandaragan and Geraldton shires

* Broomehill-Tambellup, Cranbrook, Kojonup, Plantagenet (ABS Census 2021)

** Value of chicken meat production unavailable for WA

^ Includes value of pigs generated by the Wheatbelt region ($5,270,855) in 2021

Recent climate

The climate across southwest WA has changed noticeably over the past 60 years with average maximum temperatures rising by about 0.5–0.7°C and rainfall declining by about 10–20% (Table 2). The number of days above 35°C have also generally increased across the region – especially in northern areas of the region (e.g., Harvey).

Rainfall

Since 1990, there has effectively been a westward shift in rainfall zones across the entire southwest corner of WA by up to 100 kilometres in some areas (Figure 5). The rainfall reductions are associated with persistent high-pressure systems over the region. While heavy rainfall events can still occur, they are often interspersed by longer dry periods.

Streamflow

Compared with 40 years ago there is now significantly less runoff and streamflow across southwest Western Australia (Figure 6). The region has lost a third of its 10mm and 25mm rainfall events making its natural catchments less effective. Modelling studies at the large water supply catchment scale have shown that for every one millimetre of lost rainfall about three millimetres of run-off are lost – making it harder to fill dams.

Table 2. Change (%) in average annual rainfall (mm) across southwest WA between 1961–1990 and 1991–2021

Years	Rainfall (mm)	Herne Hill	Gingin	Harvey	Margaret River	Manjimup	Mount Barker
1960–1990	Annual average	780	694	1015	1130	989	734
	May–Oct	660	575	838	932	775	514
	Nov–April	119	119	177	197	215	220
1991–2021	Annual average	701 (-10%)	604 (-13%)	888 (-12.5%)	1043 (-8%)	884 (-11%)	654 (-11%)
	May–Oct	582 (-12%)	497 (-14%)	751 (-10%)	869 (-7%)	702 (-9%)	446 (-13%)
	Nov–April	118 (-0.8%)	107 (-10%)	138 (-22%)	173 (-12%)	183 (-15%)	208 (-5%)

*Data in brackets indicates change in rainfall over the past 30 years.
Source: BOM data via Dr Meredith Guthrie DPIRD

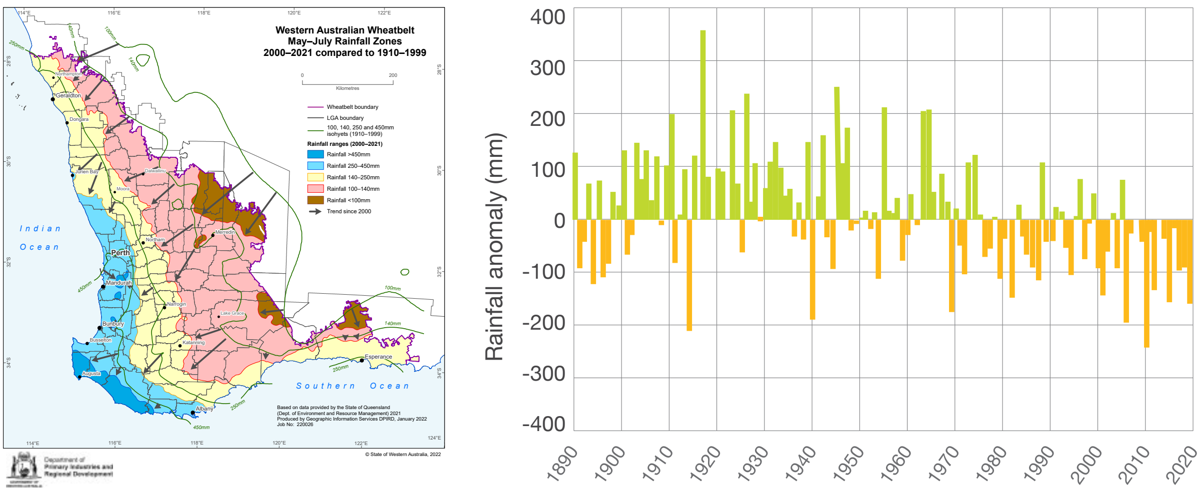


Figure 5. Shift in May–October rainfall isohyets (left) and April to October rainfall anomaly (right) over the past 100 years as the climate has dried across southwest Western Australia. Sources: left: DPIRD and right: Bureau of Meteorology

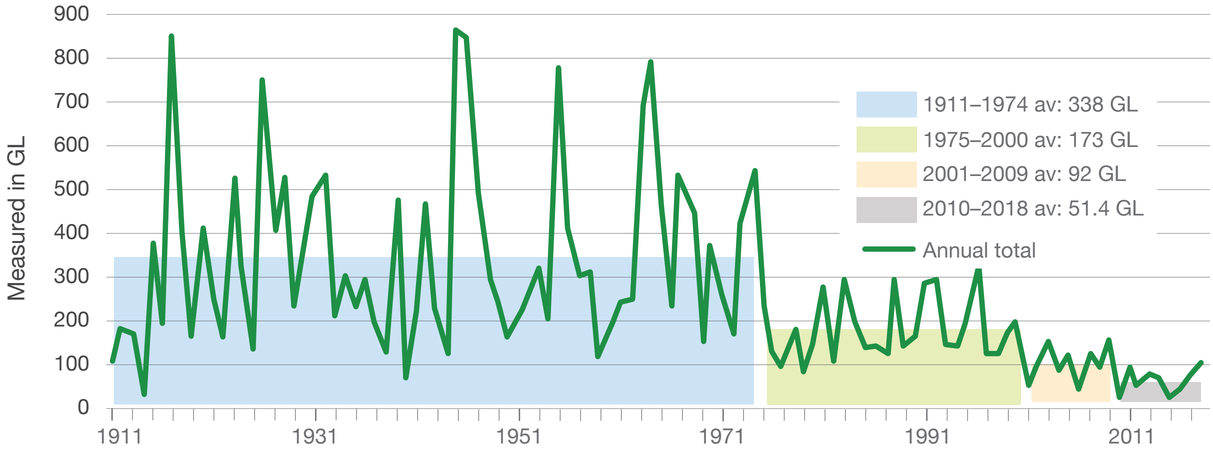


Figure 6: Annual streamflow data (GL) across southwest Western Australia over the past 100 years

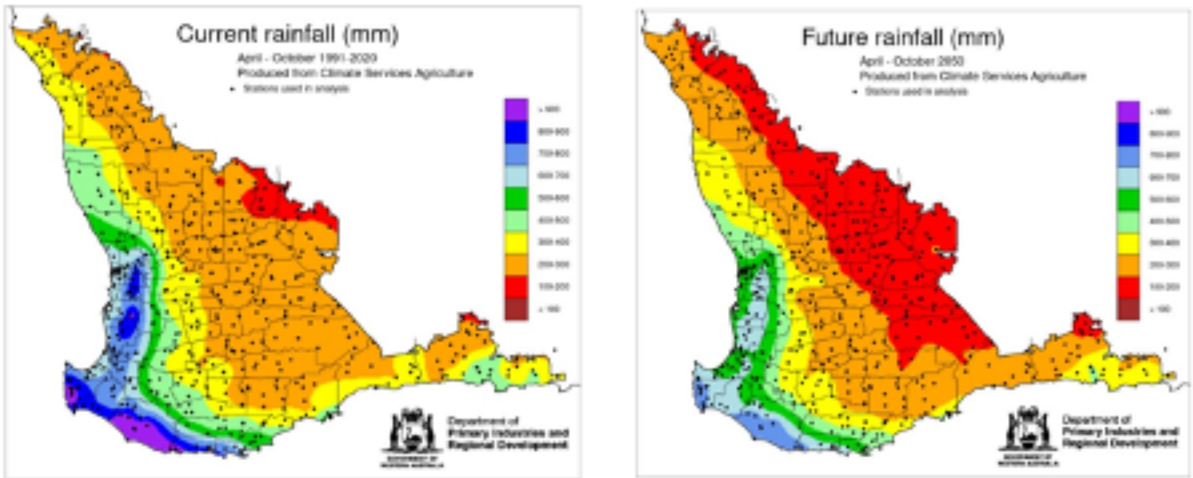


Figure 7. Projected change in growing season rainfall across southwest Western Australia by 2050 compared with the past 30 years (1991–2020) Source: DPIRD

Future climate

Rainfall

Climate models show high confidence that, across southwest WA, there will be less rainfall in winter and spring and that annual rainfall will decline, but changes to autumn and summer rainfall remain unclear. As the atmosphere warms, it can hold more water vapour, potentially leading to higher rainfall rates from weather systems. While overall rainfall will decline, there is medium confidence that the intensity of heavy rainfall events will increase, but low confidence in the magnitude of the change.

Under a high-emission scenario, rainfall is expected to decline by 29% in winter and by 36% in spring by 2090. Figure 7 outlines the extent to which growing season rainfall is projected to decline across southwest WA by 2050 compared with the past 30 years (1991–2020).

Table 3 outlines the projected changes to annual rainfall, summer rainfall (Dec-Jan) and heat risk under medium and high emission scenarios at specific locations across southwest WA by 2045. Annual rainfall is projected to decline at all locations with Margaret River rainfall expected to drop by about 10%. Rainfall at Herne Hill and Gingin (north of Perth) is expected to drop by about 5%. Heat risk days (days above 35°C) are expected to increase at all locations – with Harvey, Herne Hill and Gingin projected to receive more than five extra days per year above the threshold.

Temperature

There is very high confidence in projections that average, maximum and minimum temperatures

Table 3. Projected rainfall and heat risk days across southwest WA by 2045 under medium and high emission scenarios compared with recent climate (1991–2020)*

	Annual rainfall (mm)		Summer rainfall (mm)**		Heat risk: days >35°C***	
Emissions scenario	Medium	High	Medium	High	Medium	High
Herne Hill	670 (-4%)	669 (-4%)	33 (-21%)	39 (-7%)	39.0 (+5.8)	38.6 (+5.4)
Gingin	577 (-6%)	578 (-6%)	35 (-19%)	41 (-5%)	36.3 (+6.2)	35.7 (+5.6)
Harvey	840 (-6%)	836 (-6%)	34 (-15%)	39 (-2.5%)	20.0 (+4.4)	20.1 (+4.5)
Margaret River	918 (-10%)	916 (-11%)	38 (-19%)	41 (-13%)	2.0 (+0.5)	2.1 (+0.6)
Manjimup	813 (-7%)	814 (-7%)	48 (-23%)	53 (-14.5%)	7.6 (+1.5)	7.9 (+1.8)
Mount Barker	737 (-2.5%)	767 (+0.7%)	73 (-21%)	82 (-11%)	14.3 (+2.6)	14.7 (+3.0)

*Medium emissions: greenhouse gas emissions reduced substantially by end of the century, but not enough to stop continued warming. Adaptation continues to become increasingly harder over time. High emissions: rapid increases in greenhouse gases continue towards the end of the century. Some systems are unlikely to be able to adapt to the large changes in climate. **(Dec-Feb) ***(Jan-Dec).

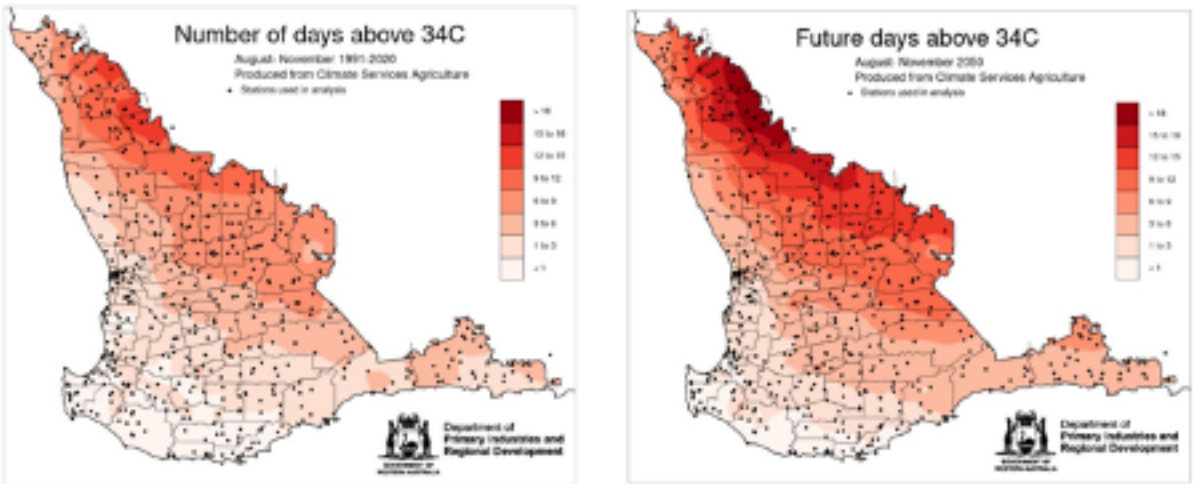


Figure 8. Projected change in days above 34°C across southwest Western Australia by 2050 compared with the past 30 years (1991–2020) Source: DPIRD

will continue to rise to the end of the century. Temperatures rise in all emission scenarios and are greater for higher emission scenarios.

By 2030, mean annual temperature is projected to increase by 0.5–1.2°C under medium- and high-emission scenarios, compared to current conditions (the average of conditions between 1986 and 2005). The number of days above 34°C are also expected to rise across southwest WA by 2050 (Figure 8).

By 2090, mean annual temperature is projected to increase by 1.1–2.1°C in a medium-emission scenario and 2.6–4.2°C in a high-emission scenario. Average maximum and minimum temperatures are projected to increase by similar amounts. There is little seasonal variation in projected temperature increase.

The intensity and duration of hot spells is projected to increase across WA, wet years are likely to become less frequent and dry years (and drought) are likely to become more frequent.

Streamflow

Projected climate change is expected to reduce streamflow into dams and groundwater recharge in western and south-western areas of the state. Surface water and groundwater resources are very sensitive to climate change and recharge is expected to be greatly reduced. Small changes in rainfall result in larger changes to water yield; for example, in catchments along the Darling Scarp, an 11% decline in rainfall results in a 31% decline in water yield.

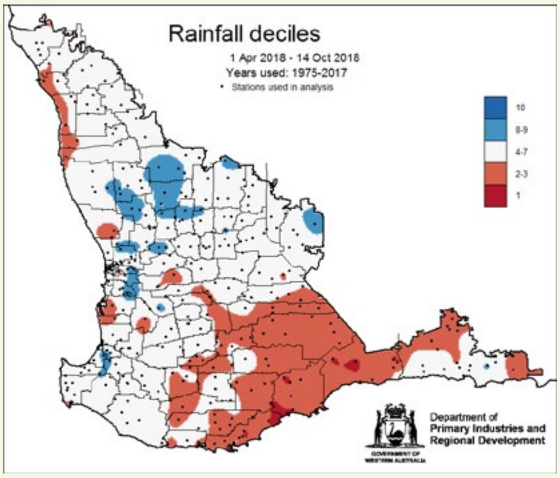
Across southwest WA the projections are for median streamflow to decline by 24% by 2030, and by 45% and 64% for medium- and high-emission scenarios in 2090.

Drought

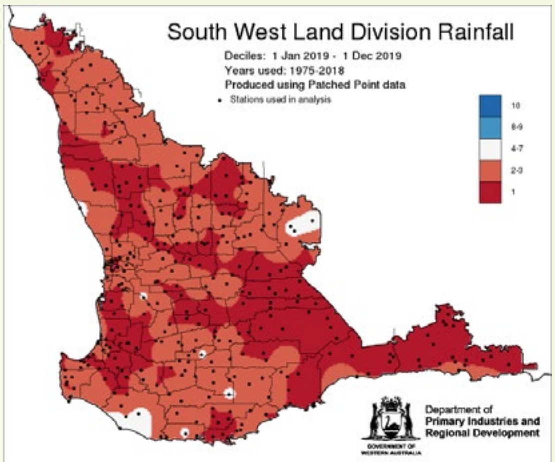
The number of dry days is likely to increase over all of WA. Agricultural drought months (defined as a month of extremely low soil moisture) are projected to increase by up to 20% over most of Australia by 2030 and up to 80% in southwest WA by 2070. The projected duration and frequency of droughts in the southwest increases for all emission scenarios, with a high level of confidence in these projections. Evaporative demand is also projected to increase – with potential evaporation projected to increased by about 2.5% by 2030 compared to current figures and by 5.4% by 2090 under a medium-emission scenario and 10.3% under a high-emission scenario.

In 2020 a record 12 water deficiency declarations were enacted across southwest WA after several dry years in a row (see maps below). Many farm dams were down by 75% of water supply with some completely dry. Water carting for livestock was essential and many farms in the southeast de-stocked.

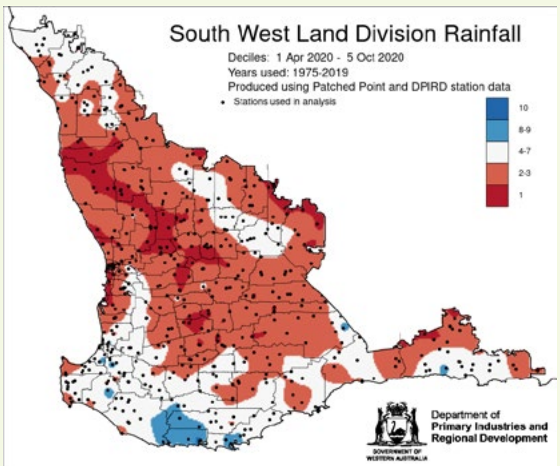
The following sections of this report outline the 10 primary industries across southwest WA in more detail and discuss the implications that a drier and hotter climate will have on their productivity and viability.



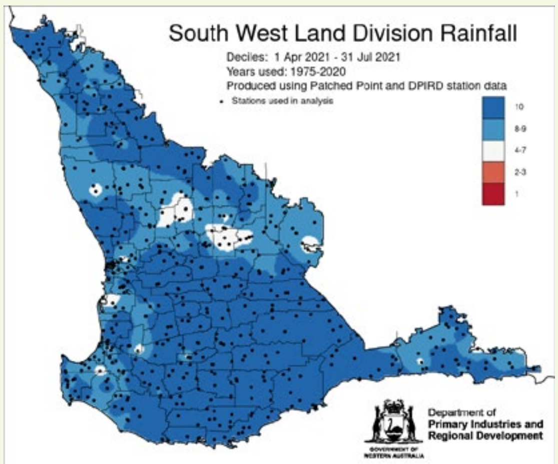
2018



2019



2020



2021

The far southwest of WA has yet to experience several very dry years in a row but projections are for drought periods to increase by up to 80% in the region by 2070.

Extensive Livestock

The South West and Peel NRM regions generated about 87% of WA's dairy milk production value in 2021, a third of WA's total sheep meat and wool production value and just under a fifth of beef cattle value (Table 4). The South Coast NRM region contributed about 25% of WA's total sheep meat and wool production value, 14% of beef cattle value and 13% of dairy milk value (Table 4).

Recent climate change across the southwest of WA has impacted extensive livestock production in both positive and negative ways. The decline in rainfall across the far southwest has resulted in less waterlogging, which coupled with warmer winter and spring temperatures, has meant pastures grow more quickly. However, more variable starts and finishes to the growing season have resulted in pasture supply issues in some years – especially in autumn-early winter.

Climate models for southwest WA are predicting with a high degree of confidence that annual rainfall (particularly in winter and spring) will decline further out to 2050 and beyond. The number of heat stress days (days above 35°C) are also predicted to rise. This inevitable climate change will further impact forage and water supplies across the southwest and heat stress could affect reproductive rates and livestock water requirements (Table 5).

Key messages

- Climate models for southwest WA indicate annual rainfall (particularly in winter and spring) will decline further out to 2050 and beyond.
- Later and more variable starts to the growing season will increase the need for deferred grazing and supplementary feeding.
- However, once established, pastures will likely benefit from less waterlogging and warmer winter temperatures.
- Water supply and quality could become issues for irrigated dairy and cattle farms and less run-off will be available to fill farm dams.
- Incidence of heat stress could increase, leading to poorer reproductive rates and higher livestock water requirements.
- Innovations and adaptations across the sheep, beef cattle and dairy industries will be required to meet future forage, water and stock shelter needs.

Table 4. Proportion (%) of total WA sheep, beef and dairy production value ($m) in 2021 across NRM regions

NRM region	Sheep meat (%)	Wool (%)	Beef cattle (%)	Dairy (%)
South West	26	25	14	73
Peel-Harvey	7	7	4	14
South Coast	24	24	14	13
Wheatbelt	31	31	3	0
Northern Agriculture	12	12	5	0
Rangelands	<1	1	60	0
TOTAL	**607,037,135**	**570,245,607**	**929,345,467**	**193,632,015**

Source: ABS Census Data 2021

Table 5. Potential impacts of projected climate on sheep, beef cattle and dairy enterprises across southwest WA.

