Investigating the environmental impacts of drought in regional Western Australia

Regional Drought Resilience Planning 2022

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1 CONTENTS

PROJECT BRIEF

This work was commissioned by the Department of Primary Industries and Regional Development in collaboration with the Great Southern Development Commission.

LA.ONE was requested to review the available environmental data for each of the three pilot regions and identify regional vulnerabilities, needs and priorities for promoting environmental resilience to future drought.

The three pilot regions comprise of:

- A Northern Agricultural consortium of the Midwest Development Commission (MWDC), the Northern Agricultural Catchments Council, the City of Greater Geraldton, and the Shires of Northampton and Chapman Valley.
- The Southern Wheatbelt consortium is the Wheatbelt Development Commission (WDC) Local Government Areas – Dumbleyung, Kulin, Kondinin, Lake Grace, Wagin.
- The Great Southern Inland consortium of the Great Southern Development Commission (GSDC) Local Government Areas – Jerramungup, Kent, Gnowangerup, Katanning, Kojonup, Cranbrook, Woodanilling, Broomehill-Tambellup.

The request was to:

1. Review the extent and severity of **environmental impacts of drought** in the regions historically, and
2. **Assess the likely environmental impacts of drought in the future**.

The requested method was to:

1. Conduct a review of the historical impacts of drought on natural resources that support and surround farming, rural and regional communities in the three project regions and assess potential future environmental impacts of drought on regional natural resources.
2. Identify natural resource management (NRM) practices and technologies that could improve the drought resilience of the agricultural landscapes in each region.
3. Identify the key responses, initiatives and programs that may mitigate the adverse environmental impacts of drought, including an overview of what has been done in the past to make farming communities, agribusiness, and supply chain sectors more resilient to environmental impacts of drought and an assessment of the effectiveness of these interventions.
4. Identify a roadmap with high-level options and pathways including any new / transformational interventions that build environmental resilience to drought in the focus regions.

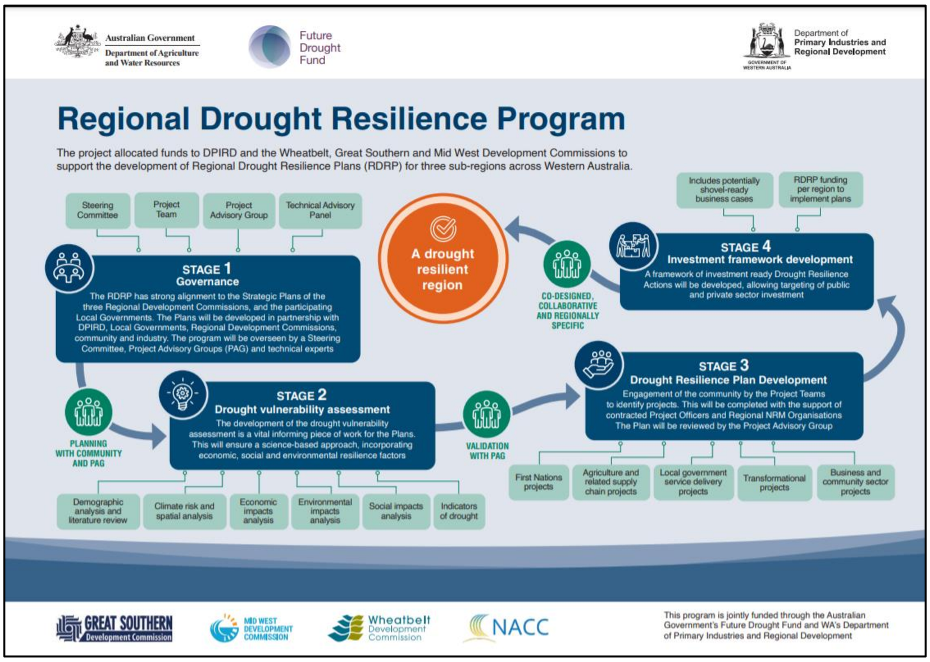

Figure 1. Regional Drought Resilience Program Plan

This work is a component of the project "Regional Drought Resilience Program" for the Northern Agriculture Region, Great Southern Region and the Southern Wheatbelt. It contributes to the Regional Drought Resilience Plans for the three sub regions across Western Australia and needs to be aligned with national initiatives currently being undertaken under the Future Drought Fund.

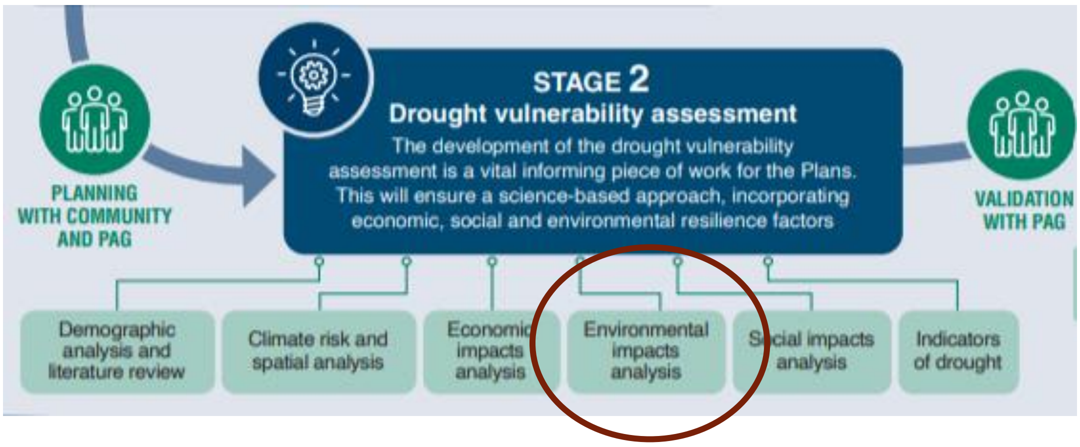

Figure 2. Environmental Impacts is part of the stage 2 Drought vulnerability assessment

EXECUTIVE SUMMARY

The challenge for agriculture is to feed a population of ten billion people by 2050, sustainably with a drying and more variable climate. Globally the industry will need to produce 30% more food in the same land area, while stopping deforestation, cutting greenhouse gas emissions, reducing poverty and loss of vegetation, preventing freshwater depletion, and cutting pollution. This problem worsens with more frequent and severe droughts.

The Southwest of Australia is experiencing a more drying climate, with greater climate variability and extremes. In the past 60 years, the average rainfall has declined by 20% while temperatures have increased, and these trends are predicted to continue.

Unlike other natural hazards such as floods, earthquakes, cyclones, and fires which occur over a finite period and result in visually obvious damage, drought develops slowly and quietly, lacking highly visible and structural impacts.

By assessing the impacts of previous droughts on the environment, we can build a picture of how things will look with more frequent and severe droughts. Four years - 2002, 2006, 2010 and 2019 – were identified as previous drought years for our pilot regions. Condition scores from ANU's environmental condition scorecard reports showed a significant decline in environmental condition during and following years after these periods.

The past does not always inform the future, but a review of past experiences and selected literature and studies can improve our understanding about the impact of drought on the environment and how we can manage future droughts and minimise their impact. This review has considered our natural resources in three broad themes, Land, Water and Vegetation, including biodiversity. An important distinction between Natural Resource Management of agricultural landscapes and Natural Resource Management of non-agriculture landscapes was made at the start.

In Australia, the term 'natural resource management' (NRM) refers to government investment in environmental programs on agricultural land.[1] It also refers to environmental management on non-agricultural land, like the management of national parks and nature reserves. For clarity, this review makes a distinction between NRM for agricultural land and non-agricultural land.

An alternative way to describe the policy framework around 'NRM' on agricultural land is agri-environment. A terminology used by the Europeans and Common Agriculture Policy. Although not generally used in Australia because it has a 'feel' of government support and protection, but it also includes the notion that our agricultural lands are not just about the production of saleable commodities (e.g., Food and Fibre). They are also a space that provides a range of ecosystem goods and services that are valued by the broader public (e.g., biodiversity and rural amenity).[1]

Building resilience into the environment to enable it to withstand severe climatic events is more important than ever. Resilience comes from healthy ecosystems, which are created through healthy soils, freshwater security, and abundant vegetation and biodiversity. Managing these fundamentals should be the priority of the pilot regions to ensure we have a healthy and resilient environment, able to meet the challenges of food security and sustainability for future generations.

Land managers need to the support to meet these challenges and the additional requirements that will be imposed on them through Environmental Social Governance frameworks.

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[1] Ansell, D., Gibson, F., Salt, D. (2016) Learning from agri-environment schemes in Australia: investing in biodiversity and other ecosystem services on farms. ANU Press. https://press-files.anu.edu.au/downloads/press/p346093/html/imprint.xhtml?referer=&page=3#

RECOMMENDATIONS

1. **Improve collection of real time data for environmental health on agricultural land and non-agricultural land including waterways and wetlands.**
2. **Use data to identify the priority areas for stabilisation & restoration of ecosystems on agricultural land and non-agricultural land**
3. **Review and update the state of the environment report for WA using new technologies available.**
4. **Continue to improve agriculture production systems that reduce the impacts on the environment by using technology and education**
    a. **Supporting networks of grower groups and NRM groups**
    b. **Protecting soil health**
    c. **Identify opportunities to improve sustainability of resource use and supply chains e.g., Fertiliser from fossil fuels**
5. **Support policy with outcomes to improve conservation**
    a. **Review land clearing**
    b. **Work on strategies for reducing carbon footprint to net-zero**

Land management

Soil health underpins our land management and is critical to supporting a productive and sustainable agriculture industry.

- Seventy-five per cent of soils in the pilot regions are healthy by 2030

Water

Monitor and protect the health of waterways in the pilot LGA's

- Improve existing technologies and seek new technologies to understand the impact of drought our wetlands and water

Vegetation and Biosecurity

Protect, improve, and expand existing vegetation and biodiversity in the pilot LGA's with an assessment of vegetation and biodiversity health in the pilot regions by 2030.

- Assess the level of health of vegetation and biodiversity in the pilot regions.
- Revegetate low production areas
- Improve biodiversity and vegetation on farms


Photo: Darren Hughes

INTRODUCTION

The Regional Drought Resilience Planning (RDRP) program aims to support regional organisations, local government, communities and industry to partner together to develop regional drought resilience plans (DRPs). The plans will identify and guide actions to build the region's resilience to future droughts, with a focus on agriculture and allied industries. Plans will be developed through a triple bottom line, collaborative and evidence-based approach. The government is delivering the program in partnership with states and territories.

The RDRP in WA will focus on three pilot regions during the 2021-22 foundation year, being:

- A Northern Agricultural consortium comprising of the Midwest Development Commission (MWDC), the Northern Agricultural Catchments Council, the City of Greater Geraldton, and the Shires of Northampton and Chapman Valley.
- The Southern Wheatbelt consortia comprising of the Wheatbelt Development Commission (WDC) Local Government Areas, Dumbleyung, Kulin, Kondinin, Lake Grace and Wagin.
- The Great Southern Inland consortia comprising of the Great Southern Development Commission (GSDC) Local Government Areas Jerramungup, Kent, Gnowangerup, Katanning, Kojonup, Cranbrook, Woodanilling, and Broomehill-Tambellup.

Combined, these three regions cover over 670,000 square kilometres and sit within WA's grain belt - the largest agricultural producing area in WA and a key contributor to the economy. These regions generate much of WA's agricultural value and, in addition to large-scale broadacre cropping, also support a diverse range of other primary production activities including aquaculture, livestock and livestock products (wool, eggs, milk), horticulture and viticulture, amongst others.

There are also vast tracts of natural vegetation in National Parks and Nature Reserves, 32% of the land is non-agricultural production land providing a high degree of biodiversity and amenity to the community.

The purpose of this review is to identify the extent and severity of the environmental impacts of drought in the regions and to assess the likely impacts of drought in the future.

The past does not always inform the future, but a review of past experiences and selected literature and studies can improve our understanding about the impact of drought on the environment and how we can manage future droughts and minimise their impact. This review has considered our natural resources in three broad themes, Land, Water and Vegetation, including biodiversity. An important distinction needs to be made between Natural Resource Management of agricultural landscapes and Natural Resource Management of non-agriculture landscapes.

In Australia, the term 'natural resource management' (NRM) is used to describe government investment in environmental programs on agricultural land.[1] It is also used to describe environmental management on non-agricultural land, like the management of national parks and nature reserves. This review makes a distinction between NRM for agricultural land and non-agricultural land.

An alternative way to describe the policy framework around 'NRM' on agricultural land is agri-environment.[1] A terminology used by the Europeans and Common Agriculture Policy. Generally, it is not used in Australia because it has a 'feel' of government support and protection, but it also includes the notion that our agricultural lands are not just about the production of saleable commodities (e.g., Food and Fibre). They are also a space that provides a range of ecosystem goods and services that are valued by the broader public (e.g., biodiversity and rural amenity).[1]

In this review the agri-environment refers to agriculture land and NRM will refer to our non-agricultural natural resources and land. By using the term agri-environment it helps to move the discussion to managing Natural Resources as part of production in agricultural landscapes.

First, a background which helps provide context for thinking about management of vegetation, biodiversity and natural resources in the agri-environment.

2 BACKGROUND

The world population is expected to be almost 10 billion people by 2050 and Australia's population is expected to be 35.9 million. Not only can we expect a lot more mouths to feed, but improvements to the socio-economic status of people across many regions, including Asia and Africa, will lead to changes in diet. A large increase in food demand, which will in turn require increased food production through the expansion and intensification of agriculture.[2] This quest for ever-increasing standards of living by an ever-growing human population is the cause of the loss in biodiversity [3]

The conversion of land to agriculture has impacted worldwide on the loss and degradation of habitat and biodiversity. This directly impacts on plant and animal populations and communities and alters ecological and hydrologic processes that underpin key ecosystem functions.[4] In addition to habitat loss, farming practices such as tillage, burning, livestock grazing and nutrient and chemical usage have significant negative impacts on biodiversity as well as soil, water and air quality.[5] And, it is widely recognised that agriculture practices contribute to climate change, a drying climate and therefore increased risk of drought, Figure 3.

"People have been living with drought for 5,000 years, but what we are seeing now is very different."
Mami Mizutori, UN Secretary General's Special Representative for Disaster Risk Reduction

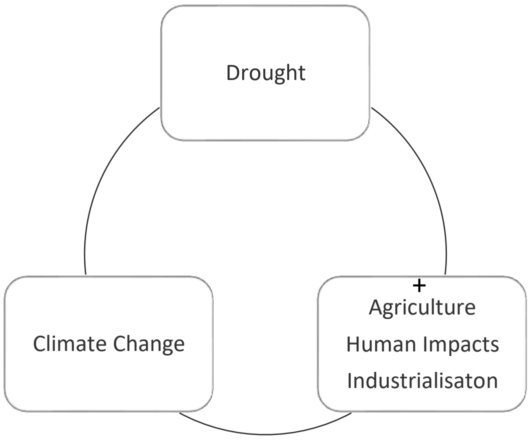


Figure 3.The cycle of drought

It is widely accepted by science that the future of Southwestern, Western Australia (WA), will see a drying climate with more variability and extremes. In addition, drought conditions have a significant impact on our

[2] Phalan, B., R. Green, and A. Balmford (2014) Closing yield gaps: Perils and possibilities for biodiversity conservation, Philosophical Transactions of the Royal Society B: Biological Sciences 369(1639): 20120285. DOI:10.1098/rstb.2012.0285.
[3] O'Brien, J. (2015) Technologies for conserving Biodiversity in the Anthropocene Issues in Science and Technology 32, no. 1
[4] Millennium Ecosystem Assessment (2005) Ecosystems and human well-being: Synthesis, Island Press, Washington, DC. DOI:10.1088/1755-1307/6/3/432007.
[5] Stoate, C., N.D. Boatman, R.J. Borralho, C.R. Carvalho, G.R. de Snoo and P. Eden (2001) Ecological impacts of arable intensification in Europe, *Journal of Environmental Management* 63: 337–65.

natural resources. These impacts include irreversible damage to soil and vegetation, leading to dust storms and a loss of topsoil, soil nutrients, organic matter and soil carbon. [6,7]

These are the natural resources regional communities in WA depend on for their economic security and social connectedness. There is a high level of dependency on land, water, natural vegetation and biodiversity, people's wellbeing and economic outcomes are inextricably linked to these natural resources. This reliance means they require careful management and stewardship is critical.

Classical biodiversity conservation thinking aims to maximise the preservation of species and genetic diversity sometimes and often with opposing philosophies and conflict with agricultural landscapes, because they are characterised by significant historical loss of biodiversity and great emphasis on utilitarian production values, that is the production of food and fibre. Ecosystems services thinking combines these two philosophies.[8]

The concept of ecosystems goods and services is a way to communicate agriculture's dependence on the environment.[9] For example pollination by insects, water provision and purification, healthy and productive soils, and protection from pests.[10]

Many existing studies focus on the impacts of agriculture on ecosystem conditions, or on agriculture as a source of ecosystem services supply.[10] However, ecosystem services also provide important services to agricultural production, for example through soil structure and fertility; nutrient cycling; soil retention; crop pollination; food sources; water provision and purification etc. Figure 4.

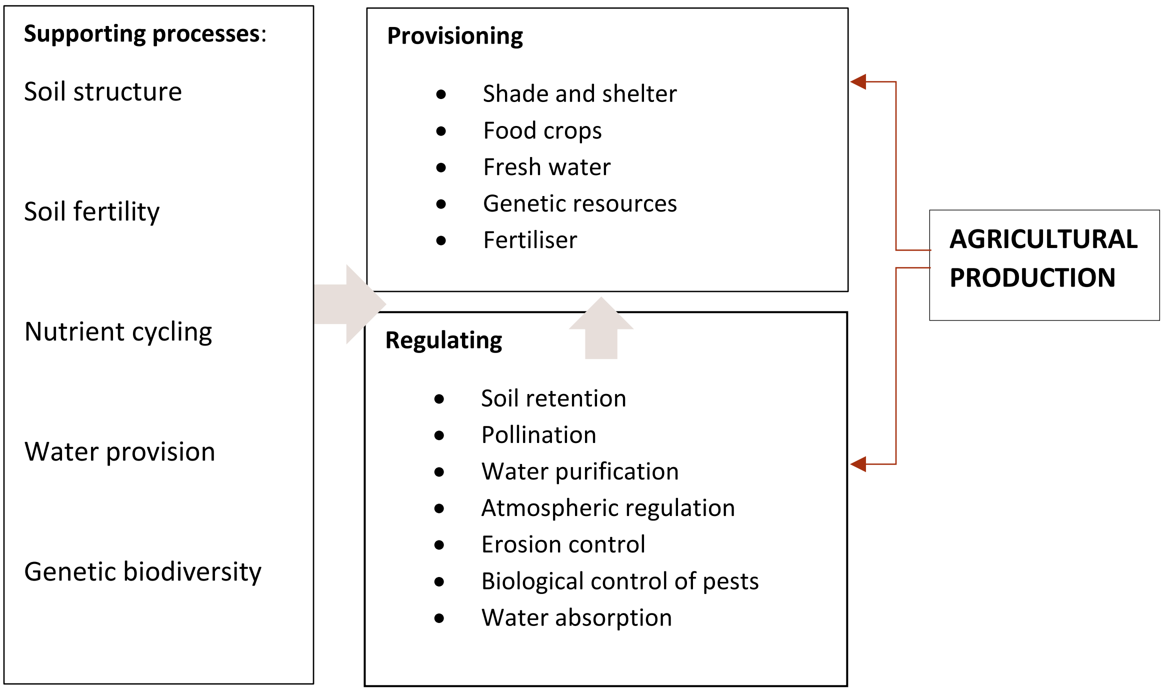


Figure 4. Example of ecosystem services and their contribution to agricultural production[10]

[6] Tozer P. and Leys J. (2013) Dust storms – what do they really cost? *The Rangeland Journal 35: 131-142.*

[7] Hess P. and Ham M. (2018) What causes a dust storm? *The Lighthouse (Macquarie University).* Retrieved 10 January 2022 from https://lighthouse.mq.edu.au/please-explain/what-causes-a-dust-storm

[8] Kragt, M.E, Dumbrell, N.P. (2017) Motivations and barriers for Western Australian broad-acre farmers to adopt carbon farming, Environmental Science & Policy 73 115-123

[9] Gomez-Baggethuan, E., De Groot, R., Lomas, P.l. and Montes, C. (2010) The history of ecosystem services next term in economic theory and practice: From early notions to markets and payment schemes. Ecological Economics, 69, 1209-1218.

[10] Aisbitt, E and Kragt, M. (2010) Valuing ecosystem services to agricultural production to inform policy design: An introduction. Research report Environmental Economics Research Hub ISSN 1835-9728

Although classical conservation philosophy and production focus do not often align, ecosystems services thinking has potential to influence the uptake of conservation actions and the design of strategies required to meet conservation goals within agricultural landscapes.[8]

Further pressure is mounting on agriculture (and not just agriculture) to meet sustainability goals with significant shifts in thinking around reporting on sustainability measures. For example, company performance measures are shifting to include other measures besides financial metrics. Frameworks like the International Integrated Reporting Framework developed by the International Financial Reporting Standards Foundation are using an integrated approach with Six Capitals, Financial, Manufactured, Intellectual, Human, Social and Relationship and Natural Capital, Figure 5.

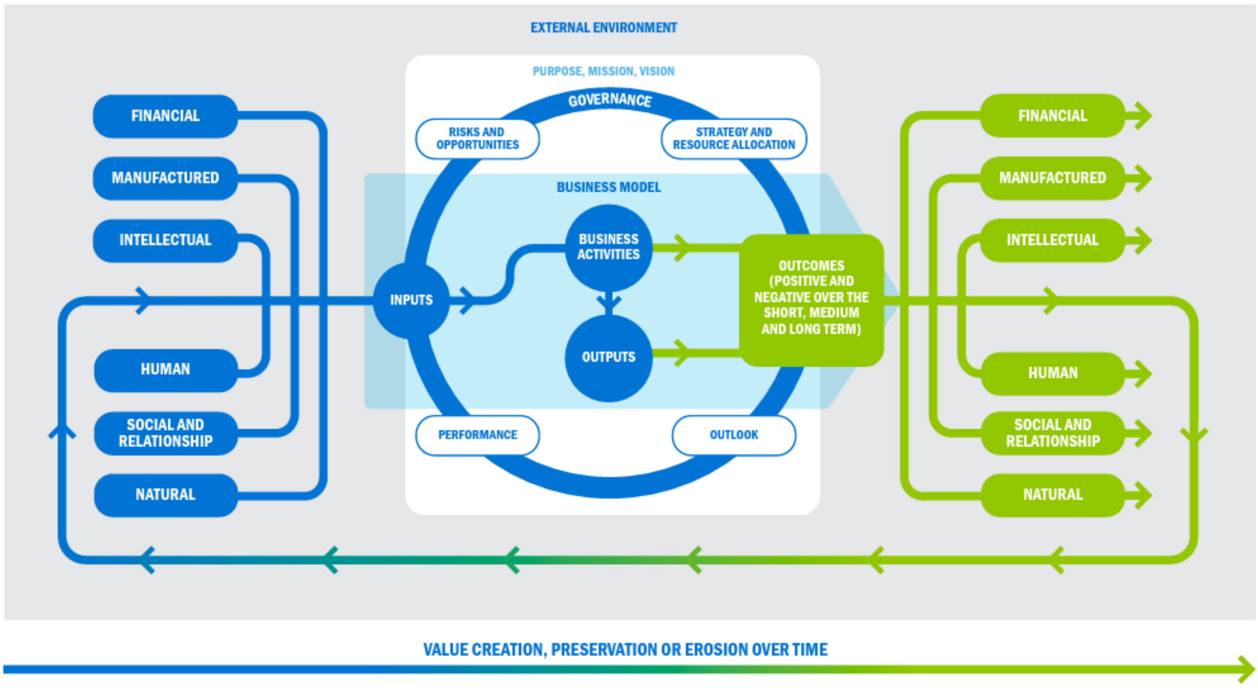


Figure 5. Six capitals for integrated reporting[11]

These Environmental, Social Governance frameworks acknowledge that reporting on financial measures only is not adequate and that by not measuring other capitals like Natural Capital it fails to value these resources. These frameworks are being developed and data collected to meet investors and consumers expectations[12]

In 2021 the United Nations adopted this new reporting framework which includes the contribution of nature when measuring economic prosperity and human well-being. The System of Environmental-Economic Accounting – Ecosystem Accounting (SEEA EA) goes beyond the commonly used statistics of gross domestic product (GDP) which has dominated economic reporting since the end of World War II. It will ensure that the natural capital – forests, wetlands and other ecosystems are recognised in economic reporting.

The question is, 'how will these reporting frameworks effect the family owned and operated farming businesses which are most farm businesses in Australia, and are not usually responsible for reporting to shareholders?'

Family owned and operated farm businesses may not be directly responsible to shareholders; however, they provide goods and services to companies who are and who need to meet consumers expectations. Farm businesses also need to access capital in the way of loans from banking institutions. New banking standards in

[11] International Financial Reporting Standards Foundation (2021) International Integrated Reporting Framework. https://www.integratedreporting.org/what-the-tool-for-better-reporting/get-to-grips-with-the-six-capitals/

[12] Environmental Social Governance investing https://moneysmart.gov.au/how-to-invest/environmental-social-governance-esg-investing

the form of BASAL III and IV require more complex risk analysis and measurements using qualitative and quantitative measurements including competency in managing a farm business and its environmental and sustainable track record.

In summary, the governance landscape is changing with increasing intensity to measure the impact companies have on the environment whilst producing goods and services to consumers, the agriculture industry will not be exempt and more intense scrutiny is likely and although droughts evoke community empathy expectations will not tolerate poor environmental or animal welfare outcomes.

3 Landscapes and environmental characteristics of the pilot regions

The southwestern corner of Australia is internationally recognised as a biodiversity hotspot, partly because the species diversity, but also because those species and communities are being lost to a host of environmental assaults. Two-thirds of the vegetation has been cleared and over much of the agricultural region many areas have less than 5-10% of their original bushland left.[13]

The climate is characterised by long, hot dry summers and cool, wet winters. Seventy-five per cent of annual rainfall occurs during the winter months, between April and October. Significant rainfall can occur in the summer months from high intensity thunderstorms or rain-bearing depressions associated with tropical cyclones. Land use and farming systems respond to the varying climatic and geographic conditions and most of the agricultural land mass (excluding the rangelands) is used for extensive cropping and livestock grazing activities, defined as broadacre agriculture.[14]

The Australian Bureau of Agriculture and Resource Economics and Sciences (ABARES) divide the broadacre region into three main climatic zones: High-rainfall, Wheat-sheep, and Pastoral zones, Figure 6.

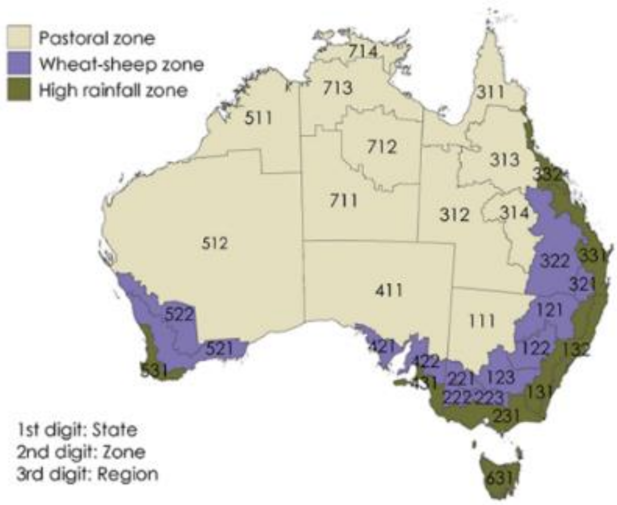
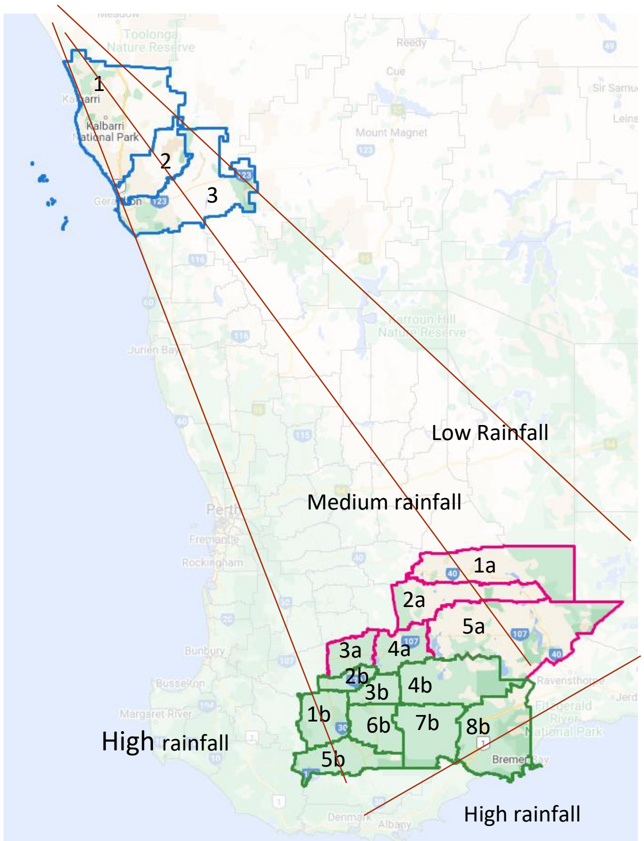


Figure 6. ABARES regions for Australia

[13] https://gondwanalink.org/about-us/why-gondwana-link/

[14] Anderton L (2017) Financial, Productivity and socio-managerial characteristics of broadacre farms in Western Australia: A decadal assessment. Master's Thesis.

The local government areas (LGA's) in the pilot region outlined in Figure 7 are across three rainfall zones. Low rainfall is less than 325 mm per annum, medium rainfall is around 450 mm, and high rainfall is above 550 mm. The rainfall is highest near the coast.



Northern Agricultural Region (NAR)
1. Northampton
2. Chapman Valley
3. City of Greater Geraldton

The Southern Wheatbelt
1a. Kondinin
2a Kulin
3a Wagin
4a Dumbleyung
5a Lake Grace

Great Sothern inland
1b. Kojonup
2b. Woodanilling
3b. Katanning
4b. Kent
5b. Cranbrook
6b. Broomehill Tambellup
7b. Gnowangerup
8b. Jerramungup

Figure 7. Location of Local Government Areas for the three pilot regions and rainfall zones

Several of the LGA's are in more than one rainfall area, for example, Northampton shire includes high, medium, and low rainfall areas where the annual rainfall is highest immediately inland from the coast and it reaches 500 mm per year but declines rapidly with increasing distance inland to less than 300 mm east of Mullewa on the fringes of the agriculture areas.[15]

Mixed farming enterprises are typical. In the last 30 years the area of crops on most farms has increased. The average crop percentage in the medium rainfall (Southern Wheatbelt) is 65 to 75% and trending higher in the low rainfall areas especially in the NAR (ABS, 2015-16).[16] Sheep numbers have declined since the peak in the late 80's mostly due to the low profitability of the sheep enterprise after the collapse of the wool price in the early 1990's concomitant with improvement in technology and therefore the productivity for the cropping enterprise.[16] In the last ten years, the area of crop grown averaged 8.2 million hectares with low variance, the highest amount was 8.6 million in 2016 and lowest in 2015-16 was 7.8 million hectares, Figure 8.

[15] Natural Resources Assessment Group, Agriculture Western Australia, and Landcare Western Australia. (1997) Soil information sheets for the northern agricultural areas. Department of Primary Industries and Regional Development, Western Australia, Perth. Report 13/97.
[16] MLA. (2018) Profitable integration of cropping and livestock management guideline. Rural Directions PTY LTD, Farmanco Management Consultants.

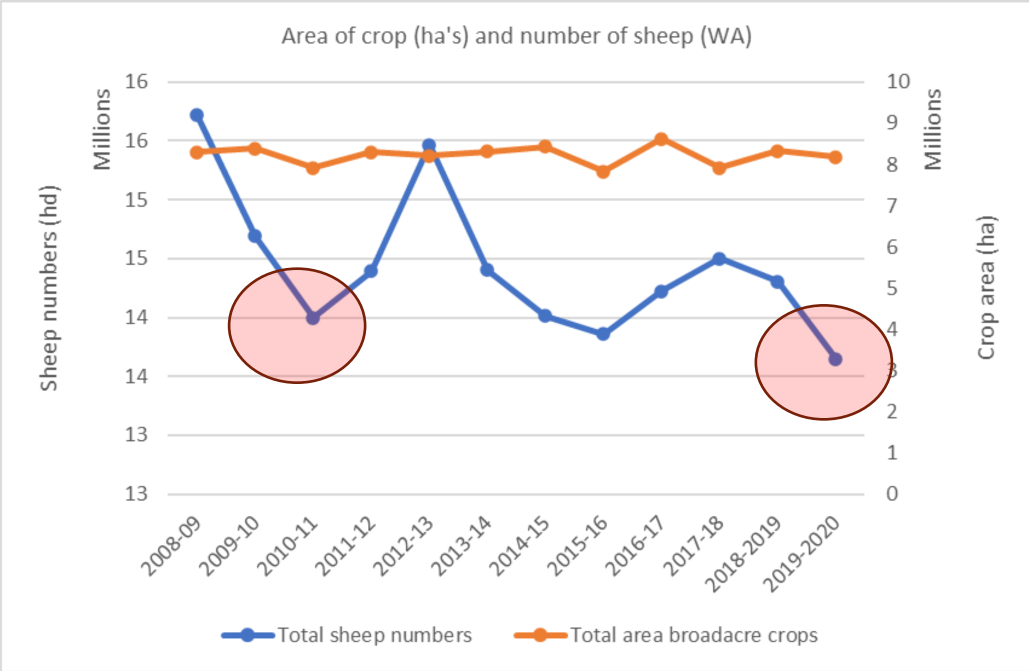


Figure 8. Crop area (ha) and livestock numbers (head) 2008- 2020

The variation in sheep numbers is a function of seasonal conditions and market value. The two years highlighted in Figure 8 with red circles are where numbers decreased significantly due to the impact of drought.

