final report

Project code:	B.TGP.1702
Prepared by:	Cathleen Waters New South Wales Department of Primary Industries
Date published:	24 September 2018

PUBLISHED BY
Meat and Livestock Australia Limited
Locked Bag 1961
NORTH SYDNEY NSW 2059

Addressing feed supply and demand through total grazing pressure management

Meat & Livestock Australia acknowledges the matching funds provided by the Australian Government to support the research and development detailed in this publication.

Abstract

Less than half the herbivory in Southern Australian Rangelands is managed by pastoralists. While livestock management which rotationally graze paddocks and allows effective rest and recovery of pastures can maintain higher levels of feedbase and ground cover as well as increasing floristic diversity and perennial grass content, these benefits may be reduced by unmanaged herbivory.

The quantity and quality of forage available in the rangelands for all herbivores is frequently low, and as seasonal conditions deteriorate, there is direct competition between managed and unmanaged species for forage. With an expected long-term increase in the frequency of variable seasonal conditions, negative impacts of unmanaged herbivores will likely be exacerbated in particular environmental impacts. This will subsequently impact on short and long term production and threaten the social licence to operate for livestock industries.

While views on the cost of unmanaged herbivores to the pastoral business are contested, there is a need for R&D to identify production benefits and cost effective management options for total grazing pressure management. Early detection of an impending imbalance between feed supply and demand will mitigate negative environmental impacts. Verification of minimal negative environmental impacts and the ability for the red meat industry to demonstrate continual environmental improvement through the management of total grazing pressure will enable a defensible case for the increasing social licence of the red meat industry.

Executive summary

Total grazing pressure (TGP) influences the demand for forage by all grazing animals (both domestic and non-domestic) relative to forage supply. Successful rangeland management relies on managing grazing pressure from non-domestic herbivores, adjusting livestock numbers in response to available feed and strategically resting pastures. A central tenet in TGP management is achieving the balance between supply and demand for feed, and avoiding an imbalance occurring when feed demand exceeds feed supply. This imbalance can be detrimental to livestock productivity and animal welfare and damage resource condition.

Despite the past R&D in TGP management and the recent uptake of exclusion/TGP fencing across some areas in the Southern Australian Rangelands there is a gap in knowledge for viable TGP management options for maintaining or improving livestock production and resource condition. In addition, there is an inability to identify when an imbalance between feed supply and demand occurs. Industry knowledge and technical expertise is currently fragmented across different jurisdictions preventing the sharing of information. This current operating environment of the Southern Australian Rangelands is precluding the capacity for industry to make informed decisions about cost effective, practical solutions for TGP management. An inadequate understanding of TGP management solutions is preventing sustained productivity growth and threatens the pastoral industries ability to adapt to climate variability through the effective management of all herbivores.

This project used a coordinated approach at the national level to capture common issues in TGP management. It was undertaken as a partnership between four states (Queensland, New South Wales, South Australia and Western Australia). This ensured national and regionally relevant information and context was captured on TGP impacts, opportunities and management and to identify key knowledge gaps, providing an opportunity to deliver production gains to more than 1.9 million km^2 of Australian rangelands.

A key feature of this project was to ensure a synthesis of information drawn from science and practice. Consultation at the regional level was undertaken to capture local knowledge through a formal industry and stakeholder survey (n=266) across the Southern Australian Rangelands. The project design was able to identify existing and new regional producer networks, scientists and extension agencies to identify a community of practice to support future MLA Research, Development and Adoption (RD&A) in TGP management. Our approach aimed to strengthen the ability for MLA to target RD&A investment with the greatest benefits at property and regional scales and outline opportunities for RD&A co-investment.

There were three project objectives:

i. Undertake a review of literature and expert opinion (featuring producer experiences) to quantify the impacts of TGP management on primary production, natural resources and identify relevant knowledge gaps.

ii. Develop a TGP knowledge database of current knowledge and industry relevant information.

iii. Deliver a RD&A Investment Plan and Prospect Statement for investment

This project will support economically defendable production and environmental stewardship practices for the sheep meat and grassfed beef industries. The review of literature and supporting bibliography will serve as foundation information for regional NRM bodies on TGP management. The Investment Plan aligns to the Australian Beef Sustainability Framework which aims for continual improvement in production and environmentally sustainable practices. The implementation of the Investment Plan will have short-term benefits for livestock businesses and long-term benefits such as increased economic earnings for the industry and positive natural resource outcomes.

Key findings and recommendations

There were three investment priorities identified and six specific R&D activities which need to be implemented together in the one “Addressing feed supply and demand through total grazing pressure management” program.

Each of these themes are to be implemented where unmanaged herbivory is highest in areas protected behind the National Dog Fence (QLD, NSW and SA) and where there is an unprecedented opportunity to manage TGP across extensive areas with exclusion and TGP fencing in south west QLD and western NSW.

1. **Increasing the technical capacity for industry to manage all herbivores**

1.1 Assessing feasible solutions to identify an imbalance between feed supply and herbivore demand.

1.2 Pilot and validate a tool to predict paddock scale hot spots and hot times for herbivore activity

2. Realising the production and environmental benefits of total grazing pressure management

2.1 On-farm benchmarking of production and environmental value of TGP management

2.2 Establishing a mechanism for trading and delivery of environmental services for the red meat industry

3. Ensuring the widespread adoption of evidence-based, effective total grazing pressure management

3.1 Establishing a network of industry co-learning sites.

3.2 Identification and demonstration of cost effective TGP management options

In addition a fourth investment priority has a policy focus and is required to ensure legislative requirements to control wildlife recognise the need for pastoralists to undertake control of kangaroo populations in a timely, effective and humane manner.

4. The legal capacity for industry to manage all herbivores

4.1 National task force to co-ordinate and develop TGP management policy

Table of contents

1 Background

Globally, the management of grazing intensity has been identified as a major factor in rangeland degradation (Rutherford et al. 2012). Where grazing intensity is high and prolonged, there are negative impacts on sustainable production, biodiversity (Cowie et al. 2011) and soil carbon (Pineiro et al. 2010). However, there are inconsistencies in the literature on the role of grazing management in sustainable production of food and fibre and in the restoration of degraded, unproductive areas. These inconsistencies are due in part due to the grazing system used (Teague et al. 2015) but also by failing to account for the additional grazing pressure from native and feral animal herbivores which can effectively double the grazing pressure from domestic livestock (Bastin 2012).

A recent comprehensive Australian study suggests that livestock grazing is unlikely to produce ecosystem benefits in Australian rangelands and non-domestic herbivores have no effect on ecological functions and biodiversity of these regions (Eldridge et al. 2016). This suggests extensive pastoralism remains the major contributing factor to land degradation in these areas. However, increased perennial ground cover and plant diversity have also been associated with total grazing pressure (TGP) management which combines long periods of pasture rest (Waters et al. 2016) and is supported by further studies in the USA (Teague et al. 2015). Anecdotal evidence from pastoralists suggest benefits to feed supply and increased lamb survival may result from the use of TGP exclusion fencing and predator-proof fencing respectively. These benefits have been recognised in some states through significant recent and planned future incentive funding programs, particularly in western Queensland ($10-15 million) and NSW ($12 million).

TGP management activities vary from culling and harvesting undomesticated animals, water point control and management, exclusion fencing (boundary, internal and cluster) and implementing grazing management to provide strategic periods of rest often as integrated approaches. While there is increasing uptake of these methods, information on costs and benefits to feed supply, the impacts on resource condition and livestock production are largely un-documented. Currently, there is considerable, industry-based requirement for understanding the impacts of TGP management, particularly the costs and production benefits, but also landscape-scale impacts which have been difficult to monitor across large pastoral properties. This is particularly urgent given the increases in investment of large areas of exclusion type fencing in some regions. Industry and NRM bodies require information on the impact of TGP management on ground cover within and outside TGP managed areas, and the implications of the redistribution of grazing intensity for ground cover, plant diversity and animal welfare is of broader concern to the livestock industries and the public to retain the social licence to operate for Southern Australian Rangelands.

2 Project objectives

The major objective of this project was to deliver a RD&A Investment Plan and Prospect Statement to support ongoing TGP management in southern Australian Rangelands. This investment plan was underpinned by a review of literature. Specifically, the project was to:

i. Undertake a review of literature and expert opinion (featuring producer experiences) to quantify the impacts of TGP management on primary production, natural resources and identify relevant knowledge gaps for southern Australian rangelands.
ii. Develop a TGP knowledge database of current knowledge and industry relevant information.
iii. A Prospect Statement and RD&A Investment Plan

3 Methodology

A systematic review was undertaken capturing published and unpublished information with an emphasis placed on reliable information with relevance to practical strategic decision making by pastoralists and other stakeholders. Specifically, the review addressed:

- Regional situation statements which compiled data from state-based monitoring programs and research to identify temporal and seasonal patterns of TGP (livestock, kangaroos and goats)
- The main issues associated with the management and non-management of TGP (production, economic, and resource)
- Implications for production (including grazing system; biomass, pasture utilisation, strategic rest and feed quality)
- Differences in grazing behaviour and diet selection of different herbivores
- The condition of natural resources (ground cover, perennial grass cover and establishment and species diversity)
- Range of practices used for managing TGP
- Compilation and evaluation of existing and emerging technology product (GIS and digital-based technologies) that may inform TGP management decisions.
- Regional-specific needs for information and adoption of TGP management options.

There was an emphasis in the review to marry the science with stakeholder views and needs identified through a survey of land managers (n=219) and service providers (n=47) across the Southern Australian Rangelands. The information from the review was then synthesised into a report that identifies specific key issues and knowledge gaps which supported the development of the Investment Plan and Prospect Statement.

4 Results

4.1 Review of literature and information database

This review (Attachment 1) aimed to understand the Research, Development and Adoption (RD&A) requirement in the Southern Australian Rangelands for total grazing pressure (TGP) management.

The major findings were:

Most TGP is unmanaged in southern Australian rangelands

- On average, less than half the herbivory in the Southern Australian Rangelands is managed by pastoralists. Recent estimates suggest that a total of 28.93 million DSE are currently grazing these areas, of which 15.57 million DSE are unmanaged Macropods and goats and 13.36 million DSE or about 45 percent is livestock.
- Unmanaged herbivory is highest in areas protected behind the National Dog Fence, areas where most of the sheep in the Southern Australian Rangelands are now grazing. In some areas beyond the National Dog Fence, there is still an issue in managing significant numbers of unmanaged Macropods which are competing with cattle for forage.
- The quantity and quality of forage available for all herbivores within the Southern Rangelands is frequently low and as seasonal conditions deteriorate, it is more likely that direct competition will occur between managed and unmanaged species for forage. With an expected increase in climate variability, periods of competition between herbivores may become more common, leading to a further decline in the natural resource base. This will subsequently impact short and long term production and threaten the social licence to operate for livestock industries. This will be most apparent when high densities of herbivores coincide with periods of low rainfall.
- Livestock management involving rotational grazing of paddocks allows effective rest and recovery of pastures. This can increase ground cover, floristic diversity, perennial grass content and long-term soil organic carbon levels. While various forms of rotational grazing and pasture spelling are being practiced by land managers, grazing by Macropods in particular can reduce the benefits pastoralists may gain from early destocking and resting pastures.
- Land managers obtain little or no benefit from grazing Macropods, and there are contested views on the cost they impose upon the pastoral business through both impacts on resource condition and feedbase quantity and quality.

Recent and current investment in TGP management

- In NSW from 2004 to September 2012, the Western CMA invested approximately $9.4 million in some 284 projects involving TGP management (largely feral goat management). Western Local Lands Services has continued to invest in direct on-ground grants to landholders with the objective of improving natural resource outcomes. The 2014 TGP Project committed $2.8 million to 58 landholders to erect 1005 km of TGP fencing, 42 trap yards and undertake grazing management plans.

The project objective is to '… increase productivity, native vegetation and soil health by reducing total grazing pressure, particularly of unmanaged goats'. Conservative estimates suggest at least 1 million hectares in western NSW are currently being managed within TGP fencing either through incentive funding or within carbon farming areas.

- Seven Collaborative Area Management or 'cluster' groups have been formed as part of a South West NRM, QLD state government funded initiatives. These groups of land managers came together and formed associations, allowing them to purchase fencing materials at a reduced cost. These groups then built exclusion fences surrounding their properties, helping each other and sharing fencing equipment. Once these fences are completed, the groups will work to mitigate shared issues within the clusters. Some of these issues include unmanaged herbivores which apply an unsustainable grazing pressure and wild dogs that predate on livestock.
- The Collaborative Area Management project aims to increase livestock diversity on properties, allowing land managers to continue with or return to sheep enterprises. The sheep and wool industry can then benefit local towns through increased production. Our best estimates suggest that approximately 7 million hectares in SW Queensland are now managed within cluster fencing.
- Anecdotal evidence suggests both TGP and cluster style fencing continues to be erected independent of incentive programs in NSW, Queensland and WA. Motivation for exclusion fencing is primarily occurring to protect livestock from wild dogs but also excluding goats and Macropods.