Production factor	Climate impact
Forage supply	• A later and more variable start to the growing season will increase production risk for pastures. • Deferred grazing of pastures at the break of season will likely become more important. Supplementary feeding costs could increase. • Reduced rainfall and higher temperatures could reduce forage production by up to 10%. • Flexible lot-feeding or confined feeding systems will be needed to maintain or finish livestock in dry years • In the higher rainfall areas of the southwest, increased temperature in winter and early spring and reduced waterlogging could benefit livestock production by increasing forage production.
Water supply	• Reduction in reliability of run-off into farm dams. Roaded and natural catchments will need to be larger or amended with polymers or plastic to increase run-off and fill existing dams. Stock water quality could become an issue. • Water security and quality could become issues for irrigated dairy and cattle farms.
Heat stress	• Increased temperatures during summer could increase heat stress of livestock leading to poorer reproductive rates and increasing livestock water requirements.

Source: Adapted from Sudmeyer et al (2016)

Sheep - meat and wool industries

National industry

A strong start to Western Australia's season coupled with above average rainfall patterns for most sheep regions of NSW and Victoria will see the national flock rise by 7.2% or 5.1 million in 2022, to 76 million head (Figure 9). On the back of this growth, lamb production is forecast to reach record levels in 2022 at 549,000 tonnes with higher carcase weights driving the increase. Out to 2023, Meat Livestock Australia (MLA) expects further growth to 78.75 million, which is 23% or 14.75 million head higher than the 100-year low in 2020 (MLA sheep update, July 2022).

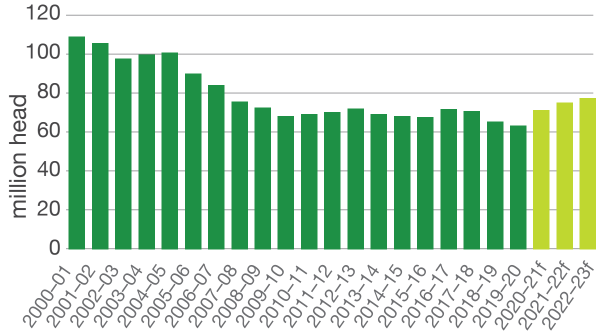


Figure 9. National sheep flock (numbers) 2000-2022. Source: ABS; MLA forecasts

WA industry

WA has about 5000 sheep properties and manages about 20% of the national sheep flock (approx. 14 million head) with most of the flock in the Wheatbelt region (Figure 10). The South West NRM region reported about 824,094 sheep and lambs across 479 properties in 2021 (Table 6).

The WA sheep flock has restructured over the past 30 years with the breeding ewe proportion of the flock increasing and the proportion of wethers decreasing largely in response to increasing sheep meat vs wool production. Despite the fall in sheep numbers over the past few decades, productivity of the WA flock has increased with weight of lamb produced per ewe mated increasing from 4 to 8kg during the past 20 years.

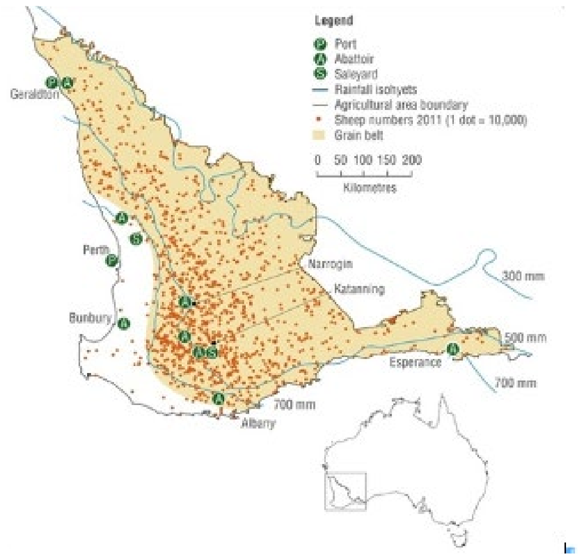


Figure 10. Distribution of sheep within the Western Australian agricultural area showing rainfall isohyets and location of abattoirs and ports. Source: ABS and DPIRD analysis)

Exports

The value of sheep meat exports has almost trebled in the past 15 years while the value of live sheep exports has halved (Figure 11). Over the past 30 years, WA's wool production has declined in line with the drop in total sheep numbers but wool production per head has increased and this, along with a decrease in average fibre diameter and an increase in price, has seen the value of wool production increase. The gross value of sheep meat and wool production has increased significantly over the past 30 years, from about $25/head in 1990 to $93/head in 2021 (Figure 12).

Climate impacts

Significant R&D is underway to better equip the WA sheep industry for a drier, hotter climate. Table 7 outlines recent and current RD&E connected with climate change adaptation and mitigation across the sheep meat and wool industries. While the southwest WA sheep industry is in a strong position, the impacts of projected climate change on water supply and quality, seasonal feed gaps and extreme heat days will intensify as projected climate change is realised. The work needed to meet these challenges is outlined in Table 6.

Table 6. Number of sheep and lambs and sheep properties across the South West NRM region in 2021

Location	Number of sheep & lambs (2021)	Number of sheep farms (2021)
Boyup Brook	452,438	137
Bridgetown-Greenbushes	132,875	40
Busselton	79,350	68
Augusta Margaret River	46,724	69
Manjimup	41,515	51
Donnybrook-Balingup	23,726	40
Capel	16,103	13
Nannup	12,130	13
Harvey	11,143	24
Collie	6,758	8
Dardanup	2,332	14
TOTAL	**824,094**	**479**

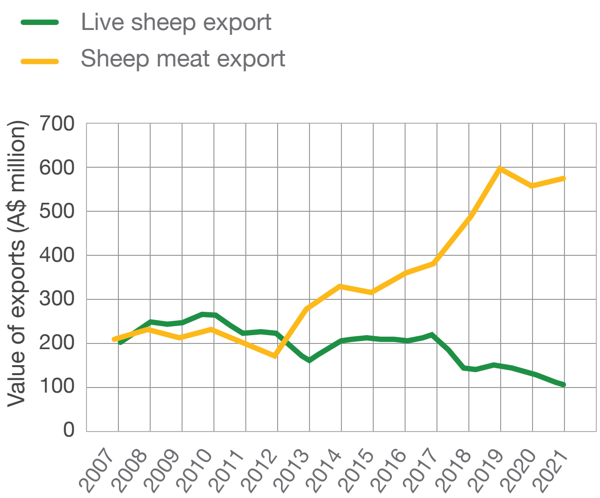


Figure 11. Value of sheep meat exports (2007–2021). Value of sheep meat exports has almost trebled since 2011. Over the same period, the value of live sheep exports has declined by 50%. Source: Kate Pritchett DPIRD

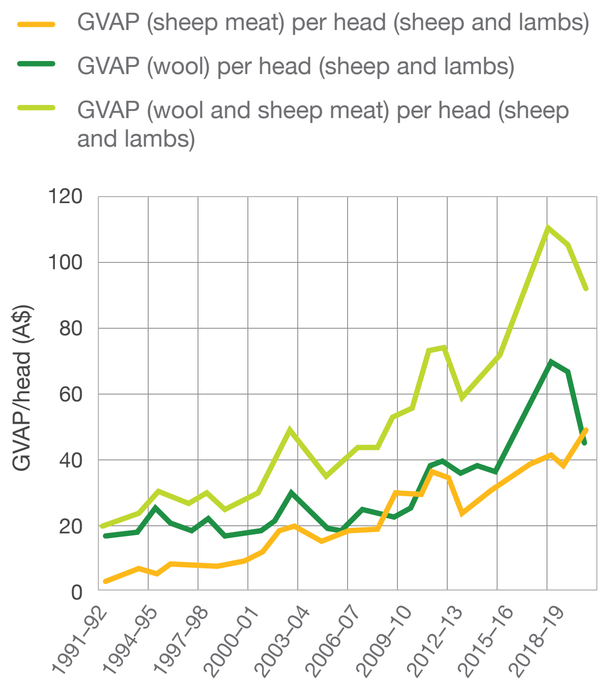


Figure 12. Gross value of sheep meat and wool production has increased significantly over the past 30 years – from about $25/head in 1990 to $93/head in 2021. Source: Kate Pritchett DPIRD

Table 7. Summary of drought mitigation levers available to the South West sheep meat and wool industries and the RD&E gaps needing attention to better equip the industries under projected future climate change.

Drought Lever	What's worked/being done?	What's needed?
Water	*Smart Dams project* (Richard George) Sheep Sustainability Framework	Dam design for a drying climate: • capture more, quality water • reduce evaporation • water use efficiency measures • training of contractors needed as skill base is ageing and exiting industry What are the economics of improving dam infrastructure in the south west? Long term business planning to be ready for the future climate.
Heat	*Sheeplinks – FutureSheep*: DPIRD-MLA funded project that investigates how sheep farmers in the medium to low rainfall zones can adapt to impact of climate in 2030 and 2050. The first tranche of work has been a climate study predicting what the wheatbelt will look like for sheep farmers in the next 20 years. '*Investigating heat stress in ewes – reproductive performance' project*: will quantify the effect of heat events on sheep reproduction, behaviour, nutrition, and wellbeing over three seasons in a range of climatic conditions. MLA Donor Company investment project, led by UWA with Murdoch and CSIRO collaboration. Improving reproductive performance has consistently been ranked the highest priority by our sheep producers and advisory committees. *Impact of shade availability and heat stress on joining behaviour and success in merino sheep* (MLA & WALRC): determine if there is a link between heat stress, merino behaviour and merino reproductive success in order to better understand what influences reproductive success. *Water intake during joining under heat stress* (UWA, MLA, WALRC): determine whether access to shade changes water consumption and behaviour leading up to drinking and how this may impact reproductive performance in merino ewes. *Design and management of edible shelter* (MLA, CSIRO, UWA, Murdoch): currently no recommendations for producers regarding shrub species selection, density and planting configuration to optimise shelter and feeding value. The project will investigate the structure and design of edible shrub shelter belts.	Infrastructure needed to better manage sheep production in drier, hotter climates? *Sheeplinks – FutureSheep* project will investigate a range of adaptations for sheep producers in a drying climate: 1. Feedbase - Pasture and shrub species that are better adapted to hotter and drier conditions and able to fill feed gaps. A number of these are currently being field tested by the SheepLinks Feed365 project. 2. Animal management and genetics – Altered management calendars such as joining date, improved reproduction or feed conversion and heat tolerance. 3. Business models – Enterprise balance including crop alternatives and conservation grazing models, alternative markets, for example carbon or sustainable farming, risk management and business diversification. 4. Evaluate methods to reach whole farm carbon neutrality.
Feed	*Feed Intake Efficiency project* (MLA/DPIRD): aims to improve the feed conversion efficiency of sheep, which require less feed to produce more meat, as well as less methane and carbon dioxide. *Feed365 project* (focus currently on wheatbelt not high rainfall): • To re-design the pasture/forage systems in the wheatbelt of WA to be more productive and resilient in the face of a drying climate and increasing seasonal variability.	Issue of feed gap going to become more of an issue as climate changes. Need sheep production systems that consider: • Containment feedlots • Forage conservation • Forage shrubs • Pasture species mixes for higher rainfall areas and range of soil types

Drought Lever	What's worked/being done?	What's needed?
	• To measure the impact of trees in the landscape on pasture productivity. *Pastures from Space*: partnership between DPIRD, Commonwealth Scientific & Industrial Research Organisation (CSIRO) and Landgate that provides estimates of Pasture Growth Rate (PGR) and Feed on Offer (FOO) on a weekly basis across the South West Agricultural region.	
Production efficiencies	Lamb and ewe survival is the #1 ranking issue for WALRC *Sheep Reproductive Strategic Partnerships* (MLA): seeks to profitably and sustainably increase lamb production by increasing weaning rates and decreasing mortality. *Towards 90* (MLA): adoption program aiming to accelerate the adoption of sheep reproduction best-practices. *Lifetime Ewe Management* (AWI): The content of LTEM is based largely on scientific outcomes from the Lifetime Wool project which quantified the impacts of nutrition throughout the reproductive cycle on ewe and progeny performance over their lifetime. About 4000 sheep producers across Australia have joined or completed LTEM. AWI currently supports woolgrower participation by offering levy payers a $1,000 subsidy on the LTEM course fee. *Genetic Evaluation*: productivity, Efficiency and Profitability (GEPEP): AWI project seeking to quantify the variability in feed intake, energy reserves and energy partitioning between Merino sire groups within the MLP Project (Merino Lifetime Productivity Project) and develop relative economic values and indices that will enable ram breeders to select sheep to improve stocking rate and profit per hectare.	MLA – overarching target for Australian sheep industry to reach 100% weaning by 2026 Shelter systems for lamb survival + shade for ewes during joining/gestation Lots of sheep production information available but would benefit from being pulled together into one central spot – link AWI + MLA + GRDC + unis + RDCs

Business efficiencies	Sheep's Back (AWI) Wool Tag committee – shearing training
	Elders – has recently appointed a livestock support officer
		Benchmarking? Producers need to 'see where they are in order to appreciate where they could be.'
		Labour and OHS issues with shearing
		Pilot Wool Tag program needs support to extend the shearing training to financial, social and cultural program for participants
		Need more grower groups with sheep extension expertise
		• Need an adoption program for carbon accounting/sequestration:
		  • Extension program that explains the sources of carbon emissions and sequestration opportunities and helps producers perform a carbon account for their businesses.
		  • Provide on-farm options to mitigation of emissions: how many hectares of eligible vegetation are needed?
		  • Tools and calculators needed that deal with mixed farms.

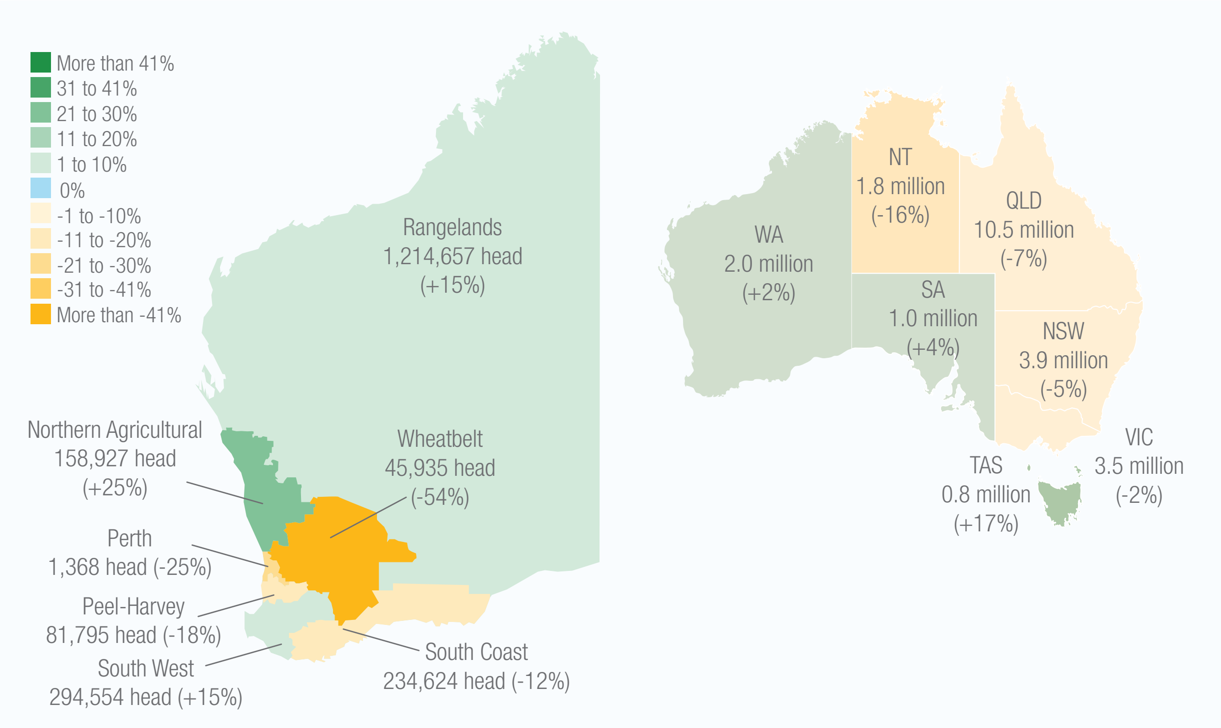


Figure 13. Changes in beef cattle numbers across Australia and within Western Australian regions between 2018-19 and 2019-20. Source: MLA

Beef cattle industry

National industry

The Australian beef cattle herd sits at about 24,431,174 head (across 47,758 farms). As favourable seasonal conditions remain through 2022 and the herd rebuild continues, the national herd is expected to grow by 6% to reach 27.6 million head (MLA beef update, July 2022) (Figure 14).

WA industry

Western Australia manages about 9% of the national herd (2,132,146 head in 2021) across 2,691 farms. Most WA cattle are in the rangelands (>1.2 million in 2020) with about over 800,000 head spread across southern WA. The South West NRM region reported about 215,016 head of cattle in 2021 across 879 farms (Table 8). The South Coast

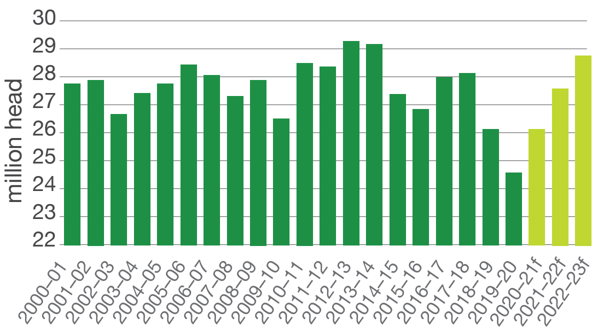


Figure 14. National cattle herd numbers 2000–2022.
Source: ABS; MLA forecasts

Table 8. Number of beef cattle and beef cattle properties across the South West NRM region in 2021

Location	Number of beef cattle (2021)	Number of farms (2021)
Manjimup	40,121	154
Boyup Brook	29,451	103
Harvey	27,763	115
Busselton	26,475	112
Augusta Margaret River	18,342	88
Donnybrook-Balingup	17,366	84
Capel	15,481	64
Nannup	13,482	44
Dardanup	12,853	65
Bridgetown-Greenbushes	8,649	30
Collie	4,129	16
Bunbury	903	3
TOTAL	**215,016**	**879**

NRM region supports a similar number of beef cattle to the South West region (Figure 13).

Production value

Total turn-off (slaughter and live export) reached 792, 000 head in 2019–2020; the highest on record over the past decade and an 11% increase year on year. Of this, domestic slaughter accounted for 58% of turn-off while live export accounted for 42% (Figure 15).

Demand has fuelled continued record prices across saleyards throughout WA over the past couple of years. Total beef production value across WA in 2021 was reported at $0.93 billion with 60% of this value arising from the rangelands and about 32% from the South West, South Coast and Peel regions (Table 9).

Climate impacts

Recent climate change has reduced waterlogging across southwest beef pasture areas with warmer winter and spring temperatures boosting growth rates. However, the autumn break to the season has become later and variable which, coupled with early spring finishes, has limited forage supply in some seasons. With 60% of annual pasture grown in just three months, extending the autumn and spring forage gaps through hay/silage conservation and supplementary feeding remains the most challenging issue for the industry.

Table 10 outlines the recent and current beef industry RD&E that has tackled forage supply and conservation. The table also identifies the RD&E priorities for the industry under projected climate change.

About 56% of the cattle sent for slaughter are consumed domestically while 46% are exported as chilled beef predominantly to China (26%), USA (16%) and Indonesia, Korea and Japan.

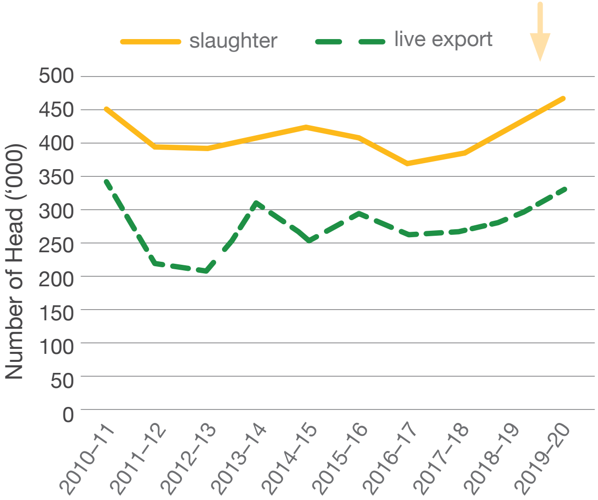


Figure 15. The number of WA cattle turned off via domestic slaughter and live exports 2010-2020 (Based on ABS data, DPIRD analysis)

Table 9. Beef cattle production value ($m) across WA NRM regions in 2021

Region	2021 production value ($m)	%
Rangelands	557,543,554	60
South Coast	129,595,370	14
South West	127,651,425	14
Northern Agricultural	48,561,814	5
Peel	41,453,877	4
Wheatbelt	24,418,055	3
Perth	121,372	<1
TOTAL	**929,345,467**	

Table 10. Summary of drought mitigation levers available to the southwest WA beef cattle industry and the RD&E gaps needing attention to better equip the industries under projected future climate change.