The balance of land use in broadacre farming between livestock and cropping is unlikely to alter radically for the foreseeable future, however prices and seasonal conditions are factors that have a high degree of variability and are factors which farmers constantly respond.

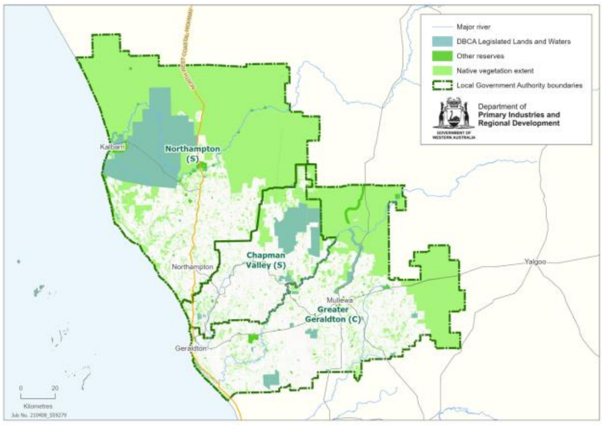
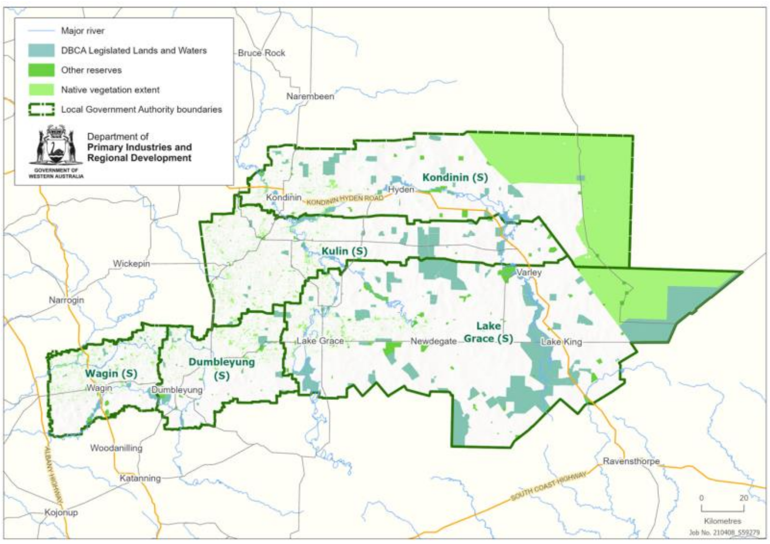
Partly in response to drought conditions of 2006-07 and partly due to technological advances, the farm management system has changed in all regions. In the NAR the lighter sandier soils often with high levels of acidity both in the topsoil and sub-surface, has meant less livestock, use of minimum till combined with deep ripping and soil amelioration incorporating lime and more diverse crop rotations using canola and additional legumes. In the southern wheatbelt similar trends have occurred but with retention of more livestock and less deep ripping. A significant trend in the Great Southern is the increase area of Canola and for all three regions the average size of properties has increased.

There are 5.4 million (67.3%) hectares of land in the pilot region used for agriculture production and a further 2.6 million (32.6%) of non-agriculture land, which is 13% of the 20 million hectares in WA that host a complex ecosystem with a wide diversity of plants and animals. Farm managers are responsible for the other 67% of the land mass in the pilot regions, often managing production near areas of environmental significance

Figure 9 illustrates the management of agriculture landscape next to areas of natural vegetation conserved in a national park like the Stirling Ranges.

Figure 9. Swathing Canola near the Stirling Ranges National Park

The agriculture production land and non-agriculture production land for the pilot regions outlined in Figure 10 and Appendix 2 identifies the nature reserves and national parks for the LGA's.

Northern Agricultural Region	
Agriculture production land, Ha (%) Greater Geraldton, 911,452 (92%) Northampton, 808,899 (64%) Chapman Valley (NA) **Non-agriculture land, Ha (%)** Greater Geraldton, 79,448 (8%) Northampton, 446,272 (36%) Chapman Valley (NA)	
Southern Wheatbelt Region	
Agriculture production land, Ha Dumbleyung, 159,049 (63%) Kondinin, 466,769 (63%) Kulin, 295,360 (63%) Lake Grace, 744,130 (63%) Wagin, 147,231 (76%) **Non-agriculture land, Ha (%)** Dumbleyung, 94,874 (37%) Kondinin, 277,411 (37%) Kulin, 176,532 (37%) Lake Grace, 444,502 (37%) Wagin, 47,387 (24%)	

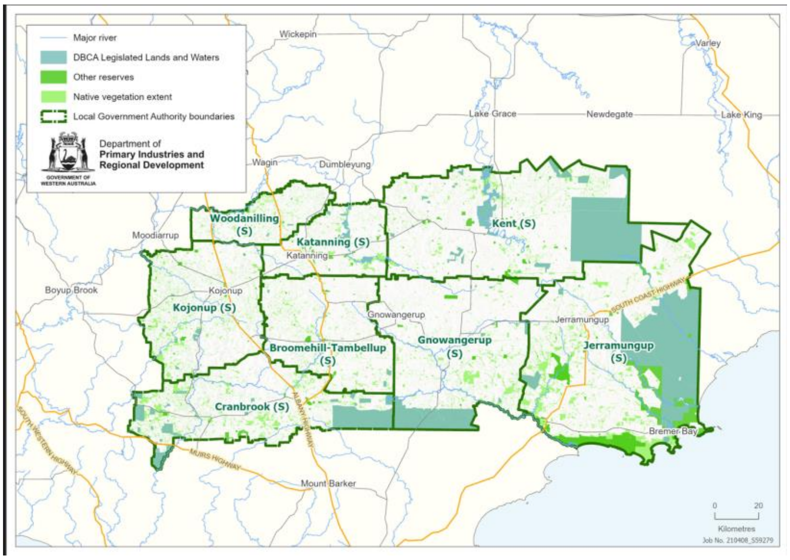
<table>
<tr><th>Great Southern Inland</th><th></th></tr>
<tr><td>Agriculture production land, Ha (%)
Jerramungup, 391,000 (60%)
Cranbrook, 246,116 (75%)
Kent, 381,802 (68%)
Kojonup, 293,347 (82%)
Woodanilling, 97,770 (87%)
Katanning, 159,049 (NA)
Broomehill-Tambellup, 213,133 (82%)
Gnowangerup, 165,831 (39%)
Non-agriculture land, Ha (%)
Jerramungup, 263,000 (40%)
Cranbrook, 81,489 (25%)
Kent, 180,656 (68%)
Kojonup, 53,752 (82%)
Woodanilling, 15,114 (87%)
Katanning, (NA)
Broomehill-Tambellup, 47,833 (18%)
Gnowangerup, 260,673 (61%)</td><td>
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Figure 10. Maps show the native vegetation in the pilot regions.

The Australian Bureau of Statistics estimates the value of Australia's environmental assets to be $6,138 billion. More than 80 per cent of this ($5,105 billion) is derived from land based natural capital, including environmental assets on private agriculture land. [17] Figures on the value of environmental assets are likely to be underestimated, as Environmental Economic Accounts do not consider the intrinsic value of the environment, or many of the socio-economic values that healthy ecosystems support.[18]

3.1.1 Northern Agricultural Region

The Geraldton-Northampton area has a distinctive landscape of flat-topped hills and extensive areas of gently sloping land with mature valleys. Soils are divided by the Darling Fault, running in a line extending through Mullewa and Three Springs. East of this fault and in the City of Greater Geraldton, soils are dominated by red loamy earths and yellow deep sands. On the west side, there are large areas of undulating sandplain comprising of pale deep sands and yellow deep sands. Because this half of the district is drained by a number of rivers, the main ones being the Hutt, Bowes, Chapman, Greenough, Irwin and Lockier (see Appendix 2) the country is more dissected and there are a variety of duplex soils and red earths on the valley sides and river flats. Much of sandy soil types require careful management to prevent wind erosion, they generally have low to moderate water holding capacity which means in dry seasons or drought they are even more susceptible to wind erosion events occurring.[15]

Using van Gool, et al., (2018) as a guide the soil types in Figure 9 are the predominant soils. There are more soil types but less significant like clay and shallow loamy duplexes, shallow sandy duplexes, shallow loams over

[17] Australian Bureau of Statistics (2017) Australian Environmental Economic Accounts, 2017, accessed at http://www.abs.gov.au/ausstats/abs@.nsf/mf/4655.0

[18] National Landcare Advisory Committee (2016) Advice on the National Landcare Program Review, prepared for the Australian Government Natural Heritage Ministerial Board

rocks, and sandy earths are also present in parts of the region.[19] All, except the clay and shallow loamy duplexes, are prone to wind erosion., for more detail see van Gool, et al., (2018).

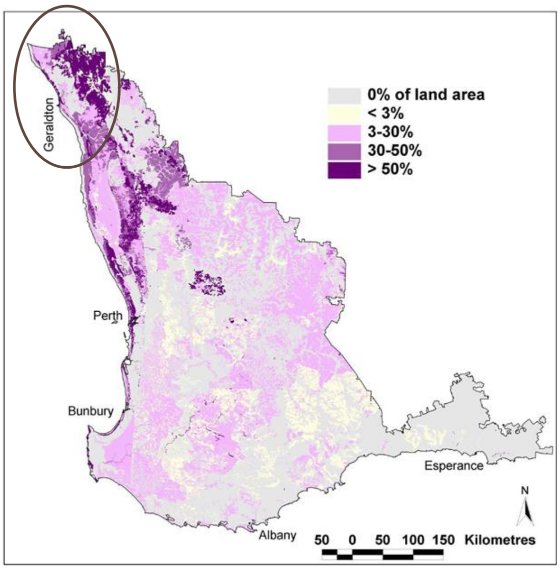
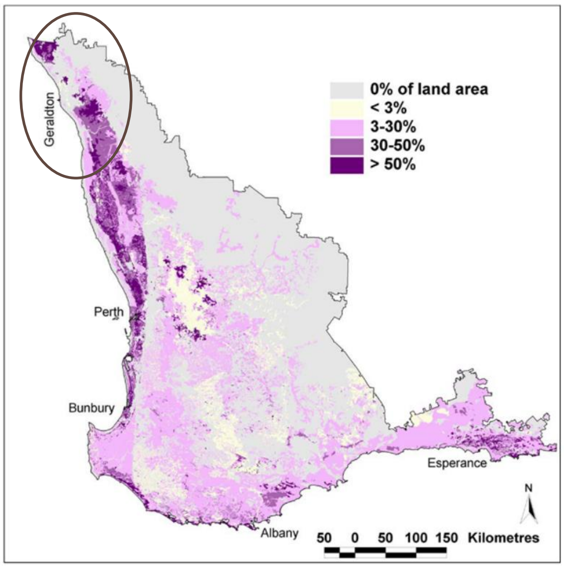
Coloured sands	Pale sands
	

Figure 11. Soil types in the Northern Agriculture region

Coloured sands are typically low in natural fertility and requiring higher inputs and fertilisers and can be highly acidic in the subsurface horizons requiring amelioration with lime. The sandy textures result in generally low to moderately low soil water storage and can be prone to water repellence. Despite these issues combined with good crop rooting conditions and good management techniques the better sands are very productive.[19]

The risk of wind erosion and soil degradation in dry or drought conditions is high in these landscapes. Farming techniques using minimum tillage, stubble retention and restricted grazing in summer and autumn prevent wind erosion.[19]

3.1.2 The Southern Wheatbelt and Great Southern

These two regions share similar topography and soil types, although there is also a significant range in differences between landscapes for each shire and within shires. For example, the landscape in Jerramungup differs significantly between the coast at Bremer Bay to the far north of the shire

Using van Gool, et al., (2018) as a guide the soil types in Figure 12 are the predominant soil types. There are more types found but less significant and for more detail see van Gool, et al., (2018).

[19] van Gool, D, Stuart-Street, A and Tille, P. (2018) Distribution of classified soils in south-west Western Australia, Resource management technical report 401, Department of Primary Industries and Regional Development, Perth.

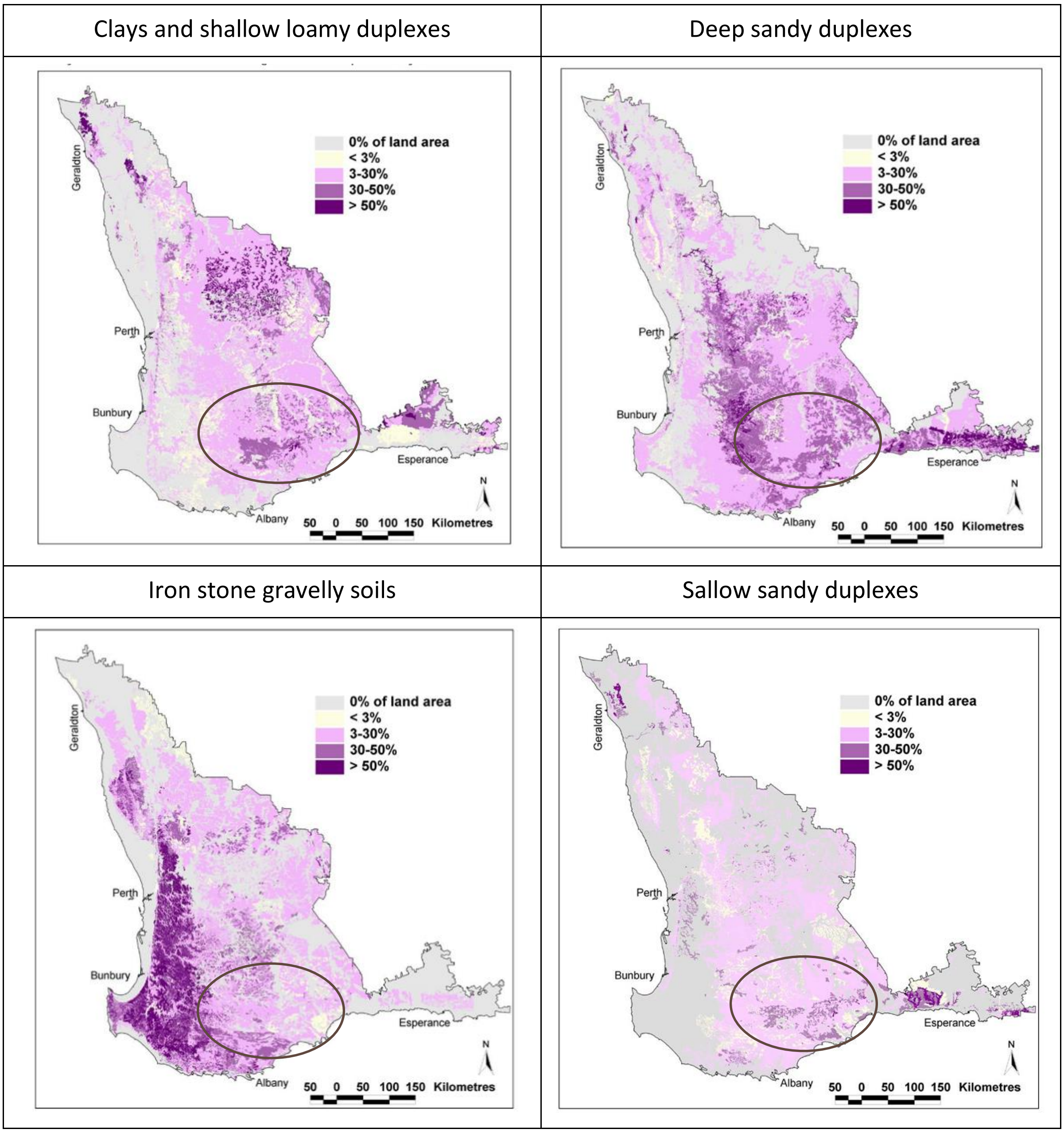


Figure 12. Soil types in the Southern Wheatbelt and Great Southern pilot regions

Clays and shallow (Figure 12) loamy duplexes defined by van Gool, et al., (2018) typically have moderate or high natural fertility but still require fertiliser. A small proportion have low levels of acidity near the surface and due to hard setting surfaces they do not have a high level of risk to wind erosion. Duplexes with sandy loam surfaces are commonly water repellent. But the clays and shallow loamy duplexes often have very low (<50mm/m) soil water storage, although this is highly variable

Deep sandy duplexes (Figure 12) defined by van Gool, et al., (2018) typically have low or moderate natural fertility and require fertiliser, acidity and aluminium toxicity occur and acid sandy topsoil is common. They have low to moderately low soil water holding capacity and are highly prone to wind erosion on exposed flats and rises. Water erosion can also be a problem on slopes receiving run-off. These soils can create complexities for management as many cannot be worked when too wet or are very hard when too dry.

Shallow sandy duplexes (Figure 12) are usually deep but moderately shallow crop rooting is common on poor clays (sodic or saline). They have moderate natural fertility, but the sandy surface topsoil's may be moderately to highly water repellent and often they have very low water storage capacity. They are highly prone to wind erosion on exposed flats and rises.

The iron stone gravelly soils (Figure 12) can be prone to wind erosion too, especially with sandy topsoil, but the presence of gravel on the surface can reduce the risk. They can have low to moderately low estimated water storage; however, crop performance seems to indicate this is better than estimated.[19]

The risk of wind erosion and soil degradation for all these soil types increases in dry or drought conditions. Farming techniques used to prevent wind erosion are minimum tillage, stubble retention and restricted grazing in summer and autumn.

Soil degradation through erosion

Soil is a non-renewable source that is critically vulnerable to loss and degradation, particularly during periods of extreme climatic conditions like drought. Erosion is one of the greatest risks to soil health, as it strips away the fertile top layers of soil and organic matter[20] taking with it most of the fertility and organic matter of the soil.[21]

The impact drought has on soil is complex. Reduced rainfall and higher temperatures dry out the soil, creating cracks that reduce the moisture and volume of the soil, affect the activity of soil organic matter reducing soil particle cohesion, change soil texture decreasing its water holding capacity, and limits plant growth reducing vegetation and crop residue cover.[22] This leaves soil vulnerable to erosion through water runoff and wind.

Wind erosion can cause significant environmental and economic damage and can have a detrimental impact on human health.[20] Major dust storms can sandblast vegetation and crops, and deposit unwanted nutrients threatening plants and animals and causing harmful algal blooms.[20] They also pose a risk to human health by polluting the air causing asthma and other health problems.[20]

Increasing climate variability indicates that rainfall events will become more extreme and intense.[23] This, combined with drought affected soils that have a lower water holding capacity leads to greater surface water movement, resulting in water soil erosion.[22] Erosion from drought breaking rainfall has the potential to make up 90% of total soil loss in a 20–30-year cycle.[24] The cost of water erosion to dryland faming in WA is estimated to be approximately $10 million annually.[25]

Soil erosion has a profound effect on both natural resources, and the agri-environment. Agricultural productivity is affected by the loss of the most fertile layers of the soil. Water quality is also degraded because of eutrophication, siltation, and sedimentation.[22]

3.2 Water resources

Water scarcity is a persistent issue in Australia given the relatively dry and variable climate and the emergence of climate change is exacerbating the problem. Water is a valuable commodity particularly within agriculture,

[20] NSW Department of Planning and Environment (2020) Wind erosion, NSW Government. https://www.environment.nsw.gov.au/topics/land-and-soil/soil-degradation/wind-erosion Retrieved 30 May 2022

[21] Agriculture Victoria (2021) Protecting the land in dry times, Victoria State Government, https://agriculture.vic.gov.au/farm-management/managing-for-and-during-drought/protecting-the-land-in-dry-times Retrieved 30 May 2022

[22] Masroor, M., Sajjad, H., Rehman, S., Singh, R., Rahaman, H. Md., Sahana, M., Ahmed, R. and Avtar, R., (2022) Analysing the relationship between drought and soil erosion using vegetation health index and RUSLE models in Godavari middle sub-basin, India, Geoscience Frontiers 13 (2) 1-9

[23] Howden, M. (2022) Climate change science and Australian agriculture and food, WA Climate Smart Agricultural Fellowship 2022, Australian National University, Institute of Climate

[24] Department of Primary Industries (2020) Soil management - drought recovery, Primefact 367(2), NSW Government. Retrieved 30 May 2022

[25] Department of Primary Industries and Regional Development (2022), Water erosion in the south-west of Western Australia, Government of Western Australia, https://www.agric.wa.gov.au/water-erosion/water-erosion-south-west-western-australia Retrieved 30 May 2022

which accounts for around three quarters of total use. Water is also of value to other industries, households and increasingly environmental agencies.

For communities in regional areas water resources are becoming an increasingly problematic issue because the south-west of WA has experienced a fifteen per cent decline in average annual rainfall since 1975. This has reduced recharge to groundwater aquifers from Geraldton to Esperance. Across much of the south-west corner of the state, groundwater is an important part of the water supply mix and is used for town drinking water supplies, to irrigate public open space, and for irrigated horticulture. Perth's groundwater resources provide more than 40 per cent of scheme supplies to households and businesses; almost all the water supply used for parks, sports grounds, and agriculture; and one in four domestic gardens.

3.2.1 On-farm water resources

Most farms in the pilot region are reliant on rainfed water supplies to meet their water demand, which means they require adequate storage using dams and tanks to supply both their domestic and farm business requirements. Water use is changing with a growing need for clean good quality water for spraying crops, caused by large and expanding cropping programs whilst there is reduced demand for livestock water in some areas.

In 2019 many farmers and communities had significantly low water reserves, especially after two consecutive years of low rainfall. Consequently, twelve water deficiency declarations announced by State Government from May 2019 to June 2020 meant water was carted to replenish community supplies and the needs for farmers. A declaration requires the government to provide water for livestock needs at a central storage point within a 40-kilometre radius of the farms concerned. Farmers carting livestock water were encouraged to cart to closed storages or tanks rather than into dams where water losses are high because of evaporation. LGA's are in the pilot regions requiring water were Lake Grace, Jerramungup, Kent and Dumbleyung.[26] The total cost for carting water to the water deficiency areas was $3.7 million.[27]

The State Government also invested $915,902 through the Community Water Supply Program in 2020–21, helping nine local governments deliver 10 projects to improve their emergency community water capacity and reduce their future use of scheme water grants to undertake works, including improving the stormwater reuse network, fitting new pump, pipe and tank facilities, and realigning catchment channels. This builds on works the government have previously undertaken on community water supplies, bringing the total to nearly $1.5 million for 17 projects. The Rural Water Planning works program also invested $741,890 to upgrade 32 agriculture area dams vested with the Department of Water and in priority areas to continue to build on the strategic water supply network across the dryland agricultural area.[27]

In response to the 2019 drought a water infrastructure rebate scheme was introduced for farmers for a period by the Federal government with State government making a co-contribution.

Waterways and wetlands in catchments are important for nature conservation and local ecology health water ways and local drainage for floodwater discharge.

3.2.2 Natural water resources

Western Australia has 120 nationally listed wetlands of importance covering more than 2.5 million hectares. Most of these occur within existing or proposed reserves managed by Parks and Wildlife while some occur on private property.

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[26] DWER Annual Report 2019-20 Operational performance, https://www.awe.gov.au/abares/research-topics/water#australian-water-markets-reports

[27] DWER (2021) Annual report 2020-21

There are also 208 major waterways and fringing vegetation that has important ecological, economic and cultural values (Appendix 2 lists the natural water resources and location for the shires in the pilot regions). They provide habitat for birds, frogs, reptiles, native fish and macroinvertebrates and form wildlife corridors between patches of remnant bush. Estuaries, where river and ocean waters mix, connect the land to the sea and have their own unique array of aquatic and terrestrial flora and fauna.[28] For example, Lake Dumbleyung is recognised as a Directory of Important Wetlands in Australia (DIWA) and is a drought refuge for water birds and a moulting area for the Australian shelduck.[29]

Waterways reflect the land use, topography, rainfall and geology in a catchment. Conserving and restoring waterways, together with better understanding of waterways and catchment management practices, help improve water quality and ecosystem health, and reduce environmental problems in estuaries and coastal areas, leading to increased productivity and land values and allowing us to maintain a wide diversity of values and uses.[28]

Many waterways are degraded because of activities such as agriculture, land clearing, urban and industrial land use, recreation and tourism. Droughts further impact on already fragile environments. Changes in waterway condition can have dramatic consequences that are difficult to reverse. Water quality, from leaching of excess nutrients and increasing salinity cause a decline in freshwater and estuarine fish habitats. Harmful algal blooms (HAB) are a signal that aquatic systems are no longer able to accommodate the changes made to a catchment.[28]

Figure 13. Lake Dumbleyung[30]

Impact of drought

Drought severely impacts natural aquatic ecosystems, with the major impacts being the loss of water and habitat availability, and the reduction, if not severing, of connectivity.[24]

Droughts can not only have a negative impact on water availability, but also the quality of the water remaining in these systems. Low flows and water levels increase the residence time of water and reduce flushing rates.[31] In freshwater systems this causes enhanced stratification causing salinisation, and in combination with increasing temperatures can result in major algal production, including HABs, decrease in dissolved oxygen concentrations, and increases in nutrient build-up. [31] These changes in ecosystems can put a huge amount of stress on other plants and animals that rely on them for their own survival. High temperatures and low oxygen levels may eliminate some fish species.[30]

[28] Department of Environment (2004) The importance of Western Australia's Waterways
[29] Dumbleyung Lake https://en.wikipedia.org/wiki/Dumbleyung_Lake
[30] Hughes Darren, https://commons.wikimedia.org/w/index.php?curid=110550255

Harmful Algae Blooms

Algae blooms are the rapid growth in algae in a water body. Harmful algae blooms (HABs) refer to blooms of algae that produce toxins that can be harmful to aquatic life, animals and even humans.[31] These blooms thrive in warm, calm, shallow bodies of water, where the water is alkaline and rich in nitrogen, phosphates, carbonates, and organic matter.[32] Freshwater systems are more susceptible to HAB's although they can also occur in marine (salt) water and brackish (a mixture of fresh and salt) water. Climate change and drought conditions increase the risk of HABs occurring[33].

The frequency and intensity of these blooms have increased in the past three decades. Although, records of HAB's in the pilot regions were not found. This trend is partly attributed to the effects of ocean warming, marine heatwaves, oxygen loss, and eutrophication and pollution of waterways. HABs can be toxic to fish and other animals, and the drying up of the water systems kills their habitats.[34]

Water temperature increases, and enhanced stratification of water systems occurs during drought due to higher temperatures and less rainfall increasing hydraulic residence times.[34] This environment fosters algal production, promoting blooms of toxic cyanobacteria. Eutrophication caused by inflow of water containing fertile soils that have been eroded also encourages algal growth.[32]

Cyanobacteria, or blue greens, produce potent toxins that can be a risk to livestock and other animals that drink or swim in contaminated water.[35] They can kill native birds and can pose a threat to human health by direct skin contact and consumption of shellfish that have lived in contaminated water.[35]

In times of drought where water resources can already be scarce, the degradation and pollution of freshwater systems with these HBAs create a significant risk to aquatic ecosystems and the animals and humans that rely on them.

Information about the condition of the water ways and wetlands in the pilot regions is limited. This review was unable find recent studies or evaluations of the health of water ways. The State of the Environment report in 2007 reports on the condition of major Western Australian rivers (Figure 14) showing that the rivers in the study regions were either significantly impacted or impacted, measured.by key macro-invertebrates as an indicator of the river ecosystems. Jatlin, et al., (2021) more recently report on the impact of a drying climate and how many rivers and lakes are now dry through summer and autumn causing major problems for freshwater biodiversity. The number of invertebrates in seventeen lakes in WA fell from over 300 to just over 100 from 1998 to 2011. And that the impact on freshwater fish unable to migrate to spawn means they are near to extinction. [36]

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[31] Department of Water and Environmental Regulation, Algal Blooms, Government of Western Australia https://www.water.wa.gov.au/water-topics/waterways/threats-to-our-waterways/algal-blooms Retrieved 30 May 2022

[32] Department of Primary Industries and Regional Development (2020) Toxic algal blooms, Government of Western Australia, https://www.agric.wa.gov.au/small-landholders-western-australia/toxic-algal-blooms Retrieved 30 May 2022

[33] Bond, N.R., Lake, P.S. and Arthington. A. (2008) The impacts of drought on freshwater ecosystems: an Australian perspective, Hydrobiology 600 3–16

[34] Mosley, LM, (2015) Drought impacts on the water quality of freshwater systems; review and integration, Earth-Science Reviews 140 203-214

[35] Water and Rivers Commission (1998) Water facts – Algal Bloom, Government of Western Australia

[36] Jatin, K., Robson, B., Fountain, J., Beatty, S., Wernberg, T. (2021) Drying land and heating seas: why nature in Australia's southwest is on the climate frontline. https://theconversation.com/drying-land-and-heating-seas-why-nature-in-australias-southwest-is-on-the-climate-frontline-17037

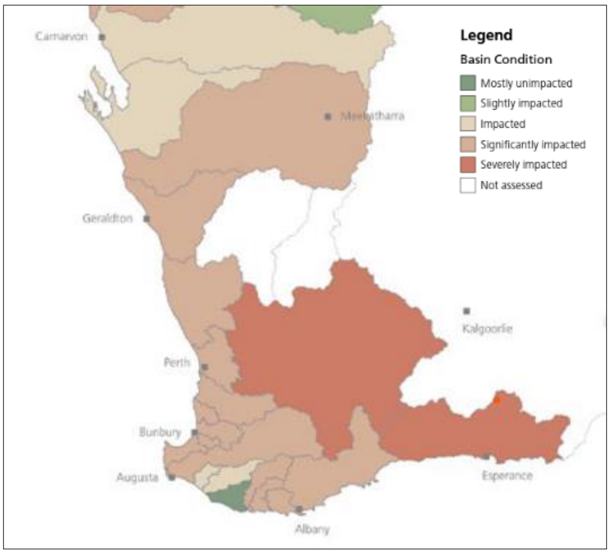

Figure 14. Condition of major Western Australian rivers, by river basin[37].

In summary, our water resources are essential for ecosystem services, businesses and sporadic assistance happens to assist farmers and communities with becoming self-sufficient. Monitoring and evaluation appear limited or is not easy to access.

3.3 Vegetation & biodiversity

Biodiversity underpins a range of ecosystem services including[38]

- Provisioning Services – food, fibre and fuel, genetic resource, biochemicals, freshwater
- Cultural Services – spiritual & religious services, recreation, knowledge, education, and inspiration
- Supporting Services – primary production, provision of habitat, nutrient cycling, soil formation and retention, atmospheric oxygen production, water cycling
- Regulatory Services – invasion resistance, pollination, herbivory, seed dispersal, climate regulation, pest and disease regulation, natural hazard protection, erosion regulation, water purification

Western Australia has eight of the 12 biodiversity hotspots in Australia, with the south-west being one of the world's top 34 hotspots.[39] Drying trends and drought threaten the biodiversity of these ecosystems through reduced access to water for vegetation growth and animal survival.[40] Decreased ecosystem productivity and increased mortality of plants and animals are characteristic of these conditions.[41] Competitive species, species adapted to the cold and wet, and species with low reproductive rates and limited mobility are most affected by drought.[41] Most species numbers will decrease during drought. The long-term consequences of drought on biodiversity depend on species abilities to resist, and to recover after drought, and on competitive interactions between species.[41]

Drought-induced vegetation declines are widely reported across the globe, and Australia. The decline in vegetation productivity and increase of plant mortality due to drought is identified as having the potential to

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[37] Halse, SA, Scanlon, M.D. & Cocking, J.S. (2002) First national assessment of river health: Western Australian program, Milestone report 5 and final report, Department of Conservation and Land Management, Perth.

[38] Queensland Government (2014) What is biodiversity, Queensland Government https://www.qld.gov.au/environment/plants-animals/biodiversity/about Retrieved 7 June 2022

[39] State of the Environment Report (2007) Biodiversity, Environmental Protection Authority WA 120-163

[40] Wernberg, T, Kala, J et al (2017) Why nature in Australia's southwest is on the climate frontline, University of Western Australia https://www.uwa.edu.au/news/Article/2021/October/Why-nature-in-Australias-southwest-is-on-the-climate-frontline Retrieved 7 June 2022

[41] Archaux, F, Wolters, V (2006) Impact of summer drought on forest biodiversity: what do we know? Annals of Forest Science, Springer Nature 63(6) 645-652

trigger abrupt and irreversible changes in ecosystem structure and function, with profound implications for biodiversity, ecosystem services, and carbon storage.[42]

Biodiversity describes the variability among living organisms from all sources (including terrestrial, marine, and other aquatic ecosystems and the ecological complexes of which they are part) and includes diversity within and between species and the diversity of ecosystems. Biological diversity underpins ecological processes essential for maintenance of marine and estuarine quality, soil fertility and clean, fresh water and air. It is also fundamental to the quality and character of the landscape and in providing recreational opportunities, aesthetic value and cultural identity. Governments look after biodiversity on behalf of the public through the creation and operation of National parks and reserves.