Future needs

- Despite the requirement for land managers to manage the natural resource on pastoral leases or freehold land to at least maintain resource condition, an inability to control the unmanaged herbivore populations precludes effective rest and recovery of pastures. Land managers are prepared to tolerate some forage demand from unmanaged herbivores but in some areas, view the current populations of unmanaged herbivores is placing unprecedented demand for forage which is negatively impacting pastoral businesses and the resource base. In addition, there is a view that this TGP exaggerates the effects of drought and accelerates the negative impacts on resource condition.
- The uptake of fencing provides an unprecedented opportunity to manage TGP across extensive areas of south west QLD and western NSW but as yet there is limited direct evidence of benefits to resource condition and primary production beyond financial benefits from reduced dog predation.
- In recent years, practical non-lethal, non-fencing methods to influence livestock grazing distribution have been developed in Western Australia, referred to as Rangelands Self-herding and are currently being evaluated but is virtually unknown in Southern Australian Rangelands.
- Despite a range of other TGP management options (including re-introduction of the dingo and guardian animals) no comprehensive economic analysis of the cost-

effectiveness of various TGP management options or the impacts on resource condition has been undertaken.

- Government surveys on changes in Macropod and goat populations employ different methods as well as information being fragmented across jurisdictions making a defendable, reliable assessment of TGP for the Australian red meat industry difficult. These surveys are also undertaken at temporal and spatial scales that preclude land managers making timely decisions to respond to TGP.
- Southern rangeland land managers are vulnerable to the consequences of unmanaged TGP with an inability to identify temporal and spatial changes in herbivore distribution at a paddock scale and to assess the consequences to feedbase and resource condition. There is an absence of technology products for land managers to provide this information which can underpin management decisions. The ability to quantify the proportion of TGP which is domestic livestock and unmanaged herbivores and the impact of unmanaged herbivores on resource condition, forage availability and financial returns is required to allow land managers to determine how much to invest in control of unmanaged herbivores.
- To improve TGP management early warning of when an imbalance between forage supply and forage demand is imminent is required.
- Changing consumer preferences are dictating that the red meat industry is able to demonstrate production system practices that use natural resources wisely as well as care for animals. The red meat industry also needs to respond to global expectations for sustainable development and mitigation of climate change. The management of total grazing pressure provides an opportunity for southern rangeland pastoral industries to increase livestock productivity, meet changing consumer preferences for sustainably produced meat and fibre and maintain its social licence.

4.2 RD&A Investment Plan

The RD & Investment (Attachment 2) for total grazing pressure management in the Australian Rangelands aims to deliver sustained productivity growth and enable the pastoral industry to respond to changing market preferences and community expectations for the wise use of natural resources. This plan will allow the industry to be better equipped to adapt to drought and climate variability through the effective management of all herbivores.

The Investment Plan also aims to allow red meat production in the Southern Australian Rangelands to verify minimal negative environmental impacts and demonstrate continual environmental improvement. Over time, this will enable a defensible case for the increasing social licence of the red meat industry.

The Investment Plan targets SE Australia for two reasons; the unmanaged herbivory is highest in these areas and there has been large scale uptake of fencing to exclude or manage TGP offering the greatest opportunities for potential production and environmental gains to be made through this early adoption. Stakeholder survey results revealed that kangaroo management and fencing may offer the greatest impact on TGP management over the short term. As such, a network of sites to demonstrate and validate the impacts (economic and resource condition) of alternative TGP management options through multiple paddock contrasts (inside/outside fenced areas) to evaluate traditional (water point management, culling) as well as emerging management (self-herding, fencing) to be compared. Because the network of sites will be established in a co-learning environment, local pastoral groups will have autonomy over determining locally relevant TGP management options to evaluate as well as implementing adaptive livestock management.

By 2024 the investment plan aims to:

- provide the means to quantify current total grazing pressure impacts by developing a predictive tool that identifies density/damage functions to inform proactive management decisions;
- Raise awareness of 1,500 land managers (~ 25 percent of the pastoral industry of Southern Australian Rangelands) of cost-effective total grazing pressure management;
- Directly engage 2000 landholders in co-learning and information exchange activities;
- Have 100 landholders contributing meta-data to the R&D program; and
- Establish a network of RD&A co-learning and monitoring sites within six nodes across three states (QLD,NSW, and SA).

4.3 Prospect Statement

The Prospect Statement (Attachment 3) outlines a vision for the industry to deliver sustained productivity growth which has responded to changing market preferences and community expectations.

5 Discussion

5.1 Project steering committee comments

The project steering committee raised some important additional considerations for the Investment Plan. Firstly that ‘tool’ or technology product proposed to be developed to assess an impending imbalance between feed supply and demand will not solve the TGP problem but provide a mechanism by which a livestock management decisions or e.g. kangaroo management decisions can be made. As such, the application or the use of the information provided by the ‘tool’ within the livestock management context is of central importance. Secondly, the tool needs to be simple to use and co-developed with industry to ensure its relevance which can be achieved through iterative user group development. The Investment Plan outlines user group validation of the ‘tool’ that would allow for such iterative development of the ‘tool’.

5.2 Social acceptability of pest animal management in meeting TGP targets (B.TGP.1701)

Project B.TGP.701 was undertaken at the same time as the current project (B.TGP.702). Two major recommendations from project B.TGP.701 were to ensure an industry code of practice for non-commercial kangaroo was developed and promoted and that the consequences of exclusion fencing as well as the humaneness and effectiveness of other TGP control practices be examined. The network of TGP management sites suggested as part of our investment recommendations will provide a mechanism to develop an industry acceptable code of practice as well as an assessment of animal welfare issues associated with various TGP management options. We see that it is essential to understand how animal welfare standards can be maintained within the context of alternative TGP management options.

5.3 NSW Kangaroo Management Task Force and NSW Interagency Kangaroo Working Group

In NSW a Kangaroo Management Task Force has been recently set up. This is a multi-stakeholder advocacy platform which aims to influence politicians and the general public on alternative perspectives for kangaroo management. In addition a high level, intergovernmental Working Group (chaired by Western Local Land Service) was formed in mid-2018. Between both groups they have been influential in recent changes to streamline the non-commercial kangaroo cull. These changes include reducing administrative red tape to allow faster approvals for culling as well as increasing the number of kangaroos that can be culled. This will ultimately enable land managers to be more responsive in managing local kangaroo populations than has been previously been possible. Some of these efficiency measures include removing the need for physical tags; increasing the number of non-commercial shooter licences and connecting landholders to experienced commercial kangaroo harvesters (addressing animal welfare concerns). Our understanding is that these changes are to be implemented in August/September 2018 as part of the NSW Government 2018 Drought Support measures. This model of government agencies to working together to respond to issues associated with kangaroo grazing pressure may be applied in other states under Sub-program 4 of the Investment Plan with a National Kangaroo Management Task Force.

However, there remains a lack of understanding of the impact of kangaroo populations on natural resource condition. While a Kangaroo R&D project team has also been established as a result of the NSW Task Force which may ultimately address this issue, there is a requirement to address both public perception as well as R&D to support TGP management. That is, public recognition of the requirement to manage kangaroo populations at a farm scale needs to be based on animal welfare, resource condition as well as impacts on farm enterprise profitability. Each of these issues are required to be addressed simultaneously rather than as discrete bodies of R&D and as such the four sub-programs described in the Investment Plan each need to be implemented as a program of R&D. For example, building an early warming 'tool' which indicates an impending imbalance between feed supply and demand will be of little utility value if policy related issues are unresolved for a land manager to respond by managing all herbivores.

6 Bibliography

Cowie, A.L., Penman, T.D., Gorissen, L., Winslow, M.D., Lehmann, J.L., Tyrrell, T.D., Twomlow, S., Wilkes, A., Lal, R., Jones, J.W., Paulsch, A., Kellner, K., Akhtar-Schuster, M. (2011). Towards sustainable land management in the drylands: Scientific connections in monitoring and assessing dryland degradation, climate change and biodiversity. Land Degradation & Development. 22, 248-260

Bastin, G. (2012). ACRIS Kangaroo Density Update 2009-2012. Updated information to that provided in Rangelands 2008 – Taking the pulse. Gary Bastin, ACRIS Management Unit. http://www.environment.gov.au/system/files/resources/01aa82ce-d910-4a45-b98a-ea17c7269549/files/acris- kangaroo-density-update.pdf

Eldridge, D. J., Poore A. G., Ruiz-Colmenero M., Letnic M., and Soliveres S. (2016). Ecosystem structure, function and composition in rangelands are negatively affected by livestock grazing. *Ecological Applications* 26, 1273-1283.

Piňeiro, G., Paruelo, J.M., Oesterheld, M., Jobbágy, E.G., (2010). Pathways for grazing effects on soil organic carbon and nitrogen. *Rangeland Ecology and Management* 63, 109-119.

Rutherford, M.C., Powrie L.W., and Lusted, L.B. (2012). Herbivore-driven land degradation: Consequences for plant diversity and soil in arid subtropical thicket in south-eastern *Africa Land Degradation & Development* 25, 541-553.

Teague, R., B. Grant, and H. H. Wang. 2015. Assessing optimal configurations of multi-paddock grazing strategies in tallgrass prairie using a simulation model. *Journal of Environmental Managemen*t 150, 262-273.

Waters, C. M., S. E. Orgill, G. J. Melville, I. D. Toole, and W. J. Smith. (2016). Management of grazing intensity in the semi-arid rangelands of southern Australia: effects on soil and biodiversity. *Land Degradation & Development* 28, 1363-1375.

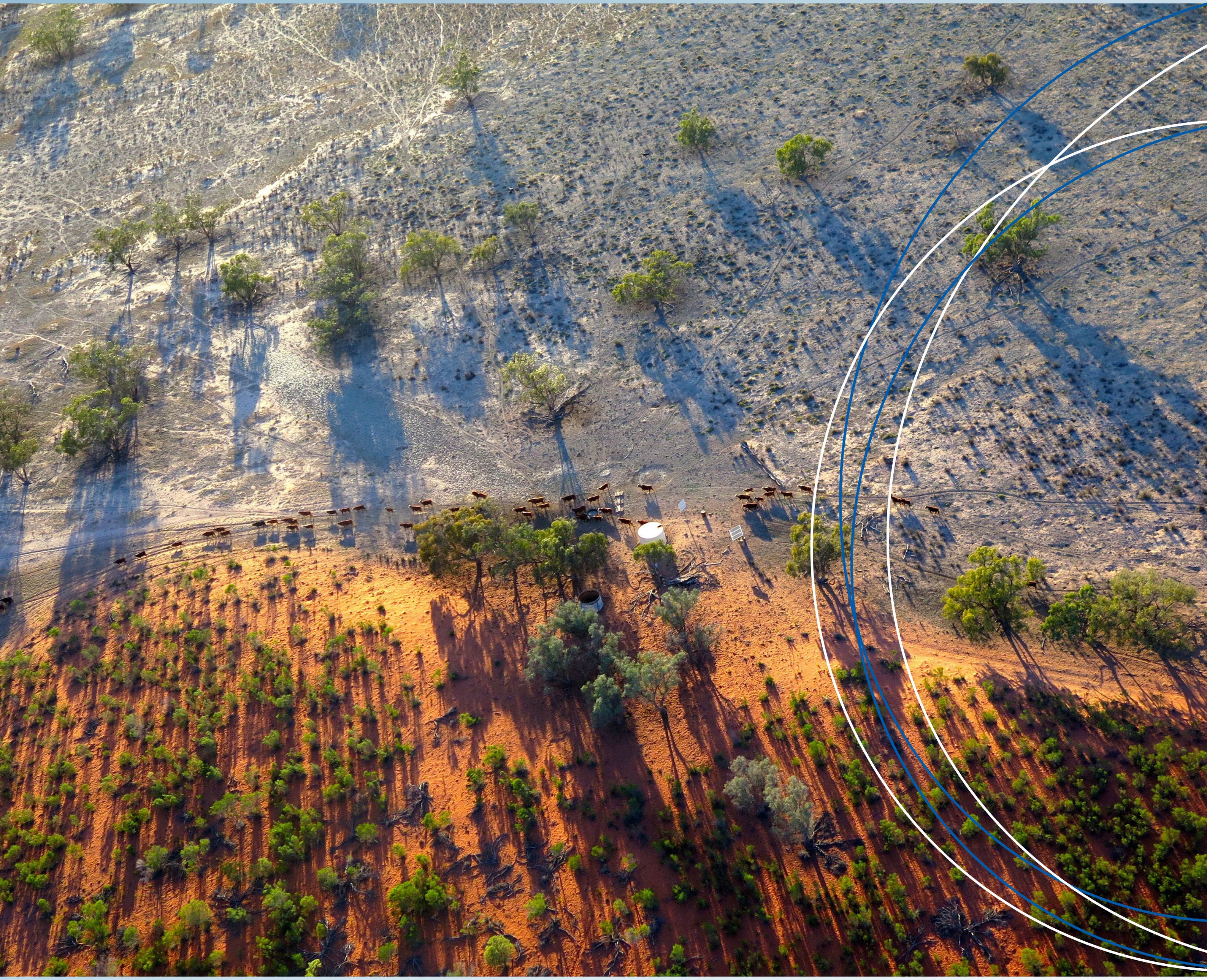
7 Appendices

Appendix 1.
Waters C, Reseigh-O'Brien J, Pahl L, Atkinson T, Burnside D and Revell D (2018). Addressing feed supply and demand through total grazing pressure management. NSW Department of Primary Industries.