Beef industry	What's worked/being done?	What's needed?
Water	*Southern Forests Irrigation Scheme* – plan to secure more water for livestock and horticultural businesses in Manjimup area (proposal on hold) *Smart Dams project* (Richard George)	Farm water (and water quality) security – extension required around regulation issues (new licenses and spring-fed dams). Dam design for a drying climate: • capture more water • reduce evaporation • water use efficiency measures • training of contractors needed as skill base is ageing and exiting industry

Beef industry	What's worked/being done?	What's needed?
Heat		Information on multi-use shelterbelts needed (Drought Hub-funded project currently being designed through Murdoch University) Manjimup cattle producer Mark Bending: All cattle producers will have to plant carbon offsets in the future. What trees and mix of trees will best for this region? How will we measure carbon accumulation? What are the best fencing options? Practical information is needed around shelterbelt design and carbon measurement.
Feed	*Grazing Matcher workshops*: a 12-month program delivered via a supported coaching model with one-on-one and group learning. Grazing Matcher is an initiative of animal production advisor Jeisane Accioly, who partnered with former dairy researcher Martin Staines and agronomist Dan Parnell, to help producers improve grazing management and business performance. Farmers match grazing inputs with outputs and develop grazing strategies using rotational grazing and monitoring of pasture leaf growth stage and animal condition. Participants have noted they now have more pasture and higher stocking rates since employing the rotational grazing system. *SWCC: Making hay/silage workshops*: developed following some short/dry winter years – big uptake in Harvey, Vasse and South Coast. *Rumen8* (originally developed for DPIRD Vasse Research Station): calculates best supplementary diet for dairy and cattle classes (heifer, dry, bull, lactating etc). Calculates $/L or $/kg – calculates cost of ration and predicts animal growth rate. Identifies most cost-effective supplementary feed ratio. Links nutritional and disease information. Allows user to design a diet from up to 15 feeds or mixes and ensure the dietary needs of animals are met. *Pastures from Space*: partnership between DPIRD, Commonwealth Scientific & Industrial Research Organisation (CSIRO) and Landgate that provides estimates of Pasture Growth Rate (PGR) and Feed on Offer (FOO) on a weekly basis across the South West Agricultural region. *EverGraze*: national RD&E project that designed, tested and implemented farming systems based on perennials to increase profitability of livestock enterprises and at the same time reduce ground water recharge and soil loss by water and wind in the high rainfall zone of southern Australia. *Not enough nodules: impact of herbicides, pesticides and other farm management tactics* (MLA-funded project through Murdoch University Centre for Rhizobium Studies): Recent surveys of commercial pasture	• Perennial pasture system needed for Manjimup/Harvey areas. Manjimup Pasture Improvement Group: all have tried perennials, but none have worked to date – if they survive the summer, they are not robust enough to be grazed. • High rainfall pasture information needed – need a regional approach to pasture management as different issues in different areas. • Poor nodulation in legume pastures – why? (Murdoch University Centre for Rhizobium Studies investigating) • 60% of pasture in the southwest is grown in just three months of the year. Information/ extension packages needed on how to extend the growing season 'shoulders'. • Information on best time to cut for silage • Mixed species fodder crops to adapt to a changing climate, to reduce feedbase variability and to enhance farming systems (current WALRC producer-identified RD&E priority) • Management and extension packages around time of calving to even out turn-off numbers and better match to feed supply • Incorporate MLA feed library into Rumin8 and extend program to farmers. • Develop adoption tools to support the utilisation of Pastures from Space. (MLA has plans to work with DPIRD to progress this). • Revisit EverGraze messages?

Beef industry	What's worked/being done?	What's needed?
Feed	paddocks have shown more than 90% have inadequate legume nodulation. Without adequate nodulation, legumes respond poorly to applied phosphorus restricting pasture production and therefore feed supply to livestock can be significantly restricted.	
Production efficiencies	From WALRC RD&E priority setting document: The traditional beef production system in the southern regions of WA is based around calving in Autumn with the objective of turning off a high percentage of calves at the end of spring or soon afterwards. This system results in a relative oversupply of high-quality beef in Spring and a relative scarcity in Autumn and winter months. The remainder are grown out and finished on high quality summer forages or grain, and a small proportion are carried over to be sold as 1–2-year steer beef. Modern consumers demand high quality cuts year-round at an affordable price. Supermarkets issue contracts to meet and capture this demand but there remains a large supply deficit in Autumn and Winter.	The most important driver of farm business profit is in optimising stocking rate. Herd fertility next most important factor but of considerably lower importance. Calving in Autumn does not allow for stocking rate to be optimised because peak grazing pressure occurs during calving and early lactation when feed supply is tightest (Autumn). Need to examine alternative production systems based around a winter calving and a stocking rate that reflects the equivalent of an Autumn calving cow with calf at foot. This system would produce more calves per unit of land and more beef turnoff into a finishing market which would better deliver on consumer demand.

Business efficiencies	*Red Sky* national benchmarking system (but little take up)
	
	Australian Beef Sustainability Framework: defines sustainable beef production and tracks performance over a series of indicators annually.
	
	Inform producers of their carbon footprint. It should concentrate on standardising methodologies, identifying gaps in knowledge and coordinating appropriate research projects to satisfy unknowns.
		• Benchmarking – why so little take up by the WA beef industry?
		• Need a 'train the trainer' program to get better uptake national benchmarking system
		• Also need to understand WA industry nuances: WA produces lighter carcase weights than the eastern states (WA processors set up for lighter carcases and heavier carcases receive penalties) – this creates production inefficiencies on a kg/mm basis.
		• Need to translate Australian Beef Sustainability Framework on the ground in WA
		• Need an adoption program for carbon accounting/sequestration:
		  ◦ Extension program that explains the sources of carbon emissions and sequestration opportunities and helps producers perform a carbon account for their businesses.
		  ◦ Provide on-farm options to mitigation of emissions: how many hectares of eligible vegetation are needed?
		  ◦ Tools and calculators needed that deal with mixed farms.
		• Plastic waste from hay nets and silage wraps – 'could become a big market issue' China no longer taking waste for recycling. NZ produces different recycling drums for each product for recycling. Recycling system needed in WA to develop waste reduction accreditation scheme (could use Drum Muster as collection points).

Dairy industry

National industry

In 2018–2019, there were an estimated 5,800 dairy farms in Australia. Between 2000 and 2019 the total number of Australian dairy farms fell by about 47% — a phenomenon repeated across all Australian states. Over the same period, average milk production per farm has risen from 811,000 litres per farm to 1.5 million litres per farm due to increases in average herd size and stocking rates. While the number of farms across Australia has decreased, the average herd size is growing. In 1985, the average herd size was 93 cows and in 2019–2020 it had grown to 279. There is also an emerging trend of large farm operations of more than 700 dairy cattle.

WA industry

The Western Australian dairy industry is located around three main areas of southwest WA: Harvey, Margaret River and Denmark on the south coast (Figure 16).

The processing sector for the industry is dominated by three main companies along with several small businesses including organic operations.

The industry currently (2022) has about 116 registered dairy farms and a total herd size of about 50,000 cows. Dairy farm numbers have dropped steadily over the past 40 years (Figure 17).

WA has the largest herd sizes of all Australian dairy farms. About a quarter of WA's dairy farms have more than 350 cows and five farms have more than 1000 cows.

Stopping further shrinkage of the WA dairy industry is an important focus of the state's industry body, Western Dairy. The industry is expensive to enter and labour and regional accommodation for workers are major constraints. Drier years require more supplementary feeding and labour. Financial incentives, such as low interest loans, could help new entrants into the industry. Western Dairy is also investing in dairy farm human resource management to help the industry train and retain staff.

Figure 16. Distribution of dairy farms across southwest Western Australia

WA produced just over 360 million litres of milk in 2020-2021 (Table 11), contributing 4% of Australia's total milk production (Figure 18). The value of milk leaving farms has hovered between $190-195m over the past five years (Table 11).

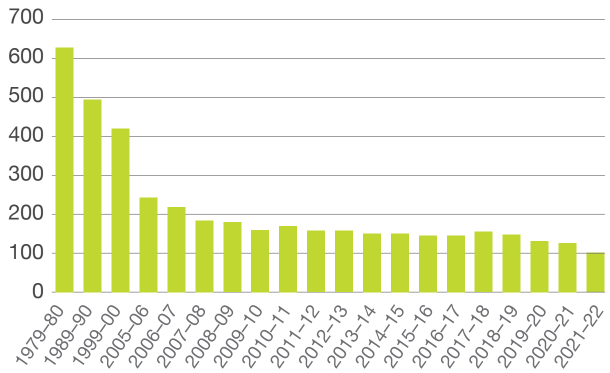


Figure 17. Change in number of registered WA dairy farms over the past 40 years (2006–2021)

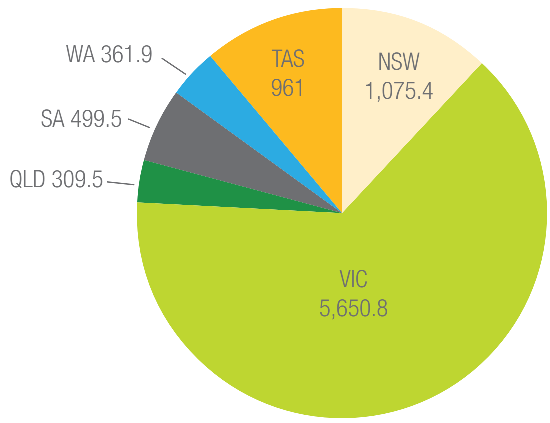


Figure 18. Milk production (millions of litres) by Australian state in 2020–21

Table 11. Volume and value of WA milk production 2016–2021

	2020-21	2019-20	2018-19	2017-18	2016-17
Volume (million litres)	362	364	374	385	385
Value ($m)	194	190	188	192	195

Source: Western Dairy

Markets

Nearly 80% of WA milk is consumed fresh with a further 10% sent for domestic manufacturing. The remainder is manufactured for export (Figure 19). At a national level, about 65% of Australian dairy is sold on the domestic market, with the remaining 35% exported.

Figure 19. Destination of milk produced across Australia (2019-2020)

Water

About 50% of WA dairy farms have access to irrigation for pasture production with the remainder sitting outside irrigation schemes and operating under dryland pasture production systems. Farms in and around Bunbury rely on irrigation water from Harvey dam – with water restrictions (as low as 40% allocation) implemented in dry years.

Traditionally, the most common irrigation method in the Harvey irrigation area has been flood irrigation via an open channel system. Sprinkler irrigation is the dominant system in areas outside the Harvey scheme. In recent years, Harvey Water has converted about a third of the open channel systems to closed pipes. Some of the open irrigated channels are more than 80 years old with about 30% of water passing through the channels lost to leakage, seepage, evaporation, or inefficient delivery practices. There is a need to eliminate flood irrigation and improve water use efficiency of milk production. Implementation of available effluent management systems is also needed to improve nutrient and water use on farms.

Climate impacts

Table 12 outlines the recent and current RD&E undertaken in the WA dairy industry to improve water use efficiency and forage productivity/quality in a drying climate. Also outlined are the RD&E priorities required to meet the challenges presented by projected climate change in the southwest WA region.

Table 12. Summary of drought mitigation levers available to the southwest WA dairy industry and the RD&E gaps needing attention to better equip the industries under projected future climate change.

Drought lever	What's worked/being done?	What's needed?
Water	*Smarter Irrigation for Profit*: a national project being delivered to the dairy industry via Dairy Australia and Western Dairy and supported by funding from DAWE. The project enables irrigators to lift productivity and profit by putting water where it needs to go, using less power and growing more pasture. About 50% of WA dairy properties (116 @2022) operate using irrigation. *WA Code of Practice for Dairy Farm Effluent* (updated 2021): encourages farmers to use effluent to meet the nutrient needs of their pasture. About a third of WA dairy farmers upgraded their effluent systems over the past four years, with more undertaking reviews and developing plans in that time. *The Dairy for Healthy Estuaries project* (built on DairyCare project): aligned with the Dairy Farm Effluent code of practice and aims to reduce nutrient footprint from dairy farm effluent. *Australian Dairy Industry Sustainability Framework*: aligned with UN sustainability goals to increase water use efficiency by improving water productivity, active monitoring of water consumption, using recycled water and developing water security management plans.	• Determine the water supply and water quality issues that the industry will face into the future as the climate dries • Additional funding for extension of effluent management systems to improve nutrient and water use on-farm. • Water use efficiency — need to remove open drains and replace with covered piped system • Flood irrigation needs to be eliminated • Investigate better use of on-farm water: water filtration system to make groundwater potable. • Interview dairy irrigators to compile their views on irrigation efficiencies and future water supply issues • Investigate Israel agricultural sector – best practice irrigation systems; what can the dairy industry learn from these?
Heat	*Ellinbank SmartFarm* (owned by Agriculture Victoria): aims to be the world's first carbon-neutral dairy farm and is the hub for Dairy Australia's Dairy Feedbase research projects. The hub is developing nutritional strategies to reduce heat stress in dairy cows and demonstrating how digital tools & real-time information can improve dairy farm decision-making at both herd and individual cow level. *DairyBio* (initiative of Victorian Government): focussed on breeding ryegrass species and dairy cows better suited to the future climate. Haddon family (largest dairy farmers in Busselton – 1300 cows): using 'loafing barns' to reduce heat stress in cows. Other farmers using semi-housed systems – combination of mixed ration feed in shed + paddock feed. Shed systems enable more efficient feeding and cows do not have to expend as much energy finding feed. *The Cool Cows booklet* (Dairy Australia): Practical information that equips farmers with the steps needed to protect cows from heat, through planning, management practices and infrastructure investments.	• No specific dairy heat stress research has been done in or for WA industry conditions • Investigate and extend shedding systems for the WA dairy industry • Modelling of future temperatures and climate conditions across SW and impact of these on cow heat stress

Feed	*The WA Seed Performance (WASP)* trials: part of a national program focussed on how farmers can maximise pasture production and utilisation in WA's relatively short growing season. *Grazing Matcher workshop*s: a 12-month program delivered via a supported coaching model with one-on-one and group learning. Grazing Matcher is an initiative of animal production advisor Jeisane Accioly, who partnered with former dairy researcher Martin Staines and agronomist Dan Parnell, to help producers improve grazing management and business performance. Farmers match grazing inputs with outputs and develop grazing strategies using rotational grazing and monitoring of pasture leaf growth stage and animal condition.	Extend 'shoulders' (autumn and spring) of pasture supply through early season and late season pasture management and species mix • Determine pasture compositions that will suit later starts to the season • Economics of imported forage vs on-farm forage • Develop perennial + legume-based opportunities for the dairy industry regions (re-seeding annuals every year expensive) • More productive clover pastures needed to replace current ryegrass + synthetic N system • If synthetic N and diesel continue to go up industry will need to grow biological N • Extend trial sites of WASP trials to different regions and introduce time of sowing trials
Business efficiencies	*Our Farm, Our Plan*: designed to help farmers identify long term goals, improve business performance and manage volatility. *Dairy Farm Monitor Project*: provides a comprehensive physical and financial analysis of 250 dairy farms across Australia. The 2020/21 DFMP collection surveyed 21 farms in Western Australia, stretching from Harvey to Scott River and across to Denmark. This is the eighth year of the project and of the 21 farms, 10 have participated since its inception. *Farm Business Snapshot*: tool to help farmers review their historical performance and interrogate their operating cash surplus, costs of production and earnings before interest and taxes. *Human resources*: Western Dairy has employed a human resources and workforce safety officer to help the WA industry lift skills in employing and retaining staff.	• Greater participation needed in Dairy Farm Monitor Project to benchmark industry. Currently fewer than 20% of farmers have participated for a consistent period. • Labour supply, retention and skill base a big issue for the WA dairy industry Need an adoption program for carbon accounting/sequestration: • Extension program that explains the sources of carbon emissions and sequestration opportunities and helps producers perform a carbon account for their businesses. • Provide on-farm options to mitigate emissions: how many hectares of eligible vegetation are needed? • Tools and calculators needed that deal with mixed farms.

Intensive Livestock

Pig industry

In 2022, there were 1,134 registered pig farms across Australia managing about 2.4 million pigs. The Western Australian pork industry manages about 15% of the national pig herd and generated about $120 million in production value in 2021 (Figure 19 and Table 13).

Most WA pork is consumed fresh in the domestic market, with about 30% exported (mainly to Singapore) (Figure 20). The industry interacts strongly with the feed grain industry (barley, wheat and lupins). Most pigs are housed indoors, but a growing number are being reared under extensive (including free-range) and straw-based systems. An increasing number of pigs are grown under contract with the processing sector. About 90% of WA's sow herd is owned by 10 producers who use independent contract grower farms that concentrate either on breeding or rearing.

Table 13. Number and distribution of pigs and pig farms in 2021 across Western Australia

Region	Pig numbers	Pig farms
Wheatbelt	*191,776	67
Great Southern	**160,317	32
Peel	14,533	5
South West	6,333	13
Esperance	8,454	3
Total	391,413	119

*56% in Gingin/Dandaragan (5 farms) and 32% Wagin-Narrogin (13 farms)

**38% in Plantagenet (10 farms). Source: 2021 ABS Census data

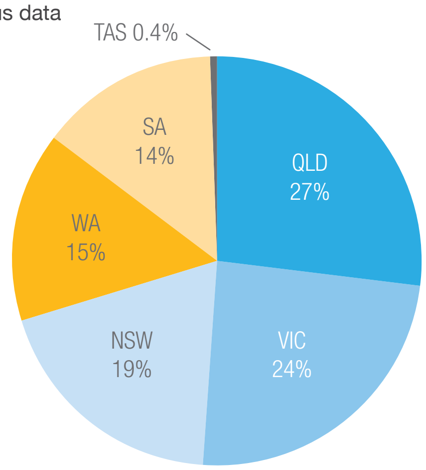


Figure 19. Distribution (%) of Australia's 2.9 million pig herd across Australian states. Western Australia has about 15% of the national herd.

Key messages

- WA's intensive pork and chicken (meat/eggs) industries are are focussed near the Perth metro (chicken meat) and in Gingin/Dandaragan (eggs/pork).
- The industries rely on groundwater (Gingin/Dandaragan) and scheme water supplies (Perth/Narrogin) with the pork industry in Plantagenet (Great Southern) relying on farm dam water.
- Feed costs typically represent 60–70% of production costs with extended drought resulting in elevated feed costs.
- Water supply and quality for intensive industries will likely become an issue as the climate changes and competition for water use increases near urban areas.
- Measures to use water more efficiently and/or recycle water will become increasingly important in the face of climate change.

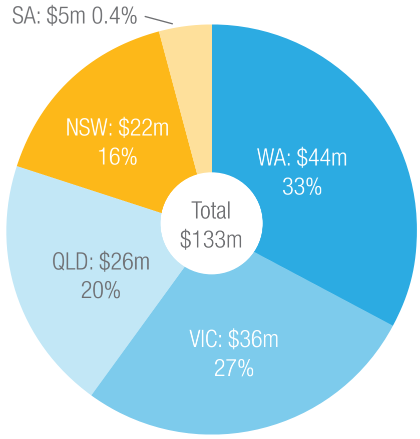


Figure 20. Australian pig meat exports by state, 2019-2020. Source: Agriculture Victoria

Climate impacts

The Australian pig industry depends on cereal grains, which are grown primarily as export crops for human consumption, making the industry vulnerable to price fluctuations driven by international demand for cereals. Drought events, either in Australia or another cereal-exporting country, can significantly affect the cost of pig production in Australia and the profitability of the sector.

In addition, as the climate dries further (see Table 3, page 50), Australian piggeries will likely face increased water stress, requiring additional measures to conserve or recycle water.

Table 14 outlines the recent and current RD&E with a focus on addressing climate impacts on the pig industry. Also outlined are the RD&E priorities needing to be considered to better equip the pig industry for projected climate change.

Table 14. PLEASE NOTE: WORKING DRAFT Summary of drought mitigation levers available to the WA pork industry and the RD&E gaps needing attention to better equip the industry under projected future climate change.