The protection and enhancement of biodiversity is guided by the National Strategy for the Conservation of Australia's Biological Diversity (1996) and the National Objectives and Targets for Biodiversity Conservation 2001-05. Also, statutory, and non-statutory mechanisms exist and are designed to protect, manage, and conserve areas identified as of high State, regional or local biodiversity value for Western Australia.

Changes in land use, planning should recognise the State's biodiversity including consideration of any future potential value, such as for medicinal purposes or as a source of genetic material.

The wheatbelt landscape has experienced significant transformational change since European settlement and much of the landscape (as much as 90% in places) is cleared of its natural habitat. The landscape pre-European settlement would have looked quite different with much more vegetation, providing a natural resilience to endure drought conditions. Wind erosion and drying of the environment would have been less severe.

Clearing of land continues in Australia and Western Australia. The data in Figure 15 is not available at a regional level and is also net of planting, which means 1 hectare of old established habitats can be cleared and the same area replanted elsewhere which means no net loss of forest in the National Greenhouse Accounts (NGA).

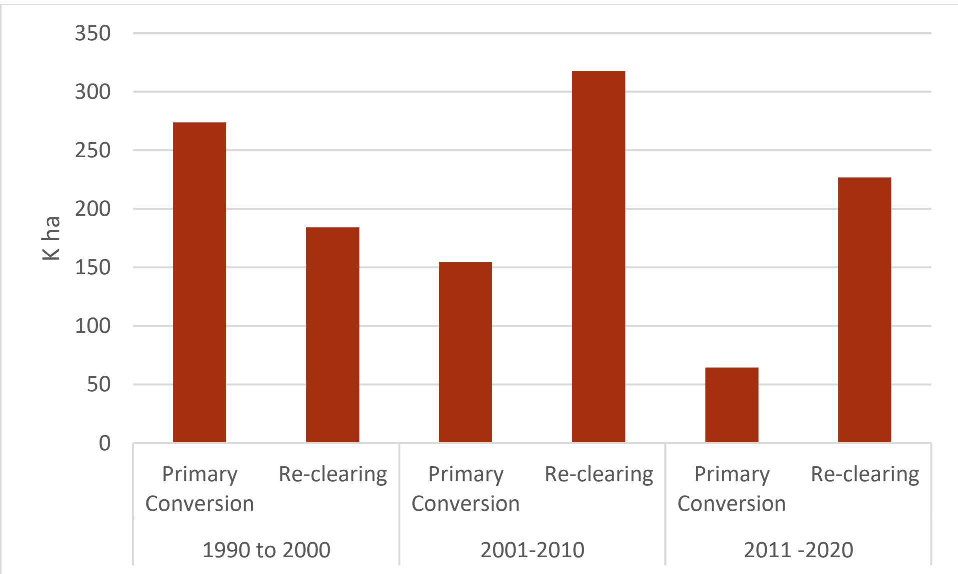


Figure 15. Area of land cleared in WA for the last three decades[43]

[42] Jiao, T., Williams, C.A., Rogan, J., De Kauwe, M.G., Medlyn, B.E. (2020) Drought impacts on Australian vegetation during the Millennium Drought measured with multisource spaceborne remote sensing. https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2019JG005145

[43] Department of Climate Change, Energy, the Environment and Water https://ageis.climatechange.gov.au/QueryAppendixTable.aspx

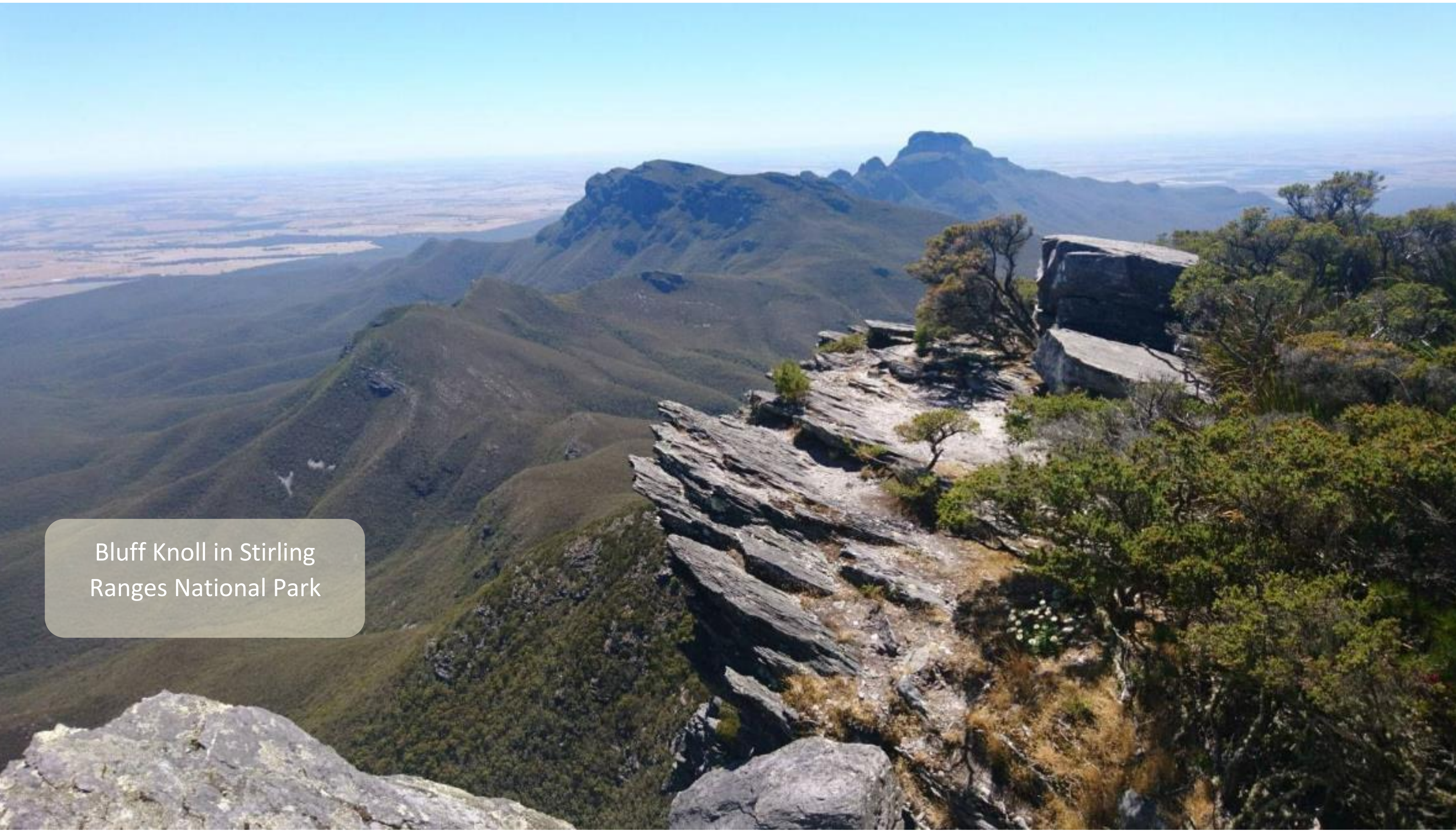
Of the 288,400 hectares cleared in WA, 68,700 hectares were primary forests at least 30 years old and the most land was cleared for agriculture, horticulture and forestry.

Protection of biodiversity exists by:

1. Nature reserves are established for wildlife and landscape conservation, scientific study, and preservation of features of archaeological, historic, or scientific interest. Recreation that does not harm natural ecosystems is allowed, but other activities are not usually permitted.
2. National parks are established for the same reasons as nature reserves, but they are also available for the enjoyment by the public. They have national or international significance for scenic, biological, or cultural values. There are three significant national parks in the pilot regions, Kalbarri National Park the Fitzgerald River National Park, recognised as an international 'biodiversity hotspot' and known as the Fitzgerald Biosphere, and the Stirling Ranges National Park.

Formed over millions of years by weathering and erosion, the Stirling Range in south-west Western Australia is an area of great biogeographic and evolutionary interest and displays one of the richest floras in the world.

Sky walk at Kalbarri National Park



Bluff Knoll in Stirling Ranges National Park

A study by Jiao, T (2020) et al., examined the effects of drought on the Australian vegetation. They analysed the magnitude and sensitivity of vegetation responses to the Millennium drought (MD), with satellite-derived information including the fraction of photosynthetically absorbed radiation (FPAR), photosynthetic vegetation cover, canopy density derived from vegetation optical depth, and aboveground biomass carbon.

Results (Figure 16) show how South-eastern Australia experienced the largest impact of the drought, as would be expected because it impacted the east side of Australia more than the west. The negative values in Figure 13 indicate drought impacts while positive indicate no drought impacts and grey indicates burn fraction more than ten per cent.[42]

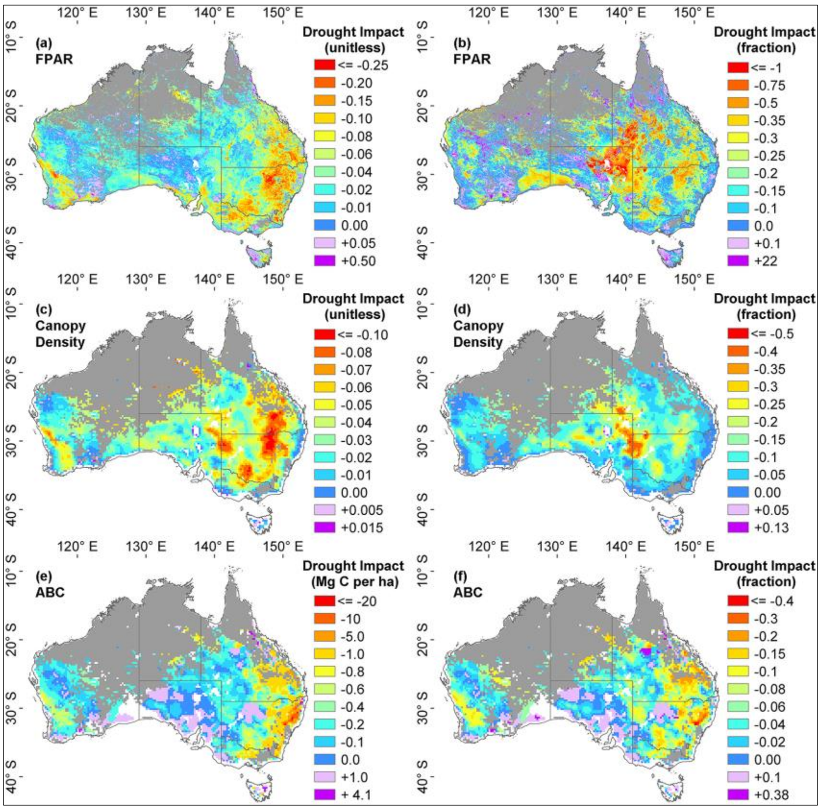


Figure 16. Mean monthly absolute (left panels) and relative (right panels) drought impacts on fraction of photosynthetically absorbed radiation (FPAR), canopy density and aboveground biomass carbon (ABC)

Other risks to the environment associated with drought.

Impact of Fire

The Mediterranean-type climate in the southwest of WA is characterised by conditions that are conducive to ignition and spread over a 4–8-month period.[44] There are various weather factors that influence the fire environment including coastal sea-breezes, strong easterly winds, abrupt wind changes, and regular lightning storms during the dry months.[44] The traditional fire season has been prolonged, sometimes by several months as a result of the sustained decrease in rainfall during the past three decades.[44]

The timing, intensity, and frequency of drought events have divergent impacts on fuel flammability and fire behaviour.[45] Droughts after a wet spring can result in an abundance of rapidly drying fuels in bushland and

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[44] McCaw, L., and Hanstrum, B. (2002) Fire environment if Mediterranean south-west Western Australia, Fire in ecosystems of south-west Western Australia: impacts and management. Symposium proceedings 1 87-106

[45]Drought.gov, *Drought Impacts on Wildfire Management*, National Integrated Drought Information System https://www.drought.gov/sectors/wildfire-management Retrieved 30 May 2022

forest understories, but prolonged droughts can limit fire occurrence due to a reduced availability of fuels from a lack of rainfall stimulating vegetation growth.[45]

Fire has devastating effects on the environment. Fires that tear through forests and bushland can cause serious loss of vegetation and biodiversity, as plants are burnt off, and animals are killed both from the fire, and from the loss of their home and food source following.[46] Farmland is scorched, destroying pastures crops, and infrastructure, and killing livestock.[46] Ash can pollute both the air and waterways, causing issues to human health, and depositing unwanted nutrients that can stimulate HABs.[46]

It is important to note that bushfires can play an important role in Australia's environmental ecology.[47] Fire can trigger natural processes like stimulating seed germination and can benefit biodiversity. By clearing out thick undergrowth germination and regrowth of native vegetation is encouraged, while freeing them from competition with weeds, and eliminating diseases and damaging insects.[47] Recurrent fires however potentially threaten regeneration by killing seedlings and impoverishing the seed bank, therefore reducing forest postfire recovery ability.[48]

Figure 17 shows the area of land burnt (%) in 2019 derived from MODIS satellite imagery by the National Aeronautics and Space Administration (NASA).[49] A dot identifies the pilot region LGA's.

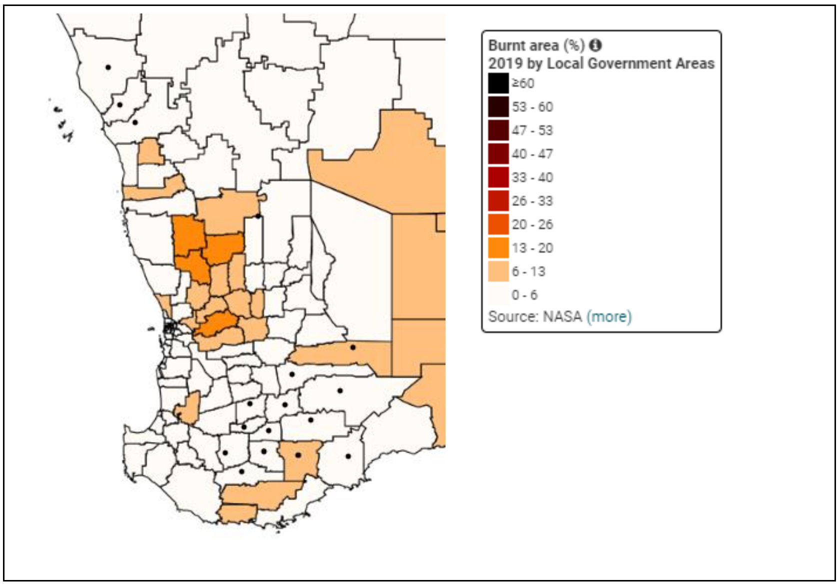

Figure 17. Area burned in LGA WA 2019

Risk of Feral Animals

Feral animals are non-native or introduced exotic animals that have established feral populations in WA that are considered pests.[50] An animal is classified as a pest because of one or more of the following:[50]

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[46] UN Environmental Programme (2020) Ten impacts of the Australian bushfires, https://www.unep.org/news-and-stories/story/ten-impacts-australian-bushfires Retrieved 6 June 2022

[47] Department of Environment and Water (2020), How bushfires play an important role in biodiversity, Government of South Australia. https://www.environment.sa.gov.au/goodliving/posts/2020/03/bushfires-and-biodiversity Retrieved 6 June 2022

[48] Thays dos Santos Cury, R., Montibeller-Santos, C. (2020) Effects of Fire Frequency on Seed Sources and Regeneration in Southeastern Amazonia, Frontiers for Global Change, 3, 82 https://www.frontiersin.org/articles/10.3389/ffgc.2020.00082/full Retrieved 6 June 2022

[49] Van Dijk, A.I.J.M. and Rahman, J. (2019) Synthesising multiple observations into annual environmental condition reports: the OzWALD system and Australia's Environment Explorer. In Elsawah, S. (ed.) MODSIM2019, 23rd International Congress on Modelling and Simulation. Modelling and Simulation Society of Australia and New Zealand, December 2019, pp. 884–890. ISBN: 978-0-9758400-9-2. https://doi.org/10.36334/modsim.2019.J5.vandijk

[50] Department of Primary Industries and Regional Development (2019) Declared animal pests, Government of Western Australia https://www.agric.wa.gov.au/amphibians-and-reptiles/declared-animal-pests Retrieved 6 June 2022

- The prey on domestic animals and farm livestock
- They damage crops and food production
- They pose a threat to native animals and ecosystems
- They are a nuisance and health hazard to people

Multiple animals in Western Australia like foxes, wild dogs, feral cats, rabbits, feral pigs, and camels Rabbits, cats and foxes are widespread and considered pests. Wild dogs are an issue on the east-side of the NAR whereas feral pigs are an issue in high and medium rainfall areas around the Great Southern.

Pressure from feral animals can have a major impact on soil, waterways and the biodiversity and populations of native plants and animals.[51] They cause soil erosion by degrading vegetation, and unlike domestic livestock are hard to remove from these areas to allow for regeneration.[51] Pests impact on native species by preying on them, competing for food and shelter, destroying their habitat and spreading diseases.[51] Diseases carried by feral animals can be difficult to control, and can infect domestic and native animals. Outbreaks of some diseases among wildlife could have widespread effects that would be disastrous for the environment.[51]

Like native animals, populations of feral animals are usually affected by prolonged drought.[52] If the breaking of drought provides an abundance of food and shelter, they have the potential to quickly increase their populations, as many of these species can multiply rapidly from a single pair.[52] This is also supported by reduced numbers of their predators from the drought that would otherwise help control their population.[52]

4 THE HISTORICAL IMPACTS OF DROUGHT ON NATURAL RESOURCES

In the last twenty years four were significantly dry years, these were, 2002, 2006, 2010 and 2019 (Figure 18). These drought years are where dry conditions were experienced by most regions across the State.

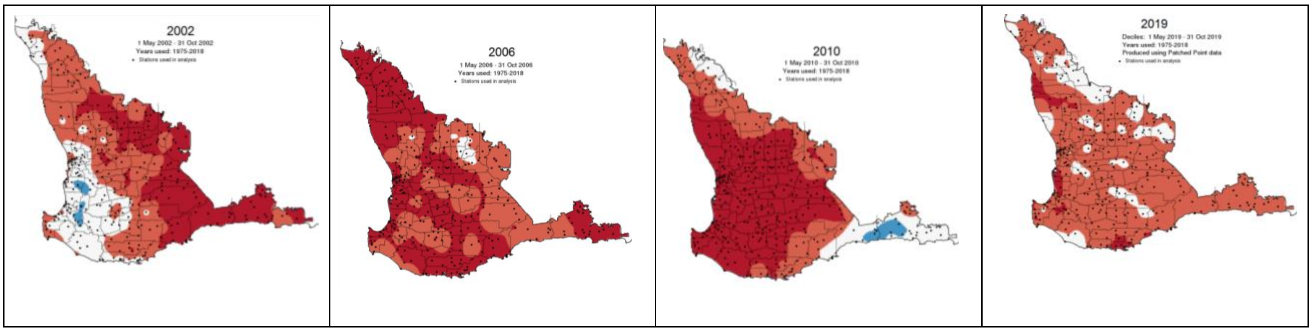


Figure 18. Rainfall decile maps showing drought years for WA between 2002 and 2022, source DPIRD

Other years, Figure 19, are where dry conditions were experienced by more localised regional locations, for example the Northern Agriculture region experienced dry conditions in 2007 which meant the impact of 2006 and 2007 was severe. In the Great Southern Region dry conditions were severe in 2018, so the accumulative effect by 2019 meant the impact increased for this region. Appendix 1 shows the rainfall deciles for the last 20 years using Bureau of Meteorology data to show the difference between years.

[51] Department of Agriculture, Water and the Environment, Feral animals in Australia, Australian Government https://www.awe.gov.au/biosecurity-trade/invasive-species/feral-animals-australia Retrieved 6 June 2022

[52] Department of Primary Industries (2015) Controlling vertebrate pests after a drought, NSW Government, https://www.dpi.nsw.gov.au/biosecurity/vertebrate-pests/publications/controlling-vertebrate-pests-after-drought Retrieved 6 June 2022

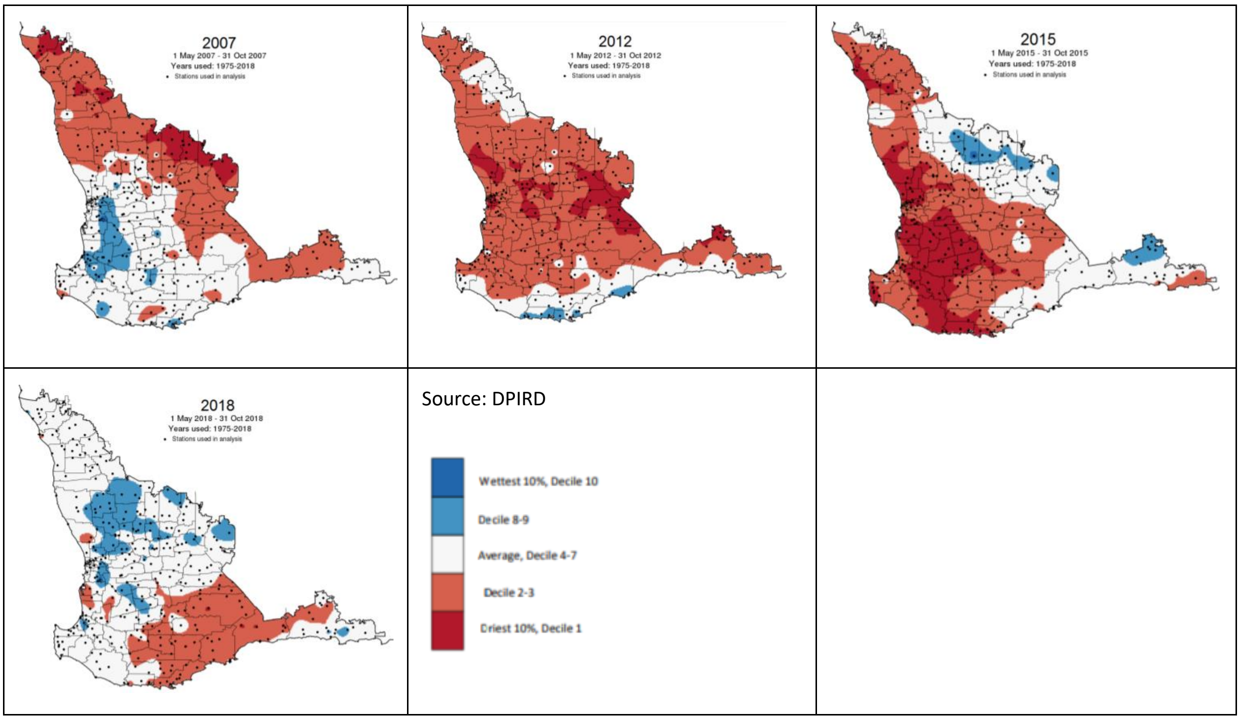


Figure 19.Rainfall decile maps showing dry seasons and drought conditions for regional areas, source DPIRD.

Elements of data which contribute to the annual environmental condition reports generated by Australian National University (ANU) are used to identify the impact the drought years had on the natural resources for each LGA in the pilot regions.[49]

The environmental condition scorecard summarises observations on the trajectory of our natural resources and ecosystems and reports on several measures to give an overall environmental score between 0 and 10 relative to previous years. Calculated as the average of the ranking of component scores

The measures of the condition of natural resources and ecosystems are summarised from several spatial data sources. Land cover, inundation, fire occurrence, burnt extent, exposed soil and vegetation leaf area are derived by automated analysis of satellite imagery. The other indicators, tree cover, soil moisture and vegetation growth are estimated by integrating ground and satellite data with environmental prediction models. Further details about the method and collection of data are in Appendix 3.

The summary score for Western Australia displaying the environmental health of Western Australia for 2021 is in Figure 20.

4.1.1 Environmental Health

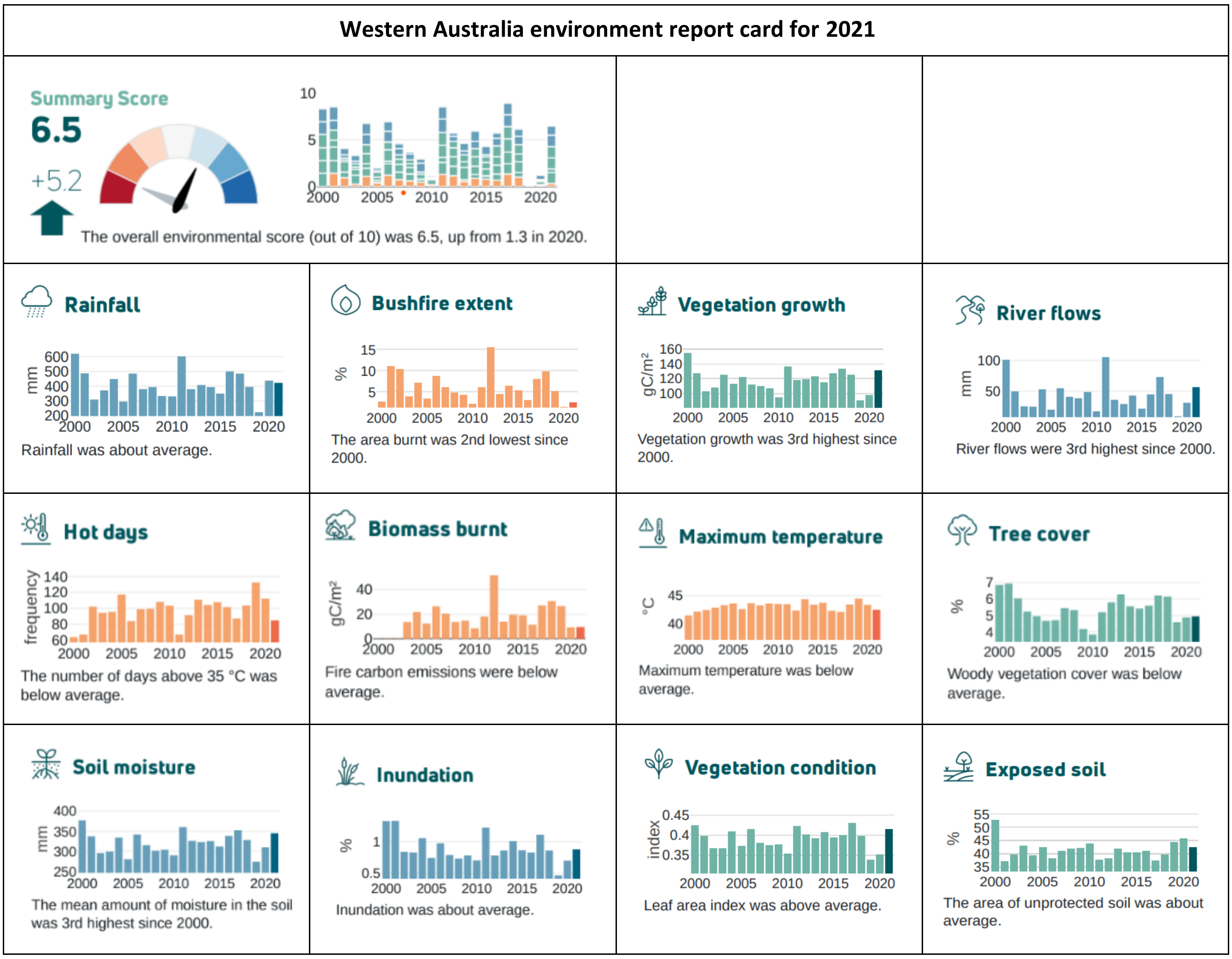


Figure 20. Environmental score card for Western Australia 2021

By using this data, we can see the impact of drought on our environment by LGA. The indicators used show the impact are exposed soil (soil protection), leaf area, plant growth and river flows. Figures 21, 24,25 and 26 show the four indicators for the year of drought and the year after, because the impact of the drought on these measures appears often appears the year following the drought year.

Exposed soil uses annual mean percentage of soil unprotected by living vegetation or litter, derived from MODIS imagery and CSIRO mapping by the OzWALD model -data fusion system. The severity and area of exposed soil was highest in 2020 suggesting that the impact of drought is increasing.

It is interesting to note that the NAR exposed soil was severe in 2007 yet in 2011 and 2020 it was average. Farming practices may have Improved and contributed to less soil exposure.

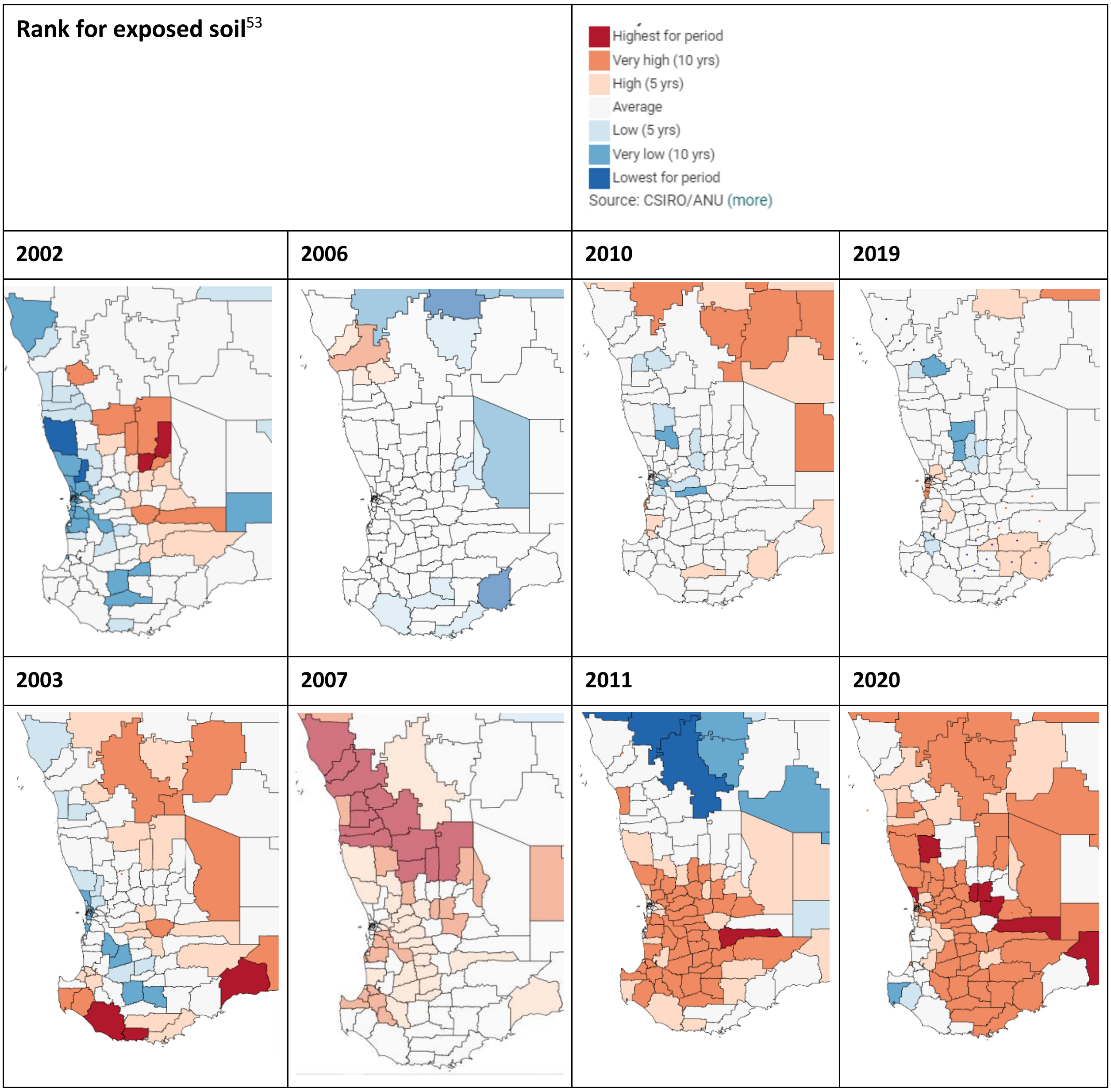
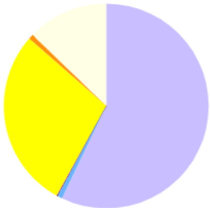
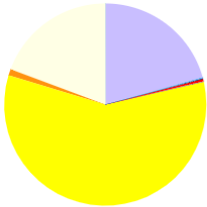
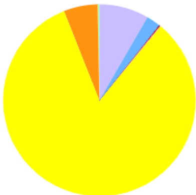
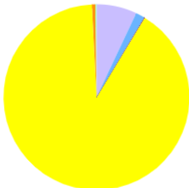
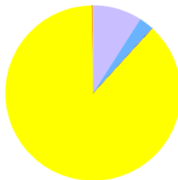
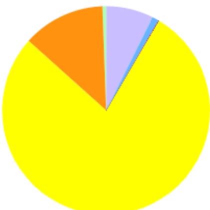
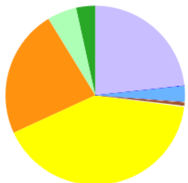
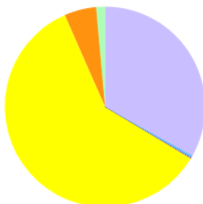


Figure 21.Exposed soil for Local Government Associations in Western Australia for specific drought years identified

A dot identifies the pilot regions LGA's in the year 2019 in Figure 21. In Figure 21 the years after the drought years showed highest area of exposed soil for the 10-year period. Vigilance to manage soil wind erosion in the year of drought for agricultural and non-agricultural landscapes is required and the year after drought when the risks are higher.