Appendix 2.
Waters C, Reseigh-O'Brien J, Pahl L, Atkinson T, Burnside D and Revell D (2018). Investment Plan. Addressing feed supply and demand through total grazing pressure management. NSW Department of Primary Industries.

Appendix 3.
MLA (2018). Prospect Statement. Addressing feed supply and demand through total grazing pressure management.

Addressing feed supply and demand through total grazing pressure management



Authored by:

Cathy Waters - NSW Department of Primary Industries

Jodie Reseigh-O'Brien - Primary Industries and Regions – Rural Solutions

Lester Pahl - Department of Agriculture and Fisheries

Trudie Atkinson - NSW Department of Primary Industries

Don Burnside - D.G. Burnside & Associates

Dean Revell - Revell Science

Published by NSW Department of Industry

Addressing feed supply and demand through total grazing pressure management

First published: August 2018.

ISBN: 978-1-76058-281-4

More information: Cathy Waters (Livestock Systems, Orange) - cathy.waters@dpi.nsw.gov.au

Publication citation: Waters C, Reseigh-O'Brien J, Pahl L, Atkinson T, Burnside D and Revell D (2018). Addressing feed supply and demand through total grazing pressure management. NSW Department of Primary Industries.

Contents

Tables

Figures

Abbreviations and Glossary

Abbreviation/ term	Full name/ title
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DM	Dry matter
DSE	Dry sheep equivalent
FOO	Feed on offer
livestock	Includes all breeds of sheep and cattle, and managed goats
LFH	Large Feral Herbivore
Macropods	Includes all types of kangaroos, wallaroos and euros
ME	Metabolisable energy
MLA	Meat & Livestock Australia
MJ	Mega joules
NRM	Natural Resource Management
PIRSA	Department of Primary Industries and Regions, South Australia
R&D	Research and Development
RD&A	Research, Development and Adoption
Spelling / resting	Refers to the practice of removing livestock from an area of country to allow annual forage to grow and perennial plans to establish and/or grow
TGP	Total grazing pressure
WARMS	West Australian Rangeland Monitoring System
WLLS	Western Local Land Service

1. Executive summary

This review aimed to understand the Research, Development and Adoption (RD&A) requirement in the Southern Australian Rangelands for total grazing pressure (TGP) management. Successful rangeland management relies on managing grazing pressure from non-domestic herbivores, adjusting livestock numbers in response to available feed and strategically resting pastures. A traditional, but narrow definition of TGP revolves around the combined grazing pressure exerted by all managed and unmanaged herbivores on the vegetation, soil and water resources of rangeland landscapes. TGP is therefore important because it provides a measure of the demand for forage (feedbase) by all herbivores, relative to supply. In this review we focus on how TGP management is able to achieve a balance between supply and demand for feed, avoiding an imbalance occurring when feed demand exceeds feed supply. This imbalance can be detrimental to animal welfare, livestock productivity and may damage resource condition.

The specific objectives of the review were to:

i. Undertake a review of literature and expert opinion (featuring producer experiences) to quantify the impacts of TGP management on primary production, natural resources and identify relevant knowledge gaps for southern Australian rangelands.

ii. Compile an inventory of resources which reflects current knowledge and industry relevant information.

This review was undertaken as a partnership between four states (QLD, NSW, SA and WA) to deliver a cross-jurisdictional and cross-sector approach to identify information gaps to inform an RD&A investment plan for Meat & Livestock Australia. A wide stakeholder group including land managers, researchers, extension agencies, policy developers and NRM bodies were consulted to ensure science and practice were captured.

Most TGP is unmanaged in southern Australian rangelands

On average, less than half the herbivory in the Southern Australian Rangelands is managed by pastoralists. Recent estimates suggest that a total of 28.93 million DSE are currently grazing these areas, of which 15.57 million DSE are unmanaged Macropods and goats and 13.36 million DSE or about 45 percent is livestock. Unmanaged herbivory is highest in areas protected behind the National Dog Fence, areas where most of the sheep in the Southern Australian Rangelands are now grazing. In some areas beyond the National Dog Fence, there is still an issue in managing significant numbers of unmanaged Macropods which are competing with cattle for forage.

The quantity and quality of forage available for all herbivores within the Southern Rangelands is frequently low and as seasonal conditions deteriorate, it is more likely that direct competition will occur between managed and unmanaged species for forage. With an expected increase in climate variability, periods of competition and high TGP may become more common, leading to a further decline in the natural resource base. This will subsequently impact short and long term production and threaten the social licence to operate for livestock industries. This will be most apparent when high densities of herbivores coincide with periods of low rainfall.

Livestock management involving rotational grazing of paddocks allows effective rest and recovery of pastures. This can increase ground cover, floristic diversity, perennial grass content and long-term soil organic carbon levels. While various forms of rotational grazing and pasture spelling are being practiced by land managers, grazing by Macropods in particular can reduce the benefits pastoralists may gain from early destocking and resting pastures. Finally, land managers obtain little or no benefit from grazing Macropods, and there are contested views on the cost they impose upon the pastoral business through both impacts on resource condition and feedbase quantity and quality.

Land managers and service providers views about TGP

Land managers (n=219) and service providers (n=47) across the Southern Rangelands responded to a survey about their approach to grazing management, and the challenges imposed by unmanaged herbivory. Key messages are presented as follows.

- Land managers and service providers in the Southern Rangelands indicated that a reduction in forage demand from unmanaged herbivores was required.
- Land managers were prepared to tolerate some forage demand from unmanaged herbivores but levels needed to be less than currently maintained.
- Unmanaged herbivores commonly include goats and kangaroos. However, importantly, camels, donkeys and pigs need to be also included when referring to unmanaged herbivores.
- Land manager perceptions of numbers of unmanaged herbivores match regional monitoring undertaken by government agencies.
- Land managers and service providers recognised that resource condition is impacted by managed and unmanaged herbivores.
- The management of livestock was reported as having both positive and negative impacts on resource condition, but this could be managed.
- Survey respondents indicated the negative impact on pasture resulted from an inability to provide pasture rest and recovery time due to unmanaged grazing pressure.
- Unmanaged herbivores were reported as having negative impacts on resource condition, but cannot be easily/readily managed.
- Land managers reported the impact of Macropods on business profitability is at odds with that reported in the scientific literature.
- Land manages and other stakeholder groups believe that kangaroo management and fencing will have the greatest impact on TGP management over the next five years.

Recent and current investment in TGP

In NSW from 2004 to September 2012, the Western CMA invested approximately $9.4 million in some 284 projects involving TGP management (largely feral goat management). Local Lands Services – Western has continued to invest in direct on-ground grants to landholders with the objective of improving natural resource outcomes. The 2014 TGP Project committed $2.8 million to 58 landholders to erect 1005 km of TGP fencing, 42 trap yards and undertake grazing management plans. The project objective is to '… increase productivity, native vegetation and soil health by reducing total grazing pressure, particularly of unmanaged goats' (URS 2015). Conservative estimates suggest at least 1 million hectares in western NSW are currently being managed within TGP fencing either through incentive funding or within carbon farming areas.

Seven Collaborative Area Management or 'cluster' groups have been formed as part of a South West NRM (SWNRM), QLD state government funded initiatives. These groups of land managers came together and formed associations, allowing them to purchase fencing materials at a reduced cost. These groups then built exclusion fences surrounding their properties, helping each other and sharing fencing equipment. Once these fences are completed, the groups will work to mitigate shared issues within the clusters. Some of these issues include unmanaged herbivores which apply an unsustainable grazing pressure and wild dogs that predate on livestock.

The Collaborative Area Management project aims to increase livestock diversity on properties, allowing land managers to continue with or return to sheep enterprises. The sheep and wool industry can then benefit local towns through increased production. Our best estimates suggest that approximately 7 million hectares in SW Queensland are now managed within cluster fencing.

Anecdotal evidence suggests both TGP and cluster style fencing continues to be erected independent of incentive programs in NSW, Queensland and WA. Motivation for exclusion fencing is primarily occurring to protect livestock from wild dogs but also excluding goats and Macropods.

Future needs

Despite the requirement for land managers to manage the natural resource on pastoral leases or freehold land to at least maintain resource condition, an inability to control the unmanaged herbivore populations precludes effective rest and recovery of pastures. Land managers are prepared to tolerate some forage demand from unmanaged herbivores but in some areas, view the current populations of unmanaged herbivores is placing unprecedented demand for forage which is negatively impacting pastoral businesses and the resource base. In addition, there is a view that this TGP exaggerates the effects of drought and accelerates the negative impacts on resource condition.

The uptake of fencing provides an unprecedented opportunity to manage TGP across extensive areas of south west QLD and western NSW but as yet there is limited direct evidence of benefits to resource condition and primary production beyond financial benefits from reduced dog predation. Further, in recent years, practical non-lethal, non-fencing methods to influence livestock grazing distribution have been developed in Western Australia, referred to as Rangelands Self-herding and are currently being evaluated but is virtually unknown in Southern Australian Rangelands. Despite a range of other TGP management options (including re-introduction of the dingo and guardian animals) no comprehensive economic analysis of the cost-effectiveness of various TGP management options or the impacts on resource condition has been undertaken.

Government surveys on changes in Macropod and goat populations employ different methods as well as information being fragmented across jurisdictions making a defendable, reliable assessment of TGP for the Australian red meat industry difficult. These surveys are also undertaken at temporal and spatial scales that preclude land managers making timely decisions to respond to TGP.

Southern rangeland land managers are vulnerable to the consequences of unmanaged TGP with an inability to identify temporal and spatial changes in herbivore distribution at a paddock scale and to assess the consequences to feedbase and resource condition. There is an absence of technology products for land managers to provide this information which can underpin management decisions.

Rangeland managers require real-time information and cost-effective technologies to be able to manage total grazing pressure. To improve management of existing enterprises, they need to be able to:

- Identify early when an imbalance between forage supply and forage demand is imminent so that they can take action;
- Quantify the proportion of TGP which is domestic livestock and unmanaged herbivores;
- Quantify the impact of unmanaged herbivores on resource condition, forage availability and financial returns, allowing land managers to determine how much to invest in control of unmanaged herbivores.

Changing consumer preferences are dictating that the red meat industry is able to demonstrate production system practices that use natural resources wisely as well as care for animals. The red meat industry also needs to respond to global expectations for sustainable development and mitigation of climate change. The management of total grazing pressure provides an opportunity for southern rangeland pastoral industries to increase livestock productivity, meet changing consumer preferences for sustainably produced meat and fibre and maintain its social licence.

2. Introduction

Total grazing pressure (TGP) influences the demand for forage by all grazing animals (both domestic and non-domestic) relative to forage supply. Successful rangeland management relies on managing grazing pressure from non-domestic herbivores, adjusting livestock numbers in response to available feed and strategically resting pastures.

This review is an output from project B.TGP.1702 to inform a TGP Research, Development and Adoption Investment Plan for Meat & Livestock Australia (MLA). The project was conducted as a partnership between four states (Queensland, New South Wales, South Australia and Western Australia). A cross jurisdiction, coordinated approach was employed to capture national and regionally specific information on TGP impacts, opportunities and management in the southern Australian rangelands and to identify key knowledge gaps.

2.1 Project objectives

The objectives of project B.TGP.1702 were to deliver:

i. A review informed by science and practice of current knowledge on TGP management and impacts on production and environment.

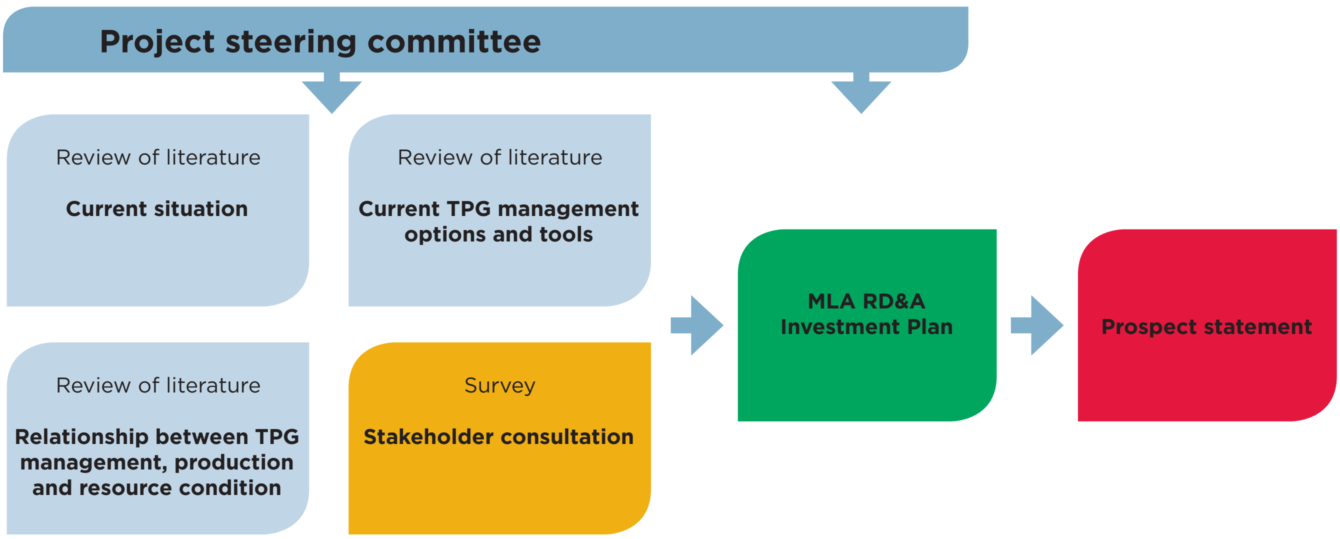
ii. A TGP knowledge database of current knowledge and industry relevant information.

iii. A Prospect Statement and Research, Development and Adoption (RD&A) Investment Plan that identifies knowledge gaps and producer prioritised delivery channels connected to TGP management and underpinned by production, environmental and economic justification for investment.