Drought lever	What's worked/happening?	What's needed?
Heat	Heat stress conditions in summer reduce pig production efficiency. Reduced farrowing rate of sows mated in summer, increased carcass fatness of pigs born to the sows mated in summer, and reduced growth rate and carcass weights of pigs finished under hot conditions are the three major impacts causing a significant economic loss in the pig industry. Current research investigating heat impacts on pork production in Australia: • *Heating up the house: Evaluating the effect of novel monitoring and heating systems on the productivity, welfare and economics of farrowing houses* (Dr Maria Jorquera-Chavez, Rivalea) (APRIL funding). • *Long term impacts of late pregnancy heat stress on sows and progeny* (Dr Kate Plush Sun Pork Group & Melbourne University Prof Frank Dunshea). Examining the impacts of heat stress in gilts during the last week of gestation on aspects of farrowing performance and piglet survival (APRIL funding).	(From Liu et al 2022 What have we learned about the effects of heat stress on the pig industry?): Australian pig industry requires commercially viable solutions to (1) reduce early pregnancy loss of sows mated in summer, (2) to improve foetal development of the progeny pigs born to the sows mated and gestated in summer, and (3) to develop strategies to improve the growth rate of finisher pigs under hot conditions. Most of the solutions investigated in the past decade are mainly nutrition-based. In future, strategies such as implementing cost-effective cooling strategies, breeding genetics with better heat resilience, etc. should also be explored.
Water	Fresh water is required to produce Australian pork, with on-farm use of fresh water estimated at 55 - 65L of water per sow-place per day for drinking (including spills) and cooling and an additional 20 - 29L of fresh water per sow-place per day for wash down (APL, 2016; Murphy et al., 2016). Australian Pork final report (2018): *Strategic Evaluation of Opportunities and R&D Needs for Water Management in Piggeries*: "Australian piggeries will likely face increased water stress, requiring additional measures to conserve or recycle water. Whilst, conservation measures are effective at minimising the current water use, there is concern that, in order to minimise fresh water in-take, piggeries may in the future need to treat wastewater to a higher quality for higher quality end-use purposes."	Water supply and quality likely to become an issue as the climate changes and competition for water use increases. In WA, many piggeries are in the Gingin area north of Perth as significant groundwater is available. In contrast, piggeries near Narrogin in the wheatbelt rely on scheme water, which is expensive while those near Mt Barker rely on dams. • Modelling work needed to predict future water needs of the pig industry. • Recycling options for wastewater for use as piggery drinking water – cost, regulations, installation. • Need to engage with Pork Industry WA and APRIL (Australasian Pork Research Institute) to determine RD&E needs re climate change/drought.

Drought lever	What's worked/happening?	What's needed?
Water	Edwards & Crabb (2021) *Water quality and management in the Australian pig industry*. Animal Production Science. 61: Australian pig farms draw water from a range of sources including bore water, surface water, farm dams and town water supplies. The quality of the water at its source and at the point of consumption on the farm, can significantly affect its suitability for use and the effectiveness of in-water treatments. Water tests across 57 farms from five states in Australia showed that most water quality parameters were outside the acceptable standard at both the source and at the point of consumption. The research concluded: further research is required to understand the impact of suboptimal water quality and in turn the most cost-effective water treatment and management practices to ensure that pig performance, health and welfare are optimised. UNSW Canberra and ANU researchers (with APRIL funding) have developed a proof-of-concept device known as a bubble column evaporator which sterilises water using un-pressurised carbon dioxide to destroy bacteria and viruses in effluent. Along with piggeries, the device has potential for use in other intensive industries such as dairy and horticulture. Many waste disposal industries, like landfills, piggeries, waste-water treatment plants, bio-gas plants and coal power plants emit large amounts of CO_2. There is the potential to use these emissions in water treatment processes to sterilise water. The developers are now seeking commercial partners to upscale the water sterilisation system. Pork Industry WA research (ongoing): *A case study: assessing the quality of source water fed to pigs in Western Australia* (funded by APC Pork Producers Committee)	
Feed	*State of the Industry Report 2021* (APL): Feed grain inputs are a significant cost to the pig industry, representing nearly 60% of the operating cost structure. Feed grain purchases are often locked in ahead of the pig rearing schedule by pig producers, via future delivered contracts or wheat financial hedging products. Analysis has shown that feed grain price movements often have a leading influence on pig price levels. Pork CRC (2014) investigated the use of triticale for pig production as an alternative to wheat. The goal was to establish direct supply contracts between triticale growers and pig production companies. Triticale can be sown late, copes with acidic and waterlogged soils and can be grazed without any yield penalty but is susceptible to frost. Trials showed pigs fed diets containing triticale – performed as well or slightly better than those fed wheat. However, the WA grains industry did not take up triticale as an alternative grain crop.	• Impact of future climate on grain supply and quality for WA pig production • Alternative feeds?

Chicken meat industry

National industry

The chicken meat industry is distinct from other livestock industries in Australia in that it is largely operated by vertically integrated processing companies. There are 10 vertically integrated processing companies in Australia. Two of them – Baiada and Inghams – produce about 70% of Australia's chicken meat. They operate plants across multiple states and market their chicken meat nationally. The next four largest companies supply 20% of Australia's chicken meat and operate out of the eastern states. Mt Barker (WA) is one of four smaller integrated processing companies, which all have contract meat chicken farms and processing plants.

Australian chicken meat production was valued at $2.9 billion in 2019-2020; WA produced about $191 million or 6.6% of national production (Figure 21).

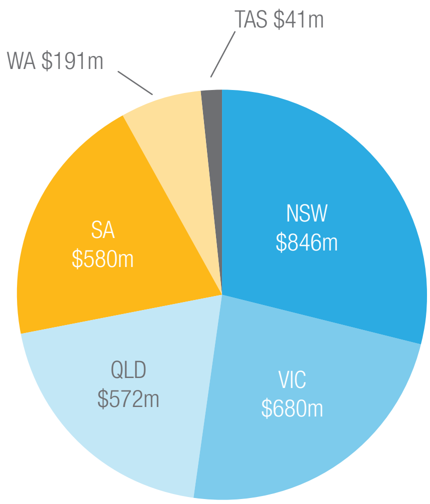


Figure 21. Gross value ($m) of chicken meat production and processing across Australian states in 2019-2020

WA industry

In WA, about 70% of chicken meat production (4.3 million birds) is concentrated in the Perth and Peel regions near processing plants (Table 15).

Table 15. Distribution of meat chicken numbers across WA NRM regions and shires (2021)

Region	Shire	Meat chicken numbers
Perth	Armadale	313,615
	Belmont	46,797
	Chittering	286,156
	Gosnells	164,400
	Swan	338,454
	Wanneroo	1,279,135
	TOTAL	**2,428,558**
Peel	Murray	225,966
	Serpentine-Jarrahdale	182,427
	TOTAL	**1,850,538**
South Coast	Broomehill-Tambellup	219,752
	Cranbrook	411,690
	Kojonup	502,990
	Plantagenet	171,834
	TOTAL	**1,039,835**
Northern Agricultural	Dandaragan	8,656
	Gingin	1,850,495
	TOTAL	**1,859,151**
	GRAND TOTAL	**6,002,369**

The remaining 30% of production is in the Great Southern (South Coast NRM region) and in Gingin/ Dandaragan (Northern Agricultural region) (Table 15).

Markets

Most Australian chicken meat production is consumed domestically with just a few per cent of production exported in 2021-22. Exports primarily comprise low value cuts and offal, for which there is little domestic demand. About 95 per cent of exports are frozen cuts and offal, such as feet, kidneys and livers. These attract a higher price in export markets than in Australia. The remaining five per cent of exports are largely frozen whole chickens.

Per capita chicken meat consumption now surpasses total red meat consumption. Chicken is the most frequently eaten meat product in most Australian households, representing about 45% of all meat eaten (Figure 22).

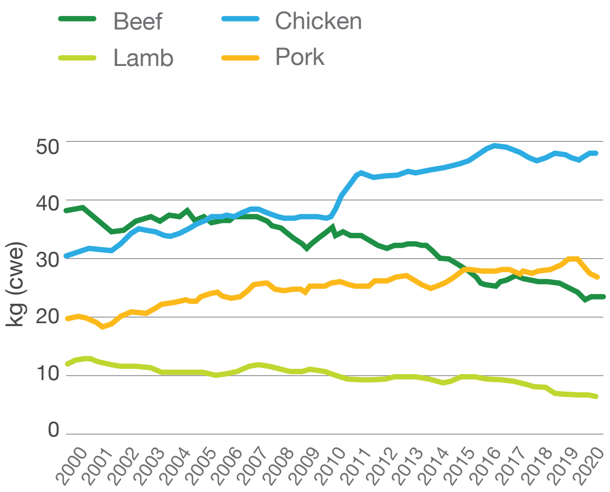


Figure 22. Per capita meat consumption in Australia over the past 20 years. Source: ABS, DA, MLA calculations. Note: rolling 12-month average per capita consumption kg/head

Chicken egg industry

In the 2020-21 financial year, Australian egg farmers produced 6.3 billion eggs (525.2 million dozen) (Table 16) from a flock size of 21,947,297 layers. Supermarket egg sales were reported at about $1.1 billion in the 2021 financial year.

Western Australia manages about 8% of the national layer flock (Figure 23). Registered commercial egg producers produce about 75% of eggs in Western Australia using caged, barn and free range production methods (Figure 23b). The WA egg industry supplies 66% of eggs sold in WA with the remainder of eggs supplied from interstate.

Table 16. National egg production 2016-2021

Year	Eggs produced	
	(billions)	(million dozen)
2020–21	6.3	525.2
2019–20	6.1	507.4
2018–19	6.2	518.1
2017–18	6.2	515.7
2016–17	5.5	459.2

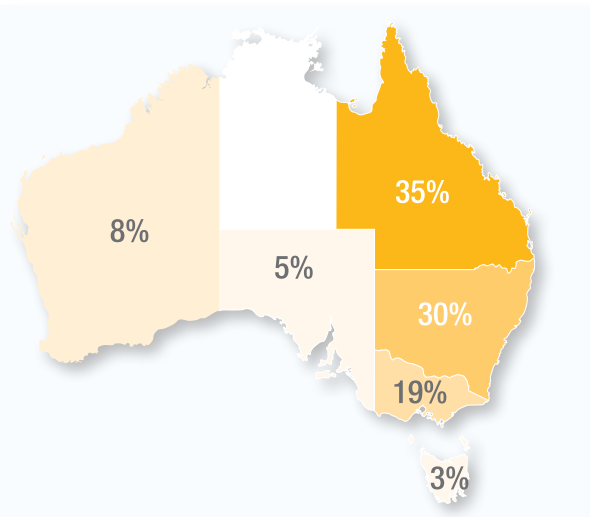


Figure 23. Proportion (%) of national commercial egg chicken flock across Australia in 2020–21

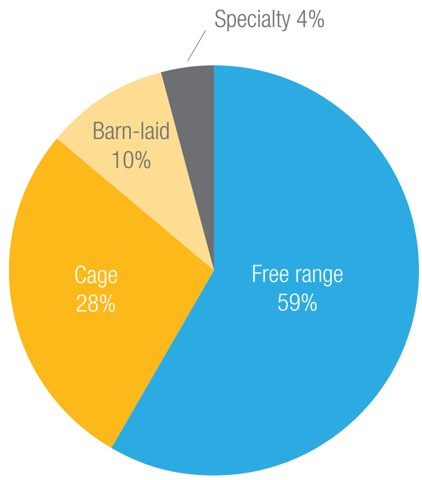


Figure 23(b) Relative value (%) of Australian egg sales by production type in 2021. Source Egg Farmers of Australia

WA industry

The commercial egg industry is concentrated in the Gingin/Dandaragan shires of the Northern Agricultural NRM region (Table 17). There were a reported 22.8 million dozen eggs produced across WA in 2021 from 42 egg farms with 88% of production coming from four farms in Gingin/Dandaragan (Table 17).

Markets

Australians consumed 249 eggs (about 14.4kg) on a per capita basis in 2021 (Figure 24). Most Australian consumption is from domestic chicken egg production but, over the past five years, Australia has gone from being a net exporter of eggs to a net importer, on a value basis (Figure 25). Imported egg products from the United Kingdom, China and United States include egg powder, egg pulp and preserved or cooked eggs (valued at $7.1 million in 2020–21).

Egg exports in 2021 ($0.9 million) were down considerably on those of 2017–18 and 2018–19 ($10 million) due to record exports to the Philippines in 2017 when the country suffered an outbreak of Avian Influenza (AI). In 2020, Australian egg exports were again impacted by an outbreak of AI but this time among several Australian commercial flocks. However, subsequent efforts by industry and state and federal government agencies resulted in Australia officially regaining freedom from AI in 2021.

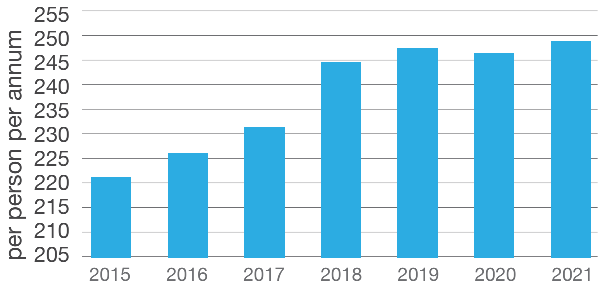


Figure 24. Australian per capita egg consumption 2015–2021. Source: Australian Eggs

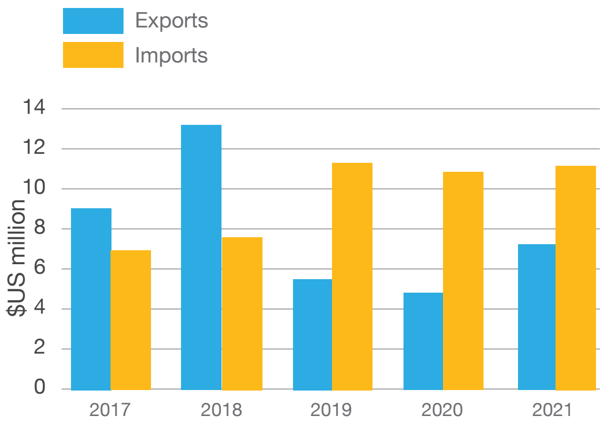


Figure 25. Imports and exports of Australian eggs 2017–2021. Source: WITS, TEM

Climate impacts

Feed costs typically represent 60–70% of layer production costs with extended drought resulting in elevated feed costs. As the climate dries further (see Table 3, page 50), Australian chicken meat and egg industries will likely also face increased water stress, requiring additional measures to conserve or recycle water.

Table 18 outlines the recent and current RD&E with a focus on addressing climate impacts on the chicken industries. Also outlined are the RD&E priorities needing to be considered to better equip the chicken industries in the face of projected climate change.

Table 17. Volume of eggs (dozens) produced across WA NRM regions in 2021 (Source: ABS Census 2021)

Region	Egg production (dozens)	% Production	Commercial chicken egg farms (#)
Northern Agricultural	20,079,917	88	4
Perth	2,029,690	9.0	8
South West	221,141	1.0	15
Wheatbelt	170,801	0.7	10
Peel	134,601	0.6	2
South Coast*	1,038,488	0.6	3
TOTAL	**22,774,637**		42

*72.5% of production in Esperance

Table 18. PLEASE NOTE: WORKING DRAFT Summary of drought mitigation levers available to southwest chicken meat and egg industries and the RD&E gaps needing attention to better equip the industries under projected future climate change.

Drought lever	What's worked/happening?	What's needed?
Heat	Reducing heat stress is particularly important in meat chickens housed in indoor sheds as chicks cannot maintain their own body temperature (ideal maintenance temperature is 28-30°C) and adult birds give off considerable heat and must be maintained at about 21°C. Heat stress is a welfare issue and is also detrimental to meat quality and production. Water consumption can be 2-3 times normal consumption in heat stressed birds.	• Investigate the impact of increasing incidence of hot days and egg and meat production in free-range systems. • Need to engage with the chicken meat and egg industries to determine RD&E needs re climate change/drought and heat.
Water	*Water security in the chicken meat industry* (ongoing from 2021) (AgriFutures funding) Review water use by the chicken meat industry, identify water security issues currently affecting the industry, and identify likely impacts under future climate change scenarios. Identify novel solutions to improve water use efficiency and water harvesting. Identify barriers to closed loop water usage within the chicken meat industry. (Good survey questions used to engage the industry). Examining the effect of climate change on the chicken meat industry across four Australian regions (Perth region one of these) – how much water can be caught on-farm from sheds etc as an additional water source?	• Investigate new technologies/designs for water capture, storage and treatment at chicken meat and egg farms. • Engage with AgriFutures water security researchers re status of WA industry and water needs/quality.
Feed	Chicken industry: feed made up of 85-90% grains, such as wheat, sorghum, barley, oats, lupins, soybean meal, canola and other oilseed meals and grain legumes.	• Model impacts of climate change on future grain feed supplies for the WA chicken industry. • Wheat-soybean meal diets main diets used in Australia but the industry is also trialling alternative ingredients. However, digestibility of alternatives such as sorghum and barley is poor in chickens. Research underway to investigate the use of enzymes and additives to improve digestibility.

Perrenial Fruit

Industry overview

The main areas of fruit production in southwest WA are the Perth Hills, Harvey, Donnybrook and Manjimup (Figure 26). Olive production occurs mainly in the Gingin and Dandaragan shires where there are also larger scale citrus producers and some production of low chill stonefruit.

In 2019, there was an estimated 5,750 fruit production businesses in Australia with about 8% of these (486) in WA. The area of fruit production (excluding grapes) in WA was estimated at just over 9,000 hectares.

The major fruit crops grown in the southwest of Western Australia are avocados, olives, apples, strawberries, stonefruit, blueberries and citrus. The total production value of these industries in 2019-2020 was just under half a billion dollars ($495.3m) (Figure 27).

Avocados made up about 40% ($202m) of the perennial fruit production value in 2019-2020, followed by olives (18%), apples (13%) strawberries (11%), blueberries (5%), oranges (4%) and mandarins (2%).

Key messages

- Climate models show very high confidence that average, maximum and minimum temperatures will continue to rise across southwest WA until the end of the century. There is also high confidence that annual rainfall will decline and that there will be less rainfall in winter and spring.
- Insufficient winter chill will adversely affect dormancy and productivity of deciduous fruit such as apples, pears, nectarines and peaches.
- Streamflow and freshwater resources will become more limiting and water salinities of some aquifers and dams may increase.
- Water use efficiency measures and protective cropping systems will become increasingly critical.

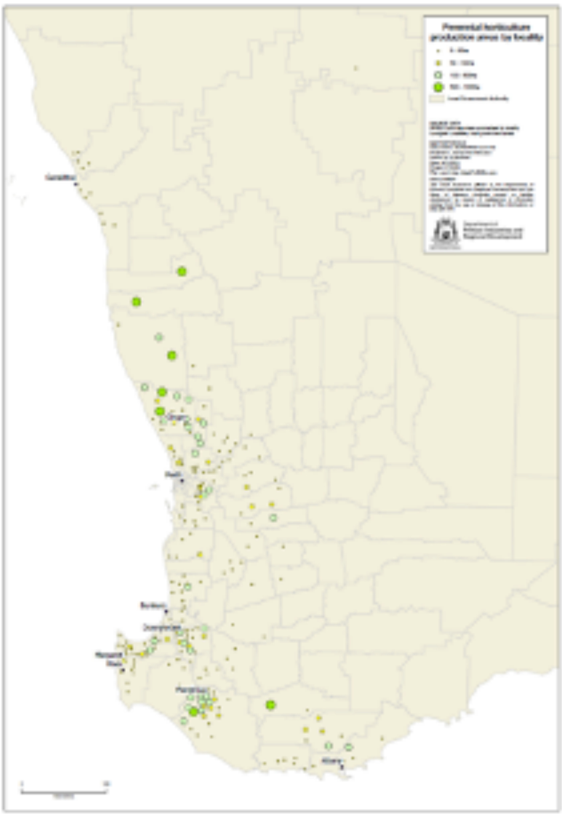


Figure 26. Location of perennial horticultural production (excluding grapes) in southwest Western Australia, Source DPIRD.

The total value of the vegetable industries in 2019-2020 was $495.3m.