The data in Figure 21 showing the exposed soil is measuring all land use types. Figure 22 breaks this into land use types with pie charts (note, there is an explanation for the colours and legend in Figure 22).

[53] Australian National University, & TERN. (2022b) Australia's Environment Explorer. Wenfo.org; Australian National University. http://wenfo.org/ausenv/#/2020/Exposed_soil/Region/Rank/Local_Government%20Areas/options/-31.36/118.28/7/none/White/Opaque

Northern Agricultural Region			
Northampton (S) 2020 Exposed soil (km^2) Total by land use type 	Greater Geraldton (C) 2020 Exposed soil (km^2) Total by land use type 	Chapman Valley (S) 2020 Exposed soil (km^2) Total by land use type 	Legend: Yellow: Dryland cropping Mauve: Natural environment White: Grazing on native pasture Orange: Grazing on modified pasture Blue: Natural water and wetlands Light green: Plantation forestry Dark green: Production native forests
Southern Wheatbelt			
Wagin (S) 2020 Exposed soil (km^2) Total by land use type 	Dumbleyung (S) 2020 Exposed soil (km^2) Total by land use type 	Lake Grace (S) 2020 Exposed soil (km^2) Total by land use type 	Kulin (S) 2020 Exposed soil (km^2) Total by land use type 
Kondinin (S) 2020 Exposed soil (km^2) Total by land use type 			
Great Southern Inland			
Broomehill-Tambellup (S) 2020 Exposed soil (km^2) Total by land use type 	Woodanilling (S) 2020 Exposed soil (km^2) Total by land use type 	Cranbrook (S) 2020 Exposed soil (km^2) Total by land use type 	Jerramungup (S) 2020 Exposed soil (km^2) Total by land use type 

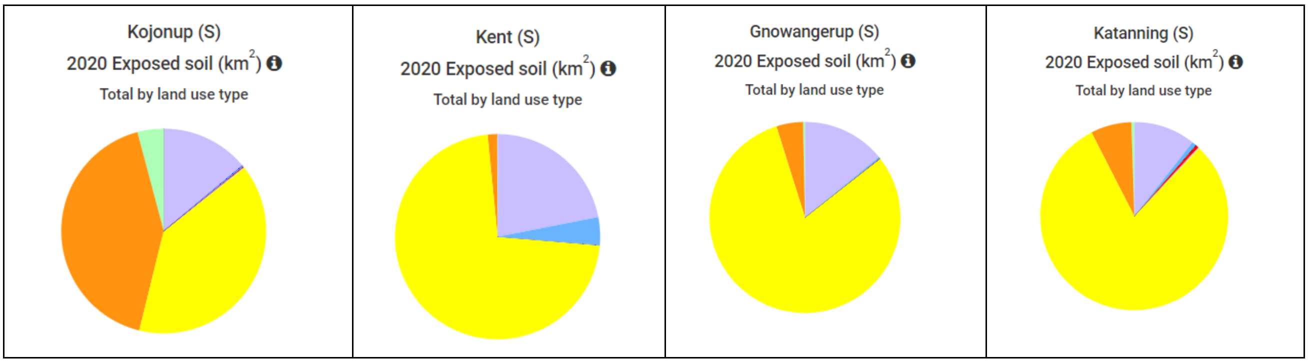


Figure 22. Exposed soil by land use type for each LGA in pilot region

Exposed soil in the national parks in the pilot regions, Figure 23, provide an indicator of their ecosystem health and shows the impact drought can have on the environment. The Kalbarri national park has more exposed soil due to the type of vegetation and low rainfall environment compared to the Fitzgerald River National Park and Stirling Range National Park, it is a much more arid environment, but soil exposure increased after the droughts in 2006 and 2007 and does not seem to have recovered suggesting irreversible damage.

The Fitzgerald River National Park suffered with fires in 2008, as did the Stirling Range National Park in January 2020 after drought in 2019. The impact of drought and fires is significant on the health of our ecosystems.

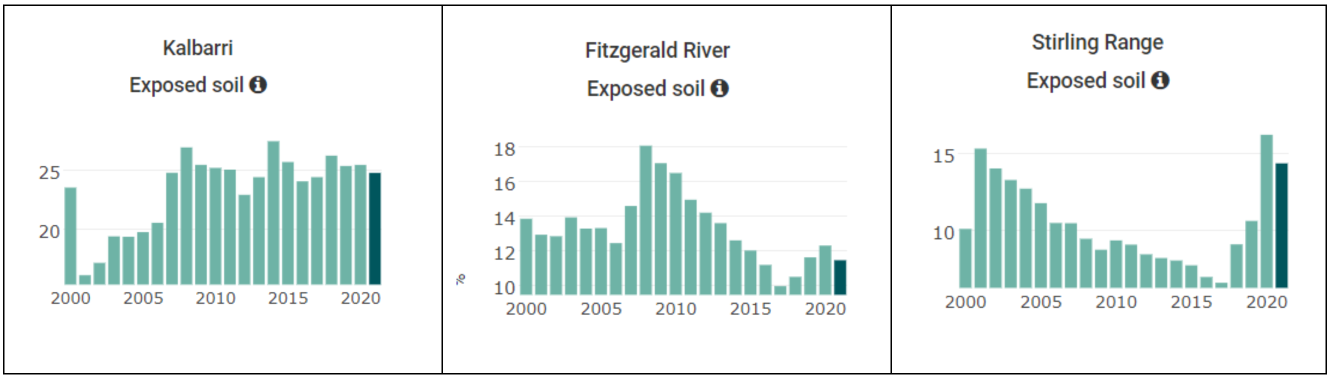


Figure 23. Expose soil for the National Parks in pilot regions from 2000 to 2020

The leaf area index (LAI) is calculated from the amount of foliage measured in the tree canopy[54]. This measurement can give an estimate on the average biomass, photosynthetic activity and water and nutrient uptake.[109]

The condition of vegetation, or the leaf area measured improved in 2020 compared to 2018 and 2019 for Western Australia as a whole (Figure 20), whereas for Jerramungup 2020 was the lowest for the period and for Gnowangerup it was very low, Figure 24.

[54] TERN. (2020) Do you use or want Leaf Area Index data? Please let TERN know. TERN Australia. https://www.tern.org.au/do-you-use-or-want-leaf-area-index-data-please-let-us-know/

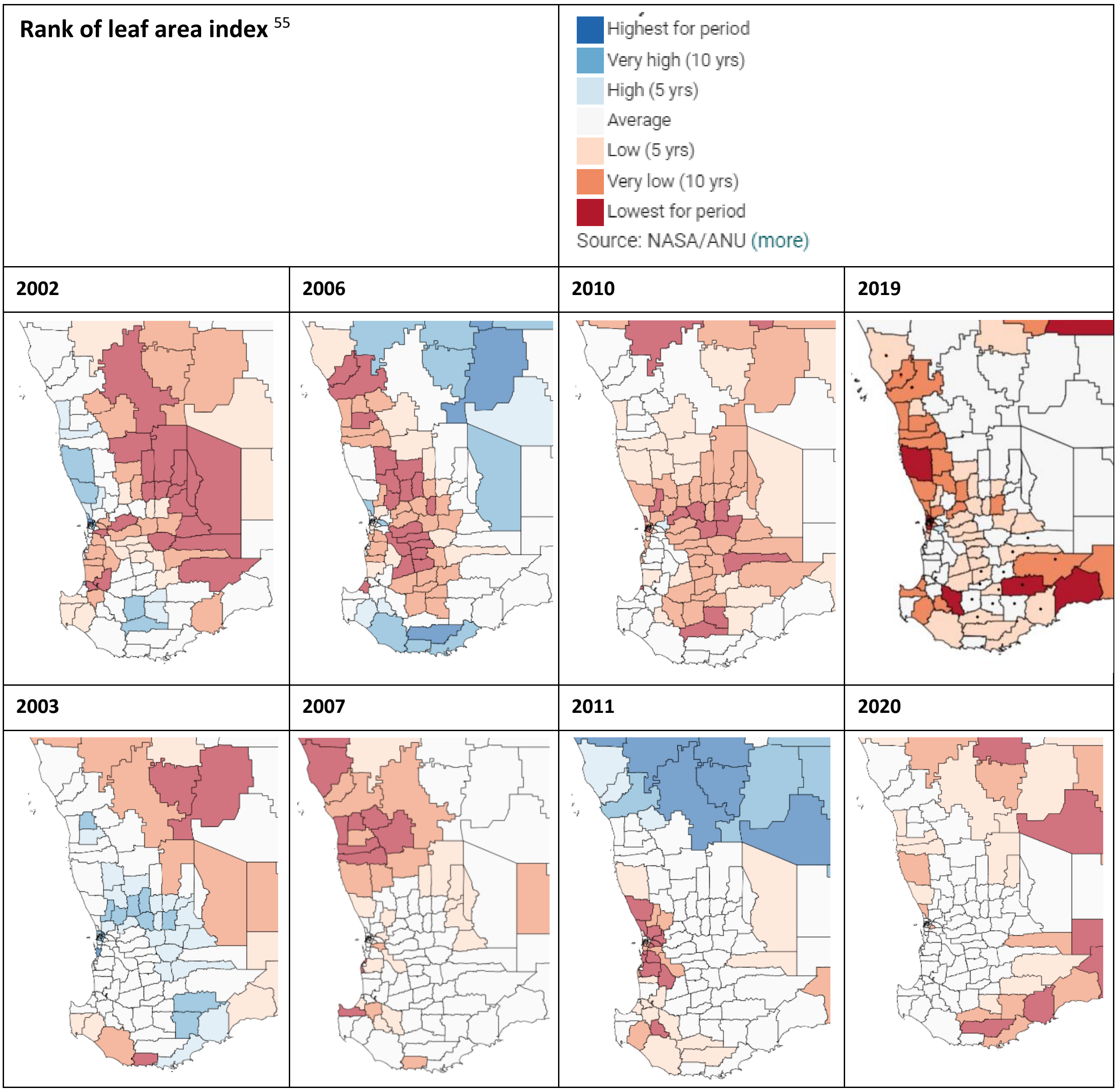


Figure 24.Vegetation condition for Local Government Associations in Western Australia for specific drought years identified.

A black dot identifies the LGA's in the pilot regions in year 2019 in Figure 24

The rank of vegetation carbon uptake in Figure 25 illustrates the impact of drought and how these years have a significant negative impact on our vegetation and its ability to grow. This measure Is the gross primary production, the annual amount of carbon taken up the vegetation through photosynthesis, as estimated by the Oz WALD model data fusion system

[55] Australian National University, & TERN. (2022b) Australia's Environment Explorer. Wenfo.org; Australian National University.http://wenfo.org/ausenv/#/2020/Vegetation_leaf%20area/Region/Rank/Local_Government%20Areas/options/-31.36/118.28/7/none/White/Opaque

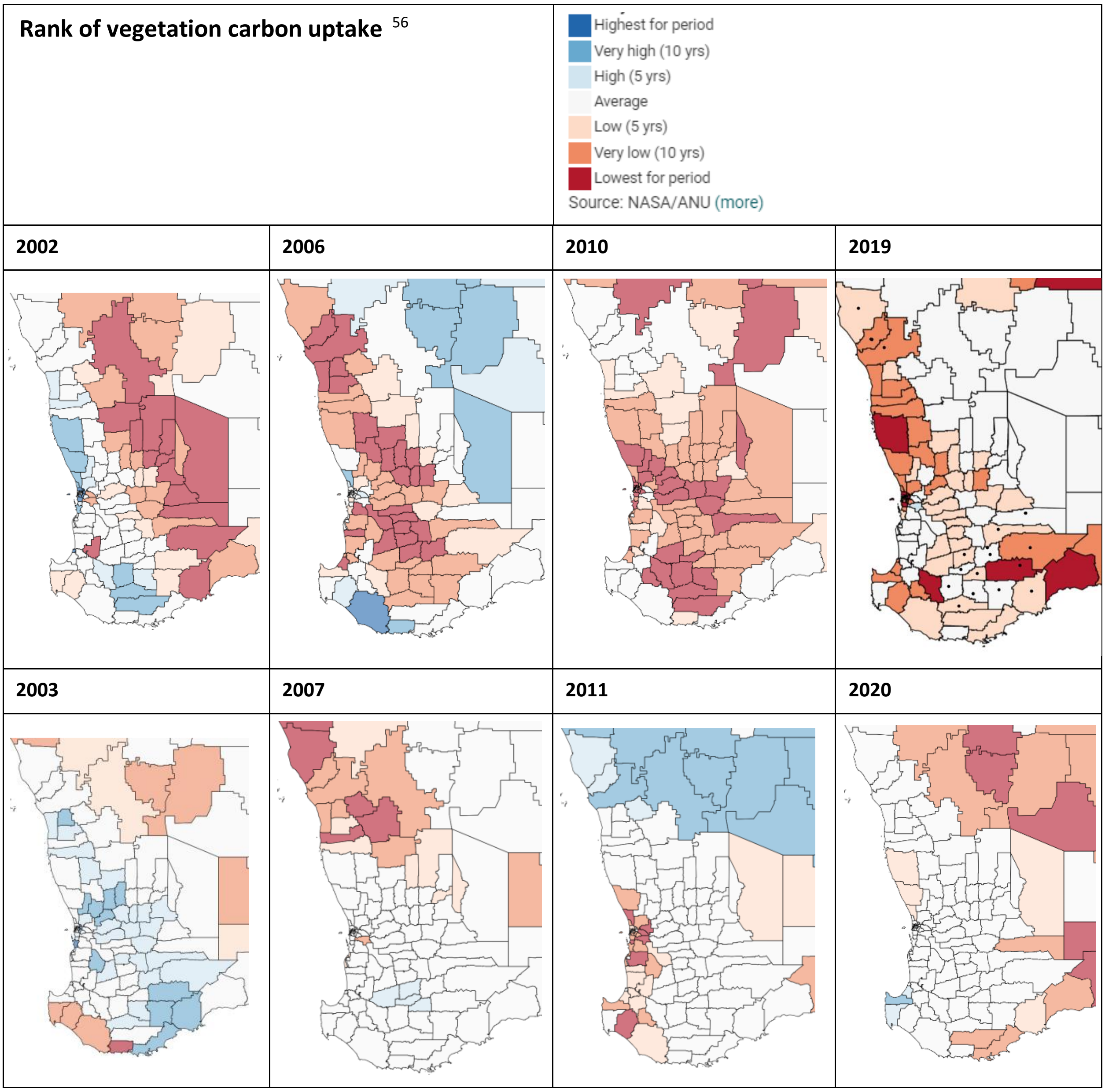


Figure 25.Vegetation growth for Local Government Associations in Western Australia for specific drought years identified

A black dot identifies the pilot regions LGA's in 2019 in Figure 25

The rank of river flow in Figure 26 is the total surface and subsurface runoff into the river, estimated by the OzWALD model data fusion system. The impact of drought is significant the year of drought and strongly correlated to rainfall.

[56] Australian National University, & TERN. (2022b) Australia's Environment Explorer. Wenfo.org; Australian National University. http://wenfo.org/ausenv/#/2020/Vegetation_growth/Region/Rank/Local_Government%20Areas/options/-31.36/118.28/7/none/White/Opaque

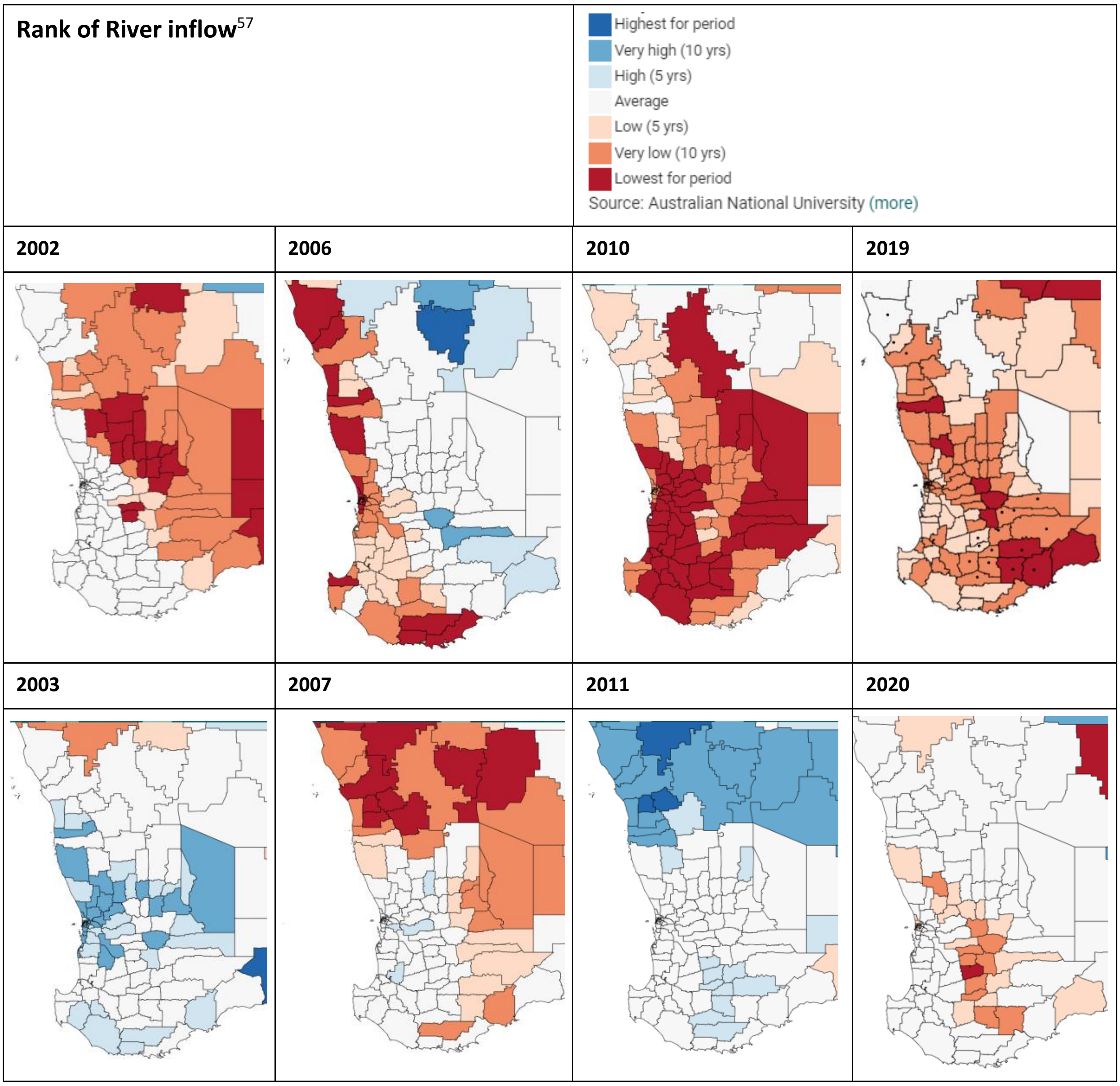
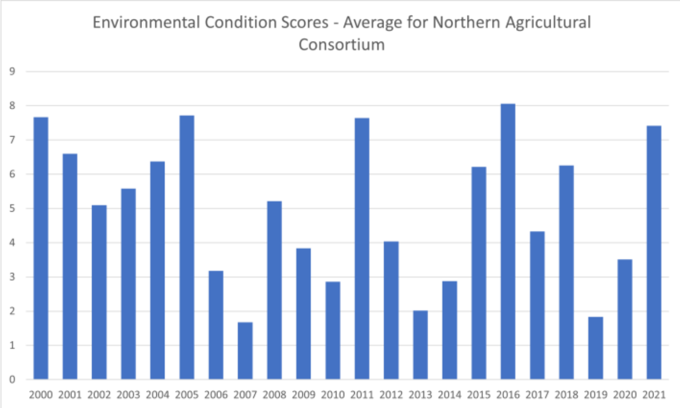
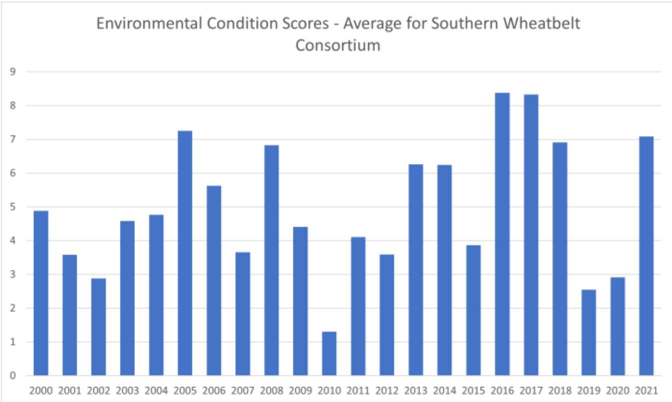


Figure 26 River Flow for Local Government Associations in Western Australia for specific drought years identified

To summarize the impact of drought on the environment for the pilot regions over the last 20 years, these indicators were combined to create an average score for each year, Figure 27. The accumulative impact of prolonged drought is evident from the trends. The Northern Agricultural region environmental condition was at its lowest in 2007. This year was another severely dry year for this region, following the drought year of 2006. A similar trend can be seen in the Great Southern in 2019, where environmental condition had been in decline since 2016, and which followed a dry year of 2018, accumulating in severely low condition scores for 2019, that then carried on into 2020.

[57] Australian National University, & TERN. (2022). Australia's Environment Explorer. Wenfo.org; Australian National University. http://wenfo.org/ausenv/#/2020/Runoff/Region/Rank/Local_Government%20Areas/options/-31.36/118.28/7/none/White/Opaque





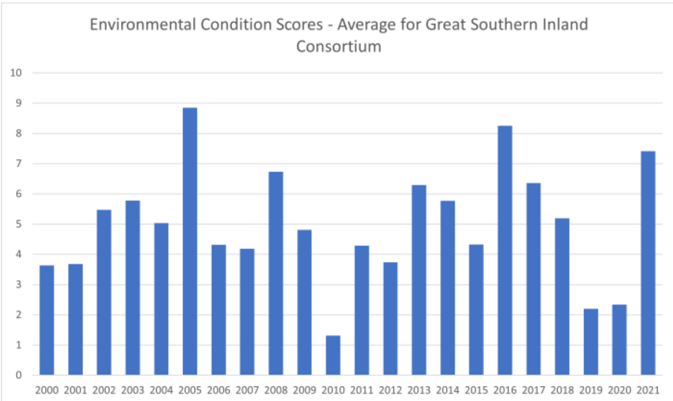


Figure 27.Annual average overall condition scores for pilot regions from 2000 to 2021

The data indicates recovery from drought can occur quite quickly in years following drought, for example 2021, especially when rainfall is above average. However, considering the exposed soil the year after drought the risk of water erosion is high with intense rainfall events.

The data provided by the four indicators selected show the historical impacts of drought. The risks are the impact on soil with increased exposure especially in the year after drought and reinforces the need for careful management to prevent wind erosion in these years. The risk to vegetation and its growth is high, exasperated by extensive clearing of land in the Wheatbelt which has exposed the soil and the remaining vegetation to further stress.

5 POTENTIAL FUTURE IMPACTS OF DROUGHT ON REGIONAL NATURAL RESOURCES.

As the climate becomes drier and warmer, the accumulative effect of this warming has potential to increase the risk to the environment through drought. The historical effects show the negative impact of drought from an accumulative effect of two consecutive years of drought or more and suggests that the impact of future droughts could be more severe. This means, more wind erosion, damage to the vegetation and biodiversity.

Although there is high level of diversity between the three pilot regions, they all have similar characteristics in soil, water and biodiversity, they all face similar, or the same impact from drought, that is low vegetative state and growth, increasing risk of soil degradation from wind erosion/soil erosion, increasing risk of fire hazards (if there is a fuel load), incursion of pests and weeds and loss of biodiversity, and possible HAB's in waterways.

The potential future impacts for the environment in the pilot regions are likely to be similar for the three regions but the difference between the pilot regions is likely to be the level of impact and the level of risk. Table 1 provides an estimated level of risk based on the analysis and literature in this review. Five X means high risk and high level of impact, One X means low risk and low level of impact.

Table 1. Risk assessment for future impacts of drought on regional natural resources

	Northern Agriculture Region		Southern Wheatbelt		Great Southern Inland	
	Level of Risk	Level of Impact	Level of Risk	Level of Impact	Level of Risk	Level of Impact
Increasing soil degradation	XXXXX	XXXXX	XXX	XXXXX	XXX	XXXXX
Increasing risk of HAB's	XXXXX	XXX	XXX	XXXXX	XXXX	XXXXX
Increasing risk of fires	XXX	XXXX	XXXX	XXXXX	XXXXX	XXXXX
Increasing risk of feral animals	XXXXX	XXXXX	XXX	XXXXX	XXXXX	XXXXX
Increasing loss of biodiversity	XXXXX	XXXXX	XXXXX	XXXXX	XXXXX	XXXXX

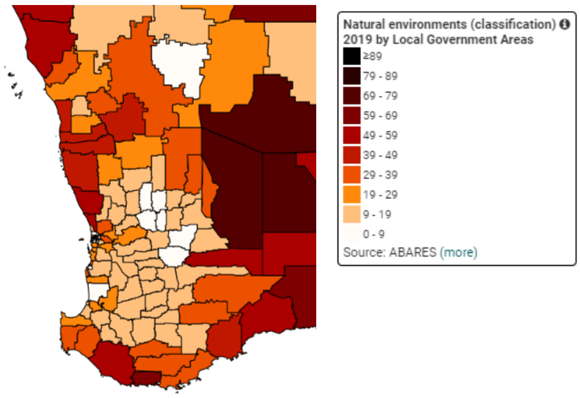
Explanation of ratings in Table 1:

- The sandy soils in the NAR increase the risk for soil degradation compared to the Southern Wheatbelt and Great Southern Inland but all are at risk, and all have a high level of impact when affected by poor soil health and further degradation.
- The increasing risk of HAB's occurring is higher in the NAR with their freshwater systems. But some LGA's in the Great Southern inland are also at risk and the impact is high.
- The vegetation and biodiversity in high and medium rainfall areas are more susceptible to fires.
- Feral animals in the NAR and Great Southern Inland were considered higher risk than the Southern Wheatbelt due to the national parks and high level of natural vegetation.
- All three regions were considered high risk of biodiversity loss due to human activity.

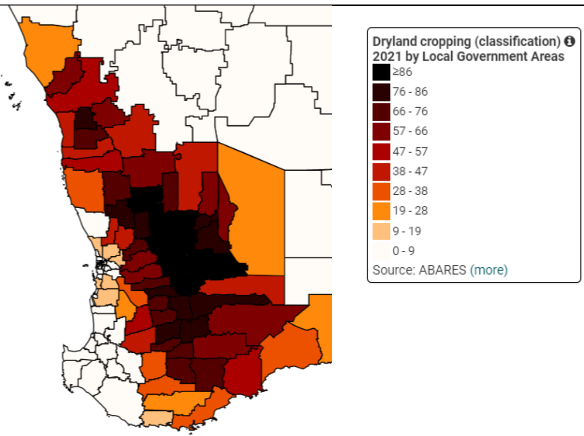
6 LAND AND NATURAL RESOURCE MANAGEMENT

The land use maps derived from the Catchment Land Use Mapping program developed by ABARES summarises the Natural landscape and Dryland cropping land use by LGA showing a significant area of land is used for dryland cropping.

Natural landscape land use (km^2)



Dryland cropping land-use (km^2)



Grazing on modified pasture (km^2)

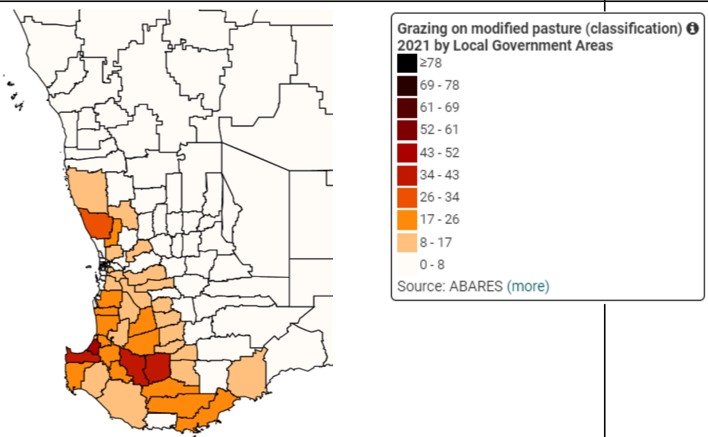


Figure 28.Broad Land use (km2) category derived from the Catchment Land use Mapping program[58]

Most agriculture land is owned as private property and managed by individuals, corporates and most are family-owned farming businesses. Whereas much of our Natural landscape and therefore biodiversity is vested in Crown land which occupies 92% of the State, its sustainable management is essential for the effective protection of biodiversity and heritage.[59] Crown land is all land in Western Australia for which there is no certificate of title under the Transfer of Land Act 1983 (TLA), or a memorial or grant registered under the Registration of Deeds Act 1832.

Several government State agencies are entrusted with varying degrees of management roles over Crown land, with the major roles being played by the Department of Biodiversity Conservation and Attractions, the Water Corporation, the Department of Mines, Industry Regulation and Safety, Department of Water and Environmental Regulation and, to a lesser extent, the Department of Transport.

[58] Australian National University, & TERN. (2022) Australia's Environment Explorer. Wenfo.org; Australian National University. http:// http://wenfo.org/ausenv/#/2021/Natural_water%20and%20wetlands/Region/Actual/Local_Government%20Areas/bar,pie,timeseries,options/-30.45/119.74/6/none/White/Opaque

[59] Environmental Defenders Office of Western Australia (inc.) 2010 Crown Land Management. Fact sheet

Nearly all roads are Crown land (road extends from fence line to fence line of the properties on each side of it, not just the bituminised portion set aside for vehicles). Most recreation reserves, river foreshores and beaches are Crown land, and public utilities (dams, pump stations, electricity switch yards, etc.) are usually constructed on Crown land.

There are several legislation and governance framework which impacts on the governance of crown land include[60]:

- Land Administration Act 1997
- Land Administration Amendment Act 2000
- Parks and Reserves Act 1895
- Reserves Acts (various)
- Conservation and Land Management Act 1984
- Environment Protection and Biodiversity Conservation Act 1999
- Environmental Protection Act 1986

There are also several others, like the Soil and Land Conservation Act 1945 (WA) which impact and influence what can be done on Crown land.

Besides Government agencies there are regional natural resource management (NRM) organisations and grower groups in the pilot regions working on projects with communities on NRM activities and working with landholders (farmers) on NRM and agri-environment activities to achieve positive environmental outcomes.

The WA Landcare Network (WALN) which is a not-for-profit peak body providing support to a range of groups works to improve the natural environment. Table 2 outlines the organisations working toward this in the pilot regions and provides a snapshot of their current programs and projects.