2.2 Methodology

A cross-jurisdictional and cross-sector approach, involving land managers, researchers, extension agencies, policy developers and NRM bodies was employed. This approach provided a coordinated and consistent review of past and present knowledge as well as the identification of information gaps that captured national and regional perspectives.

Considerable innovation with TGP management is currently occurring and past R&D in TGP management has been substantial across southern Australian rangelands. A key feature of this review is to provide a synthesis of information drawn from science and practice. To achieve this synthesis, industry consultation captured 266 stakeholder experiences and was considered with an assessment of published/unpublished information to identify the most effective RD&A investment for MLA. An overview of the context of this review in framing the RD&A investment plan is shown below.



2.2.1 Project partners and Steering Committee

Project partners included Department of Agriculture and Fisheries (Queensland), Department of Primary Industries and Regions South Australia, Revell Science, National Rangeland NRM Alliance, and Regional NRM Organisations including Western Local Land Service (WLLS), Rangelands NRM, Natural Resources SA Arid Lands and South West NRM.

The project Steering Committee consisted of 9 members: Rangeland NRM Alliance: Kate Forrest, Chair; Land Managers: Neil Grinham (WA), Jason Hastie (WA), Rikki Allen (NSW), Kylie Hudson (QLD), Peter Whittlesea (SA); WLLS (Russell Grant); Consultant: John Gavin; MLA (Cameron Allen).

Project team: NSW Department of Primary Industries, Dr Cathy Waters (Lead) and Trudie Atkinson (Industry Consultation); Department of Agriculture and Fisheries Queensland (Dr Lester Pahl); Department of Primary Industries and Regions South Australia (Dr Jodie Reseigh) and Dr Dean Revell (Revell Science).

Regional collaborators: Western Local Land Service (Russell Grant), Rangelands NRM (Kieran Massie), Natural Resources SA Arid Lands (Melissa Horgan) and South West NRM.

Project Team

Cathy Waters: Project leader

Cathy is a Senior Research Scientist with NSW Department of Primary Industries and was responsible for understanding national and regional changes in TGP, the range of TGP management options, environmental impacts of TGP management as well as capturing information from and relevant to New South Wales.

Jodie Reseigh: Collaborator

Jodie a Senior Environmental Consultant, Rural Solutions SA (PIRSA) and was responsible for reviewing existing and emerging technology products and information from and relevant to South Australia as well as editing.

Trudie Aktinson: Industry consultation

Trudie is a Development Officer (Pastures & Rangelands) with NSW Department of Primary Industries and was responsible for conducting regional-based industry consultation and feedback.

Lester Pahl: Collaborator

Lester is a Principal Scientist with Department of Agriculture and Fisheries (Queensland) and was responsible for understanding the implications of TGP management for production, TGP management on diet (quality and quantity) as well as capturing information from and relevant to Queensland.

Dean Revell: Collaborator

Dean is a consultant with Revell Science and was responsible for understanding the impacts of TGP management on diet (quality and quantity) animal interactions (behaviour) as well as capturing information from and relevant to Western Australia.

Don Burnside: Collaborator

Don is a consultant with D.G. Burnside & Associates and has worked in the rangelands in both the public and private sectors for over 40 years. The majority of this time has been spent in WA rangelands and he was able to provide a SW rangeland perspective to the literature review as well as reviewing/editing.

3. The current situation

3.1 Summary - key messages and knowledge gaps

Key messages

The Southern Rangelands support unmanaged native and feral animal populations which at times are responsible for more than half of the TGP.
Temporal and spatial variation in unmanaged and managed herbivore numbers and relative contributions to TGP highlight the challenge facing land managers in controlling grazing pressure, when they may only have control of half of that pressure.
Macropods and unmanaged goats comprise 15.57 million DSE, land managers control 13.36 million DSEs or about 46 percent of the total herbivory in the Southern Rangelands, which is estimated at 28.93 million DSEs.
There are large spatial and temporal fluctuations in Macropod and unmanaged goat populations which may guide regional targeting of TGP control methods and extension programs.
Between 2011 and 2016, Macropod densities across Southern Rangelands ranged from 10/km^2 (WA) to 40/km^2 (QLD, WA and SA).
In some years, the highest average Macropod densities (0.2 DSE ha) were found in QLD and SA.
The data show that most of the sheep in rangelands are now in the areas protected by the National Dog Fence in Western NSW and the southern parts of the SA pastoral zone. In WA sheep are con-fined to properties in the West Gascoyne and the Nullarbor Plain. In Queensland, sheep numbers are being maintained by the building of dog-proof fencing around clusters of properties.
Macropod harvest quotas have not been reached in any state between 2010 -2016.
In NSW and QLD, Eastern grey kangaroo populations exhibit the greatest fluctuations in population numbers, but in SA and WA, Red kangaroo populations vary the most.
A number of regional case studies with known, high and low unmanaged herbivore populations which can be used to illustrate when an imbalance between feed supply and demand occurs.
Camels and donkeys are common in some central regions but no estimates of broad-scale numbers or densities are available.
No estimates of emu densities were available.
The value of a DSE for herbivores is contested. This is particularly the case for Macropods with several conversion factors used, depending on author (0.35-0.70 DSE).
There is no ongoing, coordinated, national effort to compile changes in unmanaged and managed herbivores. State agencies do not use consistent methods to monitor changes in kangaroo and un-managed goat populations.
Macropod harvest quotas were not been reached in any state between 2010 -2016.

Knowledge gaps

Real-time, temporal and spatial verification of herbivore populations at a paddock scale.
Nationally coordinated measurement of Macropod and other unmanaged herbivore and livestock density trends.
A number of regional case studies with known, high and low unmanaged herbivore population can be used to illustrate when an imbalance between feed supply and demand occurs.

3.2 Introduction

3.2.1 Defining TGP

Total Grazing Pressure has been defined as the combined grazing pressure exerted by all managed and unmanaged herbivores on the vegetation, soil and water resources of rangeland landscapes (Fisher *et al*. 2004). We suggest a definition of TGP should be framed to reflect the demand for forage (feedbase) by all herbivores, relative to supply. A central tenet in TGP is the balance between supply and demand for feed, an imbalance occurring when grazing pressure exceeds feed supply.

Grazing pressure is the ratio of animal units or forage intake units per unit of forage mass available at a particular time and location (Allen *et al*. 2011). Hence, grazing pressure is a ratio of animal demand to feed supply. Total grazing pressure has two components, domestic animals (livestock) that are managed, and wild animals (native and unmanaged) that are largely unmanaged (URS 2014) as well as spatial and temporal dimensions.

The species of grazing animals which most often contribute to TGP are domestic cattle and sheep, the larger species of Macropods (red, eastern and western grey kangaroos, common wallaroo or euro) and unmanaged goats. In 2018, rabbits are not currently large contributors to TGP, and unmanaged camels, donkeys and horses contribute significantly to TGP when in high densities. Similarly, numbers of farmed goats are few relative to other livestock and Macropods.

3.2.2 Why is TGP important?

The quantity and quality of forage available for all herbivores within the Southern Rangelands is frequently low, during which time animal performance can be poor and pastures risk being degraded. This is most apparent when high densities of herbivores coincide with periods of low rainfall (McKeon *et al*. 2004). However, an imbalance between feed supply and feed demand may also occur under a range of seasonal conditions.

There is widespread agreement that, leading up to, during and immediately following periods of drought, numbers of herbivores need to be reduced. However, significant reductions in the livestock component of TGP, an inevitable outcome of these events, incurs high economic costs for land managers. Further, opinions differ regarding the extent that domestic livestock, and native and unmanaged herbivores each contribute to periods of excessive demand for forage. Likewise, there is disagreement as to the extent each group of herbivores should be reduced. This is particularly the case for livestock and Macropods.

According to Fisher *et al.* (2004), total grazing pressure in the rangelands has been consistently excessive, in part due to persistent populations of unmanaged and native herbivores. Unmanaged goats and Macropods are examples of herbivores that have been able to maintain substantial populations in regions where artificial sources of water are abundant, and where dingoes have been controlled (Fisher *et al.* 2004). These authors noted that most non-livestock grazing animals are not managed in proportion to the resources they consume, and are not harvested for economic return as efficiently as livestock.

3.3 Total grazing pressure in the rangelands

3.3.1 Introduction

In this section, we report the latest available information on current numbers and recent trends of herbivores grazing in the Southern Rangelands – being the areas in Australia south of the Tropic of Capricorn (23^{0}s). These areas include:

- Western NSW, approximating the Western Lands Division;
- South West and Central West Queensland;
- virtually all of the pastoral areas in South Australia; and
- the Gascoyne, Murchison, Goldfields and Nullarbor regions in WA.

The data come from a range of sources, including state agency data and the Australian Bureau of Statistics (livestock), as well as regional knowledge. There are major limitations in using Macropod and unmanaged goat density data collected from state agencies to make cross jurisdiction comparisons[1]. These inconsistencies revolve around differences in survey methods employed and the frequency in which the surveys are undertaken. There is currently no routine, consistent collation of national changes in herbivore populations.

3.3.2 Comparing herbivores when rated as Dry Sheep Equivalents (DSE)

There is general agreement on the definition of a 'Dry Sheep Equivalent' (DSE). Meat and Livestock Australia [2] defines one DSE as representing the energy requirement of a non-lactating 50 kg ewe (or 50 kg wether) at maintenance; being 8.3 megajoules (MJ) metabolisable energy (ME) per head per day (MJ ME/hd/day) . From this baseline for a DSE, the equivalent DSE numbers can be derived for other classes of sheep, cattle and Macropods, with examples shown below in Table 3-1.

There has been some concerted effort and debate on the 'dry sheep equivalent' (DSE) of kangaroos. Estimates have been based on metabolic rate and body water turnover, with the expectation (and confirmation) that the lower energy demands of kangaroos compared to sheep mean their DSE will be less than one. Earlier predictions of the DSE of kangaroo put the value at about 0.7, but more recent work has refined the DSE for a kangaroo to a lower rating as shown in Table 3-1. Throughout this report, unless otherwise specified, a conservative estimate is used, being 0.35 DSE for all Macropods.

[1] NSW kangaroo surveys are undertaken annually across the whole state in 1 degree survey blocks (NSW Office of Environment and Heritage, 2017) whereas QLD surveys are undertaken using a fixed number of survey blocks designed to be representative of a larger region, each of which are not measured annually (Department of Environment and Heritage Protection, 2016a and b)

[2] https://www.evergraze.com.au/library-content/stocking-rate-calculator/

Table 3-1: DSEs for major herbivores

Class of animal	# of DSEs	Reference
Sheep		
45 kg wether (or non-lactating ewe)	0.9	[3] NSW DPI (see footnote)
50 kg wether (or non-lactating ewe) at maintenance	1	
50 kg wether (or non-lactating ewe) gaining 50g/d	1.3	
50 kg pregnant ewe carrying a single lamb (6 weeks before birth)	1.5	
50 kg ewe with single lamb at foot	3.0	
Cattle		
400 kg steer or dry cow at maintenance	7	[4] MLA (see footnote)
500 kg steer or dry cow at maintenance	8	
400 kg pregnant cow (last 6 months)	9	
400 kg wet cow with 0-3 month old calf at foot	14	
Kangaroos		
25 kg kangaroo	0.31-0.37	Munn *et al*. (2009); Munn *et al*. (2011)
35 kg kangaroo	0.44	Munn *et al*. (2013)

Knowing the DSEs of different types and classes of herbivores needs to be combined with accuracy in the number of animals in a particular area, and the available forage. Key real-time, paddock level knowledge gaps include:

1. The numbers of different classes of herbivores. Animal numbers and their average body weights are not always known with great accuracy, especially for unmanaged (native and unmanaged) populations. Knowing animal numbers at a fine scale of time and space can be problematic for all classes of animals, including livestock if grazing locations at a patch scale and time spent in particular areas are not well understood.
2. The amount of forage that can sustainably be consumed by herbivores. Quantifying feed on offer (FOO) is not straightforward in landscapes with a high level of diversity in plant species and biomass across time and space. Small errors in quantifying FOO have considerable implications to balance feed supply and demand when herbage biomass is low, which is often the case under dry seasonal conditions (refer to Section 5).
3. Competition between herbivores for feed base: understanding diet selection and diet quality of all classes of herbivores. The degree of competition amongst herbivores types can be estimated using total herbage mass and utilisation (refer to Section 5).