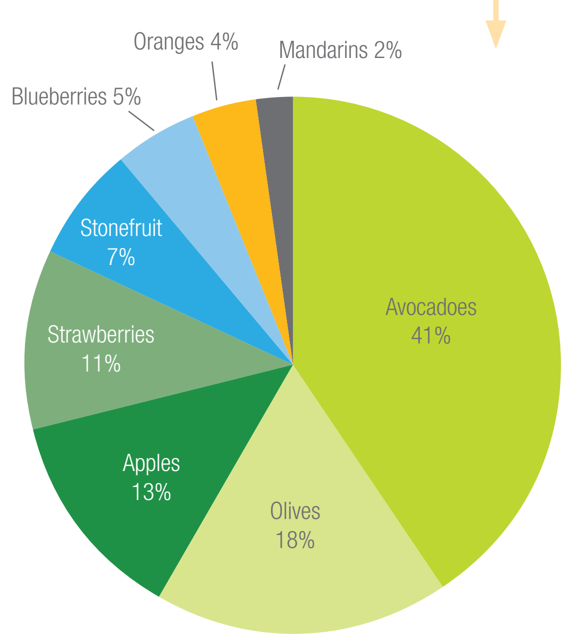


Figure 27. Relative value of the major perennial fruit industries in southwest Western Australia 2019-2020

Water supply

Commercial fruit production in WA is irrigated mainly from bores and farm dams which are generally licenced for use of an annual maximum amount of water extraction. Local demand for fresh fruit is rising, including in the Perth and Peel regions where the population is forecast to grow from its current size of 2 million people to 3.5 million by around 2050. The forecast growth in WA's agriculture sector is expected to result in an increase in water demand from 650 GL in 2016 to between 1170 and 1580 GL per year by 2050. This projected growth in water demand (between 2.0 and 2.9 per cent per year) is faster than historical growth over the previous 30 years (Department of Water and Environmental Regulation, Lantzke pers comm.).

Markets

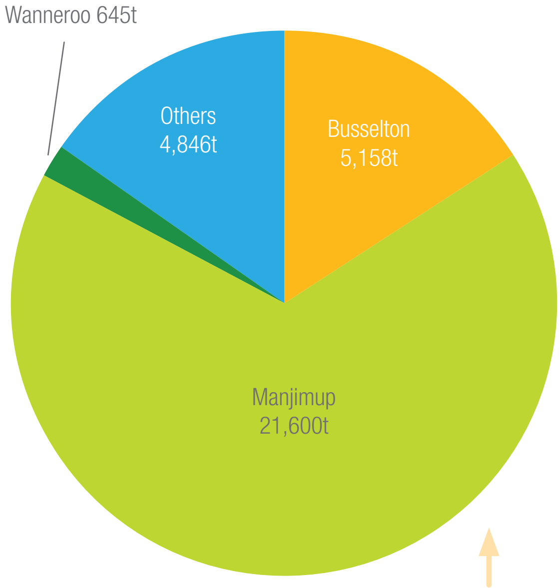
Most of the fruit produced in southwest WA is sold domestically in WA. The exception is avocados, with the Busselton, Manjimup and Pemberton areas suppling a significant proportion of Australia's spring and summer avocados.

Only a small proportion fruit that is grown in southwest WA is exported, however a few fruit industries have actively pursued exports:

- Strawberries from the Wanneroo, Bullsbrook and the south west are exported by air freight.
- Citrus from the Moora area is exported in considerable volumes (navels and mandarins).
- Stone fruit from the Perth Hills and south west, however the volumes of plums are much less than in past years.
- The rapid expansion of the avocado industry in recent years will, if adequate export prices can be achieved, necessitate increased overseas sales.

Avocados

WA avocado production was 32,240 tonnes in 2020 up nearly 30% on 2016 levels (25,000 tonnes). Most of the production was consumed domestically with just over 1% (449 tonnes) exported to Malaysia, Hong Kong and Singapore. About 67% of WA avocados are produced in the Manjimup/Pemberton areas and about 16% near Busselton (Figure 28).

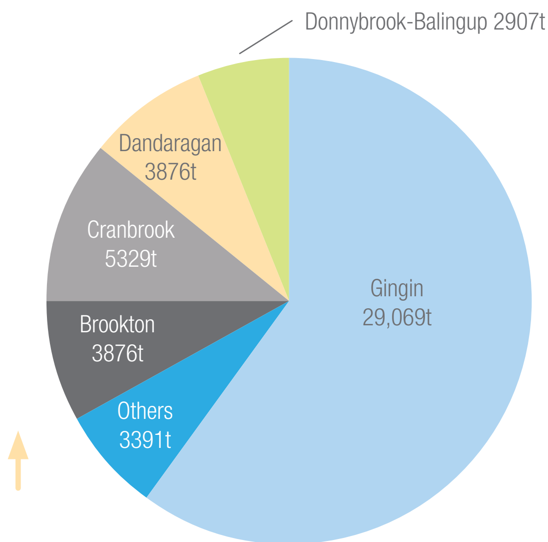


Total value of avocado production in 2020 was about $200m. Manjimup generates about 67% of the total production.

Figure 28. Relative volumes (tonnes) of avocados produced across southwest WA shires in 2020

Olives

WA olive production was 48,448 tonnes in 2020 generating a wholesale value of about $87m. Most of the production goes for olive oil extraction, which is largely consumed domestically. A small amount of oil is exported – mainly to Taiwan. Production of table olives is negligible in WA. Gingin generates about 60% of WA olives (Figure 29). The tendency for biennial production leads to yield extremes in alternative years. Olive yields can vary from 50kg per tree in a good year to just 10kg per tree in a low year.



Total value of olive production in 2020 was about $87m. Gingin generates about 52% of the total production.

Figure 29. Relative production (tonnes) of olives across WA shires in 2020

Apples

WA contributes about 9% of Australia's annual apple production with Manjimup and Donnybrook-Balingup accounting for about 80% of the apples produced in WA. The remaining 20% are grown within the Perth-Peel region (Figure 30). WA apple production was 27,931 tonnes in 2020 ($64.5m) up by just 1% on 2016 levels (25,651 tonnes). Most of the production is consumed domestically with about 82.5 tonnes exported to UAE, Singapore and Malaysia in 2020.

Strawberries

WA strawberries are grown on about 170 hectares, mostly in the Swan and Wanneroo shires north of Perth and provide most local needs as well as about 80% of total strawberry exports from Australia. Strawberry production was 8,643 tonnes in 2020 with a wholesale value of $54m, which was down 42% on 2016 value ($92m) (Figure 31). About 30% (2600 tonnes) of production was exported in 2020 – mainly to Thailand Singapore and Malaysia. Labour issues are an ongoing issue for the industry.

Blueberry

WA produces less than 1% of Australia's total blueberry volume (19,000 tonnes). In 2020 the WA industry produced about 1306 tonnes of fruit, a significant increase from the 81 tonnes produced in 2016. Wholesale value of the 2020 harvest was $23m and the fruit were consumed domestically. Dandaragan and Gingin account for 60% of WA production, followed by Manjimup at 16% (Figure 32).

Other important fruit industries in WA include oranges ($19.8M) and increasingly mandarins ($11.8m), which are both grown in Harvey Shire. Stonefruit are produced in the Perth Hills, Donnybrook and Manjimup with 2020 production of plums valued at $16.3m, nectarines at $10.3m and peaches at $7.3m.

Exports

WA exported 13,191 tonnes of fruit worth $48m in 2020, which was 46% higher than the export value five years previously (due to a 75% increase in volume). Strawberries are WA's leading export fruit (Figure 33), accounting for 40% of export value ($19.6m). Other major fruit exports from WA include table grapes, oranges, melons, avocados, watermelons and plums.

Singapore is the state's highest value export market for fruit, taking 19% of total 2020 WA fruit exports. Malaysia follows closely behind, with exports to this market at $7.7m in 2020. The state's third highest value export market for fruit is China, followed by the UAE. Other markets are Thailand, Hong Kong, Japan, Vietnam, Qatar and Indonesia.

Total value of apple production in 2020 was about $64.5m. Manjimup and Donnybrook-Balingup generate more than 80% of the total production.

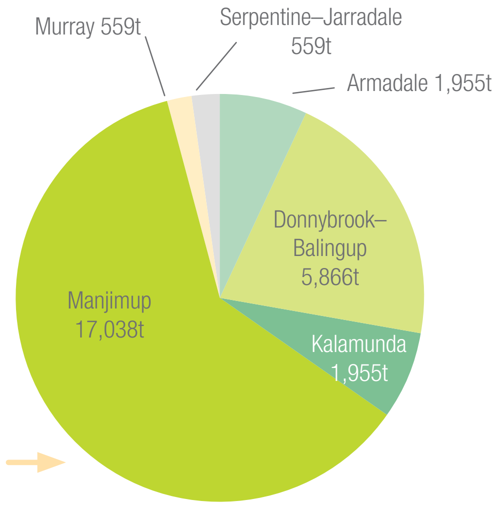


Figure 30. Relative production (tonnes) of apples across WA shires in 2020

Total value of strawberry production in 2020 was about $54m. Swan and Wanneroo shires generate about 75% of total production.

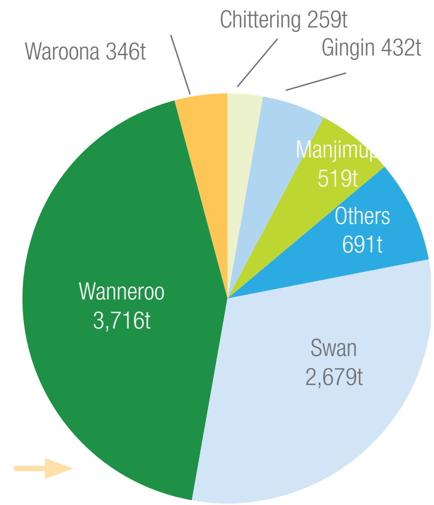


Figure 31. Relative production (tonnes) of strawberries across WA shires in 2020

Total value of blueberry production in 2020 was about $23m. Gingin and Dandaragan shires generate about 60% of total production, followed by Manjimup at 16%.

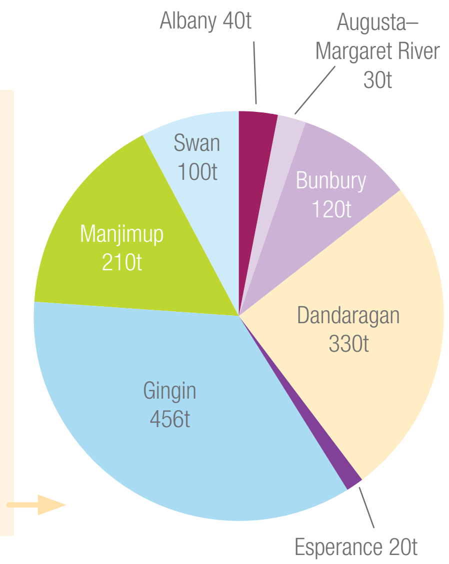


Figure 32. Relative production (tonnes) of blueberries across WA shires in 2020

Climate change and fruit crops

Fruit production will be affected by long-term trends in average daily temperature and seasonal rainfall (via impact on groundwater and dam storage), climate variability, shocks during specific phenological stages, and extreme weather events (Figure 19). Table 20 outlines the recent and current RD&E with a focus on addressing climate impacts on the southwest WA perennial fruit industry. Also outlined are the RD&E priorities needing to be considered to better equip the industry for projected climate change.

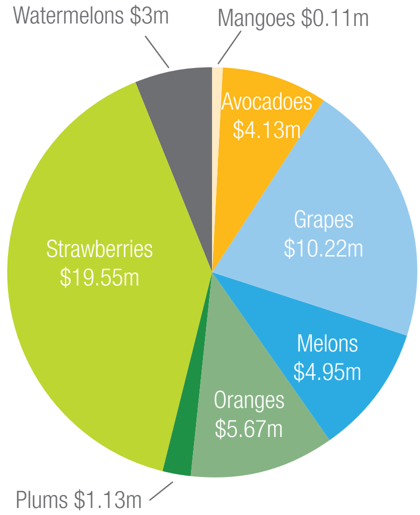


Figure 33. Relative value of fruit exports from Western Australia in 2020. Source DPIRD

Table 19. Potential impact of climate change on production of perennial fruit crops in southwest WA

Production factor	Impact of climate change
Rising temperatures – reduction in chill	Insufficient winter chill adversely affects dormancy and productivity of deciduous fruit species such as apples, pears, nectarines and peaches (Salama et al. 2021). Inadequate chilling hours may lead to several physiological disorders such as uneven bud break, weak vegetative growth, and poor flower development (Khalil-Ur-Rehman et al. 2019).
Water	Freshwater resources will become more limiting with a drying climate and the water salinities of some aquifers and dams may increase. While water for irrigation might be available on paper through allocation limits, there are issues around accessibility (quality, yield, depth etc) and it is also expected some allocation limits will be reduced in the coming years by DWER as they revise their allocation plans to accommodate climate change impacts.
Pests	Changes in climate may result in an expansion of the geographic distribution of pests, increased survival during overwintering, increased number of generations, increased incidence of insect-transmitted plant diseases, and reduced effectiveness of biological control, especially natural enemies.
Fruit flies	Mediterranean fruit fly (Medfly) is a serious pest of many fruit species in the Perth region including commercial orchards in the Perth Hills and a lesser problem in cooler fruit growing areas such as Manjimup. Queensland fruit fly (Qfly) is also a serious pest of many fruit species in Australian states where is occurs. While not currently present in WA several Qfly incursions in suburban Perth have been eradicated at substantial cost to taxpayers. Temperature is a major determinant of fruit fly populations and distribution worldwide, with minimum land surface temperature accounting for the most variation within a distribution model (Szyniszewska and Tatem 2014). Sutherst et al. (2000) correctly anticipated that the impact of Qfly on Australian horticulture will progressively increase over the next few decades and that costs of managing the pest would rise. Sultana et al. (2019) concluded that expansion of the distribution range of Qfly along with the growth of host plant industries in north-western Australia may necessitate the development of new monitoring, control and disinfestation procedures.
Diseases	Both pathogens and host plants will be affected by changing climate and dramatic changes in the magnitude of disease expression can be anticipated in terms of plant/disease combinations, geographical distribution of plant diseases and the economic importance of diseases in a given location.
Weeds	Invasive plants with tolerances for higher temperatures, could have a competitive advantage in rising temperatures.

Table 20. PLEASE NOTE: WORKING DRAFT Summary of drought mitigation levers available to South West perennial fruit crop industries and the RD&E gaps needing attention to better equip the industries under projected future climate change.

Drought lever	What's worked/being done?	What's needed?
Heat	*Understanding apple and pear production systems in a changing climate* (HIA 2017): The report developed a detailed set of recommendations for RD&E to better equip the industry for projected climate change. The project was instigated to: • Develop climate change scenarios for pome fruit growing regions of Australia in 2030 and 2050, including the likely impact of climate change on winter chill and extreme heat. • Understand how changes in autumn, winter and spring temperatures might impact the timing and quality of flowering in cultivars of apple and pear. • Identify adaptations to manage any negative effects of climate change on flowering. • Understand how changes in the frequency of extreme heat days might impact on the incidence of sunburn in pome fruit and the effectiveness of netting as an adaptation strategy. • Understand how different colours of netting impact on the orchard environment, fruit yield and quality. • Understand how the changing climate might impact the yield potential of apples. Netting over apple orchards in the south west now common (rarely seen 20 years ago). DPIRD research has shown protective netting shields fruit from sunburn, wind and hail, as well as birds and other large pests, while improving water use efficiency by as much as 20 per cent. Federal incentive scheme *Horticulture Netting Infrastructure Program* in place to subsidise installation of netting infrastructure. Up to 50% of eligible costs associated with the purchase and installation of permanent horticultural netting, to a maximum of $200,000 is available to eligible applicants.	• Quantify the potential production and business impacts of climate change on SW WA fruit industry sectors and extend likely future local climate impacts to industry to develop adaptation strategies (e.g., protected cropping systems and use of irrigation to deal with extreme heat events). • (From HIA 2017 report): Development of orchard practice guidelines for managing extreme heat (bringing together aspects of tree canopy structure, evaporative cooling, netting types, irrigation, nutrition, spray-on protectants and other stress reduction products). • Identify favoured production regions for fruit crops under future climate scenarios. • Engage Pome West, HIA, APAL, and Avocados Australia to determine perennial fruit RD&E needs in the face of climate change/drought.
Water	*Southern Forests Irrigation Scheme* – plan to secure more water for horticultural and livestock businesses in Manjimup area (proposal on hold) *More dollars per drop* (2014-2018): aimed to assess current use and develop ways to improve water use in the horticulture and dairy industries. Project activities included on-farm assessments of irrigation systems, sites to demonstrate new systems (including crop netting sites for apples - Manjimup and table grapes - Boyanup, and drip irrigation uniformity sites - Carnarvon) and equipment and development of web-based decision tools.	• Extend the water-use and cost savings possible from implementing more efficient irrigation systems • Develop and extend use of digital sensor systems to better manage irrigation scheduling e.g., sap flow meters on avocado trees to monitor water movement and tensiometers for soil water. • Improve industry water use efficiency and carry out economic assessments of implementing changes to irrigation systems, technology and management. • Investigate the economics and production impacts of using marginally saline irrigation water.

Drought lever	What's worked/being done?	What's needed?
	Water for Food program (WA Government 2015-2018): established to identify water and land resources, as well as irrigation technologies to enable Western Australia's fresh food and animal protein production to increase its contribution to regional economies and diversify WA's agricultural production. *On-farm water demand project* (Food Agility CRC 2019-current): Access to water for irrigation in many regional areas is limited and under pressure from climate change. The project will provide reliable, independent data on water demand in the Warren-Donnelly catchment in south-west Western Australia. There are 30 participating farms covering the avocado, apple, wine grape, stone fruit and truffle farm businesses. The on-farm water data will then be aggregated with planted area and other available data to calculate water demand across the catchment.	
Carbon accounting		• Better data capture and accounting of carbon emissions and sequestration in the horticulture industry. • Development and adoption of low emissions technology and practices • More efficient management of nitrogen (nitrous oxide emissions) • Opportunities for carbon storage in horticultural soils.
Energy efficiency		• Reducing electricity use for irrigation: improvements in energy productivity or reductions in energy usage in relation to irrigation • Electricity use for cooling: improvements in refrigerants and refrigeration plants • On-farm renewable power generation options. Technology options by region, cost and breakeven time frames
Business/ professional development	*Future Orchards* (APAL 2006-present) provides growers with practical and hands-on education to improve the fruit quality and productivity of their orchards and increase their competitiveness. Services delivered under Future Orchards include: • Orchard Walks • OrchardNet® online benchmarking database • Orchard Business Analysis (OBA) data • R&D updates via AFG Magazine, Industry Juice and webinars	• Engage with APAL and Pome West re Future Orchards program and climate change/drought related needs of the scheme.

Vegetables

Key messages

- Climate models show very high confidence that average, maximum and minimum temperatures will continue to rise across southwest WA until the end of the century. There is also high confidence that annual rainfall will decline and that there will be less rainfall in winter and spring.
- Protected cropping including shade protection to reduce water use, heat stress and sunburn will be needed to curb the impacts of higher temperatures.
- Streamflow and freshwater resources will become more limiting and water salinities of some aquifers and dams may increase.
- Water use efficiency and measures and adoption of wireless technology and sensors for efficient irrigation management will become increasingly critical.

Industry overview

There were an estimated 3,600 vegetable production businesses in Australia in 2019 with about 10% of these (342) in WA. The shires of Dandaragan, Gingin, Wanneroo, Harvey, Manjimup and Albany are the main vegetable producing shires of southwest WA (Figure 34 and Table 21).

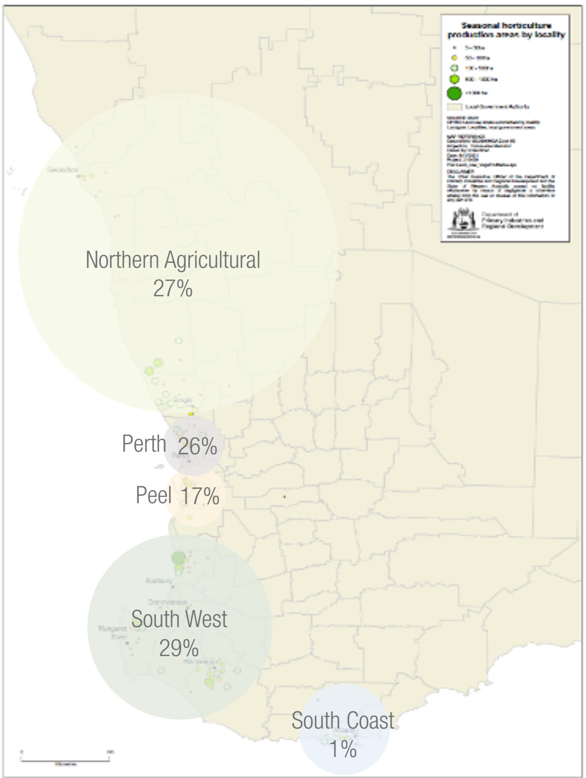


Figure 34. Location of vegetable farms across southwest Western Australia

Table 21. Value of vegetable crops across southwest WA regions in 2021

Region	Main crops	Value ($m)	% Total
South West	Potatoes, broccoli, cauliflowers	117.23	29
Peel	Onions, carrots,, potatoes, broccoli	68.59	17
Perth	Tomatoes, lettuce, Asian vegetables	106.57	26
Gingin/Dandaragan/ Geraldton*	Carrots, potatoes, broccoli, cabbage, cauliflower, lettuce, baby leaf lines, cucumbers	110.46	27
Albany**	See potatoes	5.44	1

*Northern Agricultural region

**South Coast region

The main vegetables produced in WA are carrots, potatoes, tomatoes, onions, cucumbers and broccoli (Table 22). Carrots, potatoes and onions are highly mechanised crops produced from extensive field plantings irrigated with centre-pivot irrigators or overhead sprinkler systems. Water use is high for these crops, as much as 8 to 10 ML/ha for a summer crop in the Gingin area.