Table 2. Summary of organisations and current projects in the pilot regions

Organisation	Current project
Northern Agricultural Catchments Council (NACC)	Programs: 1. Biodiversity 2. Costal & marine 3. Sustainable Agriculture 4. Aboriginal Custodianship Projects • Regional Drought Resilience Planning Program • Biodiversity community grants • Regional Agricultural Landcare Facilitator funded by Regional Lands Partnership • Gnow or Never: Supporting Communities to save Mallee fowl • 2019 WA Threatened species forum • Chapman Catchment – Collaborative Landscape scale regeneration project • BioBlitz • Building a buzz for beneficial bugs

[60] Annual report 2020-21, Department of Planning, Lands and Heritage

	• Supporting smarter farms (landholders to address Soil acidity, wind erosion, increase soil organic carbon and improve native vegetation and on-farm biodiversity. • Growing great ground – Wind erosion & improve native vegetation and on farm biodiversity through ground cover and native vegetation. • Land for wildlife • Small landholder guide • Traditional ecological knowledge • Sharing Aboriginal knowledge • Coastal community grants • Rabbit awareness project • Feral fix • Enviro stories • Community photo monitoring • Reconciliation action plan "Reflect" https://www.nacc.com.au/projects/
South Coast NRM Inc	1. Land a. Farmers helping farmers to Maximise soil moisture and producing in prolonged drought areas 2. Biodiversity a. Black Cockatoo survey b. Land for wildlife c. Managing dieback d. Protecting biodiversity restoring Gondwana e. Drone technology 3. Water a. Ramsar Wetlands b. Yakamia Creek c. Fish Friendly Farms 4. Coastal & Marine a. Coastscapes coastal corridor b. Bringing oysters back to oyster harbour c. Protecting our shorebirds 5. Culture & Community a. Restoring Noongar Boodja – by respecting, recording, applying, and sharing Noongar knowledge in NRM b. Merinj Kaartdijin – Aboriginal food knowledge forum c. Aboriginal Engagement: Strong and proud program https://southcoastnrm.com.au/what-we-do/
Fitzgerald Biosphere Group	• Water smart Dams – making dams work again • Meet our shore birds: Protecting the Wellstead Estuary's Birdlife

	• Understanding trends in falling numbers in the medium to high rainfall zones in WA • Locally relevant Spring & or summer grown cropping opportunities for grain growers suffering excessive winter water logging • Increasing ground cover to build resilient soils in the Wester Biosphere • Regenerating saline land: a new approach to an old problem • Reclaiming the margins – turning unproductive land into sustainable grazing assets using the Enrich Project Model • Regional land partnerships https://www.fbg.org.au/news
Dumbleyung Land Conservation District	https://www.facebook.com/DumbleyungLandcare/
Gillimia Centre Inc	• Connecting and protecting the Ken-Frankland region • Producer demonstration site: Productive salt land pastures for southern WA • Farmers helping farmers to Maximise soil moisture and producing in prolonged drought areas • Flora, Fauna and farming: Connecting kids to country • Community carbon & conservation • Productive salt land pastures in southern WA • RLPGIL climate and SSS trial • Kent shire fox baiting • Environment Protection and Biodiversity Conservation Posters • Bieber Trials https://www.gillamii.org.au/current-projects
Katanning Land Care District Committee (LCDC)	1. Creating and maintaining health farms 2. Improving and protecting Biodiversity and Habitat 3. Creating Sustainable Living programs 4. Improving water security – both on and off farm https://katanninglandcare.org.au/partners/projects/
Wagin Woodanilling Landcare Zone	https://www.facebook.com/waginwoodylandcare.org.au/
Yarra Yarra Catchment Group	https://yarrayarracatchment.org.au/
North Stirling's Pallium	• Restoring an Ancient Landscape • Strategic fox baiting • Regional Land Partnerships • Waterways Restoration – connecting the Pallinup River its people and culture https://www.nspnr.com.au/current-projects

Gondwana Link Ltd The Gondwana Link project is a biodiversity and cultural conservation strategy for the Great Western Woodlands. In recognition of Ngadju's people who have exclusive Native Title over 4.4 million hectares	Reconnecting country, from the karri forests of the far south-west to the woodland and mallee bordering the Nullarbor, in which ecosystem function and biodiversity are restored and maintained. • Nowanup Restoration • Nullaki feral control and fauna monitoring • Fencing the Oyster harbour catchment • Large-scale restoration at Peniup • Restoring wetlands and hooded plovers

Because, farmers are significant landholders and custodians of the natural heritage, they are identified as part of the solution to achieve better conservation and biodiversity outcomes. It makes sense that the managers of agricultural land, which is more than fifty per cent of Australia and 67.3 % of the land area in the pilot regions are part of the solution to protect and improve biodiversity. As outlined at the start of this document the environment provides significant eco-system services to agricultural production. It is in the interest of the managers of agricultural landscapes to have a healthy ecosystem and to manage land to prevent offsite impacts.

Agri-environment activities are typically designed to achieve positive environmental and/or land management outcomes. In addition to these intended benefits, these activities are widely acknowledged as often having co-benefits, particularly social or economic benefits that may not be the intended objective but emerge as people engage in managing these activities.

The next section examines the existing and emerging technologies and activities to improve the resilience of the environment on agricultural landscapes in the pilot regions.

7 Agri-environment practices and technologies that improve drought resilience of the agriculture landscapes in each region.

The focus of this section is on agricultural landscapes, land that is managed by private entities, usually by family run farm businesses but includes corporate family and corporate businesses.

A survey funded by the Department of Agriculture, Water and the Environment was conducted by ABARES. The purpose was to identify agri-environment practices producers were undertaking, including finding out what motivated them and identifying barriers to adoption with the aim of providing data to support the monitoring of long-term drought resilience indicators alongside the implementation of Future Drought Fund (FDF) activities.

The producers surveyed (n=2,355) accessed information about drought preparedness practices mostly from their peers, neighbours or friends, the internet was a source of information for 32% of respondents and a small percentage (24%) used private consultants. Only 10% used government extension officers. Although, there was a relatively high awareness of the National Landcare Program (NLP) (79%) and the Future Drought Fund (60%).[61]

[61] Department of Agriculture, Water and Environment – ABARES. (2021). Natural Resource Management and Drought Resilience – Survey of Farm Practices. *Australian Government.* Retrieved 12 January 2022 from: https://www.awe.gov.au/abares/research-topics/surveys/nrm-drought-resilience

The survey revealed that farmers are aware of the importance of maintaining groundcover as 84% of farms surveyed were retaining stubbles, most reporting they adopted this practice more than 3 years ago. This strategy had the highest uptake. Increasing drought resilience was most commonly considered a very important motivator for adopting various farm management practices on broadacre farms. Sixt-eight per cent of farms surveyed were de-stocking early in low rainfall periods to preserve groundcover and 27% were implementing a strategy of reducing long-term stocking rates and 22% increasing fodder and grain storage.

A lack of funds or lack of time were the main barriers to changing practices.

The management practices identified by ABARES as key strategies for improving drought resilience that were included and asked about in the survey are:

1. Minimising tillage or cultivation (e.g., permanent beds, direct planting).
2. Periods of fallow in crop rotation.
3. Retained stubble.
5. Controlled trafficking (e.g., constant wheel spacing, traffic lanes).
6. Incorporation of organic matter (e.g., mulch, green manure).
7. Use of cover crops, inter-row crops, mulching or matting, or other ground cover.
8. Management practices to optimise pesticide or fertiliser use and reduce reliance.
9. Planting or encouraging regrowth of native vegetation.
10. Cell, strip, or rotational grazing.
11. Setting a long-term minimum ground cover requirement
12. Planting or maintaining deep-rooted perennial pastures including fodder shrubs
13. Using technologies/tools to support climate related land management decisions (e.g., APSIM, Climate Kelpie, Yield Prophet).
14. Increasing on-farm water storage.
15. Improving soil water retention.
16. Improving soil acidity levels (e.g., lime application).
17. Using more water efficient crop or pasture varieties.
18. Increasing fodder and grain storage.
19. Reducing long-term stocking rates.
20. De-stocking early in low rainfall periods to preserve groundcover.
21. Carbon-farming/sequestration.

Optimising pesticide or fertiliser use and reducing reliance (68% of farms) and minimising tillage or cultivation (65%) were two of the top three agri-environment practices being implemented with maintaining stubbles. Three hundred and ninety-five farmers from WA participated in the survey. Ninety per cent said they retained some stubble, 69% retained stubble on all the farm, 22% most of the farm and 10% retained some stubble. Seventy-four per cent de-stocked early in low rainfall years and 73% were improving soil acidity levels (59% on all the farm), Table 3 presents the data from WA farmers.

Table 3. Agri-environment practices - adoption, time of adoption and extent of use

Farm management practice	Used practice (%)	All of the farm (%)	Most of the farm (%)	Some of the farm (%)	Adopted < 3 years ago (%)	Adopted > 3 years ago (%)
Retained stubble	90	69	22	10	10	90
De-stocking early in low rainfall years	74	58	21	21	12	88
Improving soil acidity levels	73	59	22	18	8	92
Minimising tillage or cultivation	72	65	19	16	6	94
Increasing on-farm water storage	65	58	14	28	14	86
Optimising pesticide or fertiliser use	60	73	15	11	9	91
Improving soil water retention	59	59	20	21	12	88
Increasing fodder and grain storage	53	58	14	28	7	93
Regrowth of native vegetation	52	24	9	67	13	87
Setting a long-term minimum ground cover	49	70	16	14	8	92
Cell, strip, or rotational grazing	47	45	31	25	6	94
Incorporation of organic matter	43	53	19	29	8	92
Use of cover crops, inter row crops, mulching or matting or other ground cover	43	44	14	41	14	86
Reducing long-term stocking rates	40	65	21	14	27	73
Using technologies/tools to support climate related land management decisions	39	73	12	15	11	89
Fallow	37	45	16	39	8	92
Controlled traffic	34	61	24	15	26	74
Planting or maintaining deep-rooted perennial pastures including fodder shrubs	34	62	19	20	7	93
Carbon farming/sequestration	14	51	22	27	26	74

The data is only available at State level and identifying nuances for the pilot regions is not possible. Interestingly the motivation for implementing measures were strongly influenced by building drought resilience and environmental, Figure 29.

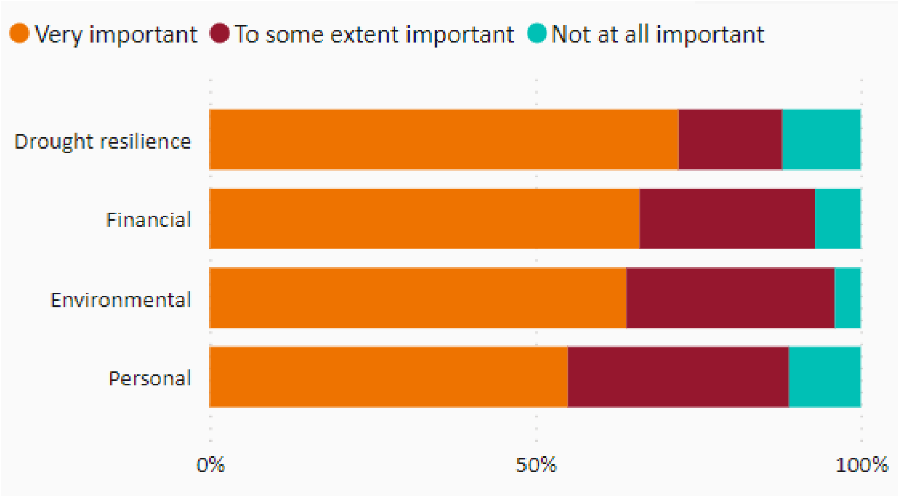


Figure 29. Motivation for implementing agri-environment practices

Agri-environment activities in the agricultural landscape are diverse, and it is likely that some have no effect on resilience to drought while others may have a positive effect for some types of farmers[62]. Results from Brown and Schimmer (2018) analysis of the Regional Wellbeing Survey (RWS) suggest that targeted investment in agri-environment strategies can help farmers build resilience to drought by designing programs that assist farmers to:

- Forward plan for a range of risks including drought: the results showed that risk planning, rather than drought planning, was the stronger predictor of drought resilience.
- Maintaining groundcover
- Feral animal control
- Increasing water use efficiency
- Increasing feed reserves and financial reserves (not exactly agri-environment practices but they were associated with improved resilience to drought)

An evaluation of the Western Australia Drought Pilot Programs done eight years after the implementation of the programs supports Brown and Schimmer's (2018) findings. Marsden Jacob Associates (2019) identified the value of the farm planning component of the Drought Pilot because it provided basic educational skills that would have otherwise been under provided if left to private decisions. New skills created a launching pad for farmers to make their own management choices and to further utilise the market for management and financial advice.[63]This leads us to our next section which gives an overview of past responses, initiatives and programs that may mitigate the adverse environmental impacts of drought

8 An Overview of Past and Current Initiatives

8.1 A Brief History of Government Investment

The NRM movement started in the 1980's, it was small and focused on engaging the community and capacity building, relying heavily on a volunteer effort. Landcare groups facilitated education, raised awareness, and

[62] Brown, K., and Schirmer, K. (2018) Growing resilience to drought: Natural resource management as a resilience intervention. Report prepared for NRM regions. Retrieved 29-03-2022 https://nrmregionsaustralia.com.au/building-drought-resilience/

[63] Marsden Jacob Associates (2019) Evaluation of the Western Australia Drought Pilot Programs

catalysed Landcare type activities on the ground. A result of a historic drought (1982-83) which ravaged production landscapes and increased awareness and the notion of sustainability.

Dealing with environmental degradation was not new, in ‘the land of droughts and flooding rains’, state governments had established soil conservation committees to address soil erosion in the 1930s (just as the US established the Soil Conservation Service following the dust-bowl years). But it wasn’t until 1983 when the Commonwealth Government established an overarching process: the National Soil Conservation Program that rural landscapes were really valued for multiple purposes, and not just for production.[64]

This program undertook research, and provided advice and extension, with the aim of achieving cooperation between community, farmers, and government.[65] Starting from a small base, funding grew over the program’s life with over $10 million being spent in its final year of 1988/99.[66] This was the start of government investment and in 1989 $360 million was announced for a Decade of Landcare. Figure 30 shows the evolution of the programs in Australia.

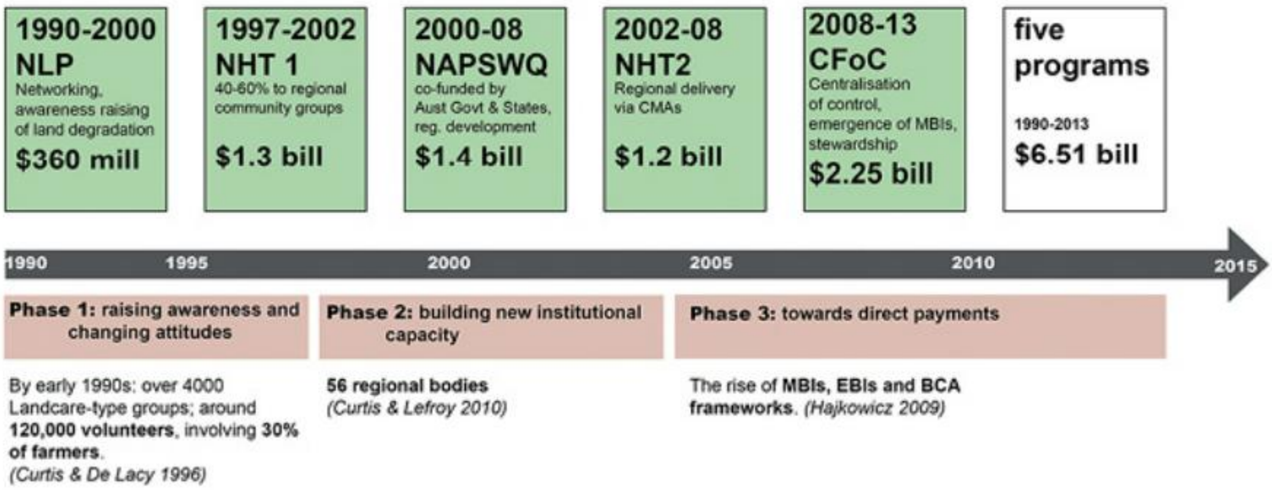


Figure 30. The evolution of Australian NRM and Agri-Environment programs

A further $2.2 billion has been invested in the National Landcare Program phase one (2014-15 to 2107-18) and phase two which started in 2018-19. Phase two funding for regional NRM bodies separated into two streams – the Sustainable Agriculture Stream and the Sustainable Environment Stream. A more detailed history of Australian Government investment can be found in ‘The review of the National Landcare Program’.[67]

Specificity to drought in past programs is not clear, but it could be argued many of the objectives were addressing its symptoms. More recent funding (Phase two of the National Landcare Program) has recognised the backdrop of a drying climate contributing to problems, such as:[68]

- Loss of vegetation
- Soil degradation
- The introduction of weeds and animals

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[64] Watson, D. (2014) The Bush: Travels in the heart of Australia, Penguin Books, Ringwood.

[65] Curtis A., H. Ross, G.R. Marshall, C. Baldwin, J. Cavalye, and C. Freeman. (2014) ‘The great experiment with devolved NRM governance: Lessons from community engagement in Australia and New Zealand since the 1980s’, Australasian Journal of Environmental Management 21(2): 175–99.

[66] Hajkowicz, S. (2009) The evolution of Australia’s natural resource management programs: Towards improved targeting and evaluation of investments’ *Land Use Policy* 26: 471–8.

[67] The Department of Environment and Energy and the Department of Agriculture and Water Resources. (2017) The Report on the review of the Nationals Landcare Program.

[68] http://www.nrm.gov.au/national-landcare-program

- Changes in water quality and flows
- Changes in fire regimes

National Landcare Program phase two: 2018-19 to 2022-23 (currently under review) is $1.1 billion investment in NRM and agri-environment practices under the broad themes listed below.

1. National Landcare Program Phase two
    I. Regional Land Partnerships
    II. Smart Farms Program
    III. Reef 2050 plan
    IV. Caring for our World Heritage places
    V. Support for Indigenous Protected Areas
    VI. Twenty million trees
    VII. Support efforts to control Yellow Crazy Ants
    VIII. Centre for Invasive Species Solutions

Table 4 outlines the programs and investments in more detail.

Table 4. Description of National Landcare program

Smart Farms Program	Go towards improving the environmental sustainability for the resources used by the primary industries (soil, water, and vegetation) and how to improve the industries' resilience to climate change and changing markets.	$136 million (2017-18 to 2022-23)
Smart Farms Small Grants	These small grants go towards multiple groups per round (77 -113 different groups) which then go towards projects that aim to create more sustainable primary industry practices, and improve the condition of the natural resources, while keeping the profitability high.	There are five rounds of grants, from $5000 to $250,000, to equal a total of $43.5 million over six years
Regional Land Partnerships projects	From 2018 to 2023, the government will support 225 projects that are focused on improving four environmental and two agricultural outcomes.	$450 million 2018 -2023
Environment Restoration Fund	Projects are funded to improve environmental sustainability, which includes improving the soil, water, plants and animal health and populations.	$100 million, from 2019-20 to 2022-23. Out of the $74.8 million distributed to the Australia States and Territories, only $5.2 million will go directly to Western Australia, with $3 million going towards black cockatoo (which is divided into each NRM region) and $2 million going towards protecting the Swan and Canning River, and the remaining $200,000 for slowing down the migration of cane toads in the Kimberly.

8.1.1 Future Drought Fund

The Australian Government's Future Drought Fund will see approximately $100 million being distributed each year for drought resilience initiatives and projects, out of the fund total, which is expected to reach $5 billion by 2028-2029. As of April 2022, $420 million has been allocated to different drought projects throughout the 2020 to 2024 period.

Figure 31 provides a framework to show how the drought fund is being allocated and further detail on the funding available for agri-environment projects in Table 5 which provides detail about the projects and funding in WA.

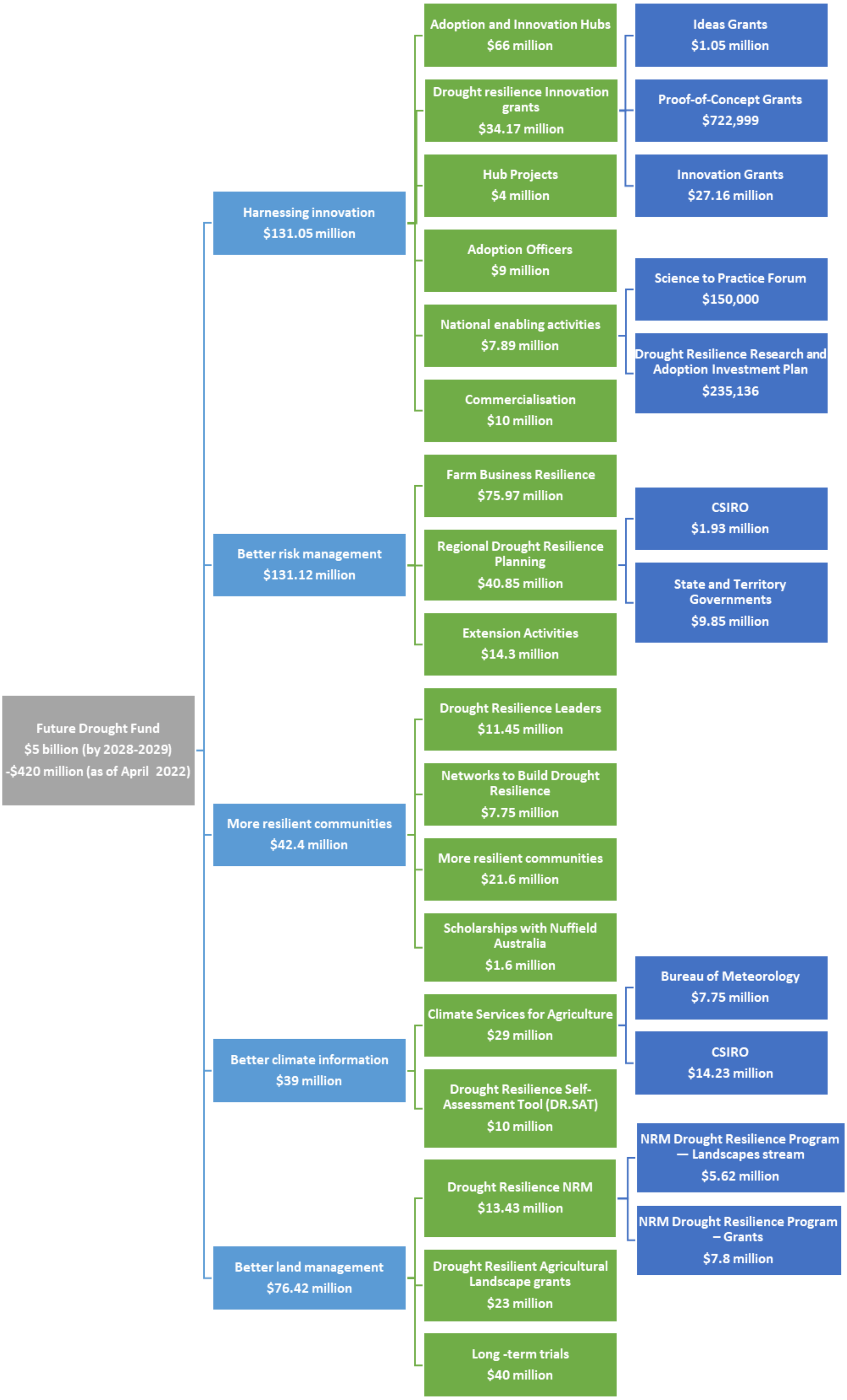
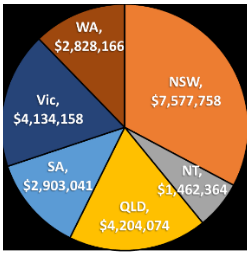


Figure 31. Future Drought Fund projects and funding structure

Table 5. Detail for Future Drought Fund projects and funding structure related to the environment and agri-environment outcomes

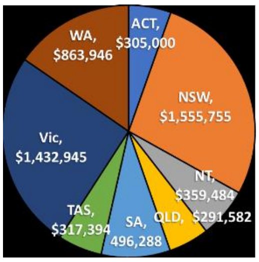
<table>
<tr><td colspan="3">Better land management
‘Trial and adoption of land management practices that support landscape resilience’ $76.42 million</td></tr>
<tr><td>Project</td><td>Description</td><td>State funding allocation and WA specific projects</td></tr>
<tr><td>Drought Resilient Agricultural Landscape grants

$23 million</td><td>Twenty-six projects, which focus on making agricultural land more resilient to drought on a broad scale, as well as improving drought resilient land management practices, which will help farmers mitigate and recover quicker from drought.[69]</td><td>

$23,109,559 divided by 26 groups in Australia.[69]

WA allocated $1.62 million.
- Mingenew - Irwin Group (Inc)
- The Western Australian Agricultural Authority.
- Also, some other projects will have trials in WA, and are reflected in the pie chart.</td></tr>
<tr><td>Long -term trials
$40 million</td><td>Trialling of new drought resilient practices, and education to farmers and the wider agricultural industry about the results</td><td>$40 million between projects around Australia.</td></tr>
<tr><td>Drought Resilience NRM

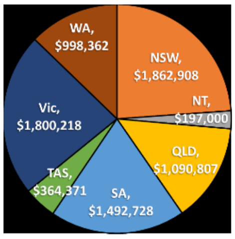
$13.43 million</td><td>NRM Drought Resilience Program — Landscapes stream ($5,622,394)

Funding for NRM groups to set up new practices that will improve the management of natural resources as well as improving the drought resilience of agricultural areas and broader landscapes.[70]</td><td>

WA allocated $863,946
- $364,922 allocated to the South Coast NRM inc.
- $499,024 allocated to the NACC</td></tr>
</table>

[69] Department of Agriculture, Water, and the Environment. (2021) Drought Resilient Soils and Landscapes grants - DAWE. Retrieved April 6, 2022, from www.awe.gov.au website: https://www.awe.gov.au/agriculture-land/farm-food-drought/drought/future-drought-fund/drought-resilient-soils-and-landscapes

[70] Department of Agriculture, Water, and the Environment. (2021) Natural Resource Management Drought Resilience Program — Landscapes stream - DAWE. Retrieved April 6, 2022, from www.awe.gov.au website: https://www.awe.gov.au/agriculture-land/farm-food-drought/drought/future-drought-fund/nrm-landscapes

Drought Resilience NRM Continued $13.43 million	**NRM Drought Resilience Program – Grants** $7.8 million Sixty-six projects to improve the drought resilience of soil and the landscape throughout drought periods.[71]	 $7.8 million to go to the States and Territory's National Resource Management groups.[71]
Better climate information 'Making climate information accessible and useful $39 million		
Climate Services for Agriculture $21,988,285 and an additional $7 million as of April 2022	**Bureau of Meteorology** in conjunction with CSIRO, developed the Climate Services for Agriculture (CSA) prototype, which enables farmers to view and adapt to future climate variability trends based on their location, which helps to improve their business and resilience.[72]	$7,753,393 [72]
	CSIRO same as above [72]	$14,234,892 [72]
Drought Resilience Self-Assessment Tool (DR.SAT) $9,994,899	**Drought Resilience Self-Assessment Tool (DR.SAT)** A free tool for Agribusinesses to view their farm, and assess its resilience to drought, based on their relevant economic, environmental, and personal influences.[73]	$9,994,899 was funded towards the tool, and it is expected to be finalised around 2024, The prototype is available to all Australian farmers now (the research has heavily focused on farms in the Wheatbelt NRM region to date).[73]

[71] Department of Agriculture, Water, and the Environment. (2021) Natural Resource Management Drought Resilience Program Grants - DAWE. Retrieved April 6, 2022, from www.awe.gov.au website: https://www.awe.gov.au/agriculture-land/farm-food-drought/drought/future-drought-fund/nrm-drought-resilience-program-grants

[72] Department of Agriculture, Water, and the Environment. (2021) Climate Services for Agriculture - DAWE. Retrieved April 6, 2022, from www.awe.gov.au website: https://www.awe.gov.au/agriculture-land/farm-food-drought/drought/future-drought-fund/climate-services

[73] Department of Agriculture, Water, and the Environment. (2022) Drought Resilience Self-Assessment Tool - DAWE. Retrieved April 6, 2022, from www.awe.gov.au website: https://www.awe.gov.au/agriculture-land/farm-food-drought/drought/future-drought-fund/drought-resilience-self-assessment-tool

Table 6.outlines some of projects the Drought Resilience Program is funding on ground to the groups in the pilot regions.

	Objective	Approach
South Coast NRM $364,922[74]	- Address rainfall changes - Change the perspective on the value of water - Mitigate drought impacts	• Help develop farm drought mitigation management plans for 30 farmers at risk of drought. • -Prepare projects for future funding projects • -Carry out demonstration activities • -Improve drought migration knowledge of 100 farmers[74]
Northern Agricultural Catchment Council $499,024[74]	- Support trials and demonstrations on new drought mitigation solutions[74]	• To trial and demonstrate • Changing ploughing dates • Rapid response ground cover and legume cover crops • Integrated shelter belts • Bio fertilizer application 74
Gillimia Centre Collaborating with SC NRM Inc and Ravensthorpe Agricultural Initiative Network (RAIN)	- Farmers helping farmers to maximise soil-moisture & prolonged drought areas	• Network and learning events • 15 Farm drought mitigation plans • 2-3 demonstration sites
Fitzgerald Biosphere Group	- Water smart dams making dams work again	• WaterSmart Dams builds on the existing WaterSmart Farms program – a collaborative DPIRD designed program researching sustainable groundwater supply options using on-farm desalinisation technology.

8.1.2 Evaluation of what has been done in the past

Government investment in NRM and agri environment activities has been extensive and the literature discussing the merits of this investment is also extensive including the best methods or policy frameworks to achieve the most efficient outcomes.

It is clear from the literature that fit-for-purpose monitoring of agri-environment solutions and improvements in natural assets is difficult, it has been a considerable criticism from both scientific and policy perspectives of agri-environmental schemes not just in Australia but in Europe too.[1]

There is a high level of complexity in the governance and management of natural assets on private land with a high level of reliance on partnerships. Programs and initiatives are often funded jointly by the Australian Government and state and territory governments. Private funds are also part of the mix. Many programs and

[74] Department of Agriculture, Water, and the Environment. (2022) Natural Resource Management Drought Resilience Program — Landscapes stream - DAWE. Www.awe.gov.au; Australian Government. https://www.awe.gov.au/agriculture-land/farm-food-drought/drought/future-drought-fund/nrm-landscapes#northern-agricultural-catchment-councils-wa

initiatives are delivered regionally creating a high level of community participation, which can lead to enhanced awareness and knowledge and better management practices. This enables all parties to contribute in an integrated way to improving natural assets.

However, assessing and tracking the progress of investments in agri-environment activities is a continuing challenge because: [1]

- Outcomes need to be achieved at a range of spatial scales
- Multiple interacting factors affect the health of natural assets
- The condition of natural assets can be highly variable naturally
- There can be long time lags between management actions and a detectable difference in the condition of natural assets
- The social context in which NRM operates can often mean there are different views on what constitutes success
- Climatic impacts especially droughts can dwarf impacts of interventions.
- Developing cost-effective indicators presents a challenge.

There are several frameworks to help with decision making on NRM and agri-environment outcomes and investments, for example the NRM Monitoring, Evaluation, Reporting and Improvement Framework (NRM MERI Framework) and the Investment Framework for Environmental Resources (IFER). [75]

The land-care movement which started in the 1980’s within communities exists but has evolved. In the last 20 years, and particularly in the decade between 2005 and 2015 the discussion moved to public V’s private benefits[76]

The framework in Figure 32 recognises that agri-environmental land managers can choose investments and allocate resources for their benefit, not always for-profit purposes. The type of policy mechanism most suitable for a particular agri-environmental project or program are categorised into (a) positive incentives (b) negative incentives (c) extension (technology transfer, education, communication, demonstrations, support for community network) (d) technology development and (e) no action. Note that the zero–zero point remains the current practice no matter how good or bad regarding public net benefits.[77]

Public net benefits are defined as benefits minus costs accruing to everyone other than the private land manager.

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[75] Pannell, D.J., A.M. Roberts, G. Park. (2012) Integrated assessment of public investment in land-use change to protect environmental assets in Australia, *Land Use Policy* 29(2): 377–87.
[76] Pannell, D., 2010 Public benefits, private benefits, and the choice of tool for land use change
[77] Pannell, D.J. (2008) Public benefits, private benefits, and policy intervention for land-use change for environmental benefits, Land Economics 84(2): 225–40. Available at: dpannell.fnas.uwa.edu.au/ppf.htm.

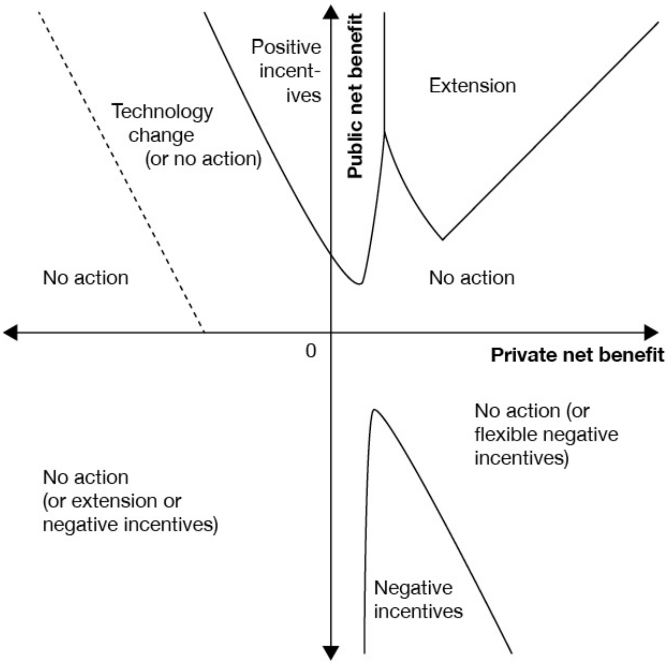

Figure 32. Efficient policy mechanisms for encouraging land use on private land

Pannell, (2010) outlines a set of rules for choosing appropriate policy mechanisms for different situations using this framework (Figure 32).

- Use positive incentives if the public net benefits of land-use change are high, and the private net benefits are not too negative
- Extension is appropriate if the public net benefits of land-use change are high, and the private net benefits are moderate
- Technology development when private net benefits are low-to-moderately negative and public net benefits are positive (Pannell 2009).

No action is required if:

- Private net benefits are positive and public net benefits are not sufficiently high
- Private net benefits are greater than public net costs
- Public net benefits and private net benefits are both negative
- When private net benefits are less than public net costs nnegative incentives are appropriate.

How does this framework relate to drought management and mitigation?