[3] https://www.dpi.nsw.gov.au/agriculture/budgets/livestock/sheep-gross-margins-october-2015/background/dse
[4] http://mbfp-pastoral.mla.com.au/Managing-your-feedbase/4-Determine-carrying-capacity-and-stocking-rate

To illustrate the importance of accurately knowing total herbivore numbers and reliably estimating the amount of herbage available for consumption, a set of hypothetical scenarios is shown in Table 3-2. The criteria for the scenarios are:

a. an area of 1,000 ha grazed with either cattle (400 kg dry cows) or sheep (45 kg dry ewes);

b. herbage biomass is 500 kg dry matter (DM)/ha and metabolisable energy (ME) content is 7 mega joules (MJ) ME/kg DM (i.e., poor quality, dry season feed);

c. 60 percent of the paddock area is used by the animals (i.e., some patches are not utilised) and the intended utilisation of herbage in grazed areas is considered high (50%); and

d. the intended duration of grazing the paddock is 200 days.

Without any grazing pressure from kangaroos, feed budgeting indicates that the paddock could be grazed by 76 cattle or 590 sheep for 200 days (Scenario A). In the presence of 135 kangaroos in the 1,000 ha paddock, and with no reduction in livestock numbers, the duration of grazing would need to be reduced by 10 percent (to 180 days) (Scenario B).

A reduced duration of grazing by 9 days is equivalent to a reduction in starting biomass of only 30 kg DM/ha, from 500 to 470 kg DM/ha (Scenario C). Predicting food on offer in the rangelands to within 30 kg DM/ha is an unreasonable expectation, which shows that in this scenario, the kangaroo-DSE value is a relatively small issue compared to accurately quantifying herbage biomass and managing herbivore numbers accordingly. To further emphasise the importance of herbage biomass, a reduction in feed availability from 500 to 300 kg DM/ha, without adjusting livestock or kangaroo numbers, would require a reduction in the duration of grazing by 40 percent, from 180 to 108 days (Scenario D). Alternatively, to return the duration of grazing to 200 days, livestock numbers would need to be halved if the kangaroo population remained (Scenario E), or reduced by about 40 percent if no kangaroos were adding to the grazing pressure (Scenario F).

Table 3-2: Six hypothetical examples of the relationship between herbage availability and herbivore numbers

Scenario	Area (ha)	Feed available for consumption (kg DM/ha)	No. livestock		No. kangaroos	Days before intended forage consumption is reached	
			Cattle	Sheep		if a kangaroo DSE is 0.44	if a kangaroo DSE is 0.70
A	1000	500	76	590	0	200	-
B	1000	500	76	590	135	180	169
C	1000	470	76	590	135	169	-
D	1000	300	76	590	135	108	-
E	1000	300	37	261	135	200	-
F	1000	300	45	319	0	200	-

The complete impact of grazing pressure will depend on a range of biotic (pasture composition and vegetation structure) and abiotic (soil type, historical land use) factors, not captured in the scenarios above. This highlights that future R&D should consider the important nuances of grazing at different stages of vegetation growth.

Given the large variability in both animal and plant populations, it is perhaps not surprising that there is no unifying hypothesis to predict impacts of TGP in Australia's rangelands. Decisions relating to TGP need to be made within a local context of time and space

3.3.3 Herbivore numbers and distribution

Total numbers in recent years

Recent estimates of total herbivores in the Southern Rangelands are shown in Table 3-3. The data are for a range of years (2016-2018) and come from a number of sources covering different areas and geographic region. As such the numbers in the columns may not add to the totals shown. However, these numbers give 'best estimates' of the numbers of herbivores grazing in the rangelands, without considering large unmanaged herbivores (horses, camels and donkeys) and rabbits.

When converted to DSEs using industry accepted conversion factors, sheep (weighted average 35 kg) and cattle (weighted average 350 kg) make up 12.98 million DSEs across the rangelands, with managed goats (weighted average 25 Kg) adding a further 0.38 million DSEs. Macropods (weighted average 19-32 kg) and unmanaged goats comprise 15.57 million DSE. Thus land managers control 13.36 million DSEs or about 46 percent of the total herbivory in the Southern Rangelands, which is estimated at 28.93 million DSEs.

Table 3-3: Estimates of current herbivore numbers in the grazed rangelands

State	Sheep	Cattle	Goats	Macropods
New South Wales	2.47 m [a]	0.17 m [b]	3.40 m [c]	13.45 m [i]
Queensland*	0.44 m [a]	0.50 m [b]	0.24 m [j]	16.34 m [k***]
South Australia	0.93 m [a]	0.17 m [b]	0.33 m [d]	4.70 m [f]
Western Australia	0.18 m [a]	0.28 m [g]	0.15 m [d]	2.49 m [h**]
Total	4.02 m [a]	1.12 m [b]	4.10 m [d]	36.98 m [l]
Managed goats			(0.51 m) [e]	
Feral goats			(3.59 m)	
DSE conversion factor	1.00	8.00	0.75	0.35
Estimated total DSEs	4.02 m	8.96 m [l]	3.01 m [m]	12.94 m [n]

* South West NRM region only; ** western grey and red kangaroos only; *** eastern grey and red kangaroos only

Sources for animal numbers:

[a] MLA (2017a); [b] MLA (2017b), [c] T. Atkinson (pers comm.), Office of Environment and Heritage (2017); [d] Pople and Froese (2012); [e] O'Connor (2016); [f] Department of Environment, Water and Natural Resources (2017); [g] Rangelands NRM (2018); [h] Department of Parks and Wildlife (2016); [i] Office of Environment and Heritage (2017); [j] Department of Environment and Heritage Protection Queensland (2016b); [k] Department of Environment and Heritage Protection Queensland (2016a).

Sources for DSE conversions: [l] https://www.mla.com.au/research-and-development/Grazing-pasture-management/improved-pasture/grazing-management/stocking-rate/ [m] http://www.rangelandgoats.com.au/grazing-management/stocking-rate; [n] Munn *et al.* 2009; Munn *et al.* 2011

[5] 19 kg for harvested kangaroos and 32 kg for unharvested kangaroos

Sheep and cattle

Sheep and cattle numbers for each of the NRM regions were reported by Meat & Livestock Australia (2017a and b) as at June 2016. These can be interpreted for the numbers in the Southern Rangelands areas. The data show that most of the sheep in rangelands are now in the areas protected by the National Dog Fence in Western NSW and the southern parts of the SA pastoral zone. In WA sheep are confined to properties in the West Gascoyne and the Nullarbor Plain. In Queensland, sheep numbers are being maintained by the building of dog-proof fencing around clusters of properties (D. Phelps per comm.)

Cattle numbers in the Southern Rangelands have increased in recent years, partly in response to market pressures, and also due to decreased wild dog control in parts of Queensland and in the WA rangelands. The recent surge in wool prices (as at June 2018), may see continued increase in sheep numbers in south-eastern rangelands. It is unknown if the trend of increasing cattle numbers will continue, although increased dog numbers and properties where sheep infrastructure would require major upgrades may limit transitioning back to sheep enterprises.

Goats

Most (83%) of the managed and unmanaged goats in the rangelands are in Western NSW, where dingo and wild dog predation is low or non-existent. In this area, sales of unmanaged goats represent a very important source of income for graziers (URS 2015). Unmanaged goat numbers have declined dramatically in the WA rangelands over the last 20 years as a consequence of dingo and wild dog predation, and a similar decline in numbers has occurred in SA and Queensland in areas without protection from predation.

Macropods

The Department of Environment and Energy (2017) reported that the combined number of red kangaroos, eastern and western grey kangaroos and wallaroos/euros estimated to be in the commercially harvested zones of Queensland, New South Wales, South Australia and Western Australia in 2015 to be 49 million. Collectively, NSW and Queensland rangelands have over 60 percent of the counted Macropod population in the Southern Rangelands, with numbers in SA and WA being smaller. These population estimates are based on aerial and ground surveys of the areas within Australia where commercial harvesting occurs. The actual national populations would be significantly higher as these figures do not include estimates for areas not surveyed.

As shown in Table 3-4, the allowable quota for Macropod harvesting has not been achieved in any state over recent years, indicating that the price for kangaroo products is insufficient. Further, harvest numbers exceeded 50 percent of the allowable quota in only three times – once in Queensland and twice in WA.

Total Macropod numbers almost doubled between 2010 and 2014, whereas harvest numbers were very similar across these years indicating that that the current commercial harvest is ineffective as a control mechanism.

Table 3-4: Macropod numbers and harvests – 2010 to 2016

State	2010	2011	2012	2013	2014	2015	2016
New South Wales*							
Macropod number (m)	7.20	8.52	9.81	11.39	15.33	17.17	16.30
Allowable harvest (m)	1.18	1.41	1.66	1.95	2.62	2.96	2.80
Actual harvest (m)	0.39	0.38	0.34	0.35	0.35	0.35	na
% allowable harvested	36	30	22	19	15	13	na
Queensland*							
Macropod number (m)	15.12	12.17	20.34	24.09	32.80	27.16	26.16
Allowable harvest (m)	2.29	1.83	3.10	3.63	5.01	4.10	3.92
Actual harvest (m)	0.83	1.01	0.97	1.14	1.04	1.06	na
% allowable harvested	36	55	31	31	21	26	na
South Australia*							
Macropod number (m)	2.15	2.20	2.33	2.73	3.22	3.33	4.14
Allowable harvest (m)	0.36	0.37	0.39	0.44	0.51	0.54	0.68
Actual harvest (m)	0.10	0.11	0.12	0.11	0.11	0.11	na
% allowable harvested	29	29	31	25	21	20	na
Western Australia*							
Macropod number (m)	2.56	2.26	1.82	1.20	1.84	1.66	2.39
Allowable harvest (m)	0.30	0.25	0.23	0.18	0.28	0.23	0.35
Actual harvest (m)	0.15	0.12	0.13	0.12	0.14	0.11	na
% allowable harvested	48	48	54	64	49	48	na
GRAND TOTAL							
Macropod number (m)	**27.04**	**25.6**	**34.30**	**39.41**	**53.20**	**49.31**	**44.85**
Allowable harvest (m)	**4.14**	**3.87**	**5.41**	**6.22**	**8.44**	**7.83**	**7.09**
Actual harvest (m)	**1.47**	**1.62**	**1.56**	**1.72**	**1.64**	**1.63**	**na**
% allowable harvested	**36**	**42**	**29**	**28**	**19**	**22**	**na**

*most of the macropods – perhaps 80-90 percent will be found in the rangelands

Source: Department of Environment and Energy (2018)

3.3.4 Variation in stocking densities across time and space

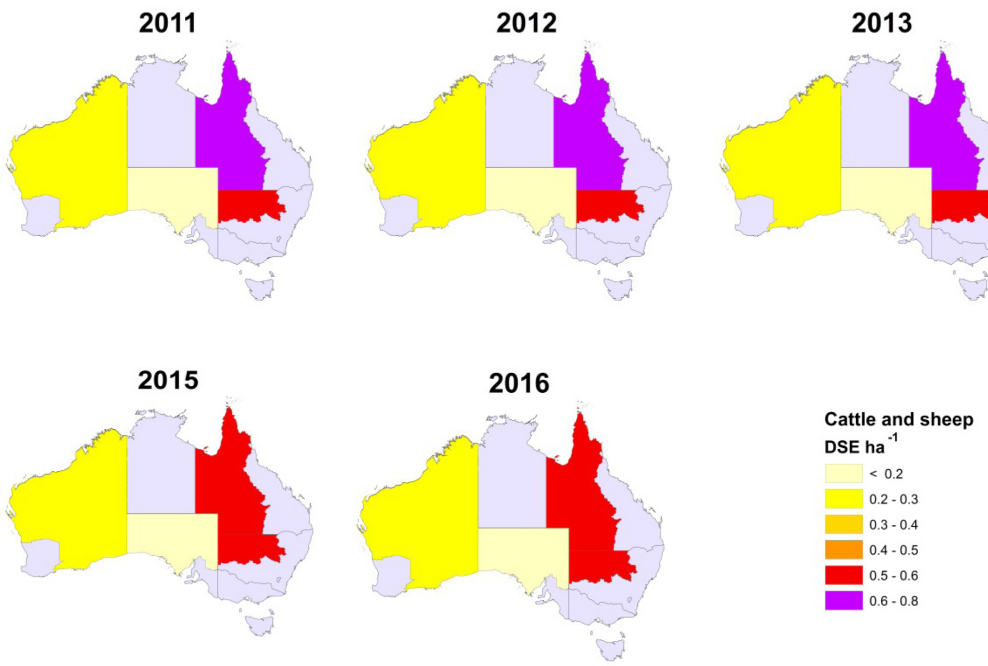
The numbers and densities of livestock fluctuated in Southern Rangelands over the period 2011-2016 as shown in Figure 3-1. Livestock densities show much less variation across time than the relatively unmanaged (Macropod and goat) populations.