Carrots are WA's highest value horticultural crop, with a wholesale value of $120m in 2020 (Table 22).

Potatoes are the second highest value vegetable crop after carrots, with a wholesale value of more than $70m (Table 22). They are the second highest horticulture industry for value-adding after wine, generating about $177m through the value chain. About 70 growers produce about 100,000 tonnes of potatoes with half this volume supplied as fresh potatoes to the local market year-round. The remainder goes to processing, (French fries) and seed production.

Winter and spring harvested potatoes are grown in frost-free northern locations (Gingin, Dandaragan and Baldivis) (Figure 35) while summer and autumn harvested crops are grown mainly in Manjimup and Pemberton with some in the Busselton-Margaret River areas. Seed potatoes are grown near the south coast between Albany and Denmark where prevailing onshore winds keep aphid (and consequently virus) levels low.

Water supply

Commercial vegetable production in WA is irrigated mainly from bores and farm dams which are generally licensed to use an annual maximum volume of water extraction.

Local demand for fresh vegetables is rising, including in the Perth and Peel regions where the population is forecast to grow from its current size of 2 million people to 3.5 million by around 2050.

Table 22. Wholesale value of production of major WA vegetables in 2020

	Value ($m)	Share of total
Carrots	119.9	16%
Potatoes fresh	76.4	10%
Tomatoes fresh	60.3	8%
Onions	53.6	7%
Cucumbers	52.4	7%
Broccoli	41.3	5%
Melons*	40.8	5%
Mushrooms	37.4	5%
Seed potato	35.0	5%
Lettuce	31.0	4%
Capsicum	27.2	4%
Sweetcorn	24.2	3%
Pumpkin	23.0	3%
Baby leaf	20.3	3%
Cauliflowers	16.6	2%
Spinach - English	14.5	2%
Celery	8.0	1%
Brussel sprouts	7.6	1%
Cabbage	7.5	1%
Broccolini	5.6	1%
Chilli	5.4	1%
Lebanese cucumbers	5.0	1%
Spring onion	4.7	1%
Leafy greens	4.7	1%
Leek	4.4	1%
Potato processing	4.3	1%
Truffles	4.2	1%

* Melon (both rock melons and watermelons are also usually included in vegetable production statistics because of their annual production systems.

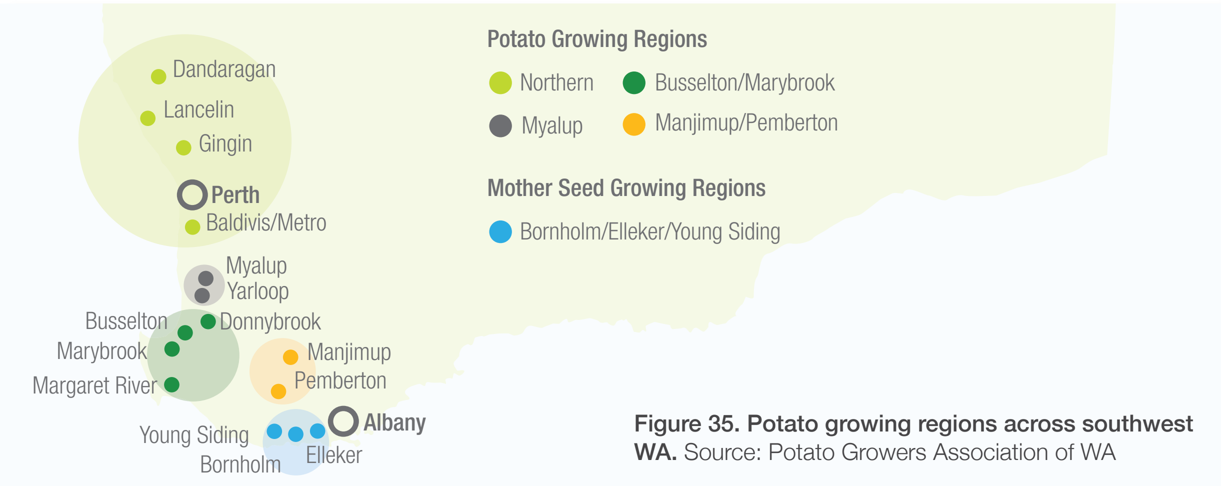


Figure 35. Potato growing regions across southwest WA. Source: Potato Growers Association of WA

Climate impacts

The forecast growth in Western Australia's agriculture sector is expected to double water demand from 650GL per year (2016) to between 1,170 and 1,580GL per year by 2050. This projected growth in water demand (between 2–2.9% per year) is faster than historical growth over the previous 30 years (Department of Water and Environmental Regulation, Lantzke pers comm.).

Declining rainfall across southwest WA, the main vegetable growing region of the state, means that water supplies for irrigation are also likely to decline (McFarlane et al. 2020). Therefore, meeting future fresh food demand from local production will become increasingly challenging (see Table 23).

Table 23. Water issues/proposals for each of the major vegetable growing areas of southwest WA

Area	Water issues/proposals
Gingin/Dandaragan	Infertile sands overlying good quality groundwater in both shallow unconfined (superficial) and deeper confined (Leederville and Yaragadee) aquifers. Potato growing area further from the coast to the north of Dandaragan has areas of better-quality sandy soils. Most groundwater fully allocated with some Yaragadee aquifer reserves set aside for future urban water supplies. Some groundwater available for irrigation in the Dinner Hill area in Dandaragan shire.
Perth Metro	Wanneroo and Carabooda areas underlain by Gnangara mound, which has become a major source of urban water for the rapidly expanding Perth population. Marked decline in winter rainfall in southwest WA since the mid 1970s and increasing demand for urban water supply saw groundwater abstraction from Gnangara mound reach unsustainable levels by the 1990s along with a concomitant decline in water tables and drying of sensitive wetlands. Through the measured time period, a 13% decline in rainfall resulted in a 26% decline in recharge into the mound. Desalination plants and pine plantation removal being used to help recover the mound. DWER has flagged that commercial water licences in the north Wanneroo area will be reduced by 10% from 2028, which will impact vegetable producers in the area (Rohan Prince, DPIRD, pers comm.). In late 2021, the WA Government made $100,000 available for eligible commercial WA horticultural businesses in the area to seek expert advice and planning from professional irrigation consultants.
Myalup	Important vegetable producing area close to the coast in the Harvey shire about 30 km north of Bunbury supplying domestic and export markets. The area has long been constrained by water availability and capable land for horticulture. Most irrigation water comes from groundwater extracted using on-farm bores and applied through fixed overhead impact sprinklers. Some shallow soaks also supply irrigation water. Over the past decade producer numbers have declined and remaining businesses have upscaled by acquiring properties to increase access to water and land. Myalup has advantage over Gingin in being cooler during the summer months. Various schemes proposed to increase Myalup water availability for irrigation with most recent ($400m) involving piping water from Wellington Dam (but water needs desalination) – but WA Government not supportive.
Manjimup	Some of the best agricultural soils in WA – major supplier of spring and summer planted fresh market and processing potatoes. Irrigation water in Manjimup/Pemberton is mostly drawn from farm dams located on water courses. Irrigated agriculture primary user of surface water, which is dominated by catchments of Warren and Donnelly rivers. Total allocation limit (including public water supply and unlicensed use) for Warren catchment is about 48GL and Donnelly about 15GL. Of this total of 63GL, about 54GL is available for licenced use, mainly irrigation (Department of Water, 2010).
Geraldton	Good quality soils but limited fresh water. Expensive scheme water (up to $3/kL) used for irrigation to supplement dam and tank water. Desalination of brackish groundwater using renewable energy being evaluated. Warming climate will potentially shorten the 'winter' season in tunnel houses which could become too hot in the shoulder seasons

Production methods

Potatoes, carrots, onions and baby leaf lines such as spinach and rocket are produced under highly mechanised broad-scale production systems. Irrigations systems are generally fixed overhead impact sprinklers or centre-pivot irrigators. These crops are mechanically planted and harvested with low labour input and packing labour is mechanised with the use of machines. For example, larger scale carrot producers in WA now use automated in-line washers, polishers, hydrocoolers, size graders, optical sorters, carton assembling machines, prepack machines, carton filling machines and robotic pallet stackers. By reducing labour costs these industries, especially the WA carrot industry, have become world competitive.

Exports

Most of the vegetables produced in WA are consumed locally or sold interstate, but exports are increasing with 121,574 tonnes of vegetables worth about $119m exported in 2020. This export value was 54% higher than the real export value in 2015 and was associated with a 40% increase in quantity and a 10% increase in real price during the five-year period (Figure 36).

Climate change

Vegetable production will be affected by long-term trends in average daily temperature and seasonal rainfall (via impact on groundwater and dam storage), climate variability, shocks during specific phenological stages, and extreme weather events (Table 24). Table 25 outlines the recent and current RD&E with a focus on addressing climate impacts on the southwest WA vegetable industry. Also outlined are the RD&E priorities needing to be considered to better equip the industry for projected climate change.

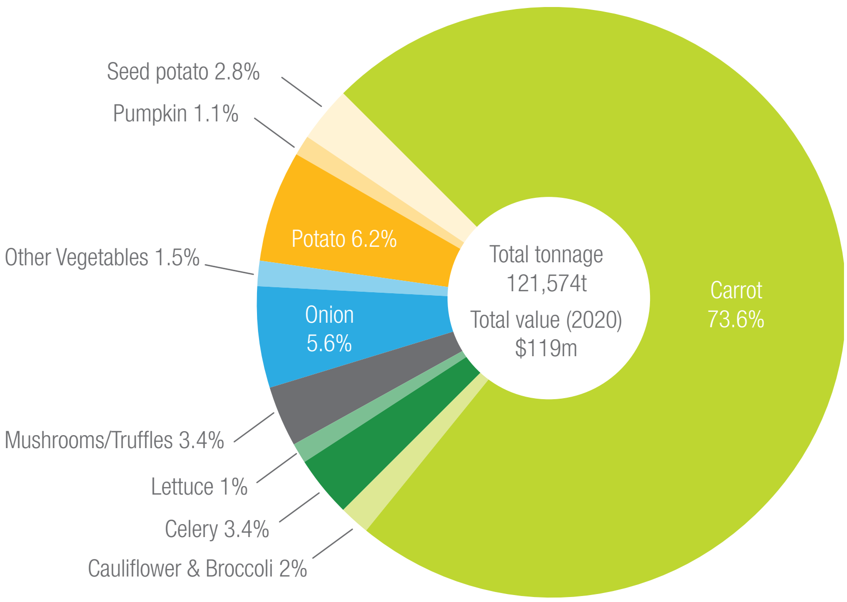


Figure 36. Value (A$) and volume (tonnes) of vegetable exports from WA in 2020.

Table 24. Potential impact of climate change on production of vegetable crops in southwest WA

Production factor	Impact of climate change
Temperature	Increases in average temperature during growing season typically cause plants to use more energy for maintenance and less for growth. With a 1°C increase in average temperatures, yields of the major food and cash crop species can decrease by 5-10% (Lobell and Field, 2007; Hatfield et al., 2011). With higher average temperatures plants also complete their growing cycle more rapidly (Hatfield et al., 2011). With less time to reproduce, reproductive failures are more likely, and this will also lower yields (Craufurd and Wheeler, 2009). Increased rates of respiration caused by higher temperatures lead to a greater use of sugars by plants. As a result, less sugar remains in the harvested product, and this can reduce market value (Hatfield and Prueger, 2015). In beans, higher night temperatures increased respiration and caused decline in yield and flowering. Potato is adapted to mild climates. Climate change means crops are more frequently being exposed to heat stress, which can significantly reduce yields and quality.
Water	Declining rainfall across southwest WA, the main vegetable growing region of the state, means that water supplies for irrigation are also likely to decline (McFarlane et al. 2020). Therefore, meeting future fresh food demand from local production will become increasingly challenging.
Pests	Plants weakened by the direct effects of weather stresses are generally more vulnerable to indirect stresses. Climate change may result in an expanded geographic distribution of pests, increased survival during overwintering, increased number of generations, increased incidence of insect-transmitted plant diseases, and reduced effectiveness of biological control, especially natural enemies.
Stable fly	Stable fly is a serious pest in agricultural areas north of Perth such as Wanneroo and Gingin. Stable flies breed to large numbers in warmer weather in plant residues, especially those remaining after vegetable crops are harvested. A warming climate could still see stable flies become problematic in more southern areas such as Myalup where vegetable production and livestock coexist.
Diseases	Both pathogens and host plants will be affected by changing climate and dramatic changes in the magnitude of disease expression can be anticipated in terms of plant/disease combinations, geographical distribution of plant diseases and the economic importance of diseases in a given location.
Weeds	Invasive plants with tolerances for higher temperatures, could have a competitive advantage in rising temperatures.

Table 25. PLEASE NOTE: WORKING DRAFT Summary of drought mitigation levers available to southwest WA vegetable industries and the RD&E gaps needing attention to better equip the industries under projected future climate change

Drought lever	What's worked/being done?	What's needed?
Heat	Protected cropping can extend or modify the harvest season, achieve higher yields per hectare and improve water use efficiency. Lower pest pressures can enable insect control to be achieved with fewer chemical applications. Yields per square metre can be four to 10 times higher than in field-grown crops, depending on crop type and the protective technology used. Potato Research WA (PRWA) in collaboration with Murdoch University (Stephen Milroy lab) are investigating the impact of heat stress on potatoes.	• Protected cropping including shade protection to reduce water use, heat stress and sunburn. Conduct return on investment studies for a range of crops. • Weather, soil and other sensor data capture on-farm. • Climate controlled greenhouse production • Conduct variety assessment trials to determine suitability of new genetics in a changing climate. • Adapting planting times and production timing within regions
Water	*Australian Vegetable Crops – Maximising Returns from Water* (Horticulture Australia 2004 -2006*)*: Case studies with vegetable growers detailing the costs and benefits which flow from a shift to more efficient irrigation systems, demonstrated real investments being made in the industry at farm level. *Water for Food program* (WA Government 2015-2018): established to identify water and land resources, as well as irrigation technologies to enable Western Australia's fresh food and animal protein production to increase its contribution to regional economies and diversify WA's agricultural production. Irrigation assessments in the north Wanneroo area by DPIRD research scientist David Rowe found that growers could improve irrigation efficiency by addressing sprinkler irrigation uniformity, pump performance and flow and pressure variations. *North Wanneroo voucher scheme:* In late 2021, the WA Government made $100,000 available for eligible commercial WA horticultural businesses to seek expert advice and planning from professional irrigation consultants to deliver productivity benefits by increasing water use efficiency.	• Government funded drilling programs and hydrological assessments to identify new groundwater resources and sustainable abstraction limits, particularly in the far south of the state where the climate will be milder. • Government infrastructure projects to make more water available for horticulture. These could include new dams or taking water from crown land and distributing to adjacent farmland. • Grants to growers for irrigation system upgrades so that acceptable application uniformity is reached. • Develop sustainable fertiliser management practices that allow unallocated water in the Peel Harvey Catchment to be used for growing crops. Reassess the very stringent fertiliser rate limits for the Peel Harvey Catchment. • Increased water-use efficiency in the face of declining rainfall, adoption of wireless technology and sensors for efficient irrigation management • Demonstration of economics and benefits of improved water use efficiency • Economics and practicalities of adoption of drip irrigation for a range of vegetable crops that are not currently grown on drip. • Use of irrigation to manage high heat events

Drought lever	What's worked/being done?	What's needed?
Energy efficiency	*Understanding and managing impacts of climate change and variability on vegetable industry productivity and profits* (Horticulture Australia 2012 -2013): Most emissions from vegetable production were from two sources - 66% from electricity usage and 19% from nitrous oxide emissions from soils. Improving electricity use efficiency was a major recommendation of the report.	• More efficient postharvest management • Reducing electricity use for irrigation: Improvements in energy productivity or reductions in energy usage in relation to irrigation • Protected cropping including shade protection to reduce water use, heat stress and sunburn. Conduct return on investment studies for a range of crops. • Electricity use for cooling: improvements in refrigerants and refrigeration plant • On-farm renewable power generation options. Technology options by region, cost and breakeven time frames
Carbon accounting	*Australian Vegetable Industry Carbon Footprint Tool – stage 2 (national development and adoption of the tool)* (HAL 2010): The Calculator provided a simple mechanism for farmers to enter their production inputs, such as fuel, electricity and fertiliser consumption and receive information about what aspects of their farming practices were contributing most significantly to their carbon footprint. The calculator is also able to help farmers understand if their carbon footprint is similar or different to other farmers, by benchmarking their emissions against others.	• HAL calculator no longer online – what is needed by the industry to measure and monitor emissions? • More efficient management of nitrogen (nitrous oxide emissions) • Opportunities for carbon storage in horticultural soils.
Business	*Vegetable Business Benchmarking (in WA)* (HIA 2017-2020): Equipping growers to make data-driven business decisions. Information was collected over three years (2016/17 to 2018/19) and delivered to industry in annual industry benchmark reports. The most profitable growers were not determined by a particular area, amount of produce or vegetable type, but by increased saleable yield and a strong focus on marketing.	• Further development of robotics for in field and packing shed deployment

Wine Industry

Industry overview

In 2019, there were an estimated 6,200 wine grape growers in Australia with about 5% of these (300) in WA. Wine grapes are produced mainly in in coastal areas of the southwest where temperatures are milder (Figure 37). Margaret River and the Great Southern are WA's major wine production regions, accounting for about 80% of total wine production.

WA produces about 3% of Australia's wine grapes across about 10,800 hectares of land. Average production between 2019–2022 was about 39,628 tonnes. The estimated value of the wine crush for WA's major wine grape regions was about $61.1m (2022), with most of the value (67%) coming from the Margaret River region (Table 26).

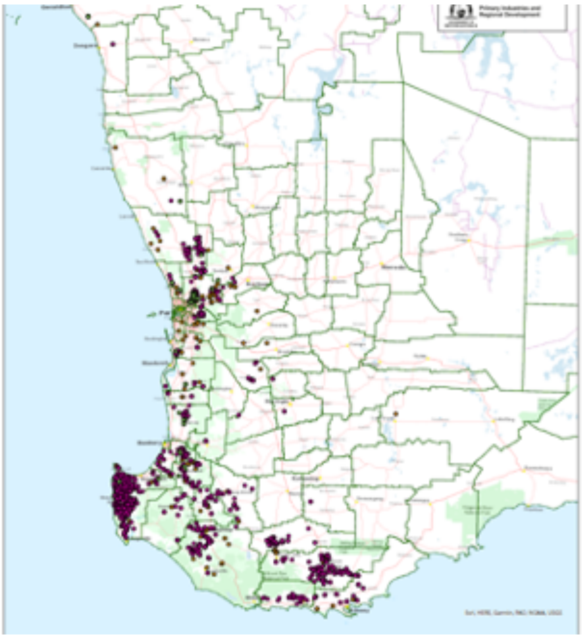


Figure 37. Location of vineyards across southwest WA. Source: DPIRD 2021

Key messages

- Average daily temperatures for Margaret River during the grape growing season could approach those of current Swan District temperatures by late this century. This could severely impact the continued production of high value 'cool' climate wines in the region.
- Reduced growing season rainfall predicted under future climate scenarios for the southwest will result in higher irrigation demand and reduced groundwater recharge and runoff into dams.
- Water use efficiency measures and more efficient capture of water into dams will be required to meet a higher demand for irrigation
- New premium grape varieties will be needed for warmer climates.

WA exported an estimated $44 million worth of wine in 2021, down 28% on 2020 because of Chinese tariffs. The exports represented just 2% of Australian wine exports, which down by 23% because of the Chinese tariffs. The UK and USA are now the major markets for WA export wine.

In June 2021, the WA wine industry (Wines of WA) gained State Government support for an export enhancement program, which aims to increase WA wine export value by 50% by 2025.

Table 26. Production (tonnes) and value ($m) of wine grapes across southwest WA regions

Region	2019	2020	2021	2022	Est. value ($m) (2022)
Margaret River	22,395	23,915	27,546	26,648	41.1
Great Southern	5,034	6,116	9,305	7,104	13.0
Swan District	3,314	2,837	2,709	2,152	2.1
Geographe	1,495	1,843	2,249	2,160	2.5
Pemberton	1,872	1,442	1,859	1,630	2.5
Other	1,134	908	1,268	1,579	-
Total	**35,243**	**37,060**	**44,935**	**41,273**	**61.1**

Source: Wine Australia 2022 National Vintage Report.