The motivation for implementing agri-environment type practices and technologies outlined above appear strong when farmers cans see the productivity gains which accompany these strategies, when there is a clear private benefit and when they can see an opportunity to build drought resilience (Figure 29). Bellottti and Rochecuste (2014) give a summary of the development and history of conservation agriculture summarised in Figure 33

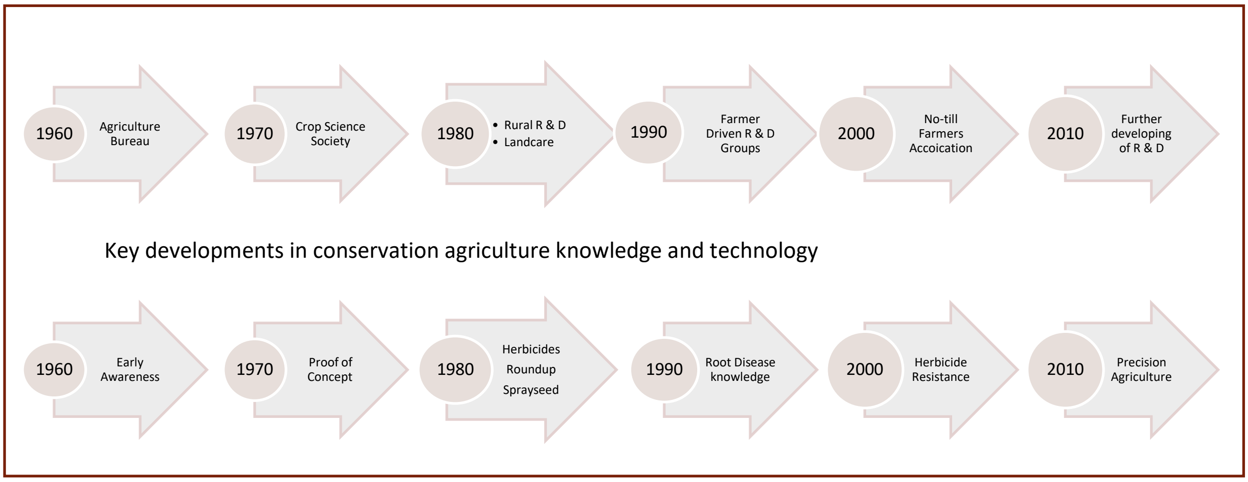

Figure 33. Key developments in conservation agriculture knowledge and technology[78]

> "Australian farmers have embraced Conservation Agriculture because it has met their needs, maintaining productivity and profitability in the face of declining terms of trade, and sustainably intensifying production with enhanced environmental outcomes."Berlotti & Rouchecouste (2014)

The challenge is to persuade farmers to see the benefit in restoring degraded ecosystems through either revegetation or regenerative agriculture type practices, reducing wind erosion with increased vegetation. Persuading farmers the merits of locking up non-productive or low productive land for environmental benefit is difficult when the value of land has increased substantially in the last 5-10 years and although the policy framework outlined in Figure 32 should still apply the market failure to see the benefit in improving the vegetation and biodiversity on farm appears high, although without real time data to verify this is difficult to determine.

As a guide to assist with determining what motivates farmers, data from a survey of a group of northern Australian farmers were asked 'how effective the following measures would be in helping you to undertake (more) conservation activities on your operation?' A five-point response scale with 1 'not at all effective' to 5 'extremely effective'.

Table 7. Preferences for policy instruments and other measures: Perceived effectiveness based on a survey of northern Australian farmers (n=104)

Policy instruments and other items	Mean score	Standard deviation
Government investment in safeguarding/expanding overseas cattle market	4.1	1.1
Income tax incentives	3.8	1.0
Financial incentive schemes (payments for ecosystem services)	3.8	1.1

[78] Bellotti, B and Rochecouste, F.J (2014) The development of Conservation Agriculture in Australia – Farmers as Innovators. *International soil and water conservation research* V2 Issue 1 https://www.sciencedirect.com/science/article/pii/S2095633915300113

Property management planning	3.5	1.1
Increased public acknowledgment of environmental achievements by graziers	3.4	1.2
More research into animals and grazing systems	3.4	1.1
Courses in grazing systems/grazing land management	3.3	1.2
Debt for conservation swaps	3.2	1.1
Environmental management plans/systems	3.1	1.0
Industry organisations promoting the benefits of farm enterprise diversification	3.1	1.2
Voluntary (industry and regional) code of practice	2.8	1.1
Increased peer recognition of grazier achievements	2.5	1.1
Community involvement (volunteers, schools) in on-ground works	2.4	1.2

There is both public and private benefit for farmers to invest in ecosystem services. Actions of an individual farmer can affect the ecosystem services provided to his private agricultural operation (e.g., planting shade trees increases livestock productivity). Individual actions can also affect ecosystem services values to other farms in the industry (e.g., planting trees lowers the water table, decreases salinity, and increases the productive capacity of the land) as well as the ecosystem services provided to society (e.g., planting trees increases carbon capture). These flows are graphically represented in Figure 34.

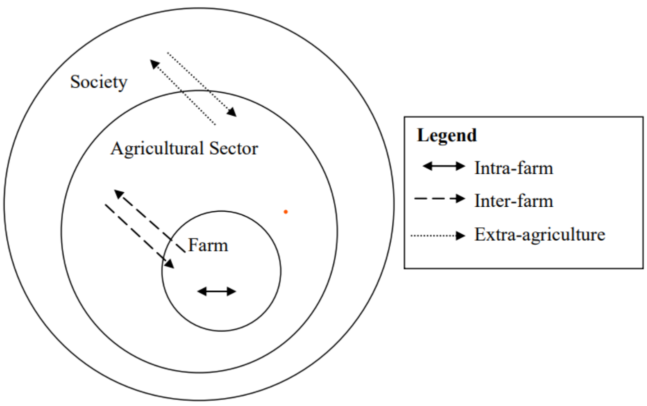

Figure 34. Schematic of ecosystem service flows in relation to Agriculture[10]

Achieving improvements in outcomes for the environment is dependent on the right policy framework and systems. As demonstrated herein, the management of the environment, both agricultural and non-agricultural land is a complex area with many actors and stakeholders. Engaging landowners in creating positive outcomes to protect and improve the environment is a much-needed part of the solution.

The competitive funding environment which has evolved with the National Landcare Program phase one (2014-15 to 2107-18) and phase two should in theory create an effective and efficient way to allocate resources, however it is proving difficult for small organisations with declining populations and a high level of voluntary burnout to access funds to support natural asset management.[79]

[79] Anderton, L. (2021) Fitzgerald Biosphere Group Operation Plan.https://www.laoneconsulting.com/projects-blog/the-fitzgerald-biosphere-group-fbg-workshop

In summary creating an enabling environment for farmers to participate in sustainable environmental and conservation practices requires strong markets enabling farmers to achieve profitability to reinvest in their sustainability. Positive incentives to reinvest in conservation are driven by creating positive environments for people to work together and feel appreciated. The barriers of time and money can be overcome with support to assist farmers with prioritising their investment decision making.

9 TRANSFORMATIONAL INTERVENTIONS TO BUILD ENVIRONMENTAL RESILIENCE

9.1.1 Non-Agricultural Landscapes

Technology is providing some solutions for managing and building resilience in the environment, technologies like:

- Real time data on health of habitats, biota and biological processes allowing us to mitigate the threats
- Imaging techniques such as those used to generate the data to understand the impacts of drought
- Remote sensing with aerial and aquatic drones
- Robotics - robots wondering around collecting data do little to disturb the biodiversity and can enter places that either cannot or should not be entered by humans.
- Cyborg animals- remotely controlled by humans using microchips linked to the animals' brain
- Camera trapping and the deployment of motion detection cameras

Two contemporary systems being developed are

1. The Australian Ecosystems Models Framework[80]

The Australian Ecosystem Models Framework project is collating, synthesising and summarising scientific knowledge of ecosystem dynamics and will capture this knowledge in a set of dynamic ecosystem models. These models will describe the dynamic characteristics and drivers of Australian ecosystems in unmodified and modified states.

2. Habitat Condition Assessment System[81]

This project is aiming to provide Australia with its first consistent, repeatable and cost-efficient national biodiversity habitat condition assessment and reporting capability—Habitat Condition Assessment System (HCAS).

It is expected that this new system will enhance our capacity to:

- identify priority areas for management interventions
- undertake national environmental reporting
- identify natural and non-natural influences on habitat condition.

The HCAS approach breaks new ground through its use of remote sensing, spatial ecological modelling, and sparse data from on ground condition assessments to generate a national view of condition.

[80] https://research.csiro.au/biodiversity-knowledge/projects/models-framework/

[81] Lyon P, Williams KJ, Dickson F, Ferrier S, Harwood T, Donohue R, McVicar T, Storey R, White M, Newell G and Ahmad M (2016) A Habitat Condition Assessment System for Australia: Developing a new approach to mapping change in habitat for biodiversity continentally. CSIRO Land and Water, Canberra, Australia.

9.1.2 Agricultural landscapes

An example of transformational change in agricultural landscapes is Silvo-Pasture systems being implemented in South America. Supported by the World Wildlife Fund and International Monetary Fund land is transformed from bare and compacted soil caused by growing cotton in the 1970's to trees and shrubs supporting a sustainable grazing system with an integrated harvestable forestry system using live fences to prevent wind erosion and improve biodiversity.

Transforming landscapes in Colombia from damaged non-productive land with poor soil structures to Silvo pasture systems

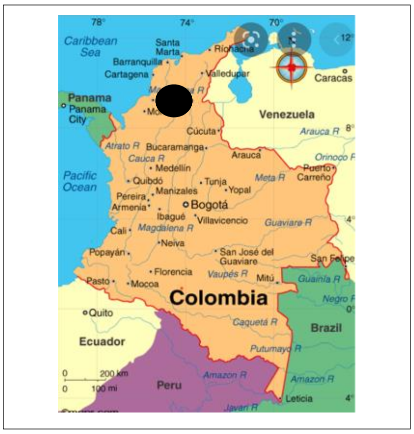

Figure 35. Example of transformational change in Colombia

Generally, in Western Australia and Australia adaptation to climate change and finding solutions to reduce emissions in agriculture has included questioning current farming practices considered best practice but with a high level of dependency on manufactured fertiliser and use of chemicals to manage weeds and pests. The cost of these inputs has recently increased and resistance of some pests and weeds has also facilitated discussion about alternative farming systems. Regenerative agriculture is potentially an opportunity to improve agri-environment outcomes and is discussed further.

Regenerative Agriculture

Regenerative agriculture is widely considered an alternative means of food production with lower, or net positive environment and social impact.[82] The report on Climate Change & Land for IPCC defined RA as sustainable land management practices focused on ecological functions that can be effective in building resilience of agro-ecosystems.[83] DPIRD have defined it as an approach to farming that uses natural systems to

[82] Newton, P, Civita, N, Frankel-Goldwater, L et al (2020) What is Regenerative Agriculture? A Review of Scholar and Practitioner Definitions Based on Processes and Outcomes, *Frontiers of Sustainable Food Systems*, Volume 4, 26/10/2020

[83] IPCC (2019) Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems, International Panel for Climate Change

increase biological activity, sequester carbon, rejuvenate soil health, improve nutrient cycling, restore landscape function, and produce food and fibre while aiming to maintain or improve farm productivity.[84]

Regenerative agricultural (RA) systems are often defined by the inclusion of practices, such as cover crops, crop rotations, and the integration of livestock into the system.[82] There are also several practices where their exclusion is definitional of RA, including no- or low-tillage, and reducing synthetic inputs such as fertiliser and pesticides.[82]

Outcomes and goals of RA revolve around improving soil health and structure of agricultural land, aiming to increase carbon sequestration into the soil, increase biodiversity and improve water resources.[82]

How does it build resilience to drought?

The Food and Agriculture Organisation of the United Nations (FAO) estimated in their report that at the current rate of soil destruction through conventional agricultural (CnvA) practices, the world will run out of topsoil in 60 years.[85] CnvA currently destroys soil structure, significantly reducing its ability to perform in climate friendly, sustainable ways, and reduces its resilience to climatic events through reduced water retention and increased susceptibility to erosion and nutrient leaching.

Transitioning to RA practices has been identified as fundamentally important to meet climate change targets, food security needs, protect farmland and build healthier food systems.[85] They can build resilience in farming systems by reducing or even reversing the effects of climate change by sequestering carbon into the soil, increasing ground cover with cover crops, improving biodiversity to reduce soil erosion and nutrient leaching, and improving soil structure to enable greater water retention and water use efficiency.[84]

What are the barriers?

There are multiple RA practices that farmers have already implemented in the WA pilot regions farming systems, including moving to low- or no-till operations, and implementing crop rotations. However, there are also many barriers preventing producers from moving more towards RA systems, particularly in broad acre farms in WA.

Yields of crops from RA are lower than those achieved with CnvA.[84] This loss of productivity equated to a decline in profitability, particularly in the first two or three years after switching to an RA system where yields are reduced due to the time for soil biomes to establish equilibrium, and when the farm is yet to be eligible for any price premiums that are available for more sustainable products.[84] This loss in profit can be particularly difficult for businesses with a high level of debt.

The transformation cost of changing to RA practices can also be a significant barrier to producers moving to this system of farming. These costs can be both financial and opportunity costs. There is a significant time cost to changing on-farm practices, including the time to research and learn the practices to enable implementation.[84] There are always financial costs associated with implementing a new way of doing things, whether it be an investment into the infrastructure for RA, or the opportunity cost from reduced yields.

RA adoption faces a major barrier in Western Australian broadacre farms through the NAR, Southern Wheatbelt and Great Southern pilot regions. There has been a change in the structure of these farming

[84] Bennett, A (2021) A review of the economics of regenerative agriculture in Western Australia, Department of Primary Industries and Regional Development, Western Australian Government

[85] EIT Food (2022) The Regenerative Ag Revolution, European Institute of Innovation and Technology Food https://www.eitfood.eu/projects/regenag-revolution Retrieved May 2022

systems over the past two decades, with many producers significantly decreasing the percentage of their farm allocated to livestock, and many farms getting out of livestock production all together.

Livestock can play's an important role in RA, as it allows for more cover crops to be planted, crop rotations to include pastures and for land to put to permanent pasture while remaining productive. These practices all have positive impacts on improving soil structure, sequestering carbon, and reducing erosion. These outcomes can be vital in building resilience to drought in agricultural systems.

9.1.3 Carbon Farming

Carbon farming is the term used to define agricultural practices and land-uses aimed at either sequestering carbon from the atmosphere or avoiding the release of more greenhouse gases.[86] Agriculture is responsible for 14% of Australia's GHG emissions, meaning finding ways to reduce these is important for meeting climate change objectives.[86] Producers can benefit from these practices through increased productivity and profitability, and by meeting national objectives with funding and special market opportunities.[86]

Atmospheric carbon dioxide can be sequestered into soils, vegetation, and the ocean. Increasing the proportion of the year a soil is actively growing a crop or pasture, and the amount of organic matter that is returned to the soil through stubbles and reducing loss from erosion can have a positive effect on soil organic carbon levels.[87] Increasing carbon levels in soil is beneficial to soil function and fertility, resulting in an increase in productivity.[87]

Reforestation and revegetation of land has the potential to sequester the most carbon per hectare.[86] Undergoing these projects can also result in co-benefits both ecologically and financially. Revegetation can provide ecosystem services, including ameliorating saline soils, preventing wind and water erosion, and improving biodiversity.[88] Return on investment may come from forest plantations or from carbon credits through the emissions reduction fund.[88]

Sequestration Practices may include:

- Increasing soil organic carbon through:
    - Application of biochar
    - Claying
    - Green & brown manuring
- Liming to increase sequestration
- Permanent environmental plantings & revegetation

Reducing the emissions of greenhouse gases is also typical of carbon farming. Agriculture emits GHGs through several activities, including burning biomass, livestock management, adding nitrogen and animal manure to soils and returning crop residues to soils.[86]

Better management of fertiliser use and manure, reducing livestock emissions, and strategically managing fire are all ways that landowners can reduce their on-farm emissions.[86]

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[86] Department of Primary Industries and Regional Development (2022) Carbon Farming on Agricultural Land in WA, Government of Western Australia https://www.agric.wa.gov.au/carbon-farming/carbon-farming-agricultural-land-wa Retrieved 19 May 2022

[87] Department of Primary Industries and Regional Development (2021) Soil organic carbon and carbon sequestration in Western Australia, Government of Western Australia https://www.agric.wa.gov.au/climate-change/soil-organic-carbon-and-carbon-sequestration-western-australia Retrieved 19 May 2022

[88] Department of Primary Industries and Regional Development, Carbon Farming and Reforestation, Afforestation and Revegetation in Western Australia, https://www.agric.wa.gov.au/climate-change/carbon-farming-and-reforestation-afforestation-and-revegetation-western-australia Retrieved 19 May 2022

Avoidance Practices may include:

- Reducing nitrous oxide emissions by using less nitrogen fertiliser
- Managing manure to reduce methane emissions
    - Composting or manure stockpile aeration
    - Using urease inhibitors to stockpiles
    - Biogas systems
- Managing livestock to reduce methane emissions
    - Using feed additives that reduce methane production
    - Breed for methane reducing genetics
    - Managing pastures

How does it build resilience?

Carbon farming activities create positive environmental outcomes, and there is believed to be a link between carbon farming and drought resilience.[89] While there is still a lot of research to do in this area, there is significant anecdotal and data-based evidence to support this.[90]

The common carbon farming activities that enhance biophysical resilience to drought include:

- Regenerative grazing practices to maximize pasture productivity
- Increasing soil carbon to create healthier soils
- Planting shelter belts to reduce water evaporation in pastures - improve water holding capacity
- Providing shade and shelter to livestock for more severe weather conditions

What are the barriers?

Policies and incentives to mitigate climate change using carbon farming have been active since 2011, including the Australian Government's Carbon Farming Initiative, and the Emissions Reduction Fund.[8] While these are aimed at encouraging farmers to adopt more sustainable practices, farmer engagement in this time has been limited, resulting in a low result in emissions reduction.[8]

WA farmers have completed surveys to explore the drivers and barriers to adopting carbon farming practices. Survey participants identified a lack of information, and uncertainty about practices and the benefits for the farm business as the most common barrier.[8] Other barriers identified included a lack of required technology, incompatibility with current farm management, and farmers not having the skills to adopt these management practices.8

Policy uncertainty was the most cited barrier for farmers participating in the Carbon Farming Initiative or Emissions Reduction Fund, closely followed by carbon pricing uncertainty.[8]**Error! Bookmark not defined.** According to Kingwell (2022), current carbon credit prices through the ERF would need to double for farmers to see a financial merit of reforesting farmland.[91] The financial incentive associated with these initiatives has clearly not been sufficient to overcome the barriers farmers perceive they face when switching to these practices.[8]

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[89] Webster, E (2022), Can carbon farming help break a drought?, Charles Sturt University https://news.csu.edu.au/in-brief/can-carbon-farming-help-break-a-drought Retrieved 9 June 2022

[90] Smith, N (2021) Grant awarded to look at links between carbon farming and better drought resilience, Climate Friendly https://www.climatefriendly.com/grant_investigating_resilience/ Retrieved 9 June 2022

[91] Kingwell, R (2022), WA Agriculture's twin challenge: carbon-neutrality and climate change, WA Climate Smart Agricultural Fellowship 2022, University of Western Australia, School of Agriculture and Environment

9.1.4 Electric Vehicles

Modern agriculture relies significantly on a fleet of heavy-duty, diesel-powered vehicles and machinery. The high power to weight ratio allowed from the energy stored in a diesel-cell explains why fossil fuels are still king in farm machinery.[92] However, as consumers demand for sustainably produced food with net zero emissions, farmers will need to adopt more eco-friendly practices to cut carbon emissions.[93]

Electric vehicles are growing in profile globally as a strategy to decrease emissions, and this is no different in agriculture. The seeds have been sown for electrification of farm vehicles, and many agricultural machinery companies have been mindful of this clean energy transition, jumping on board with the development and manufacture of electric vehicles.[92]

How to they build resilience?

Electric vehicles present major opportunities for the industry and for individual producers to work towards a carbon neutral system, decrease synthetic inputs, and improve the soil structure on agricultural land.[94] These outcomes are all important for businesses to build resilience to drought.

By replacing traditional internal combustion engines and hydraulics that are powered by burning fossil fuels with electrical drives, agricultural machinery would achieve net zero greenhouse gas emissions, which is compatible with meeting the IPCC's 2050 GHG reduction target to reduce the impacts of climate change.[95]

The replacement of traditional mechanical driven parts to electrical ancillaries leads to an increase in efficiency, flexibility, productivity, and performance.[95] Fuel consumption and maintenance costs of machines can also be reduced with the reduction of systems that require high oil pressure like hydraulics and PTO shafts that are common to break or have oil leaks.[95]

Electrification of vehicles also provides an opportunity for these machines to become increasingly versatile using 'plug and play' attachments, enabling the connection of a wide range of tools and implements on to one machine.[95]

While conventional machinery is heavy, electrification has allowed for lighter and more compact vehicles to be developed.[96] The market for drones capable of completing on-farm activities like spraying and spreading is also expected to grow in the next decade. By using drones or lighter machines, producers can access land regardless of the ground conditions and can reduce soil compaction, which can have significant benefit to the soil structure and health.[94]

With artificial intelligence innovations like weed detecting technology, chemical can be targeted at weeds without affecting the surrounding areas.[97] There are several key benefits to this sort of technology, including reducing input costs allowing for justification of using more expensive and effective products or to increase dose rates reducing chemical resistance, and a greater choice of chemical modes-of-action.[98] Weed seeking

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[92] Kowalski, K (2021)Weight, dawn-to-dusk demands pose challenges to electrifying farm vehicles, Energy News Network https://energynews.us/2021/08/18/weight-dawn-to-dusk-demands-pose-challenges-to-electrifying-farm-vehicles/ Retrieved 9 June 2022

[93] BIS Research (2022) Use of Electric Farm Vehicles in the 21st Century, Market Research Blog https://blog.marketresearch.com/use-of-electric-farm-vehicles-in-the-21st-century Retrieved 9 June 2022

[94] Gill, J, (2021) The Future of all Electric, Autonomous Vehicles in Agriculture, Harper Adams University, Mechatronics Researcher

[95] Ghobadpour, A, Boulon, L. (2019) State of the art of autonomous agricultural off-road vehicles driven by renewable energy systems, Energy Procedia 162 4-13

[96] John Deere (2022) Future of Farming, The Future of Farming Technology | John Deere, Retrieved 17th May 2022

[97] Maitland, K (2012) Selective spray units help war on weeds, SANTFA The Cutting-Edge Spring 2012, https://santfa.com.au Retrieved June 2022

[98] Cook, T, Eldershaw, V. (2012) Weed detecting technology: an excellent opportunity for advanced glyphosate resistance management, Eighteenth Australasian Weeds Conference, Tamworth Agricultural Institute https://caws.org.nz Retrieved June 2022

technology also substantially reduces the potential for chemical drift while spraying, which that can have devastating impacts on surrounding vegetation.[98]

Variable Rate Technology (VRT) allows input rates to be changed within paddocks in response to spatially variable factors that affect optimum application rate.[99] If properly implemented, it has to potential to improve input efficiency, field profitability, and have a positive impact on environmental stewardship.[99] Decreasing fertiliser inputs across a whole farm using VRT can reduce input costs for producers and reduce negative environmental impacts and GHG emissions associated with synthetic fertilizers.

Neither weed seeking technology, or VRT are particularly new to the agricultural world. However, with other innovations in this industry, these technologies are becoming more sophisticated. Original weed seeking technology focused on 'green-on-brown' detection, but this has now progressed one step further, with 'green-on-green' technology being developed, where AI can differentiate between crop and weed plants.[100]

The integration of autonomy and artificial intelligence allows these vehicles to become command centers for agricultural operations while reducing the need for one operator per machine.[96] John Deere have developed an autonomous drone sprayer with weed scanner and spraying technology that can be filled autonomously from a field station where it is also able to be charged.[96] With these sorts of vehicles, the need for scale and size in a farming business will change, as the labour costs to drive machines will no longer be an issue.[94]

What are the barriers?

The market for electric powered vehicles on farm in Australia is in its infancy. Prototypes and concept tractors are available, but it is taking time for them to go through to productions stage.[101]

With more farmers in Australia trying to incorporate sustainable practices into their management systems, electric vehicles are identified as a potential innovation for this, while also providing a low maintenance, more power efficient, and less expensive option to current diesel-powered machines.[102]

However, farmers have identified several barriers, citing concerns these electrically powered vehicles may not provide the power and torque required to do the job. Availability to good service and maintenance from qualified mechanics that can travel to farm has also been identified by producers as an influencing factor as to whether they would adopt these machines on their own farm.[102]

Farmers have also discussed the issues they already have with access to reliable power networks, especially those that are able to draw the large amounts of energy that would be needed to charge battery-powered vehicles.[102] Providing enough energy to these remote areas has the potential to significantly increase the cost of this farming system.[95]

The high cost of batteries and charging infrastructure, particularly in contrast to the convenience of fossils fuels has limited the large-scale utilization of electric vehicles on farms.[95] The high cost of electric tractors is due to the batteries and their replacement costs, and it is therefore essential to develop more efficient and effective batteries.[95]

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[99] Sawyer, JE (1994) Concepts of Variable Rate Technology with Considerations for Fertilizer Application, Journal of Production Agriculture 7 (2) 195-201 https://doi.org/10.2134/jpa1994.0195 Retrieved June 2022

[100] Benjamin (2021) Advances made in weed recognition technologies, Weed Smart. https://www.weedsmart.org.au/content/weed-recognition-tech/v Retrieved in June 2022

[101] Chong, C (2020) First fully electric and self-driving tractor hits market, Farm Machinery Sales, https://www.farmmachinerysales.com.au/editorial/details/first-fully-electric-and-self-driving-tractor-hits-market-127727/ Retrieved June 2022

[102] Borrello, E (2022), Electric cars are growing in popularity but what about electric tractors, ABC News, https://www.abc.net.au/news/2022-04-16/electric-cars-are-growing-in-popularity-but-what-about-tractors/100714854 Retrieved June 2022

To satisfy on-farm energy demands, independent on-site renewable energy power supply systems have been recommended as an alternative to relying on commercial power networks.[95] Energy production from a renewable source can increase efficiency on-farm, reduce reliance on fossil fuels, and can be stored in various forms for both short- and long-term use.[95] Oversupply can also be sold to the local network, increasing diversification of income for the farm.[95]

Discussions with Western Australian agricultural machinery dealerships indicate that they have not started pushing sales of electric vehicles to their customers because there has been no leadership from manufacturers to do so.[103] Increased exposure of farmers to these machines through trials and demonstrations is thought to be vital to get them interested in swapping over to the new technology.[103]

Table 8 summarises the information about the transformational technologies and practices discussed in this section.

[103] Personal Communication- Allan Garrity, Precision Farming Support Expert, *McIntosh & Son*

Table 8. Summary of transformational strategies in agricultural landscapes

NRM Practices	Strategies	Resilience Building Capacity	Risks to adoption	Solutions
Regenerative Agriculture[82]	• Cover crops • Crop rotations • Integration of livestock • Min/no till • Low input • Increased planting of permanent pastures and vegetation	• Sequestration of carbon • Preventing erosion of soil • Improving soil structure & water-holding capacity • Improves biodiversity & ability for system to withstand pest pressures	• Lower yields than CnvA in first years[84] • Time costs – research & implementation[84] • Move to crop focused businesses in WA – reduced livestock numbers • Lack of information sharing • No major financial motivation • Regenerative Ag has become a bit of a 'trigger' word to producers	• Education and capacity building for farmers • Payments to producers for environmental services • Market products to consumers as sustainable product

Autonomous Electric Vehicles	• Engine and hydraulic systems replaced by electrical drives
	• More efficient, reliable, and lighter vehicles
	• Artificial intelligence like weed seeking & variable rate technology
	• Drone tech for a spraying & spreading operation
	• Plug & play electrical attachments with a wide range of tools & implements on one machine
		• Reduction in soil compaction-improves soils structure
		• Eliminated emissions from use of ag machinery
		• Reduces on-farm costs
		  ○ Reduced inputs from AI tech
		  ○ Lower maintenance & labour costs
		  ○ Versatility of one machine to have multiple attachments
		• Allows for reduction in scale of cropping enterprises
			• Cost of changing over current machinery
			• Ability of battery power to supply torque & operation time required
			• Reliability of energy networks
			• Costs of batteries & their replacement
			• Access to repair and maintenance support
			• Fear of the unknown for farmers
			• Manufacturers of vehicles not leading the change
				• Assessment of energy networks supplying rural WA, and improvement where required
				• Collaboration with dealerships & manufacturers to conduct demo trials for farmers
				• Change in regulations on sales of new diesel-powered machines to phase this out by set time
				• Subsidies for farmers purchasing EV machines

Revegetation of low- & non-arable farmland	• Identify low & non-performing areas on-farm where strategic revegetation would have the most use	• Increase area and connectivity of native vegetation to create biodiversity hotspot	• Costs of revegetating land traditionally fallen to land holder with little government support	• More focus on programs like the National Landcare Program • Review of policies on land clearing

	• Use native WA plants that are more adept at surviving climate & regenerating after fires
	• Target revegetation to create vegetation corridors
	• Collaboration & employment of first nations groups to assist
		• Reduce further degradation of soils
		  ○ Prevent soil erosion
		  ○ Reduce salinity
		• Provide landholders with income from carbon credits
		• Possibility of income diversification
		• Increase ecosystem's ability to regenerate after major climate events like drought and fire through better biodiversity
			• Moves to cropping dominant farming businesses
			• Value of biodiversity & ecosystem services it provides not well acknowledged in farming communities
			• Outcomes of historical revegetation programs is relatively unknown
			• Carbon credits through sequestration harder to achieve than emissions reduction – more cost effective to target 'low hanging fruit'
				• Capacity building with land holders on the value of biodiversity & the ecosystem services revegetation of these areas can provide

Carbon Farming	• Avoidance strategies to prevent the release of GHG's
	  ○ Reducing enteric emissions from livestock through breeding for better genetics, and using emission repressing feeds
	  ○ Savanna burning to mitigate bush fire risk[104]
	  ○ Manure & fertiliser management
	• Sequestration strategies
	  ○ Revegetation & reforestation
		• Reduces emissions of GHG's
		• Sequesters carbon from the atmosphere into plants, soils & coastal ecosystems
		• Promotes healthier soils
		• Creates a biodiverse, healthy environment
		• Many carbon farming strategies produce important co-benefits[104]
		  ○ Biodiversity increases from native vegetation protection & regeneration
		• Improved soil health
			• High land values raise the cost of switching out of agriculture
			• Carbon credit prices need to at least double before farmers would see financial merit to reforesting farmland
			• Feed types & additives to prevent emissions are not readily available yet & need more research & testing[105]
			• Cost of improving soil organic carbon
			• Carbon credit eligibility requires permanence of plantings
				• Emissions Reduction Fund methodologies expanded
				• Soil carbon measurements to be more accessible
				• Develop new carbon markets for producers
				  ○ Markets that pay more for projects that deliver ACCU's and co-benefits
				• Carbon farming 'heroes'

[104] MacIntosh, A, Butler, D (18 May 2022), *Carbon and Biodiversity Markets in Australia: Opportunities, Challenges and Integrity*, Australian National university, College of Law

[105] Curnow, M (18 May 2022, *Carbon accounting & the livestock carbon project*, WA Climate Smart Agricultural Fellowship 2022, Department of Primary Industries and Regional Development, Emissions Reduction Strategy Program

	○ Improving soil organic carbon – biochar, manure & clay application ○ Environmental plantings ○ Blue carbon		• Measuring and monitoring soil carbon is too difficult/costly • Uncertainty over changing carbon policies and carbon market price[8] • Incompatibility with current farm management	

DISCUSSION AND CONCLUSIONS

Australia is an ancient landscape with highly weathered and largely infertile soils, particularly in WA. Combined with a dry and variable climate that is drying and experiencing increasing frequency of droughts the challenge is for positive environmental outcomes for future generations.

At the outset we outlined the impact agriculture has on our landscape, that increasing world populations and demand for food has created competition for space that is almost an insurmountable challenge for biological conservation.[3]

We also identified how ecosystem services flows from farmers to the environment and society, and the need for healthy ecosystems to meet the needs of agriculture, an agriculture sector which is made up of many individual farms and embedded within society, Figure 34.

Farmers focus on generating wealth to meet family and lifestyle objectives. Most see the importance of the environment to their well-being, but as we identified at the start classical conservation philosophy and production focus do not always align.

A 'super sizing' of agriculture with the constant need to improve productivity has led to structural adjustment in the pilot regions, where landscapes continue to be modified to create large scale broad-acre farms. Land clearing albeit in small areas on farms in WA continues to make way for large scale agriculture.

Ecosystems services thinking allows for conservation goals within agricultural landscapes and is an opportunity for the uptake of conservation actions.[8] The challenge is to convince time-poor individuals and communities suffering with burnout and exhaustion to see the urgent need of an ecosystems approach.

The developing Environmental Social Governance frameworks are gathering momentum and consumer and investors' expectations will demand more from producers of goods and services, including farmers.