Sheep and cattle

In the years 2011-2016, livestock densities have been relatively stable in the WA rangelands (20-30 DSE km^2), in the South Australian rangelands (10-20 DSE km^2) and in Western NSW (50-60 DSE km^2).

However, in north western, central western and south western Queensland, livestock densities have varied from 60-70 DSE km^2 in 2011 and 2012 to greater than 70 DSE km^2 in 2013, followed by a decline to 50-60 DSE km^2 in 2015 as drought conditions prevailed.

Figure 3-1: Changes in livestock densities (DSE) across southern Australian rangelands

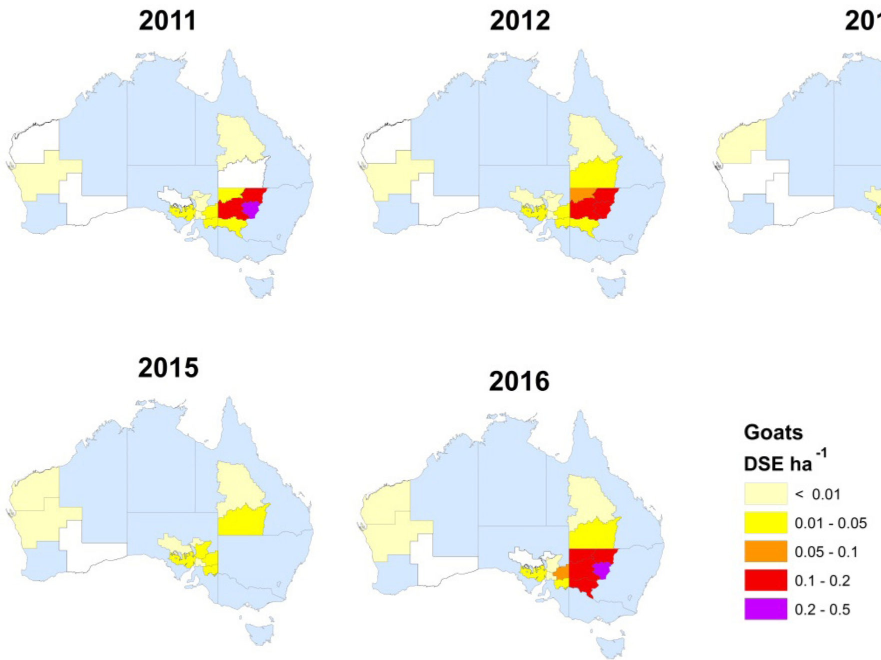


Source: Australian Bureau of Statistics

Goats

No specific goat surveys are conducted across the Southern Rangelands. However in some states goat numbers are estimated as part of routine Macropod surveys (Figure 3-2). While goat numbers were not recorded in 2014 and 2015, highest populations densities have been reported in Western NSW.

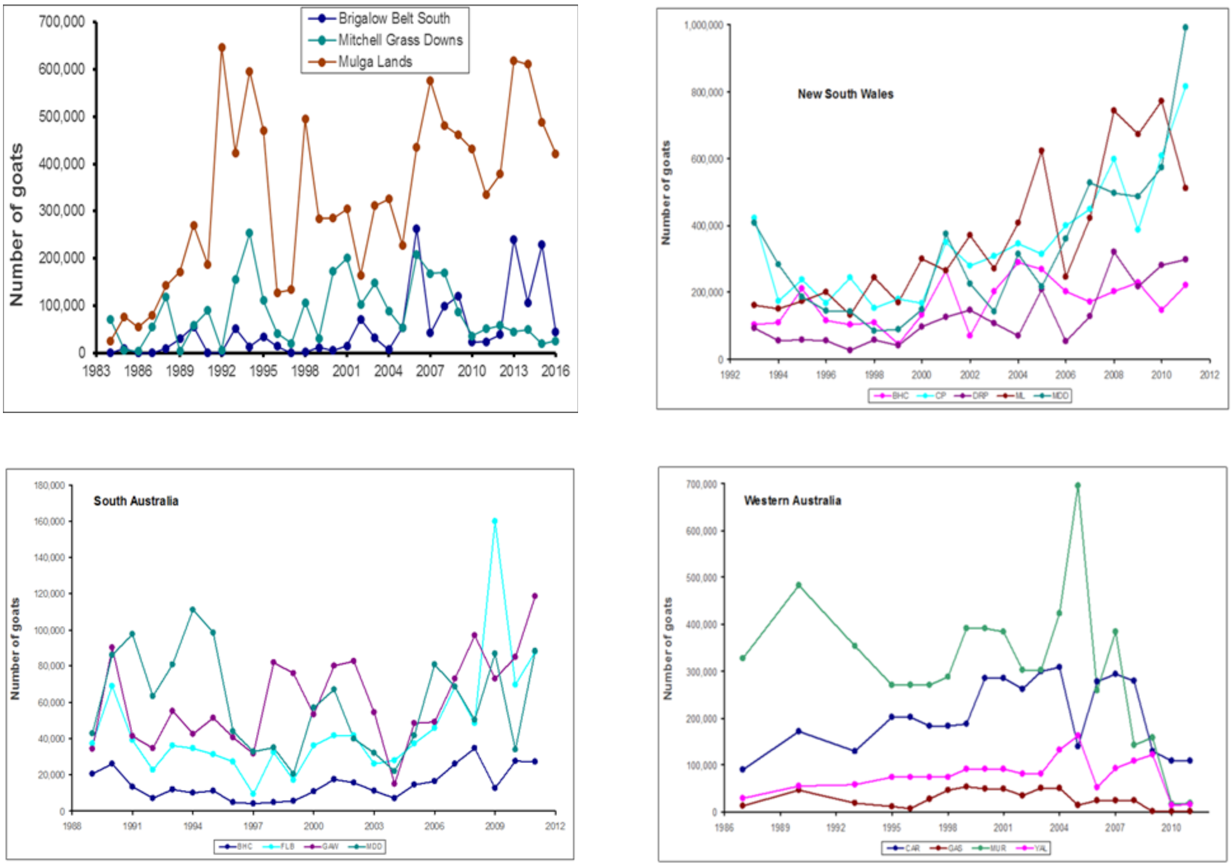
Figure 3-2: Changes in goat densities (DSE) across southern Australian rangelands



Source: NSW Office of Environment & Heritage; Department of Biodiversity Conservation and Attraction; Department of Environment, Water and Natural Resources *all unpublished data*.

Some regions show low, relatively constant numbers of goats but other regions like the Mulga Lands (ML) in Queensland and NSW, and the Flinders (FLB) in South Australia support consistently high, increasing numbers of goats (Figure 3-3).

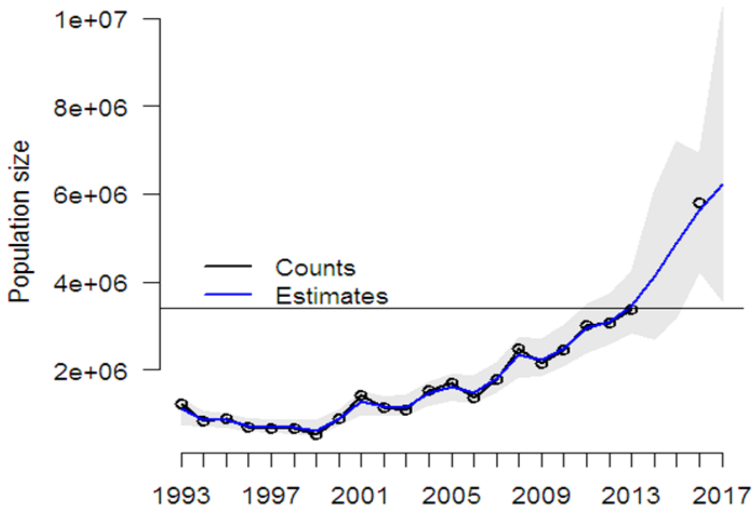
Figure 3-3: Differences between regions in the number of goats across southern Australian rangelands



After: Pople and Froese (2012) Pople and Finch (unpublished data).

As shown in Figure 3-3, goat numbers in some regions of South West Qld and Western NSW have increased dramatically since the late 1990s, despite an increasing reliance by land managers on the sale of unmanaged goats as an important source of income. As such they represent a significant component of total grazing pressure in these areas. This is in contrast to the situation in SA and WA, where unmanaged goat numbers in the rangelands are reported to have declined and are likely to decline further. While predicted number of unmanaged goats was expected to increase (Figure 3-4) in NSW, goat numbers have declined from 5.7 million in 2016 to 3.5 million in 2017 (McLeod unpublished).

Figure 3-4: Predicted (blue) and actual observations (black circles) of goat numbers in western NSW.



Predicted values are derived from a forecast model (the horizontal line in the graph represents the 3.4 million goats observed in 2017). Source: McLeod unpublished; Office of Environment and Heritage.

Macropods

The Queensland Department of Environment and Heritage Protection (2016a) estimated that, over the period 1992 to 2016, annual Queensland total Macropod population size varied from a low of 9.5 million in 1995 to a high in 2001 of 37.6 million. Within regions, populations can fluctuate between 10-60 kangaroos km^2 in eastern Australia whereas Western Australia has relatively stable populations of less than 10 kangaroos km^2. However, red kangaroo numbers in the WA rangelands have decreased from about 2.55 million in 2000 to about 1.1 million in 2016 (Department of Parks and Wildlife 2016). This is likely to be a consequence of reduced wild dog control across most of the WA rangelands.

The Macropod population in South Australia would seem to have increased in recent years with numbers in the North East Pastoral Region now at 14-21 DSEs km^2 (using a DSE rating of 0.35).

Table 3-5 presents data on Macropod densities in a number of locations and for a range of years. In most of these reported cases, the DSE rating used was 0.35. The stocking densities show that the number of Macropods in a region, or at state level can vary quite markedly over only a few years. This situation is in contrast with the relatively stable densities for livestock shown in Figure 3-1.

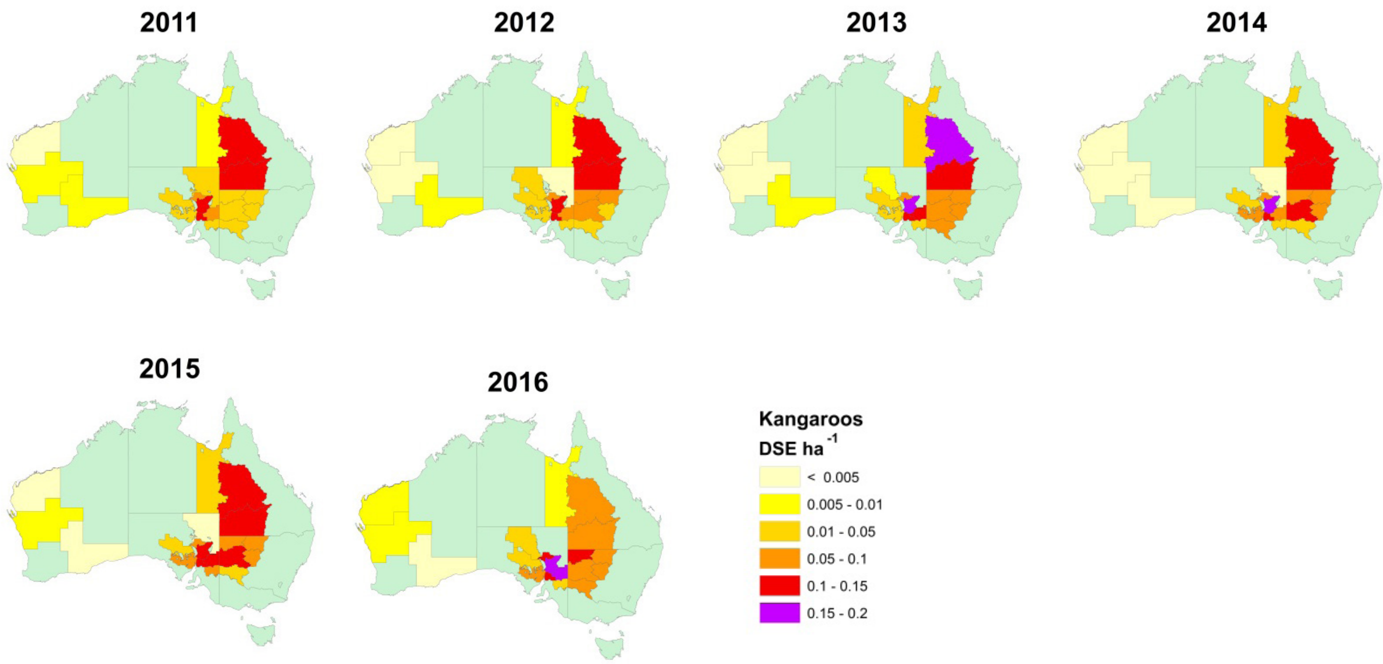
Table 3-5: Variation in stocking densities – Macropods

Year	State/ region	Densities DSEs/km^2	Source
Queensland			
2001	NSW & Qld	4-32	Gutteridge *et al.* (2001)
1993-2001	Qld	2-10	Bastin (2012)
2008-2012	NSW & Qld	5	na
2011	Charleville, Qld	56	Department of Environment and Heritage Protection (2016a)
2015	Charleville, Qld	18	Department of Environment and Heritage Protection (2016a)
2013	Central Qld	28	na
New South Wales			
1981	South Australia pastoral	10*	Pople *et al.* (2007)
1984	South Australia pastoral	3.5**	
2001	SA	1-8	Gutteridge *et al.* (2001)
1993-2003	SA	2-10	Bastin (2008)
2016	North East Pastoral Region	14-21	Department of Environment, Water and Natural Resources (2016)
Western Australia			
2001	WA	<1-8	Gutteridge *et al.* (2001)
1983	Carnarvon WA	4-5	Department of Parks and Wildlife (2016)
1983	Nullarbor Plain	3-7	Department of Parks and Wildlife (2016)
1998	Northern WA	3	Department of Parks and Wildlife (2016)
1999	Nullarbor Plain	1.4***	Department of Parks and Wildlife (2016)
2008	Nullarbor Plain	6***	Department of Parks and Wildlife (2016)

* Most references have used as DSE rating of 0.35 ** red kangaroos only *** western grey kangaroos

A summary of recent changes in kangaroo populations in Queensland, New South Wales, South Australia and Western Australia are shown in Figure 3-5. These show the much greater variation in reported numbers year-to-year as compared to livestock densities.