Water supply

Most vineyards in Margaret River and the Great Southern currently use limited irrigation via drip irrigation from farm dams. Reduced growing season rainfall will result in higher irrigation demand and the decline in annual rainfall will result in reduced groundwater recharge and runoff into dams. Salinity of dam water could also become an issue.

Some areas of the Great Southern (e.g., Frankland and Mt Barker) are already struggling to capture enough irrigation water in farm dams for their vine irrigation needs.

Climate impacts

The wine industry in southwest WA is especially vulnerable to a warming and drying future (Figure 27). Water for irrigation is already limited and growing season temperatures are already approaching the upper range for high quality cool climate wine production. Temperature increases of more than 3°C are predicted to occur by the end of the century under a high emissions scenario (RCP8.5), upon which we are currently tracking. If the climate model predictions transpire, the local wine industry will face a challenging future.

Table 27 outlines the recent and current RD&E with a focus on addressing climate impacts on the WA wine industry. Also outlined are the RD&E priorities needing to be considered to better equip the industry for projected climate change.

Table 27. Potential impact of climate change on the wine and table grape industries in southwest WA

Production factor	Impact of climate change
Temperature	By 2090, mean annual temperature across the southwest is projected to increase by 1.1–2.1°C in an intermediate-emission scenario and 2.6–4.2°C in a high-emission scenario. This means, average temperature for Margaret River during the grape growing season could approach that of current Swan District temperatures by late this century. This could severely impact the continued production of high value ‘cool’ climate wines in the Margaret River region. Earlier budburst, accelerated crop development and harvest date compression will result from a warming climate. Varieties that used to ripen over four to six weeks in the 1990s are now maturing over a much shorter period.
Water	Under an intermediate emission scenario rainfall across the southwest is expected to decline by 29% in winter and 36% in spring by 2090 compared to current conditions. Reduced growing season rainfall will result in higher irrigation demand and reduced groundwater recharge and runoff into dams. The outlook is particularly dire for the Great Southern inland areas such as Frankland and Mt Barker where irrigation water supplies are already limited.
Pests and disease	Increasing temperatures may increase the prevalence of insect pests and diseases. For example, the glass-winged sharpshooter is the vector of the bacteria caused Pierce’s disease, which was devastating to grapevines in California. The insect and disease have now become serious further north in California in the wine producing Napa and Sonoma Valleys.

Caption

Table 28. PLEASE NOTE: WORKING DRAFT Summary of drought mitigation levers available to southwest WA wine and table grape industries and the RD&E gaps needing attention to better equip the industries under projected future climate change.

Drought lever	What's worked/happening?	What's needed?
Heat	*Australia's wine future: Adapting to short-term climate variability and long-term climate change* (Wine Australia 2020): three-year project examining the impact of seasonal climate variability and longer-term climate trends on the wine sector in Australia. A large multidisciplinary project that generated climate predictions for Australian wine regions to outline how climate may change in the short, mid and long-term. The project also focused on how climate information might inform adaptation decisions across regions. *Australia's wine future: A climate atlas* (Wine Australia, 2016-2019): Aim was to help to grape growers and winemakers plan for the effects of climate change. The online atlas features indices tailored for individual regions with a focus on heat accumulation and aridity, plus the likelihood of heatwave and frost. *Helping futureproof the wine industry* (Wine Australia, 2019): book to help wine grape growers around the world navigate future global markets and the impacts of climate change.	• New premium grape varieties for warmer climates. • Further clonal selection of existing varieties for a warming climate. • Rootstocks to control increased vigour, including salt excluding/tolerant rootstocks.
Water	*Climate adaptation: developing irrigation strategies to combat dry winters* (Wine Australia, 2017-2021): aims to provide information on the best ways to manage low winter rainfall using existing vineyard infrastructure and how modifications to irrigation systems may result in better outcomes for grape growers under climate change. *Plant sensor-based precision irrigation* (Wine Australia, 2018-2022): The purpose of this project is to provide new tools to grape growers to schedule irrigation based on real-time measurements of vine water status. The project will use of low-cost microprocessors and infrared thermal sensors to compare conventional vs. sensor-driven irrigation effects on vine performance, yield, vine and vineyard water use efficiency. It is proposed to use wireless connectivity of the sensor network to Cloud-based data platforms that will be accessible by users via a smartphone application. *Mirás-Avalos and Araujo* (2021): reviewed global vineyard water management in the context of drying climates. The review provides an overview of the advances in the research on optimizing water management in vineyards, including the use of novel technologies (modelling, remote sensing). The Australian Wine Research Institute has assembled an excellent web page with links to a wide range of aspects on irrigating wine grapes: https://www.awri.com.au/industry_support/viticulture/water-management/	• Improved catchment of surface irrigation water, roaded catchments, technology for improving efficiency including use of polymer coatings. • Innovative approaches needed to capture winter runoff within vineyards. • Use of mildly saline irrigation water, what limits, impacts on productivity, wine quality, soil structure. • Further improvements to water use efficiency using sensors and wireless data capture and further extension and adopting of Reduce Deficit Irrigation (RDI) scheduling. • Managing vine canopy in warming climates to protect grapes for heat extremes while maintaining suitability for machine harvesting. • Selection and management of cover crops to meet the challenge of a drying climate – reducing cover crop water use while reducing radiant heat load on vines.

Drought lever	What's worked/happening?	What's needed?
Carbon accounting	*Climate change ready varieties and management technologies that reduce greenhouse gas emissions in the vineyard* (Wine Australia, 2013-2016): This project evaluated the potential of non-GM mildew resistant grapevines and new rootstock-scion combinations, grown at different plant densities, to reduce vineyard inputs and the overall vineyard carbon footprint. Abad et al. (2021) reviewed 272 papers related to cover crops in vineyards and concluded that the use of cover crops has a positive effect on the vineyard by increasing soil organic carbon, improving water infiltration and aggregate stability, and reducing erosion and greenhouse gas emissions.	• Better data capture and accounting of carbon emissions and sequestration in the wine industry. • Development and adoption of low emissions technology and practices • Opportunities for carbon storage in vineyard soils.

References

Abad, J., Hermoso de Mendoza, I., Marín, D., Orcaray, L., and Santesteban, L. G. (2021). Cover crops in viticulture. A systematic review (1): Implications on soil characteristics and biodiversity in vineyard. OENO One, 55(1), 295–312.

Mirás-Avalos, J.M.; Araujo,E.S. (2021). Optimization of Vineyard Water Management: Challenges, Strategies,and Perspectives. Water, 13, 746.

Honeybees

National industry

Between 2015 and 2019 the Australian honeybee industry produced an average 37,000 tonnes of honey annually from a mix of commercial and recreational beekeeping operations. The industry also generates paid pollination services, beeswax production and sales of queen bees and packaged bees. In 2019, honey represented about 80% of returns, pollination services about 15% and other hive products about 5% (Clarke and Le Feuvre, 2021).

There are an estimated 30,000 registered beekeepers in Australia operating about 670,000 hives (Table 29). Since 1962, the number of commercial beekeepers has declined by 36% while recreational beekeeping has increased 10-fold.

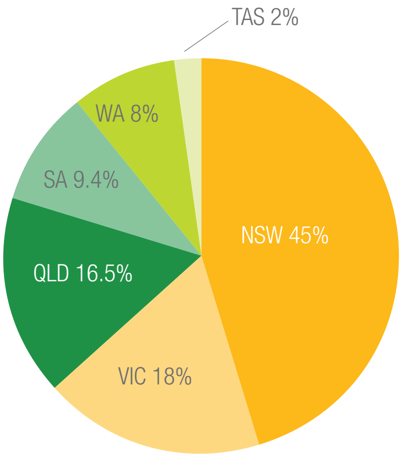


Figure 38. Distribution (%) of commercial beekeepers (>50 hives) across Australia in 2020. Source: Plant Health Australia

Key messages

- Nectar resources for the WA honeybee industry are located primarily on government-managed land, including state forest, national parks, and nature reserves, which together account for more than 75% of the state's honey production.
- Climate change and controlled burning operations are having a significant impact on forage resources for the honeybee industry.
- Several high-value WA horticultural (apples/avocadoes/blueberry) and seed crops (canola/clover/lucerne) rely totally on insect/honeybee pollination to generate yield.
- Synergies exist between shelterbelts for sheep and cattle wellbeing, capture of carbon offsets and attraction of pollinators for southwest horticultural industries.

Of the total registered beekeepers, about 6% (1,869) are commercial operators (>50 hives) and 94% are recreational beekeepers. Most commercial beekeepers operate between 400 and 800 hives, with some operating more than 3,000 hives (Australian Honey Bee Industry Council, 2019). About 79% of Australian hives are operated by 1,869 commercial beekeepers.

Table 29. Number of commercial (>50 hives) and recreational beekeepers across Australia (2020)

State/territory	Commercial beekeepers (>50 hives)	Recreational beekeepers	Total beekeepers	Total hives
New South Wales	848	8499	9347	297,362
Victoria	337	8899	9236	123,277
Queensland	309	4760	5069	105,495
South Australia	175	2284	2459	69,810
Western Australia	161	3142	3303	48,978
Tasmania	38	238	276	23,750
TOTAL	**1,868**	**27,822**	**29,690**	**668,672**

Production value

The gross value of Australian honey, paid pollination services and other honeybee products was estimated at $264 million in 2019 (Clarke and Le Feuvre, 2021) (Table 30). Annual production is highly dependent on temperature and rainfall. 'Other hive products' include honeycomb sections, propolis, royal jelly, bee venom, pollen, queen bees, packaged bees, and nucleus hives. An estimated value of $12 million was assigned to these hive 'co- products' in 2019. Queen bee sales account for more than half the estimated 'co-product' value (Table 30).

Markets

Australia currently exports about 4000 tonnes of honey each year – less than half that of the 1980s and 90s (Figure 39). There is potential to export more honey, but supply is not available. Key markets for Australian honey include China, USA, Singapore, Canada, and Malaysia.

Australia now routinely imports twice as much honey as it exports (Figure 39). Sources of imported honey include China, Argentina, and New Zealand.

Packaged bee exports for Canada are a small but important industry for Tasmania and WA. Reopening the live bee export trade with the USA would add an estimated $7.5 million to the value of the Australian honey industry.

Pollination

Most plant foods (by volume) produced for human consumption and animal feed in Australia are self-pollinating crops, such as wheat and barley. By contrast, 65% of the horticultural and agricultural crops introduced into Australia since European settlement require honey bees, other insects, wind, birds or bats for pollination.

Crops vary in their reliance or response to pollination by bees. Some industries, such as almonds, apples, pears and cherries, depend almost totally on bees for fruit and nut production. There are 35 Australian crop industries that depend on honey bee pollination services for some or all of their production, with other insects also playing a role (Table 31).

Major users of pollination services are almond, apple, avocado, blueberry, macadamia, pumpkin, and watermelon. In 2019, the almond industry, Australia's largest user of paid pollination services, hired 180,000 hives for crop pollination. The gross value of paid pollination services in 2019 was estimated to be $40 million.

Table 30. Estimated production value of honey and honey products in 2019

Industry sector	Est. production value ($m)
Honey and beeswax (levy paid)	147
Honey (small producers/levy unpaid)	65
Other hive products: queen bees, packaged bees, propolis etc.	12
Paid pollination services	40
TOTAL	**264**

Source: Clarke and Le Feuvre (2021)

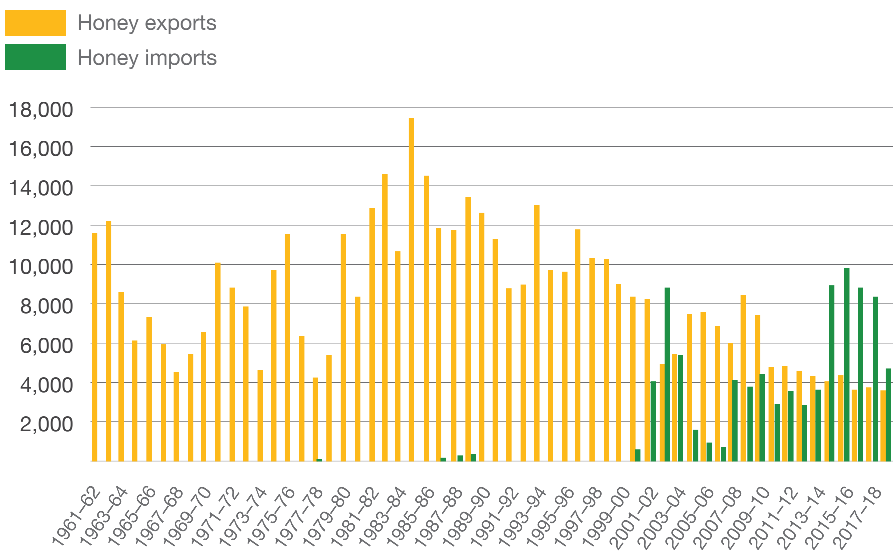


Figure 39. Volume (tonnes) of Australia honey exports and imports 1960 to 2018.
Source: Clarke and Le Feuvre (2021)

Table 31. Crops either wholly or partially (%) dependent on honey bees for yield

Commodity	Responsiveness (%)	Commodity	Responsiveness (%)
Tree crops		**Vine crops**	
Almond	100	Blueberry	100
Apple	100	Cucumber	100
Apricot	70	Kiwi	80
Avocado	100	Pumpkin	100
Cherries	90	Rockmelon	100
Citrus	0–80	Squash	10
Grapefruit	80	Watermelon	70
Lemon &Lime	20	Seed production	
Macadamia	90	Beans	10
Mandarin	30	Broccoli	100
Mango	90	Brussel sprouts	100
Nectarine	60	Cabbage	100
Orange	30	Canola seed	100
Papaya	20	Carrot	100
Peach	60	Cauliflower	100
Pear	50–100	Celery	100
Plum & prune	70	Clover	100
Ground crops		Lucerne	100
Peanuts	10	Mustard	100
Broadacre crops		Onions	100
Canola	15		
Cotton	10		
Soybeans	10–60		
Sunflower	30–100		

The relatively small production value of the beekeeping industry ($247m in 2019) understates the industry's true value to agriculture through (currently) unpaid pollination services, which have been estimated into the billions of dollars in recent studies.

WA industry

The WA beekeeping industry is located primarily in the southwest coastal strip with some production in the Goldfields (Figure 40). Between 2015 and 2019 the number of registered beekeepers more than doubled, with a 64% increase in commercial beekeeping (defined as more than 50 hives) (see Figure 40). Demand for forage sites to host apiaries has also increased responding to industry growth. As of 2018, 4479 site licenses were made available by the Department of Biodiversity Conservation and Attractions (DBCA), and of these, 70% were located within the southwest of WA.

DPIRD analysis (November 2021) of registered beekeepers indicates there are about 4,200 current WA beekeepers operating about 52,000 hives. Of these, about 63% are commercial (>50 hives), about 25% are hobbyist-amateur and 12% are backyard beekeepers. Most of the hives are operated by commercial beekeepers.

About 37% of WA honey is produced on private land and 63% on public lands. Forested areas dominated by jarrah (*Eucalyptus marginata*) and marri (*Corymbia calophylla*) are sought after for honey production. WA apiarists migrate their hives between two to six times per year following the sequence of flowering events across the state, travelling thousands of kilometres and crossing a mix of private and leased public sites in the process (Patel et al. 2020). Use of each site lasts between two weeks and a few months depending on variability in active flowering and nectar production.

Bee foraging resources are primarily located on government-managed land, including state forest, national parks, and nature reserves, which together account for more than 75% of the state's honey production (Patel et al. 2020). The beekeeping industry relies on native flora, especially eucalypt species, across a mosaic landscape of forest, woodlands, shrublands, and heathlands (Figure 40). About 31% of WA beekeepers have reported reductions in the use of public land over the past decade because of restricted site access in response to changing government policies (van Dijk et al. 2016).

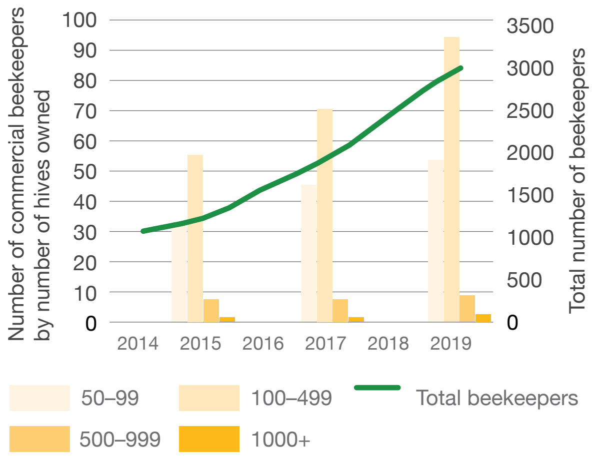
While production has remained relatively static, honey prices have risen substantially. In Western Australia prices for Jarrah honey have been edging up towards $100/kg in China and around $30/kg domestically from a base of $3/kg.

Pollination services are a minor activity within the WA honeybee industry. Most pollination services are focussed in avocado-growing areas (Swan Coastal Plain, Jarrah forest, Warren region). Average fee for service is $170/hive with a total of 139 hives in operation.

Climate and controlled burning impacts

Research has established a positive correlation between rainfall, winter survival of bee colonies (Switanek et al. 2017) and honey harvest (Delgado et al. 2012). The greatest limiting factor for bee production is the availability of food rather than climate. Excessive temperatures can decrease honeybees travelling speed and thus reduce production capacity. Honeybees will also not forage during rain. Honey production during cold temperatures may also be reduced because honeybees will not fly when it is below 13˚C, although honeybees can tolerate frost. The principal cause of attrition during winter is starvation rather than cold temperatures.

Climate change is not likely to have a huge impact on bees themselves but will have an impact on the composition of forest areas where bees forage. In WA's southwest almost 180,000 hectares across southwest WA is burnt annually to manage fuel load and avoid catastrophic fire events. However, controlled burning can lead to loss of nectar-bearing flowers and some species (e.g., Parrot bush or Banksia sessilis) can take 12–15 years postfire to reach maximum honey production. Loss of crop (nectar-bearing flowers) due to frequency, intensity, and timing (during budding season) of prescribed burns has been noted in recent surveys as the main cause of conflict between beekeepers and government.



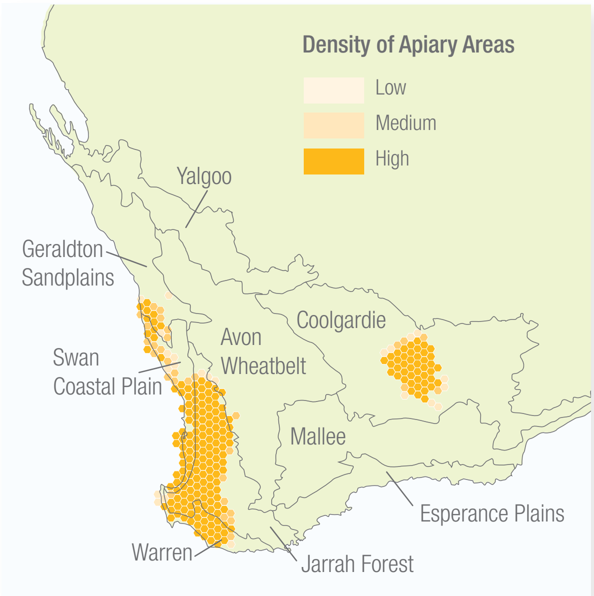


Figure 40. Distribution and number of WA commercial beekeepers (> 50 hives) between 2014 and 2019. Honey production is constrained to southwest WA. Beekeeping is migratory, following the year-round availability of high-quality forage species, such as Banksia and eucalypts from the genera *Eucalyptus* and *Corymbia*. There are 60 species of Banksia in the southwest region, with varying flowering times and beekeepers rely on Banksia species during times when eucalypts are not flowering.
Source: Patel et al., 2020.

Table 32 outlines the recent and current RD&E with a focus on addressing climate impacts on the honeybee industry. Also outlined are the RD&E priorities needing to be considered to better equip the industry for projected climate change.

Table 32. PLEASE NOTE: WORKING DRAFT Summary of drought mitigation levers available to southwest WA honeybee industries and the RD&E gaps needing attention to better equip the industry under projected future climate change.