In conclusion from reviewing the literature the following recommendations apply to the LGA pilot regions

1. **Improve collection of real time data for environmental health on agricultural land and non-agricultural land including waterways and wetlands.**
2. **Use data to identify the priority areas for stabilisation & restoration of ecosystems on agricultural land and non-agricultural land**
3. **Review and update the state of the environment report for WA**
4. **Continue to improve agriculture production systems that reduce the impacts on the environment by using technology and education**
    a. **Supporting networks of grower groups and NRM groups**
    b. **Protecting soil health**
    c. **Identify opportunities to improve sustainability of resource use and supply chains e.g., Fertiliser from fossil fuels**
5. **Support policy with outcomes to improve conservation**
    a. **Review land clearing**
    b. **Work on strategies for reducing carbon footprint to net-zero**

BIBLIOGRAPHY

[1]Ansell, D., Gibson, F., Salt, D. (2016) Learning from agri-environment schemes in Australia: investing in biodiversity and other ecosystem services on farms. ANU Press. https://press-files.anu.edu.au/downloads/press/p346093/html/imprint.xhtml?referer=&page=3#

[2]Phalan, B., R. Green, and A. Balmford (2014) Closing yield gaps: Perils and possibilities for biodiversity conservation, Philosophical Transactions of the Royal Society B: Biological Sciences 369(1639): 20120285. DOI:10.1098/rstb.2012.0285.

[3]O'Brien, J. (2015) Technologies for conserving Biodiversity in the Anthropocene Issues in Science and Technology 32, no. 1

[4]Millennium Ecosystem Assessment (2005) Ecosystems and human well-being: Synthesis, Island Press, Washington, DC. DOI:10.1088/1755-1307/6/3/432007.

[5]Stoate, C., N.D. Boatman, R.J. Borralho, C.R. Carvalho, G.R. de Snoo and P. Eden (2001) 'Ecological impacts of arable intensification in Europe', *Journal of Environmental Management* 63: 337–65.

[6]Tozer P. and Leys J. (2013) Dust storms – what do they really cost? *The Rangeland Journal 35: 131-142.*

[7]Hess P. and Ham M. (2018) What causes a dust storm? *The Lighthouse (Macquarie University).* Retrieved 10 January 2022 from https://lighthouse.mq.edu.au/please-explain/what-causes-a-dust-storm

[8]Kragt, M.E, Dumbrell, N.P. (2017) Motivations and barriers for Western Australian broad-acre farmers to adopt carbon farming, Environmental Science & Policy 73 115-123

[9]Gomez-Baggethuan, E., De Groot, R., Lomas, P.I. and Montes, C. (2010) The history of ecosystem services next term in economic theory and practice: From early notions to markets and payment schemes. Ecological Economics, 69, 1209-1218.

[10]Aisbitt, E and Kragt, M. (2010) Valuing ecosystem services to agricultural production to inform policy design: An introduction. Research report Environmental Economics Research Hub ISSN 1835-9728

[11]International Financial Reporting Standards Foundation (2021) International Integrated Reporting Framework. https://www.integratedreporting.org/what-the-tool-for-better-reporting/get-to-grips-with-the-six-capitals/

[12]Environmental Social Governance investing https://moneysmart.gov.au/how-to-invest/environmental-social-governance-esg-investing

[13]https://gondwanalink.org/about-us/why-gondwana-link/

[14]Anderton L (2017) Financial, Productivity and socio-managerial characteristics of broadacre farms in Western Australia: A decadal assessment. Thesis submitted for master's University Western Australia.

[15]Natural Resources Assessment Group, Agriculture Western Australia, and Landcare Western Australia. (1997) Soil information sheets for the northern agricultural areas. Department of Primary Industries and Regional Development, Western Australia, Perth. Report 13/97.

[16]MLA. (2018) Profitable integration of cropping and livestock management guideline. Rural Directions PTY LTD, Farmanco Management Consultants.

[17]Australian Bureau of Statistics (2017) Australian Environmental Economic Accounts, 2017, accessed at http://www.abs.gov.au/ausstats/abs@.nsf/mf/4655.0

[18]National Landcare Advisory Committee (2016) Advice on the National Landcare Program Review, prepared for the Australian Government Natural Heritage Ministerial Board

[19] van Gool, D, Stuart-Street, A and Tille, P. (2018) Distribution of classified soils in south-west Western Australia, Resource management technical report 401, Department of Primary Industries and Regional Development, Perth.

[20]NSW Department of Planning and Environment (2020) Wind erosion, NSW Government. https://www.environment.nsw.gov.au/topics/land-and-soil/soil-degradation/wind-erosion Retrieved 30 May 2022

[21]Agriculture Victoria (2021) Protecting the land in dry times, Victoria State Government, https://agriculture.vic.gov.au/farm-management/managing-for-and-during-drought/protecting-the-land-in-dry-times Retrieved 30 May 2022

[22]Masroor, M., Sajjad, H., Rehman, S., Singh, R., Rahaman, H. Md., Sahana, M., Ahmed, R. and Avtar, R., (2022) Analysing the relationship between drought and soil erosion using vegetation health index and RUSLE models in Godavari middle sub-basin, India, Geoscience Frontiers 13 (2) 1-9

[23]Howden, M. (2022), Climate change science and Australian agriculture and food, WA Climate Smart Agricultural Fellowship 2022, Australian National University, Institute of Climate

[24]Department of Primary Industries (DPI), (2020) Soil management - drought recovery, Primefact 367(2), NSW Government. Retrieved 30 May 2022

[25]Department of Primary Industries and Regional Development (2022), Water erosion in the south-west of Western Australia, Government of Western Australia, https://www.agric.wa.gov.au/water-erosion/water-erosion-south-west-western-australia Retrieved 30 May 2022

[26]DWER Annual Report 2019-20 Operational performance, https://www.awe.gov.au/abares/research-topics/water#australian-water-markets-reports

[27]DWER (2021) Annual report 2020-21

[28]Department of Environment (2004) The importance of Western Australia's Waterways

[29]Dumbleyung Lake https://en.wikipedia.org/wiki/Dumbleyung_Lake

[30]Hughes Darren, https://commons.wikimedia.org/w/index.php?curid=110550255

[31]Department of Water and Environmental Regulation, Algal Blooms, Government of Western Australia https://www.water.wa.gov.au/water-topics/waterways/threats-to-our-waterways/algal-blooms Retrieved 30 May 2022

[32]Department of Primary Industries and Regional Development (2020) Toxic algal blooms, Government of Western Australia, https://www.agric.wa.gov.au/small-landholders-western-australia/toxic-algal-blooms Retrieved 30 May 2022

[33]Bond, N.R., Lake, P.S. and Arthington. A. (2008) The impacts of drought on freshwater ecosystems: an Australian perspective, Hydrobiology 600 3–16

[34]Mosley, LM, (2015) Drought impacts on the water quality of freshwater systems; review and integration, Earth-Science Reviews 140 203-214

[35]Water and Rivers Commission (1998) Water facts – Algal Bloom, Government of Western Australia

[36]Jatin, K., Robson, B., Fountain, J., Beatty, S., Wernberg, T. (2021) Drying land and heating seas: why nature in Australia's southwest is on the climate frontline. https://theconversation.com/drying-land-and-heating-seas-why-nature-in-australias-southwest-is-on-the-climate-frontline-17037

[37]Halse, SA., Scanlon, M.D., and Cocking, J.S. (2002) First national assessment of river health: Western Australian program, Milestone report 5 and final report, Department of Conservation and Land Management, Perth.

[38] Queensland Government (2014) What is biodiversity, Queensland Government https://www.qld.gov.au/environment/plants-animals/biodiversity/about Retrieved 7 June 2022

[39]State of the Environment Report (2007) Biodiversity, Environmental Protection Authority WA 120-163

[40]Wernberg, T, Kala, J et al (2017).Why nature in Australia's southwest is on the climate frontline, University of Western Australia https://www.uwa.edu.au/news/Article/2021/October/Why-nature-in-Australias-southwest-is-on-the-climate-frontline Retrieved 7 June 2022

[41]Archaux, F., Wolters, V. (2006) Impact of summer drought on forest biodiversity: what do we know? Annals of Forest Science, Springer Nature 63(6) 645-652

[42]Jiao, T., Williams, C.A., Rogan, J., De Kauwe, M.G., Medlyn, B.E. (2020) Drought impacts on Australian vegetation during the Millennium Drought measured with multisource spaceborne remote sensing. https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2019JG005145

[43]Department of Climate Change, Energy, the Environment and Water https://ageis.climatechange.gov.au/QueryAppendixTable.aspx

[44]McCaw, L., and Hanstrum, B. (2002) Fire environment if Mediterranean south-west Western Australia, Fire in ecosystems of south-west Western Australia: impacts and management. Symposium proceedings 1 87-106

[45]Drought.gov, *Drought Impacts on Wildfire Management,* National Integrated Drought Information System https://www.drought.gov/sectors/wildfire-management Retrieved 30 May 2022

[46]UN Environmental Program (2020) Ten impacts of the Australian bushfires, https://www.unep.org/news-and-stories/story/ten-impacts-australian-bushfires Retrieved 6 June 2022

[47]Department of Environment and Water (2020) How bushfires play an important role in biodiversity, Government of South Australia. https://www.environment.sa.gov.au/goodliving/posts/2020/03/bushfires-and-biodiversity Retrieved 6 June 2022

[48]Thays dos Santos Cury, R., Montibeller-Santos, C. (2020) Effects of Fire Frequency on Seed Sources and Regeneration in Southeastern Amazonia, Frontiers for Global Change, 3, 82 https://www.frontiersin.org/articles/10.3389/ffgc.2020.00082/full Retrieved 6 June 2022

[49]Van Dijk, A.I.J.M & Rahman, J (2019) Synthesising multiple observations into annual environmental condition reports: the OzWALD system and Australia's Environment Explorer. In Elsawah, S. (ed.) MODSIM2019, 23rd International Congress on Modelling and Simulation. Modelling and Simulation Society of Australia and

New Zealand, December 2019, pp. 884–890.
ISBN: 978-0-9758400-9-2. Retrieved 30-03-2022 https://doi.org/10.36334/modsim.2019.J5.vandijk

[50]Department of Primary Industries and Regional Development (2019) Declared animal pests, Government of Western Australia https://www.agric.wa.gov.au/amphibians-and-reptiles/declared-animal-pests Retrieved 6 June 2022

[51]Department of Agriculture, Water and the Environment, Feral animals in Australia, Australian Government https://www.awe.gov.au/biosecurity-trade/invasive-species/feral-animals-australia Retrieved 6 June 2022

[52]Department of Primary Industries (2015) Controlling vertebrate pests after a drought, NSW Government, https://www.dpi.nsw.gov.au/biosecurity/vertebrate-pests/publications/controlling-vertebrate-pests-after-drought Retrieved 6 June 2022

[53]Australian National University, & TERN. (2022b) Australia's Environment Explorer. Wenfo.org; Australian National University.
http://wenfo.org/ausenv/#/2020/Exposed_soil/Region/Rank/Local_Government%20Areas/options/-31.36/118.28/7/none/White/Opaque

[54]TERN. (2020) Do you use or want Leaf Area Index data? Please let TERN know. TERN Australia.
https://www.tern.org.au/do-you-use-or-want-leaf-area-index-data-please-let-us-know/

[55]Australian National University, & TERN. (2022b) Australia's Environment Explorer. Wenfo.org; Australian National University.http://wenfo.org/ausenv/#/2020/Vegetation_leaf%20area/Region/Rank/Local_Government%20Areas/options/-31.36/118.28/7/none/White/Opaque

[56]Australian National University, & TERN. (2022b) Australia's Environment Explorer. Wenfo.org; Australian National University.
http://wenfo.org/ausenv/#/2020/Vegetation_growth/Region/Rank/Local_Government%20Areas/options/-31.36/118.28/7/none/White/Opaque

[57]Australian National University, & TERN. (2022). *Australia's Environment Explorer*. Wenfo.org; Australian National University.
http://wenfo.org/ausenv/#/2020/Runoff/Region/Rank/Local_Government%20Areas/options/-31.36/118.28/7/none/White/Opaque

[58]Australian National University, & TERN. (2022) Australia's Environment Explorer. Wenfo.org; Australian National University. http://
http://wenfo.org/ausenv/#/2021/Natural_water%20and%20wetlands/Region/Actual/Local_Government%20Areas/bar,pie,timeseries,options/-30.45/119.74/6/none/White/Opaque

[59]Environmental Defenders Office of Western Australia (Inc) (2010) Crown Land Management. Fact sheet

[60]Annual report 2020-21, Department of Planning, Lands and Heritage

[61]Department of Agriculture, Water and Environment – ABARES. (2021) Natural Resource Management and Drought Resilience – Survey of Farm Practices. *Australian Government.* Retrieved 12 January 2022 from: https://www.awe.gov.au/abares/research-topics/surveys/nrm-drought-resilience

[62]Brown, K., and Schirmer, K. (2018) Growing resilience to drought: Natural resource management as a resilience intervention. Report prepared for NRM regions. Retrieved 29-03-2022
https://nrmregionsaustralia.com.au/building-drought-resilience/

[63]Marsden Jacob Associates (2019) Evaluation of the Western Australia Drought Pilot Programs

[64]Watson, D. (2014) The Bush: Travels in the heart of Australia, Penguin Books, Ringwood.

[65]Curtis A., H. Ross, G.R. Marshall, C. Baldwin, J. Cavalye, and C. Freeman. (2014) The great experiment with devolved NRM governance: Lessons from community engagement in Australia and New Zealand since the 1980s, Australasian Journal of Environmental Management 21(2): 175–99.

[66]Hajkowicz, S. (2009) The evolution of Australia's natural resource management programs: Towards improved targeting and evaluation of investments' *Land Use Policy* 26: 471–8.

[67]The Department of Environment and Energy and the Department of Agriculture and Water Resources. (2017) The Report on the review of the Nationals Landcare Program.

[68]http://www.nrm.gov.au/national-landcare-program

[69]Department of Agriculture, Water, and the Environment. (2021) Drought Resilient Soils and Landscapes grants - DAWE. Retrieved April 6, 2022, from www.awe.gov.au website: https://www.awe.gov.au/agriculture-land/farm-food-drought/drought/future-drought-fund/drought-resilient-soils-and-landscapes

[70]Department of Agriculture, Water, and the Environment. (2021) Natural Resource Management Drought Resilience Program — Landscapes stream - DAWE. Retrieved April 6, 2022, from www.awe.gov.au website: https://www.awe.gov.au/agriculture-land/farm-food-drought/drought/future-drought-fund/nrm-landscapes

[71]Department of Agriculture, Water, and the Environment. (2021) Natural Resource Management Drought Resilience Program Grants - DAWE. Retrieved April 6, 2022, from www.awe.gov.au website: https://www.awe.gov.au/agriculture-land/farm-food-drought/drought/future-drought-fund/nrm-drought-resilience-program-grants

[72]Department of Agriculture, Water, and the Environment. (2021) Climate Services for Agriculture - DAWE. Retrieved April 6, 2022, from www.awe.gov.au website: https://www.awe.gov.au/agriculture-land/farm-food-drought/drought/future-drought-fund/climate-services

[73]Department of Agriculture, Water, and the Environment. (2022) Drought Resilience Self-Assessment Tool - DAWE. Retrieved April 6, 2022, from www.awe.gov.au website: https://www.awe.gov.au/agriculture-land/farm-food-drought/drought/future-drought-fund/drought-resilience-self-assessment-tool

[74]Department of Agriculture, Water, and the Environment. (2022) Natural Resource Management Drought Resilience Program — Landscapes stream - DAWE. Www.awe.gov.au; Australian Government. https://www.awe.gov.au/agriculture-land/farm-food-drought/drought/future-drought-fund/nrm-landscapes#northern-agricultural-catchment-councils-wa

[75]Pannell, D.J., A.M. Roberts, G. Park, et al. (2012) 'Integrated assessment of public investment in land-use change to protect environmental assets in Australia', *Land Use Policy* 29(2): 377–87.

[76]Pannell, D., (2010) Public benefits, private benefits, and the choice of tool for land use change

[77]Pannell, D.J. (2008) Public benefits, private benefits, and policy intervention for land-use change for environmental benefits, Land Economics 84(2): 225–40. Available at: dpannell.fnas.uwa.edu.au/ppf.htm.

[78]Bellotti, B and Rochecouste, F.J (2014) The development of Conservation Agriculture in Australia – Farmers as Innovators. *International soil and water conservation research* V2 Issue 1 https://www.sciencedirect.com/science/article/pii/S2095633915300113

[79]Anderton, L (2021) Fitzgerald Biosphere Group Operational Plan. https://www.laoneconsulting.com/projects-blog/the-fitzgerald-biosphere-group-fbg-workshop

[80]https://research.csiro.au/biodiversity-knowledge/projects/models-framework/

[81]Lyon P, Williams KJ, Dickson F, Ferrier S, Harwood T, Donohue R, McVicar T, Storey R, White M, Newell G and Ahmad M (2016) A Habitat Condition Assessment System for Australia: Developing a new approach to mapping change in habitat for biodiversity continentally. CSIRO Land and Water, Canberra, Australia.

[82]Newton, P, Civita, N, Frankel-Goldwater, L et al (2020) What is Regenerative Agriculture? A Review of Scholar and Practitioner Definitions Based on Processes and Outcomes, *Frontiers of Sustainable Food Systems*, Volume 4, 26/10/2020

[83]IPCC (2019) Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems, International Panel for Climate Change

[84]Bennett, A (2021) A review of the economics of regenerative agriculture in Western Australia, Department of Primary Industries and Regional Development, Western Australian Government

[85]EIT Food (2022) The Regenerative Ag Revolution, European Institute of Innovation and Technology Food https://www.eitfood.eu/projects/regenag-revolution Retrieved May 2022

[86]Department of Primary Industries and Regional Development (2022) Carbon Farming on Agricultural Land in WA, Government of Western Australia https://www.agric.wa.gov.au/carbon-farming/carbon-farming-agricultural-land-wa Retrieved 19 May 2022

[87]Department of Primary Industries and Regional Development (2021) Soil organic carbon and carbon sequestration in Western Australia, Government of Western Australia https://www.agric.wa.gov.au/climate-change/soil-organic-carbon-and-carbon-sequestration-western-australia Retrieved 19 May 2022

[88]Department of Primary Industries and Regional Development, Carbon Farming and Reforestation, Afforestation and Revegetation in Western Australia, https://www.agric.wa.gov.au/climate-change/carbon-farming-and-reforestation-afforestation-and-revegetation-western-australia Retrieved 19 May 2022

[89]Webster, E (2022) Can carbon farming help break a drought? Charles Sturt University https://news.csu.edu.au/in-brief/can-carbon-farming-help-break-a-drought Retrieved 9 June 2022

[90]Smith, N (2021) Grant awarded to look at links between carbon farming and better drought resilience, Climate Friendly https://www.climatefriendly.com/grant_investigating_resilience/ Retrieved 9 June 2022

[91]Kingwell, R (2022), WA Agriculture's twin challenge: carbon-neutrality and climate change, WA Climate Smart Agricultural Fellowship 2022, University of Western Australia, School of Agriculture and Environment

[92]Kowalski, K (2021)Weight, dawn-to-dusk demands pose challenges to electrifying farm vehicles, Energy News Network https://energynews.us/2021/08/18/weight-dawn-to-dusk-demands-pose-challenges-to-electrifying-farm-vehicles/ Retrieved 9 June 2022

[93]BIS Research (2022) Use of Electric Farm Vehicles in the 21st Century, Market Research Blog https://blog.marketresearch.com/use-of-electric-farm-vehicles-in-the-21st-century Retrieved 9 June 2022

[94]Gill, J, (2021) The Future of all Electric, Autonomous Vehicles in Agriculture, Harper Adams University, Mechatronics Researcher

[95]Ghobadpour, A, Boulon, L. (2019) State of the art of autonomous agricultural off-road vehicles driven by renewable energy systems, Energy Procedia 162 4-13

[96]John Deere (2022) Future of Farming, The Future of Farming Technology | John Deere, Retrieved 17th May 2022

[97]Maitland, K (2012) Selective spray units help war on weeds, SANTFA The Cutting-Edge Spring 2012, https://santfa.com.au Retrieved June 2022

[98]Cook, T, Eldershaw, V. (2012) Weed detecting technology: an excellent opportunity for advanced glyphosate resistance management, Eighteenth Australasian Weeds Conference, Tamworth Agricultural Institute https://caws.org.nz Retrieved June 2022

[99]Sawyer, JE (1994) Concepts of Variable Rate Technology with Considerations for Fertilizer Application, Journal of Production Agriculture 7 (2) 195-201 https://doi.org/10.2134/jpa1994.0195 Retrieved June 2022

[100]Benjamin (2021) Advances made in weed recognition technologies, Weed Smart. https://www.weedsmart.org.au/content/weed-recognition-tech/v Retrieved in June 2022

[101]Chong, C (2020) First fully electric and self-driving tractor hits market, Farm Machinery Sales, https://www.farmmachinerysales.com.au/editorial/details/first-fully-electric-and-self-driving-tractor-hits-market-127727/ Retrieved June 2022

[102]Borrello, E. (2022) Electric cars are growing in popularity but what about electric tractors, ABC News, https://www.abc.net.au/news/2022-04-16/electric-cars-are-growing-in-popularity-but-what-about-tractors/100714854 Retrieved June 2022

[103]Personal Communication- Allan Garrity, Precision Farming Support Expert, *McIntosh & Son*

[104]MacIntosh, A, Butler, D (2022) Carbon and Biodiversity Markets in Australia: Opportunities, Challenges and Integrity, Australian National university, College of Law

[105]Curnow, M (2022) Carbon accounting & the livestock carbon project, WA Climate Smart Agricultural Fellowship 2022, Department of Primary Industries and Regional Development, Emissions Reduction Strategy Program

[106] Millennium Ecosystem Assessment (2005) Ecosystems and human well-being: Synthesis, Island Press, Washington, DC. DOI:10.1088/1755-1307/6/3/432007.

APPENDIX 1

Rainfall decile years for January to November

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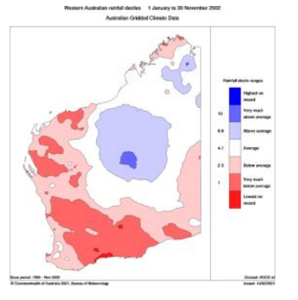
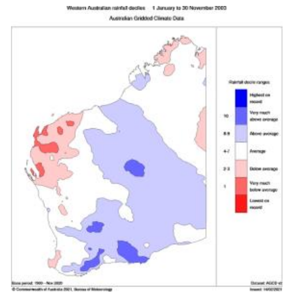
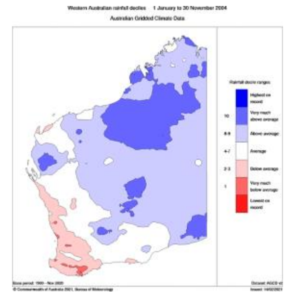
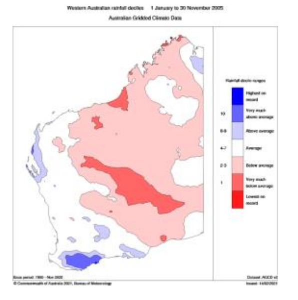
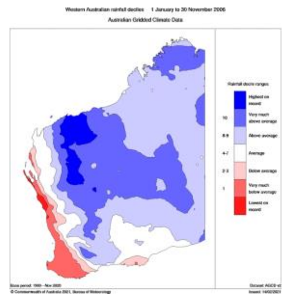
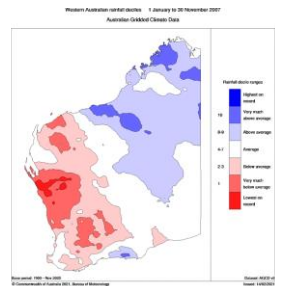
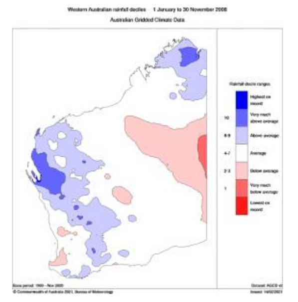
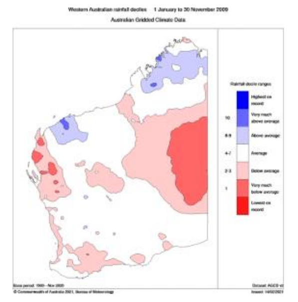
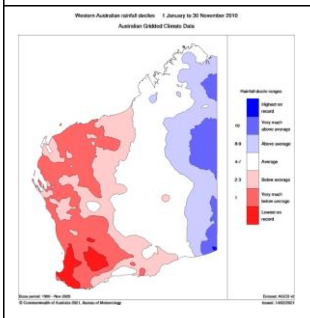
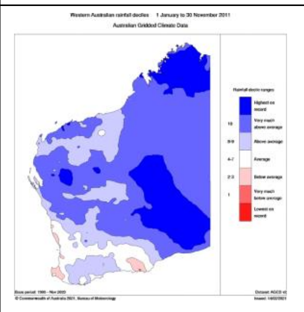
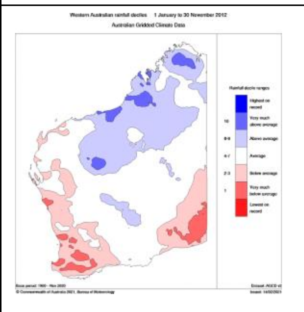
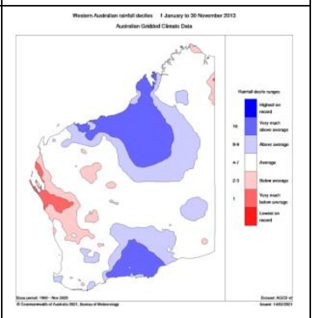
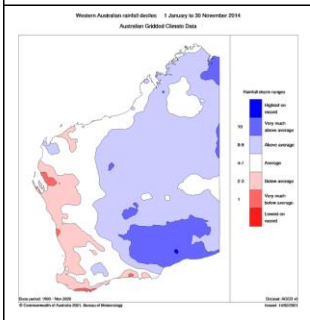
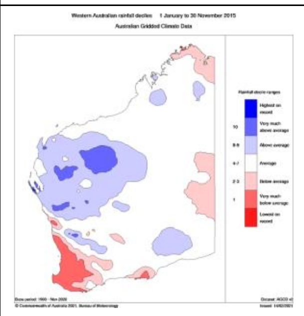
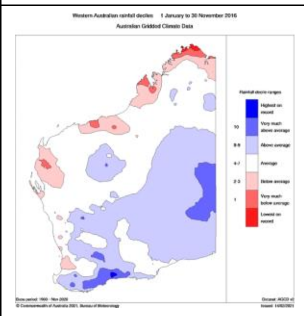
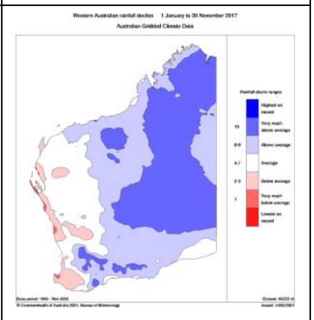
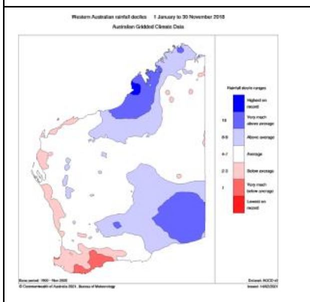
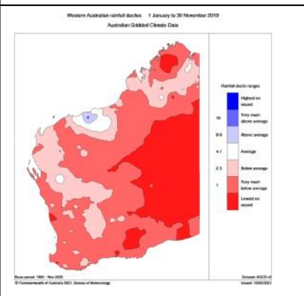
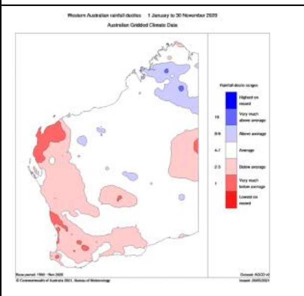
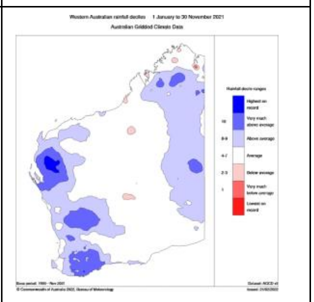
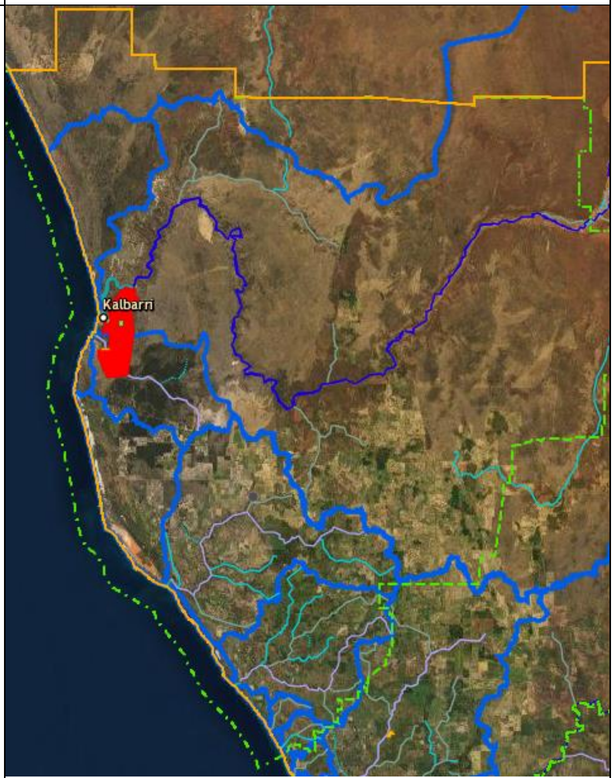
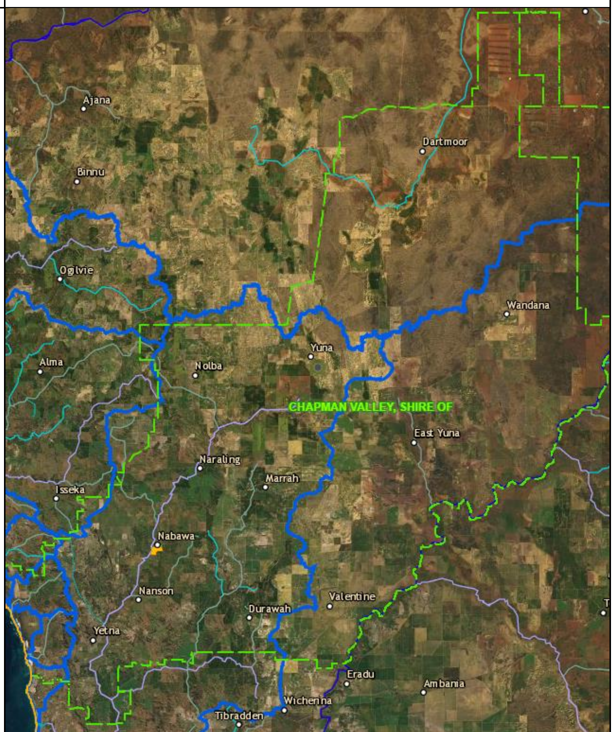
			
2006	2007	2008	2009
			
2010	2011	2012	2013
			
			
			

APPENDIX 2

<table>
<tr><th>Pilot Region</th><th>Assets</th><th>Map</th></tr>
<tr>
<td><u>Northampton</u>
Area: 12,544 km²
NRM Group-
NACC
(The Northern Agricultural Catchments Council)

<u>Average rainfall</u>
1970-2022 Kalbarri –
339.7mm (BOM Site – 8251)
<u>2000 -2020 mean rainfall</u>
288 mm</td>
<td rowspan="2"><u>Hydrographic Catchments (blue)</u>
Hutt River
Greenough River
Skelton Gully
Wooramel River
Murchison River
<u>Mainstreams </u>(dark blue)
Murchison River
<u>Lakes</u>
Waigen lakes
<u>Public drinking water source</u> (red)
Kalbarri Water Reserve drinking water source</td>
<td rowspan="2">
</td>
</tr>
<tr>
<td><u>Nature reserve</u>
Bell well NR
Burgess NR
Nilligarri NR
Ogilive NR
Galena NR</td>
</tr>
<tr>
<td><u>Chapman Valley</u>
Area: 3,981 km²
NRM Group-
NACC
(The Northern Agricultural Catchments Council)
<u>Average rainfall</u>
1877-2022 Geraldton town-
444.9mm (BOM Site – 8315)

<u>2000 -2020 mean rainfall</u>
301 mm</td>
<td><u>Nature Reserves</u>
Wanda Nature Reserve
East Yuna Nature Reserve
<u>Hydrographic Catchments (blue)</u>
Oakajee River
Greenough River
<u>Major River (purple/pink)</u>
Chapman River
<u>Public drinking water source</u> (yellow)
Nabawa Water Reserve drinking water source</td>
<td>
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Greater Geraldton
Area: 9,909 km²

NRM Group-
NACC
(The Northern Agricultural Catchments Council)