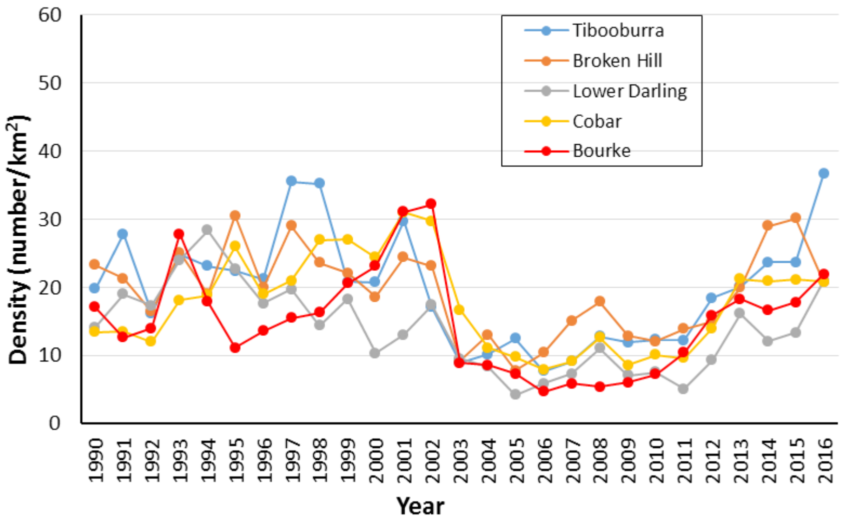
Figure 3-5: Changes in kangaroo densities across southern Australian rangelands



DSE conversion factor for kangaroos = 0.35 and therefore represent conservative estimates.

Further evidence for the fluctuations in kangaroo numbers is shown in Figure 3-6, with data presented for Western NSW. Kangaroo numbers fluctuated significantly between years and regions in the 1990s, but the onset of the 'Millennium Drought' in 2001 resulted in a dramatic fall in numbers.

Figure 3-6: Trends in kangaroo population density in western NSW



Rabbits

Gutteridge *et al*. (2001) combined their maps of sheep (1.0 DSE), cattle (7.5 DSE), unmanaged goat (1 DSE), rabbit (0.08 DSE) and macropod (0.67 DSE) densities to produce maps of total DSE km^2 for the Australian rangelands. At this time, rabbits were abundant, existing at densities up to 1,000 km^2, equivalent to 83 DSE km^2. However, rabbit densities are much lower now since release of the rabbit haemorrhagic disease virus, a type of calicivirus. Across Statistical Local Areas (SLAs) in the Southern Rangelands, for the years 1956, 1966, 1976, 1986 and 1996, total herbivore density varied from near zero to as much as 200 DSE km^2.

3.3.5 Temporal changes in total grazing pressure

As shown in previous section, livestock densities show relatively little variation through time, when compared to unmanaged goat and macropod densities. In particular, the variation in macropod density has an important impact on the relative grazing pressure imposed by livestock, unmanaged goats and Macropods at any one time, as shown in Table 3-6.

Table 3-6: Percentages of TGP contributed by livestock, goats and macropods

Year	Location	Percentage of TGP (expressed as DSE)			Source
		Sheep/ cattle	Goats	Macropods	
Queensland					
2002	South West Qld	37-72%	3-30%	16-36%	Thompson *et al*. (2002)
2012	Brigalow Belt South	90%	na	10%*	Bastin (2012), Pople and Froese (2012)
	Darling River Plains	90%	few	10%*	
	Mitchell Grass Downs	90%	few	10%*	
	Mulga lands	65-80%	na	na*	
NSW					
2001	Western NSW	37-66%	5-17%	24-44%	Gutteridge *et al*. (2001)
2011	Western NSW	26-66%	6-34%	28-40%**	Hacker (2011)
1994-2011	Cobar peneplain	70-85%	na	na	Bastin (2012); Pople and Froese (2012)
	Mulga lands	60-75%	na	na	
	Murray-Darling Depression	60-75%	na	17%*	
	Broken Hill Complex	37-52%	na	na*	
	Channel Country	35-61%	na	na*	
	Simpson Strzelecki Dunefields	22-48%	na	na*	
South Australia					
2001	Flinders Ranges	52%	na	na*	Gutteridge (2001
	Pirie Range	35%	na	na*	
1978-2001	North Flinders/ North East Pastoral	na	na	23-46%*	Jonzen *et al*. (2005)
1994-2011	Murray Darling Depression	64-84%	na	na	Bastin (2012); Pople and Froese (2012)
After 2004	Broken Hill Complex/ Gawler region/ Stony Plains	45-70%	few	35%*	

Year	Location	Percentage of TGP (expressed as DSE)			Source
		Sheep/ cattle	Goats	Macropods	
Western Australia					
1996	All pastoral areas	14-26%	na***	30-63%	Gutteridge *et al*. (2001)
1995-2011	Pilbara and Coolgardie Bioregions	90-100%	few	10%	Bastin (2012); Pople and Froese (2012)
	Gascoyne Bioregion	60-90%	na	Up to 30%	
	Yalgoo Bioregion	60-90%	Up to 40%	na	
	Carnarvon Bioregion	40-80%	na	na	
	Murchison Bioregion	40-80%	50%	na	
	Nullarbor Plains	51-77%		23-49%	

* kangaroos calculated at 0.35 DSE; ** kangaroos calculated at 0.7 DSE; *** rabbits contributed 19-35%.

Fisher *et al.* (2004) provided estimates of individual herbivore and total herbivore densities for a number of regions within the Southern Rangelands. This enabled the percentage of total DSE which was livestock to be calculated. However, total DSE only included Macropods, as densities of unmanaged goats, horses, camels and donkeys were not provided. Macropods were estimated at 0.35 DSE/animal. The estimates presented for the percentage of livestock densities are as follows:

- Mitchell grass downs (Qld), excluding rabbits and unmanaged goats, livestock were around 87-95 percent of total DSE;
- Arid Deserts (SA, WA), excluding camels and rabbits, livestock represented over 95 percent of total DSE;
- Central Cattle Grazing zone (Qld, SA), excluding horses, camels, unmanaged goats and rabbits, livestock were between 74-100 percent of total DSE;
- Pilbara (WA), excluding unmanaged horses, donkey, camels, cattle and unmanaged goats, livestock were at least 87 percent of total DSE; and
- Extensive Sheep Grazing zone (Qld, NSW and SA), excluding unmanaged goats and rabbits, livestock contribute 71 percent of total DSE.

Across these many estimates of the percentage of TGP contributed by the three herbivore categories, the percentage contributed by managed livestock has varied between as low as 22 percent in the Simpson Strzelecki Dunefields, to over 90 percent in a number of locations in particular years. While the data for unmanaged goat grazing pressure is limited, Macropods have been observed to contribute up to 50 percent in some locations in recent years (using a conversion of one kangaroo = 0.35 DSE).

3.4 Implications for managing TGP

Land managers in the rangelands are required to manage natural resources responsibly, with the aim of at least maintaining – and where possible improving – range condition. As well as a responsibility for sustainability, there is also a benefit to be gained in terms of improved animal production, mainly in drier times.

Land management is a challenging task in many rangeland environments, and it is made more so given that less than half of the herbivory (sheep, cattle and managed goats) is easily managed. The numbers of unmanaged herbivores are very high in areas protected behind the National Dog Fence, which are now also the areas where most of the sheep are grazed in the rangelands.

Macropods and unmanaged goats are the principal unmanaged herbivores, and numbers relative to livestock numbers can vary considerably over space and time. This can interfere with land managers' objectives to spell or rest areas of land to encourage immediate forage growth and longer-term rangeland recovery. More generally, Macropods and feral goats may reduce the quality of forage available for livestock. Harvesting unmanaged herbivores is ineffective as a means of region-wide population control, although financial returns from harvesting unmanaged goats provide useful income for businesses in the rangelands. While Macropod numbers can be contained by wild dog predation in areas without wild dog control, land managers in those environments can only feasible run cattle.

Improved methods for TGP management need to facilitate the rest and recovery of pastures which will be underpinned by an ability to quantify the spatial and temporal distribution of all herbivores.

4. Industry perceptions

4.1 Summary - key messages and knowledge gaps

Key messages

Land managers and service providers in the Southern Rangelands indicated that a reduction in forage demand from unmanaged herbivores was required.
Land managers in the Southern Rangelands are prepared to tolerate some forage demand from unmanaged herbivores but less than current levels.
Unmanaged herbivores commonly include goats and kangaroos. However, importantly, camels, donkeys and pigs need to be also included when referring to unmanaged herbivores.
Land manager perceptions of numbers of unmanaged herbivores match regional monitoring reports.
Land managers and service providers recognise that resource condition is impacted by managed and unmanaged herbivores.
Managed herbivores (livestock) reported as having both positive and negative impacts on resource condition, but these impacts can be managed.
Land managers reported the impact of kangaroos on business profitability which appears to be at odds with that reported in the scientific literature.
The respondents described the negative impact on pasture as the inability to provide pasture rest and recovery time, resulting from an inability to prevent unmanaged grazing pressure.
Unmanaged herbivores reported as having negative impacts on resource condition, but cannot be easily/readily managed.
Land managers and other stakeholder groups believe that kangaroo management and fencing will have the greatest impact on TGP management over the next five years.

Knowledge gaps

Cost benefit and feasibility of TGP management options, particularly fencing.
TGP Management options that allow pasture rest and recovery.
Identifying temporal and spatial densities of Macropod populations which result in competition for feed base.

4.2 Background

Total grazing pressure varies from property to property, regionally, and on a state basis due to differences in livestock production systems, abundance of unmanaged herbivores, seasonal conditions, infrastructure and state legislation and policy.

The industry consultation reported in this section captured local knowledge regarding levels of TGP, impacts of TGP, management practices for TGP current and future; to inform the review of current knowledge; and the research, development and adoption investment plan.

4.3 Survey of land managers and service providers

The Project Steering Committee, project partners and two social science specialists contributed to drafting and review of the survey. The preliminary survey was tested by 31 participants (mix of Land Managers and Service Providers) from Western Australia and by the Project Steering Committee and then finalised.

A self-administered electronic or hard-copy survey was designed to obtain opinions, attitudes and knowledge, and management practices, regarding:

i. unmanaged and managed herbivores including changes in their abundance;

ii. the impacts of unmanaged and managed herbivores on soils, pastures and business profitability;

iii. effectiveness of management practices; and

iv. future management of TGP.

Survey distribution was guided by engagement plans, prepared for each state. Engagement plans were developed in collaboration with project partners and identified regionally specific networks, groups, communication channels and industry events and field days. The project team and regional collaborators attended events to promote and distribute the survey (see Table 4-1).