Drought lever	What's worked/what's happening?	What's needed?
Heat	Climate change is affecting the composition and flowering times of forest areas – reduction in important forage resources: Jarrah, Wandoo and Banksia. Forest controlled burning is impacting areas used for honey harvesting and having an impact on the composition of the forest understory and future honey yields. Robustillo et al (2022): Research in Spain has developed a decision support system to alert beekeepers of out-of-the-ordinary situations in the hives, and thus aid in their efficient management.	• Examine the role of burning on biodiversity and honey production. • Develop flexible and adaptive burning regimes that consider flowering events, honey lost, proximity to apiary sites.
Water	Honeybees need to collect water, so bodies of fresh running water are required. Bees use two litres of water per hive a day to control temperature and keep a hive humid, so an apiary of 100 hives will need 200 litres of water a day. Once the temperature reaches 39°C bees start switching from collecting nectar to collecting water. By 43°C all the field bees have switched over to collecting water.	
Pollination services	CRC for Pollination Security being established (with lead out of Melbourne). The CRC will undertake RD&E activities to increase awareness and understanding of the role of pollinators in agriculture and the environment, build capability within the beekeeping industry and pollinator-dependent sectors across agriculture; and encourage practice change to improve pollination capability and outcomes, and strengthen Australia's food security and ecosystem health. DPIRD is leading a national project to investigate fly species as pollinators of avocado, berries (blueberry, raspberry and strawberry), hybrid carrot seed crops, hybrid brassica seed crops, mango and lychee. DPIRD's research component is examining the performance of native flies as pollinators in avocado orchards, the State's the -value tree fruit crop worth nearly $200 million annually. The research in avocado orchards has shown two fly species pollinated as many – if not more – flowers than bees in an orchard of Hass avocados while the western blue-bodied blowfly, which is widespread in mainland Australia pollinated as many fruit as trees in the open orchard serviced by bees. The European bluebottle blowfly, introduced to Australia over a century ago, also performed as well as bees in an open orchard.	• Avocado Strategic Investment Plan 2022-2026: Securing pollination for industry through robust honeybee health, pest and disease mitigation and investigation of alternate pollinators • Government support to expand pollination services in the wheatbelt and horticulture regions • Investigate potential intersection between shelterbelts for livestock wellbeing, carbon capture and attraction of pollinators.
Revegetation/ carbon	Patel et al (2020): main pressures on WA honeybee industry: • access to apiary sites, • burning of forage and habitat loss • climate change impacts	Examine the economic impact of increased biodiversity associated with revegetation and carbon farming in relation to honey production and pollination services

Land-based aquaculture

Key messages

- Land-based aquaculture in southwest WA is currently based on marron/yabbies and freshwater trout and silver perch and a range of other species from barramundi through to abalone, algae and aquarium fish and is worth about $3 million per year.
- Marron are the most valuable sector of the industry ($2.2m in 2019–20).
- The yabby industry has declined significantly over the past 20 years due partly to a run of dry years in the early 2000s.
- Marron production has hovered at about 50 tonnes/year for the past 20 years despite projections in the early 2000s that it was capable of 1000 tonnes/year.
- The main climate impacts on land-based aquaculture relate to future water supply and streamflow, high and extreme summer temperatures and large runoff events into water bodies leading to eutrophication and stock loss.

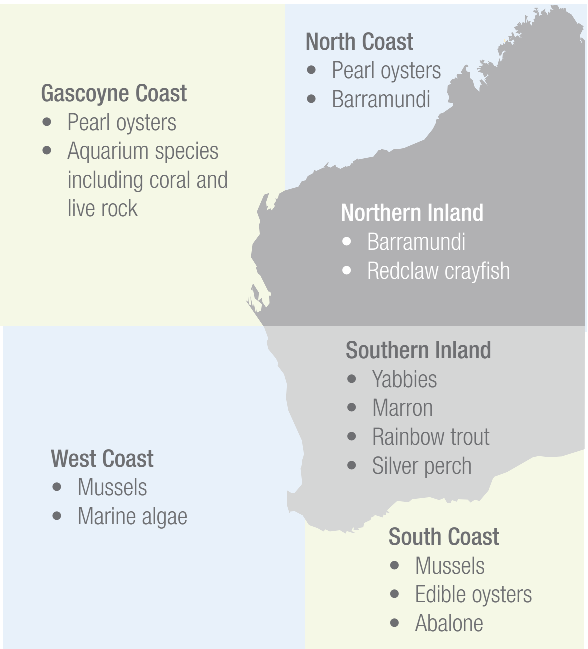


Figure 41. Location of main aquaculture species farmed in Western Australia (marine and land-based)

Location

Land based aquaculture systems include pond aquaculture systems, pen systems within tank aquaculture systems using estuarine, marine, saline groundwater, or fresh water for growing species. Western Australia's major land-based aquaculture activities are located at Pemberton in the south west (trout), Hutt Lagoon in the Mid West (algae and brine shrimp), Lake Kununurra in the Kimberley (barramundi), Bremer Bay on the south coast (abalone) and farm dams across the south west (marron and yabbies) (Figure 41).

Industry statistics

The Australian aquaculture industry (marine + land-based) has an estimated production value of about $2 billion (ABARES 2021) and is dominated by salmon in Tasmania, tuna and oysters in South Australia and, increasingly, prawns in Queensland. By national standards, the aquaculture industry (marine + land-based) in Western Australia is small — worth an estimated $83 million in production value (2017–18), with most value generated by pearl oysters and ocean-farmed barramundi (Table 33).

Marine-based aquaculture in WA is dominated by pearl oysters, barramundi and mussels with growing abalone, oyster and yellowtail kingfish industries. The marine-based aquaculture industry is worth about $80 million per year (Table 33). Land-based aquaculture is currently based on marron/yabbies and freshwater trout and silver perch and a range of other species from barramundi through to abalone, algae and aquarium fish and is worth about $3 million per year (Table 29).

The total value of WA's aquaculture industry has fallen by nearly half in the past 20 years – from a high of $170 million per year in the late 1990s and early 2000s to a low of about $87 million over the past five years (2015-2020) due largely to the decline of the pearl oyster industry, which was struck by a mysterious disease in 2016 from which the industry is yet to recover (Figure 42). Over the same period (last 20 years) land-based aquaculture (predominantly marrons + yabbies) has dropped slightly from a high of $2.9 million in the late 1990s through to about $2.5 million in the last five years. The decline in land-based aquaculture has been due to a significant drop in revenue from the yabby industry (see Figure 44).

Table 33. Estimated production value ($) of marine and land-based aquaculture in Western Australia

	Licences	Production	Value
Marine-based			
Pearl oysters[1]	-	n/a	$63.5M
Barramundi[2]	5	1083t	$12M
Other species[*2]	<3	150t	$3.4M
Mussels1	4	169t	$697,000
Ornamental fish[^1]	14	-	$307,000
Total			**$79.9M**
Land-based			
Marron[2]	179	61t	$2.2M
Yabbies[2]	9	17.6t	$431,000
Silver Perch[1]	8	21t	$480,000
Rainbow trout[1]	5	8t	$76,000
Algae[1]	<3	**	**
Aquarium fish (goldfish + carp)[^2]	4	-	$137,000
Total			**$3.3M**

^Ornamental fish include tropical fish, coral & live rock.

'Other species' refers to production where there were less than three contributing licences. Over the past 10 years this has included brine shrimp (artemia), abalone, black bream, Mahi mahi, live rock, mulloway, Murray cod, pink snapper, prawns, rotifers, western rock oysters and yellowtail kingfish. ** Industry values for algae have not been included to protect commercial individual producers as there are fewer than three production licences. DATA SOURCES from DPIRD via: 1Australian fisheries and aquaculture statistics 2017, Australian Bureau of Agricultural and Resource Economics and Sciences December 2018 and 2ABARE Australian fisheries and aquaculture statistics 2020.

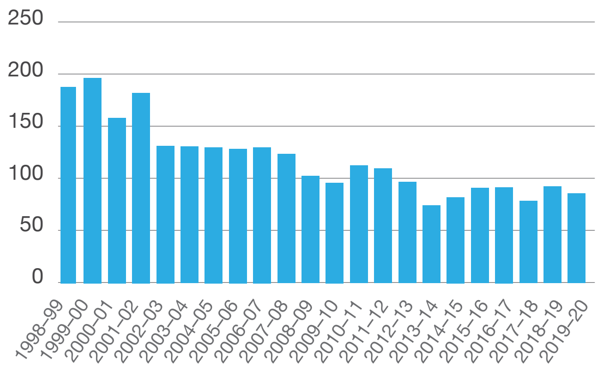


Figure 42. Total value ($'000) of WA marine and land-based aquaculture industries over the past 20 years

WA land-based aquaculture species

Marron

Marron represent the largest land-based aquaculture industry in Western Australia – generating about $2.2m in production value from 61 tonnes in 2018-19 (Table 33).

Native to southwest WA, marron are a high value product (>$30/kg wholesale) usually sold live. Income from the marron industry sector diversifies and supplements income on family farms across the south west. The industry is served by the Marron Growers Association and has the largest number of licensed producers of any aquaculture species in WA – currently 179 (Table 33). Licences take two forms; a limited licence allows farmers to grow marron on their property and sell to a holder of an unlimited or processor marron licence. About 10% of marron producers generate 50% of WA marron mainly from purpose-built marron ponds.

A concerted marron RD&E program in the 1990s and 2000s developed and extended marron production and breeding systems proven to significantly increase marron yields and profits (Lawrence, 2007).

DPIRD researchers at the Pemberton Freshwater Research Centre are currently breeding genetically improved smooth marron, with juveniles due for harvest in early 2022 to stock industry growth trials and commercial marron ponds.

Potential production estimates for the marron industry in the mid 2000s were for 1000 tonnes/year. Despite this, WA marron production has remained at about 50-60 tonnes per year for the past 20 years (Figure 43).

European and Asian markets exist for WA freshwater crayfish with production volume (seemingly) the only factor limiting market potential:

> "...research and industry representatives have recognised the advantages to marron export arising from international marketing and transport systems already established for rock lobster. In fact, in contrast to most other aquaculture industries, marketing and transport for marron are well established, the key issue is how to increase production." (Dr Craig Lawrence, 2007).

In the January 2022 NSW DPI report "Aquaculture Production Report 2020-2021" the author states:

> "The size of any export market is impossible to evaluate until supply can be maintained. There is certainly a market for crayfish in Europe, as crayfish are regarded as a delicacy and local stocks have been diminished by the "crayfish plague". However, the market in some European countries (for example, Sweden) is highly seasonal. Trial shipments have suggested that Cherax (marron) species would be accepted in the marketplace. Some products have also been exported and well received in Asia, so there is also potential there. The success of future export trade will be largely dependent on volume and continuity of supply."

Yabbies

Yabbies are native to central and eastern Australia and were introduced from western Victoria into the Narembeen area of WA in the 1930s. Yabby farming has since spread throughout the wheatbelt and is deliberately separated from the native habitats of marron, which occur mainly in natural waters in wetter areas of south west WA.

Dam harvesting of yabbies commenced in the early 1980s and progressed well until a run of dry seasons limited the capacity of the rainfed dams to produce yabbies. Production grew from 1.7 tonnes per year in 1987 to 286 tonnes in 1994 but is now at under 20 tonnes (2018-19) (Figure 44).

Cambinata Yabbies is WA's largest yabby business based in Kukerin, 300-kilometres south-east of Perth. Established in 1991, the business reportedly exports about 500 kilograms of yabbies per week sourced from about 700 farmers across regional Western Australia and has the capacity to process more than 4000 kilograms a week.

Commercial harvesters have been faced with not only the drying climate but also the lack of stock to re stock dams following good rains.

Unsuccessful commercial attempts have been made to farm yabbies more intensively in purpose-built ponds like marron. Costs and uncontrolled breeding during grow-out were identified as obstacles to success.

Silver Perch

Silver Perch have been introduced into WA from the Murray-Darling river system and can only be cultured in impounded waters where the risk of translocation to local waterways is minimal.

They are mostly grown in tanks or in approved farm dams and are sold as a live or processed product for human consumption and for aquariums and aquaponics purposes.

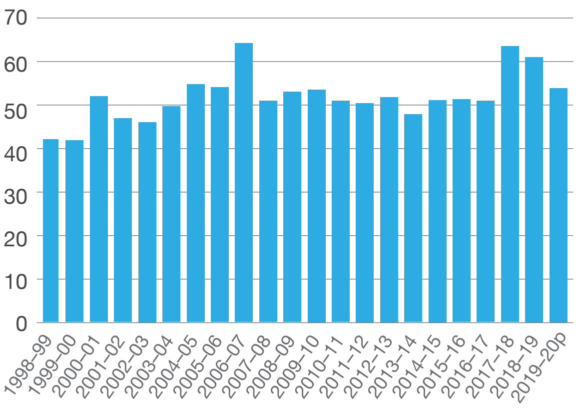


Figure 43. Production (tonnes) of the WA marron industry over the past 20 years (1998-2020)

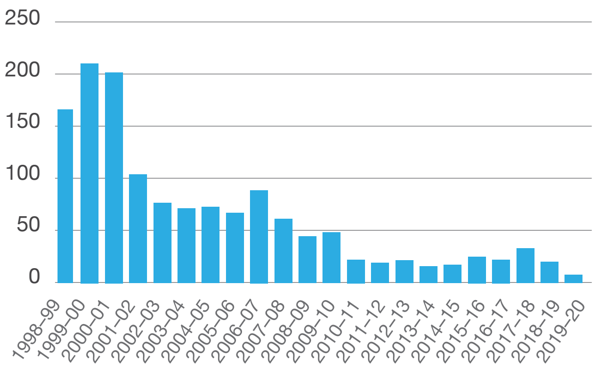


Figure 44. Production (tonnes) of the WA yabby industry over the past 20 years

Freshwater trout

Rainbow trout originate from North America and were introduced into Western Australia in 1927 to provide recreational fishing in the south west. However, in most cases the trout failed to establish as it is difficult for the species to spawn under WA conditions. In response, a trout hatchery was established (Pemberton Freshwater Research Centre) to artificially breed trout for release into selected waterways in the south west for recreational fishing.

In 2020, the Pemberton Freshwater Research Centre produced about half a million trout fry, with about 80% released for the recreational fishing – an industry worth an estimated $20 million each year to the southwest region.

In addition to supplying the recreational fishing industry, about 75,000 fry from the Pemberton hatchery are grown out each year by WA aquaculture businesses to produce trout for Perth restaurants and Asian markets –a growing industry currently worth about $75,000 per year. In 2020, a new commercial trout nursery was opened in Manjimup to supply juvenile trout (larger than fry) to local producers. Trout fry for the operation are sourced from the Pemberton hatchery and then grown out in the nursery before being supplied to trout producers to grow out in dams across the southwest.

Barramundi

The majority of farmed barramundi in WA occurs in sea cages off the Kimberley coast but the fish can also be produced in indoor recirculating systems and land-based ponds.

One farmer in Morawa is reportedly growing and marketing barramundi from a saline bore water source.

A successful recreational fishing industry based on barramundi is located at Lake Kununurra with about one million barramundi released since 2012. The latest release of 200,000 juvenile barramundi in 2020 were reared by the Aquaculture Centre at North Regional TAFE in Broome. According to a 2020 report on the restocking program, the economic value to the region of barramundi is about $7.6 million per year.

Abalone

Australia generates about 3.0% of global abalone supply, from wildcatch fisheries and farms. Farms operating from 12 sites across four southern states produced around 1,120 tonnes in 2019.

Two of the sites are in WA – a marine-based farm in Augusta and a land-based operation in Bremer Bay.

Total WA abalone production in 2018-19 was 118 tonnes (about $4.9m in production value).

Drying climate stimulates new hatchery approach

The Pemberton trout hatchery has operated for more than 80 years. Historically, up to 1,000,000 juvenile trout, called fingerlings, of about 50mm in length have been released in spring when streams fill and flow following winter rainfall. But with lower rainfall and increased water extraction by industry, these streams now dry up quickly and many no longer flow throughout summer, causing large losses of released fry. Historically up to a million trout fry (50mm in length) have been released each year into SW waterways and dams. In addition, about 20,000 larger trout (yearlings about 200+mm) were also released.

The fry take two whole summers to grow to legal capture size and with climate change and lower stream flow many of these fry were not surviving to legal size.

The new strategy releases far fewer smaller fry (150,000 in 2022) and >40,000 larger yearlings that are almost at legal capture size. Trout are only released into locations identified as having suitable stream flows.

By retaining trout in the hatchery until they are larger, the fish are more robust and can be released into larger bodies of water and compete more successfully, especially against the introduced and predatory redfin perch.

The Bremer Bay land-based abalone farm 888 includes a hatchery and nursery, weaning facility and grow out tanks and employs about 23 full-time staff in a town of 500. According to the company's website about 100 tonnes of abalone are produced each year and marketed in Melbourne, Sydney, Perth and Asia.

Abalone farmed in land-based tanks need large volumes of high-quality water to be pumped continually through them.

Algae

Microalgae are grown in WA for beta-carotene (food colouring and pre-cursor to vitamin A) production, and for shellfish and prawn aquaculture feed. The algae are reared in large shallow lagoons and ponds north of Geraldton. Hutt Lagoon in the Mid West reportedly has the world's largest microalgae production plant, a 250-hectare series of artificial ponds used to farm the microalga Dunaliella salina. Water for the farm is pumped into the ponds from the ocean. Hutt Lagoon also generates a commercial supply of Artemia brine shrimp. Artemia are a specialty feed used by prawn and fish farmers and the aquarium fish trade.

Land-based aquaculture - challenges

While there has been a push for inland saline aquaculture throughout the drier Australian states over the past 15-20 years, drought and a drying climate have limited potential. The lack of a sizable land-based aquaculture industry in WA limits the collection of levies and hence return to WA producers.

In the early 2000s black bream were promoted as a candidate species for inland saline aquaculture

but are now rarely stocked by farmers in Western Australia. While black bream possess many desirable ecological attributes, such as hardiness and a wide temperature and salinity tolerance, the fundamental problem is that current growth rates of 150g/year are too slow for profitable production.

Inland aquaculture production of rainbow trout was also touted in the early 2000s but with little success.

Growth of a land-based aquaculture industry has been restricted by:

- A drying climate restricting stream flows and destruction of habitats
- The availability of suitable water resources as water is used for alternative uses
- High capital costs of establishing ponds
- lack of investment and high capital and operating costs, investor scepticism
- difficulty in obtaining site approvals.

Climate change

The main climate impacts on inland aquaculture are future water supply, high and extreme summer temperatures and large runoff events into water bodies leading to eutrophication and stock loss (Table 34).

Table 34. PLEASE NOTE: WORKING DRAFT Summary of drought mitigation levers available to the southwest WA land-based aquaculture industry and the RD&E gaps needing attention to better equip the industry for projected climate change.

Drought lever	What's worked/being done?	What's needed?
Water	Compared with 40 years ago there is now significantly less runoff and streamflow across southwest Western Australia. The region has lost a third of its 10mm and 25mm rainfall events making its natural catchments less effective. DPIRD research at the Pemberton Freshwater Trout Research Facility is developing a new trout release strategy based on streamflow status and larger fish that are better able to survive and reach catchable size within one season.	• Monitoring of trout survival and catch rates in SW waterways and dams. • Management of streamflow into natural waterways.
Heat	Rainbow trout are cold water species, which thrive at 5-20°C. Mortalities can occur once water temperature increases to 26-27°C. Research ay the Pemberton Freshwater Trout Research Facility have been selecting for trout able to withstand the higher temperatures of local southwest WA conditions.	• Evaluate water recirculation systems for maintaining marron and trout brood stock at optimum water temperature at DPIRD hatchery facilities. • Continue breeding program for trout adapted to higher water temperatures.
Saline water opportunities	A lot of R&D done in the early 2000s re using saline water to create inland aquaculture ventures: FRDC Project No. 98/335: Developing Commercial Inland Saline Aquaculture in Australia RIRDC Project No MFR-3A: Aquaculture in Saline Groundwater Evaporation Basins	• Evaluate the use of saline water lakes and saline ground water for artemia (brine shrimp) and algal production. • Determine the size of the artemia/microa-algae market. Is there room for more production above and beyond the Hutt Lagoon operation? • Evaluate the reuse of abalone waste stream water to grow out rainbow trout in southwest WA.

Drought lever	What's worked/being done?	What's needed?
	Morawa farmers (David and Jane Coaker) using intensive recirculating aquaculture system on their 11,000-hectare grain property to pump saline and bore water into tanks to grow out fingerling barramundi and Queensland groper. Coakers worked with the Australian Centre for Applied Aquaculture Research to establish the operation. The operation was established as a drought-mitigation venture in response to dry years in the 2000s as well as way to use saline water from drained paddocks. Rehabilitated land now grows 2-3 tonne/ha barley crops.	
Production efficiencies	WA marron production has hovered at 50t/year for the past 20 years. Best practice production methods established but not adopted by all growers.	• Carry out growth rate and reproduction studies with commercial farms to improve marron returns • Co-production of marron and rainbow trout – what are the research needs? • Silver Perch – production potential for land-based WA systems.