Average rainfall
1877-2022 Geraldton town-
444.9mm (BOM Site – **8050)**

2000 -2020 mean rainfall
301 mm

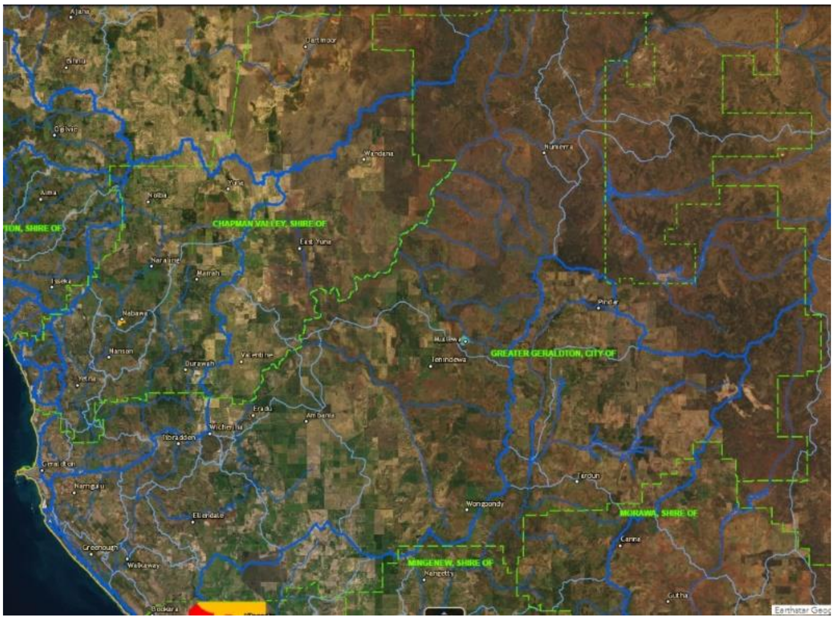
Hydrographic Catchments (blue)
- Greenough River

Mainstreams (dark blue)
- Irwin River North
- Greenough River/ Greenough Inlet

Major/minor River
- Kockatea Gully
- Urawa River
- Wooderarrung River
- Chapman River East (end)

Significant stream
- Nangerwalla Creek
- Una Brook
- Scabby Station Gully

Nature reserves
East Yuna NR
Mcguaran NR
Indarra Spring R
Urawa NR
Wonthella Bushland R
Wandana NR
Barrabarra NR
Eradu reserve lookout



Dumbleyung
Area: 2,539 km²

NRM Group-
SWCC
(Southwest Catchments Council)

Average rainfall
1910-2022
393.1mm (BOM Site – **10546)**

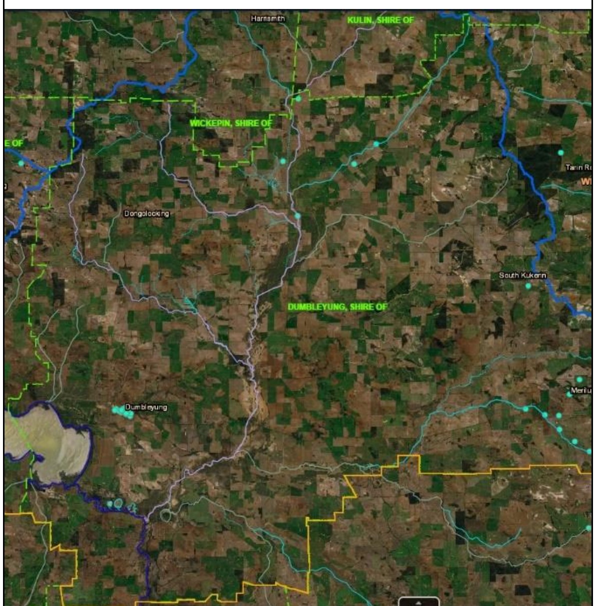
2000 -2020 mean rainfall
348 mm

Nature Reserve
- Dumbleyung Lake Nature Reserve

Mainstream (dark blue)
- Lake Dumbleyung
- Coblinine River

Hydrographic Catchments (blue)
- Blackwood River

Major/Minor River (pink/purple)
- Dongolocking Creek
- Dorradine Gully



<table>
<tr>
<td rowspan="2"><u>Kulin</u>
Area: 4,719 km²

NRM Group-
Wheatbelt Natural Resource Management

<u>Average rainfall</u>
1918-2022
357.0mm (BOM Site – 10584)

<u>2000 -2020 mean rainfall</u>
339 mm</td>
<td><u>Hydrographic Catchments (blue)</u>
• Blackwood River
• Avon River
<u>Mainstream (dark blue)</u>
• Wogalin Gully</td>
<td><u>Lakes</u>
• Jilakin Lake
• Lake Varley
• Lake Hurlstone
<u>Nature Reserve</u>
• Hopkins Nature Reserve</td>
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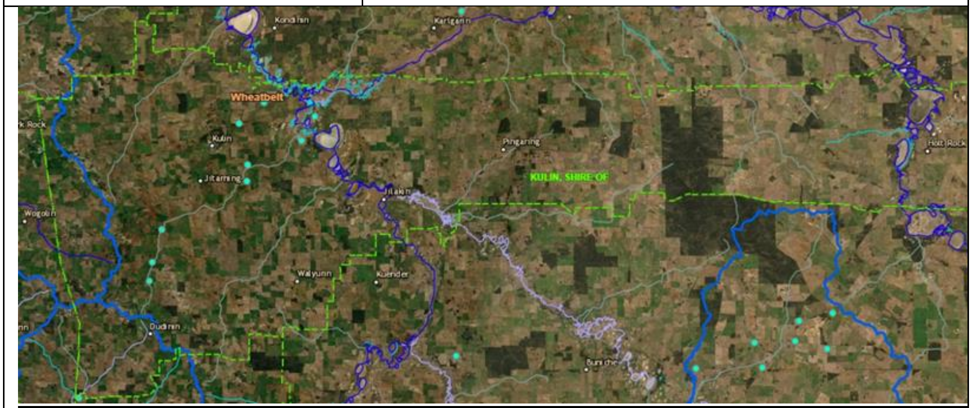
<td colspan="2">
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<tr>
<td rowspan="2"><u>Kondinin</u>
Area: 7,441 km²

NRM Group-
Wheatbelt Natural Resource Management

<u>Average rainfall</u>
1917-2022
341.7mm (BOM Site – 10583)

<u>2000 -2020 mean rainfall</u>
340 mm</td>
<td><u>Hydrographic Catchments (blue)</u>
• Avon River
<u>Mainstream (dark blue)</u>
• Camm River</td>
<td><u>Lakes</u>
• Lake Carmody
• Lake O'Connor
• Lake Kondinin
<u>Nature Reserve</u>
• Kondinin Lake Nature Reserve</td>
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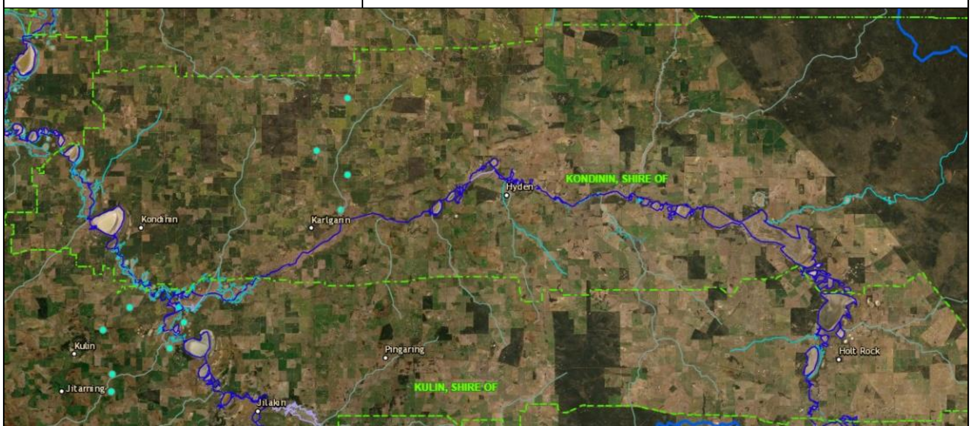
<td colspan="2">
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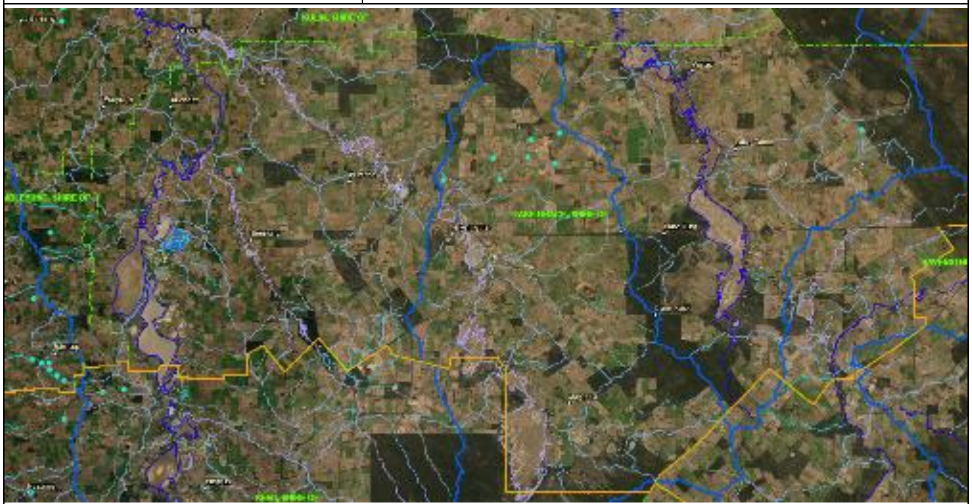
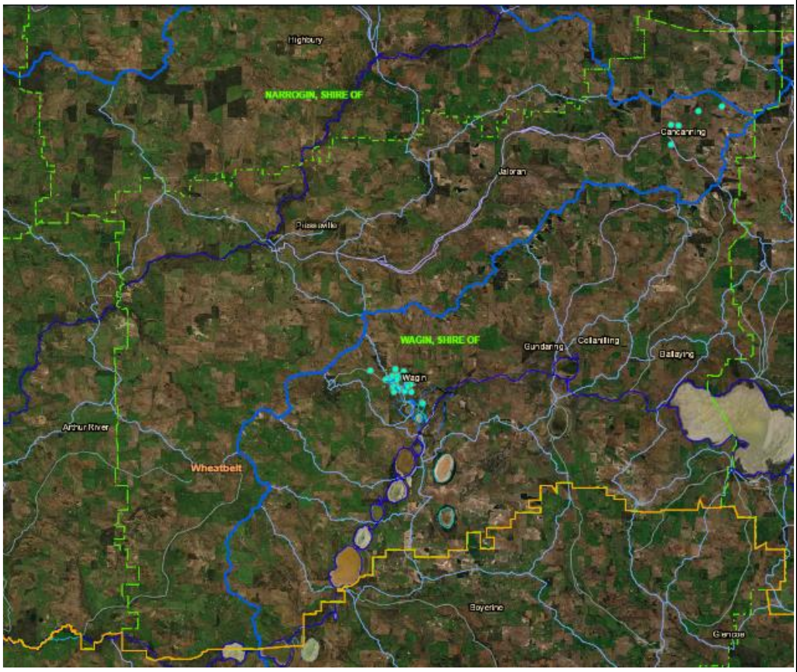
</table>

Lake Grace Area: 11,886 km² **NRM Group-** Wheatbelt Natural Resource Management **Average rainfall** 1923-2022 Edenholme- **328.0mm (**BOM Site – **10550)** 2000 -2020 mean rainfall **345 mm**	Hydrographic Catchments (blue) • Albany Coast Basin • Esperance Coast Basin • Salt Lake Basin • Avon River Small Lakes • Lake Kathleen/ Lake Belah / Lake Romani/ Lake Cobham	Lakes • Lake North Grace, Lake South Grace • Lake Tunney • Eclipse Lake • Lake Buchan • Lake Magenta • Lake King • Lake Camm • Lake Fox • Lake Gulson • Lake Pallarup
		
Wagin Area: 1,946 km² **NRM Group-** SWCC (Southwest Catchments Council) **Average rainfall** 1891-2022	Nature Reserves • Conservation Of Flora & Fauna Parks • Wagin Lake Nature Reserve • Puntapin Rock (and surrounding bushland) Hydrographic Catchments (blue) • Blackwood River Mainstream (dark blue) • Coblinine River • Arthur River	Lakes • Lake Pakeyerring • Little Norring Lake • Norring Lake • Lake Dumbleyung (left Half) Small lakes Wagin Lake

<table>
<tr>
<td>430.8mm (BOM Site – 10647)

<u>2000 -2020 mean rainfall</u>
401 mm</td>
<td colspan="2">
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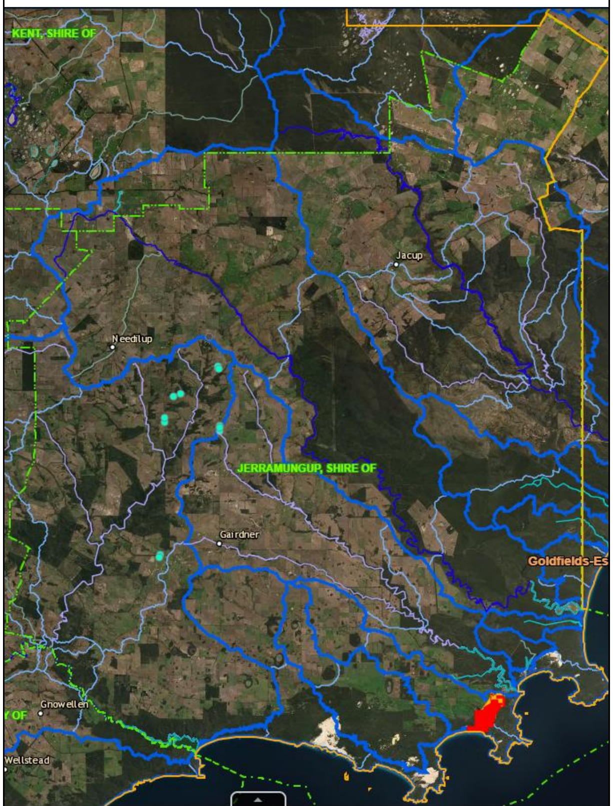
<td>Jerramungup
Area: 6,509 km²

NRM Group-
South Coast NRM
(South Coast Natural Resource Management)

<u>Average rainfall</u>
1962-2022
448.1mm (BOM Site – 10707)

<u>2000 -2020 mean rainfall</u>
448 mm</td>
<td rowspan="2">• Fitzgerald River National Park –
• Recognised as a biosphere
<u>Hydrographic Catchments (blue)</u>
• Albany Coast Basin including the Gairdner River/ Fitzgerald River/ Saint Mary River/ Boondadup River/ Bremer River/ Dillon/ Hunter River
<u>Mainstream (dark blue)</u>
• Gairdner river
• Fitzgerald River
<u>Major/Minor River (pink/purple)</u>
• Corackerup Creek
• Bremer River
• Devil Creek
• Hegarty Creek
• Peniup Creek
• Corackerup Creek
• Twertup Creek
<u>Public drinking water source</u> (red)
• Bremer Bay Water Reserve drinking water source</td>
<td rowspan="2">
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<tr>
<td>Nature reserves
Lake Magenta NR
Cherininup Creek R
Pallinup Nature reserve
Corackerup NR
Heathland NR
Tooroburup Hill
Basil road NR
Tinkelelup NR
Lake Bryde NR
Berinaga R
Monjebup R
Greeves road R
Yarrabe Wesfarmers R
Mailalup R
Red Moort R</td>
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<table>
<tr>
<td rowspan="2"><u>Kent</u>
Area: 5,625 km²

NRM Group-
Wheatbelt Natural Resource Management

<u>Average rainfall</u>
1935-2022 Pingrup South-
354.6mm (BOM Site – 10595)

<u>2000 -2020 mean rainfall</u>
354 mm</td>
<td><u>Nature Reserves</u>
• Chinocup Nature Reserve
• Lake Magenta Nature Reserve
<u>Hydrographic Catchments (blue)</u>
• Blackwood River/ Avon River
• Albany Coast Basin - Fitzgerald River
<u>Small Lakes</u>
Lake Dorothy, Carinup Lakes</td>
<td><u>Mainstream (dark blue)</u>
• Coblinine River
• Fitzgerald River
• Lake Altham
• Lake Pingrup
• Chinocup Lake
• Lake Joy
• Lake Pingarnup</td>
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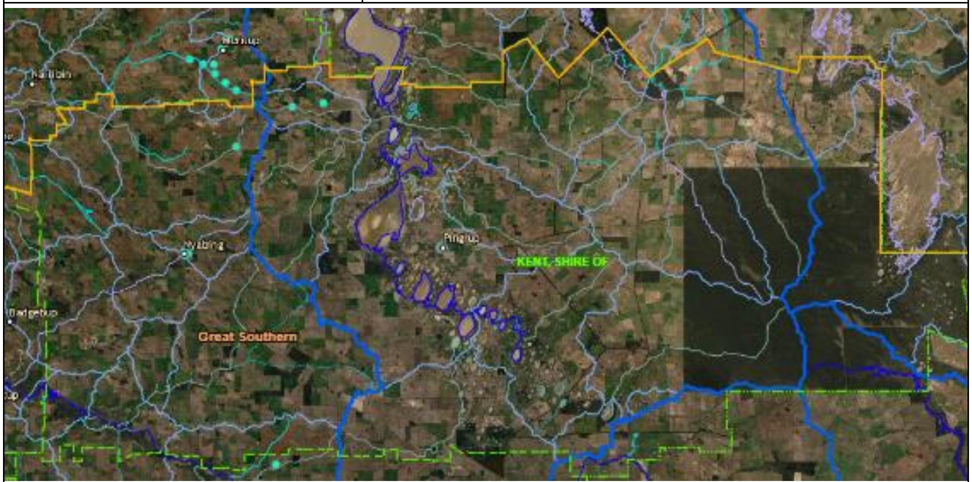
<td colspan="2">
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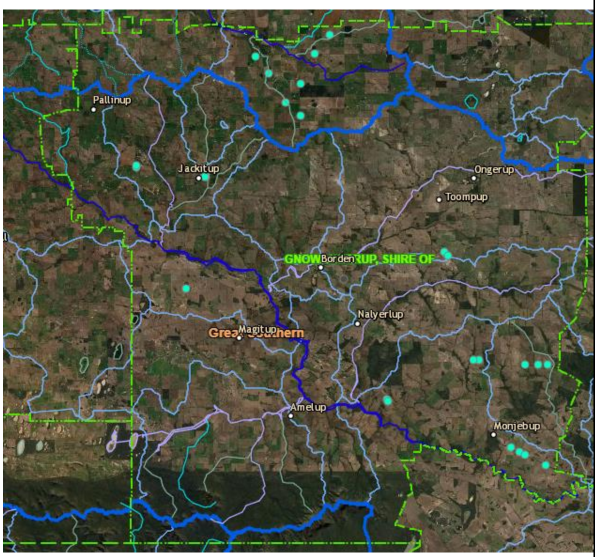
<td>Gnowangerup
Area: 4,265 km²

NRM Group-
South Coast NRM
(South Coast Natural Resource Management)

<u>Average rainfall</u>
1923-2022 Borden-
379.1mm (BOM Site – 10519)

<u>2000 -2020 mean rainfall</u>
414 mm</td>
<td><u>Hydrographic Catchments (blue)</u>
• Avon River
• Blackwood River
• Albany Coast Basin
<u>Mainstream (dark blue)</u>
• Pallinup River
• Coblinine River
• Gairdner River
<u>Major/Minor River (pink/purple)</u>
• Salt Creek
• Papa Colla Creek
• Peenebup Creek
• Warperup Creek
Chirelillup Creek TRIB</td>
<td>
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<td><u>Katanning</u>
Area: 1,518 km²

NRM Group-
SWCC
(Southwest Catchments Council)</td>
<td><u>Hydrographic Catchments (blue)</u>
• Blackwood River
<u>Mainstream (dark blue)</u>
• Coblinine River
<u>Major/Minor River (pink/purple)</u>
• Ewlyamartup Creek</td>
<td><u>Significant stream/ Major Tributary (light blue)</u>
• Kojonup Creek
• Daping Brook
• Datatine Gully
<u>Public drinking water source</u> (red)
• Katanning Catchment Area drinking water source</td>
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<tr>
<td rowspan="2"><u>Average rainfall</u>
1999-2022
450.0mm (BOM Site – 10916)

<u>2000 -2020 mean rainfall</u>
405 mm</td>
<td>• Carrolup River</td>
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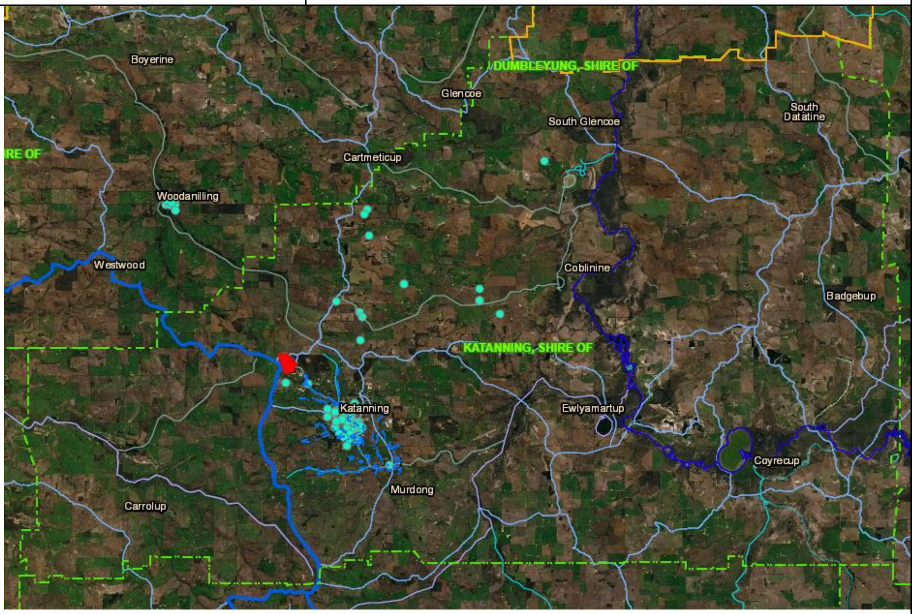
<td colspan="2">
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<td><u>Kojonup</u>
Area: 2,931 km²

NRM Group-
SWCC
(Southwest Catchments Council)

<u>Average rainfall</u>
1885-2022
531.9mm (BOM Site – 10582)

<u>2000 -2020 mean rainfall</u>
535 mm</td>
<td><u>Nature Reserve</u>
• Farrar Nature Reserve
<u>Hydrographic Catchments (blue)</u>
• Blackwood River/ Frankland River
• Warren River
<u>Mainstream (dark blue)</u>
• Murrin Brook/ Tone River
<u>Major/Minor River (pink/purple)</u>
• Carlecatup Creek
• Fifty-Two Creek
• Kojonup Brook
• Balgarup River
• Dinninup Brook
• Cockatoo Creek
• Mettabinup Brook
• Towerlup Brook
• Uannup Brook</td>
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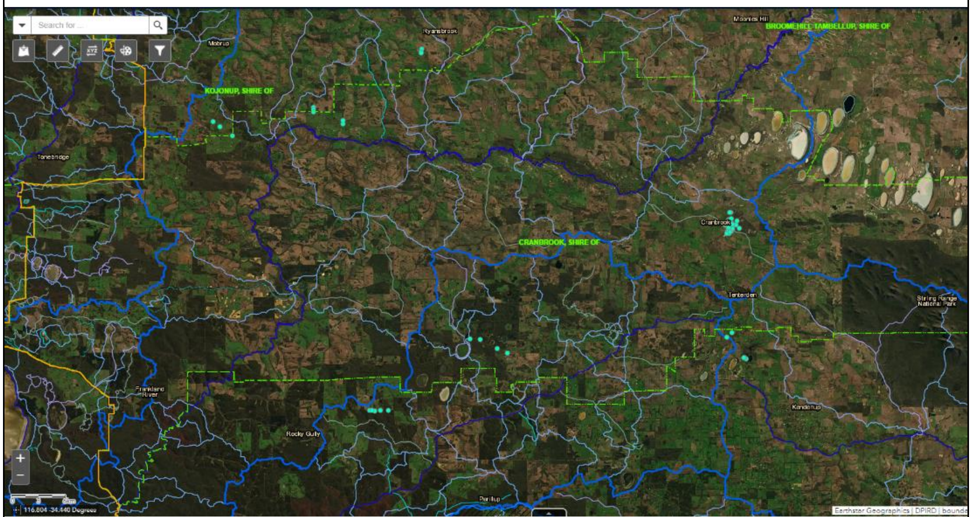
<u>Cranbrook</u> Area: 3,276 km² **NRM Group-** South Coast NRM (South Coast Natural Resource Management) **<u>Average rainfall</u>** 1891-2022 **499.8mm (**BOM Site – **10537)** <u>2000 -2020 mean rainfall</u> **568 mm**	<u>Nature Reserve</u> • Stirling Range National Park <u>Hydrographic Catchments (blue)</u> • Albany Coast Basin - Pallinup River • Frankland River/ Kent River • Shannon River Basin - Lake Muir • Warren River Basin <u>Mainstream (dark blue)</u> • Frankland River/ Gordon River • Kent River	<u>Lakes</u> • the Pink Lakes • Racecourse lake • Milyunup Lake (Pink Lakes) • Balicup Lake • Unicup Lake • Big Poorrarecup Lake • Camel Lake • Pindicup Lake • Little Unicup Lake
		
<u>Woodanilling</u> Area: 1,129 km² **NRM Group-** SWCC (Southwest Catchments Council) **<u>Average rainfall</u>** 1916-2022 **456.8mm (**BOM Site – **10659)** <u>2000 -2020 mean rainfall</u> **430 mm**	<u>Nature Reserve</u> • Woodanilling Nature Reserve <u>Hydrographic Catchments (blue)</u> • Blackwood River - Coblinine River <u>Mainstream (dark blue)</u> • Beaufort River East • Coblinine River <u>Major river (pink/purple)</u> ▪ Beaufort River	<u>Lakes</u> • Queerearrup Lake • Lake Charling <u>Small lakes</u> • Martinup Lake • Murapin Lake • Mirpin Lake • Small Lake • Billielight Swanp • Wardering Lake

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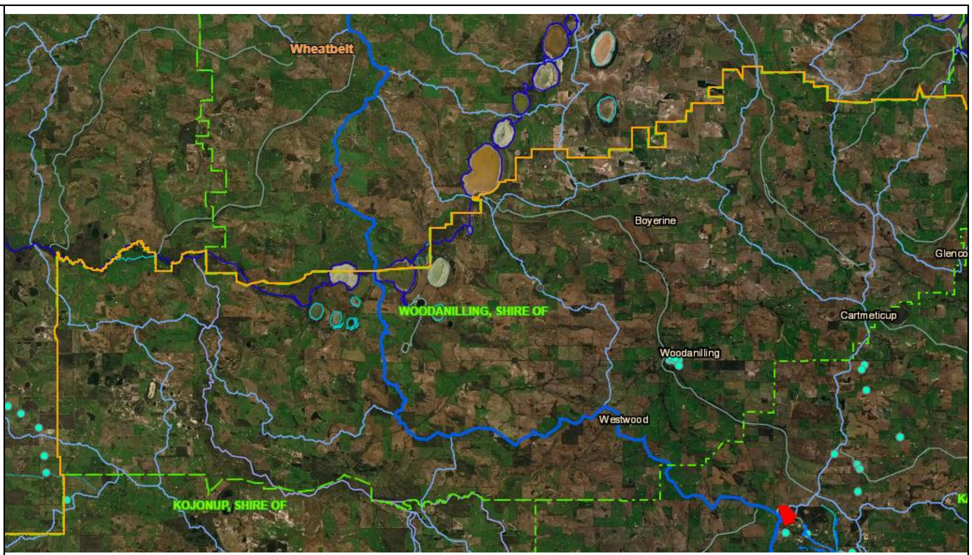
<td colspan="2">
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<td rowspan="2"><u>Broom-hill/ Tambellup</u>
Area: 2,610 km²

NRM Group-
South Coast NRM
(South Coast Natural Resource Management)

<u>Average rainfall</u>
1904-2022 - Tambellup
446.8mm (BOM Site – 10643)

<u>2000 -2020 mean rainfall</u>
427 mm</td>
<td><u>Nature Reserve</u>
• Peringillup Nature Reserve
• Gordon River Nature reserve
<u>Hydrographic Catchments (blue)</u>
• Frankland River
• Albany Coast - Pallinup River
• Blackwood River
<u>Mainstream (dark blue)</u>
• Pallinup River
• Gordon River</td>
<td><u>Major/Minor River (pink/purple)</u>
• Slab Hut Gully
• Wadjekanup River
• Carlecatup Creek
• Ewlyamartup Creek
<u>Lakes/Lagoons</u>
• Madjenapurdap lagoons
• Munrillup Lake
• Cheepanup Lake</td>
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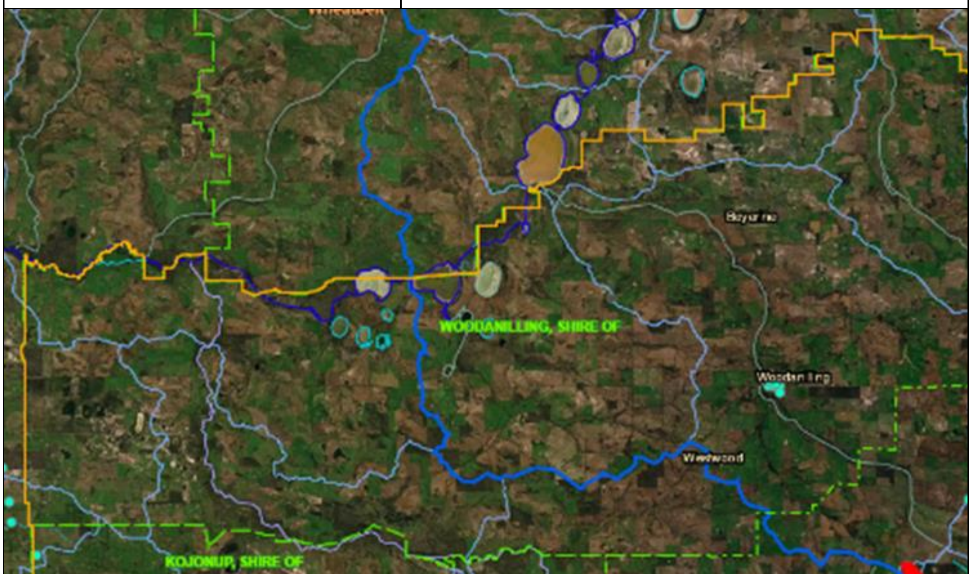
<td colspan="2">
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APPENDIX 3

Environmental score card method

These scores are calculated from a combination of the data collected from satellite data, surveys and biophysical modelling as well as sixteen field stations - TERN SuperSites around Australia[106]. Three of the TERN SuperSites are in southern Western Australia[106]. These are the Great Western Woodlands SuperSite, the Gingin Banksia Woodland SuperSite, and the Boyagin Wandoo Woodland SuperSite[106]. The SuperSites range from 10 - 200km in size[106], and include environmental monitoring towers and in hand devices to collect detailed, on ground truthing of fauna, flora and biophysical processes[107].

The Summary Score gauge and graph in Figure 20, displays the environmental health of a region and can be observed down to the shire region level. Regions are scored for their presence of seven categories out of the fifteen above, they are the inundation, streamflow, vegetation growth, leaf area, soil ground cover, tree cover (canopy), and the number of hot days experienced[108]. These seven categories are then combined and given a score out of ten[108]. The final score is then compared to the score of the previous year to show the growth or impact this year's weather and human activities have had on the environment.

The leaf area index (LAI) is calculated from the amount of foliage measured in the tree canopy[109]. This measurement can give an estimate on the average biomass, photosynthetic activity and water and nutrient uptake[109]. These measurements are taken by handheld devices at the TERN Ecosystem Surveillance plots (there are over 750 TERN monitoring sites in Australia), and by hemispherical photography at the SuperSites[109]. These results are used to ground truth the satellite data and create models for the rest of the State and Nation which allows for future predictions based on historical results and trends. The National data then comes from the MODIS satellite imagery and the OzWALD model data fusion system[110].

Vegetation Growth is calculated by the natural biomass changes observed by satellites, some of the data collected looks at the Gross Primary Production (GPP) measurements which come from the carbon uptake of plants through photosynthesis[110], are used to calculate the environments Vegetation Growth, which are also checked from the TERN sites. This data then is used by the OzWALD model data fusion system to create future predictions[110].

Exposed soil is observed from the lack of living and dead vegetation that is observed by the MODIS satellite imagery as well as the mapping done by the CSIRO using the OzWALD model data fusion system.[110]

Further details on the methods can be accessed https://www.wenfo.org/aer/data/

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[106] TERN. (2022). Data Collection Methods & Ecosystem Processes / *TERN*. TERN Australia. https://www.tern.org.au/tern-observatory/tern-ecosystem-processesF

[107] National Climate Change Adaptation Research Facility. (n.d.). *TERN Supersites / General*. Nccarf.jcu.edu.au. Retrieved April 21, 2022, from https://nccarf.jcu.edu.au/terrestrialbiodiversity/index.php/General/tern-supersites.html

[108] Australian National University (ANU), & Terrestrial Ecosystem Research Network (TERN). (2020, February 8). *Summary Indicators*. Australia's Environment Report. https://www.wenfo.org/aer/summary-indicators/

[109] TERN. (2020, March 19). *Do you use or want Leaf Area Index data? Please let TERN know*. TERN Australia. https://www.tern.org.au/do-you-use-or-want-leaf-area-index-data-please-let-us-know/

[110] Australian National University, & TERN. (2016). *Australia's Environment Explorer*. Wenfo.org. http://wenfo.org/ausenv/#/2021/Environmental_Condition%20Score/Region/Actual/Local_Government%20Areas/options/-27.00/121.52/6/none/White/Opaque