Table 4-1: Engagement plan summary

State	Project partners	Target networks	Communication channels
NSW	Western Local Land Services	Landcare Groups	Western Division Newsletter; Local Land Services e-Newsletters; Pastoralist Association of the West Darling newsletter; Contact lists of regional service providers representing Local Land Services, NSW Farmers, Rural Financial Councillors.
Queensland	Department of Agriculture and Fisheries and South West NRM	Leading Sheep and Future Beef	Contact lists of regional service providers representing Desert Channels, South West NRM, Agforce, and Queensland Department of Agriculture and Fisheries
South Australia	PIRSA and Natural Resources SA Arid Lands	Natural Resource Management (NRM) district groups and their networks	Natural Resources SA Arid Lands Facebook page and website; e-version of Across the Outback; Pastoral Board of South Australia Communique; promotion at SA Landcare Conference; and contact lists of key service providers.
Western Australia	Revell Science Rangelands NRM	Sub-regional groups and Recognised Biosecurity associations	Rangelands NRM Newsletter, Recognised Biosecurity Association communications, Department of Primary Industries and Regional Development communiques

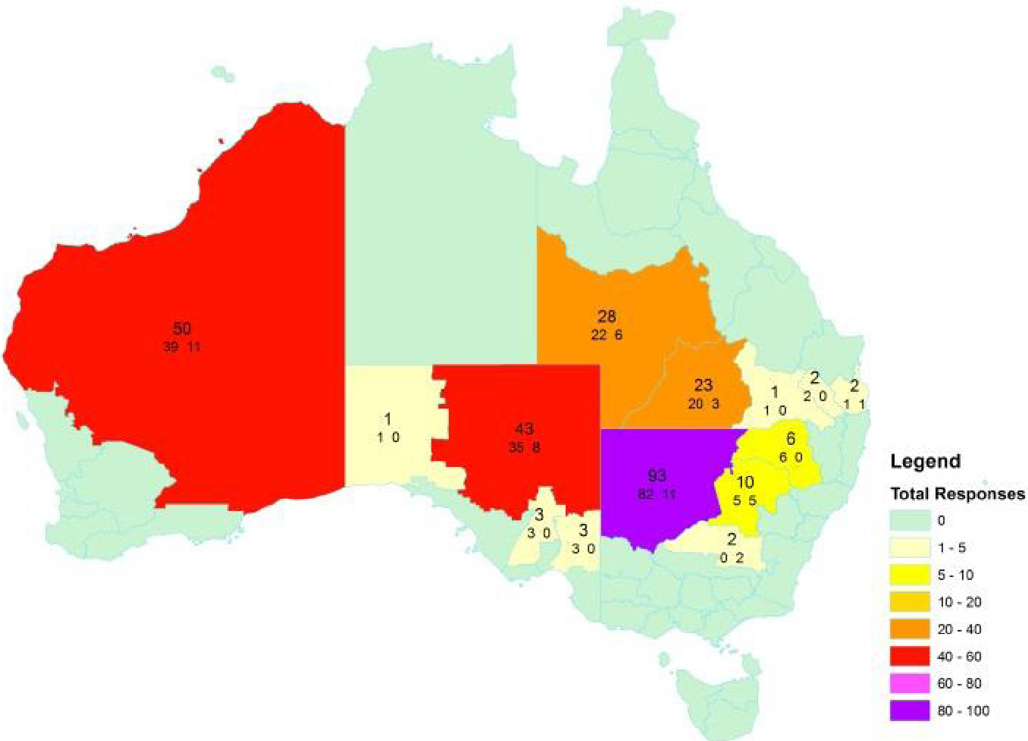
The survey responses were collected from March to December 2017. Land managers were asked to respond to the survey based on their experience over the last five years (2012-2017), and service providers were asked to respond based on their regional experience over the last five years (2012-2017). Surveys were considered valid and included in the analysis if the respondent answered at least one question relating to total grazing pressure.

Descriptive analysis was used to summarise the findings for the sample. The contributed written comments are reported without amendment. Potential sources of survey error include self-selection, non-response and participant error. Preliminary survey test responses from WA were included in the analysis as only minor amendments were made to the final version of the survey. Differences between the preliminary and final survey forms were reported in the results.

4.4 Results and discussion

Overall, 266 people participated in the survey. Land managers (n=219) and service providers (n=47) contributed from all NRM regions in Southern Rangelands (as shown in Figure 4-1).

Figure 4-1: The number of total valid surveys completed (top figure) in each NRM region, and the number completed by Land Managers (bottom left) and Service Providers (bottom right)



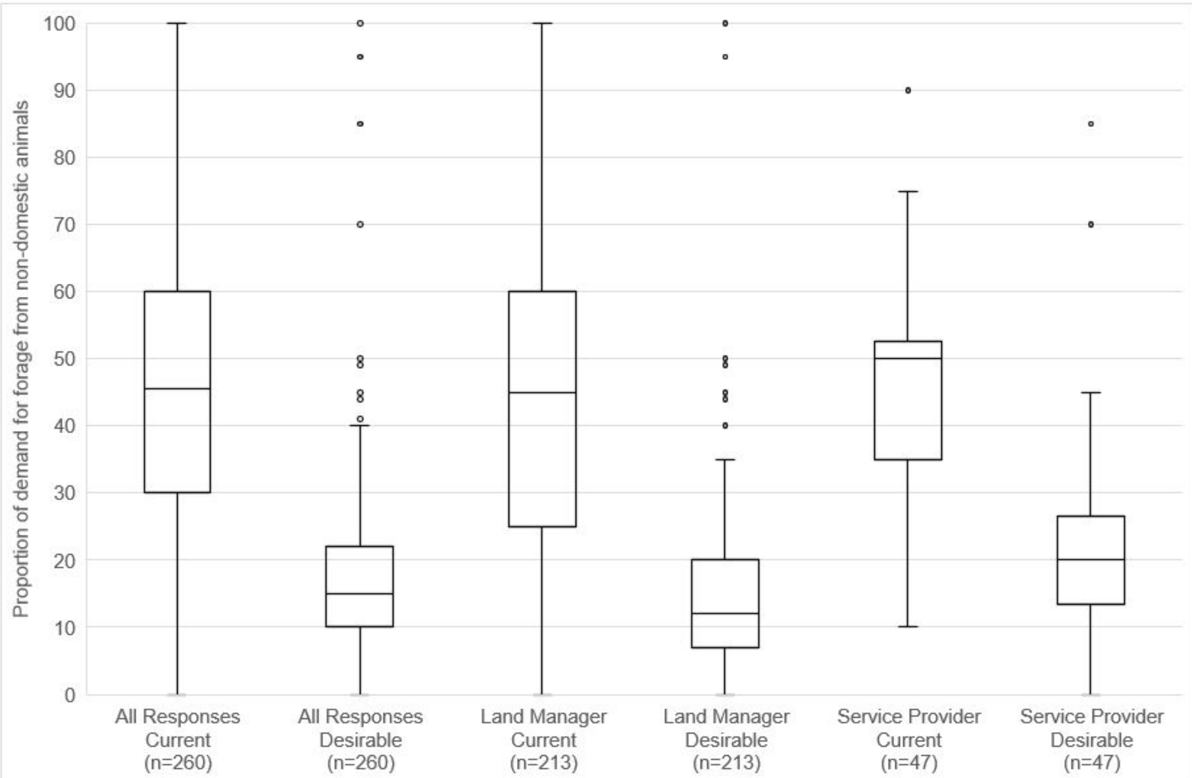
4.4.1 Forage demand by unmanaged herbivores

Land managers and service provider estimates of the current proportion of demand for forage from unmanaged herbivores[6] were similar with a median of 45 percent and 50 percent respectively (Figure 4-2). The estimates by service providers for the current proportion of demand for forage from unmanaged herbivores had a smaller range compared to the ranges estimated by land managers. The range described by service providers is not unexpected due to the larger geographic area covered by the survey.

The estimates of the current proportion of demand and the desired level of demand for forage from unmanaged herbivores indicates that a decrease in the demand for forage from unmanaged herbivores is required to achieve both the desired levels of demand indicated by both land managers and service providers.

The median desired proportion of demand for forage from unmanaged herbivores by land managers and service providers in the Southern Rangelands was 12 and 20 percent, respectively.

Figure 4-2: All responses, land managers and service providers current and desirable proportion of demand for forage from unmanaged herbivores.

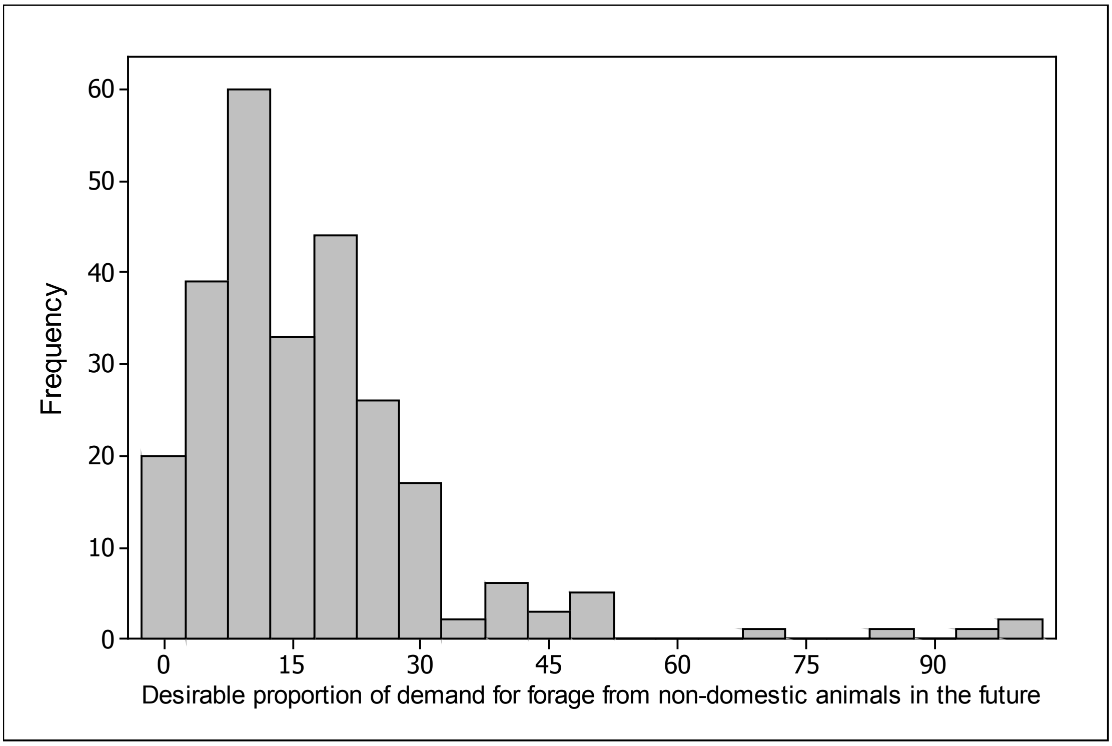


For each column, the ends of the box are the upper and lower quartiles (shows interquartile range); the median is the vertical line inside the box, whiskers denote the highest and lowest results (not including outliers), and circles indicate outliers (IQR x 1.5). Responses to Q5 – Considering current TGP, what proportion of the demand for forage comes from non-domestics animals, and Q6 – In the future (next five years), what proportion of the demand for forage coming from non-domestic animals would you consider to be a desirable level.

[6] The term non-domestic animals was used in surveys

Land managers and service providers indicated that in the future the desirable proportion of demand for forage from unmanaged herbivores would be 30 percent or less (92% of responses), with the modal value being 10 percent (Figure 4-3).

Figure 4-3: Frequency of respondents (both land managers and service providers) estimated desirable proportion of demand for forage from unmanaged herbivores in the future



Responses to Q6 – In the future (next five years), what proportion of the demand for forage coming from non-domestic animals would you consider to be a desirable level?

4.4.2 Changes in unmanaged herbivore numbers

The percentage of respondents (land managers and service providers) who stated that unmanaged herbivore numbers had changed in the last five years is shown in Table 4-2

Table 4-2: Reported change in unmanaged herbivore numbers in the last five years

Animal type	Percentage of respondents								
	Reporting +/- change	NSW		Queensland		South Australia		Western Australia	
		Increase	Decrease	Increase	Decrease	Increase	Decrease	Increase	Decrease
Kangaroos	98	>80		>80		>80			>10
Feral goats	68	36	39		56	42			>77
Camels	23	Generally stable, but insufficient data							
Donkeys	19	Generally stable, but insufficient data							
Rabbits	84		49-63	Insufficient data			49-63	41	

A high percentage of respondents reported that the main unmanaged herbivore species (kangaroos, goats, rabbits and pigs) have varied in numbers over the last five years. Most respondents in NSW, Queensland and South Australia consider that kangaroo numbers have increased over the time period, which aligns with the available data.

Unmanaged goats have varied in numbers within NSW, QLD and SA, but are reported by most WA respondents to have decreased in that state. The main reasons given for a decrease in unmanaged goat numbers were wild dogs and high sale prices for harvested goats. Where unmanaged goat numbers have increased, this is attributed to the release of underweight goats and male-biased harvesting.

Donkey numbers are generally stable, with some producers in NSW and Queensland, using donkeys as guard animals. In NSW, Queensland and South Australia, the majority of responses (49-63%) indicated that rabbit numbers had remained stable. In Western Australia, the largest proportion of respondents (41%) indicated an increase in rabbit numbers, with increased numbers attributed to seasonal conditions.

4.4.3 Resource condition

The majority of respondents (>59%) said livestock and unmanaged herbivores have a negative impact on soils, with the most frequently mentioned impact being erosion or compaction, often linked to over-grazing or low ground cover.

Respondents commonly indicated that the impact livestock (managed herbivores) have on soils depends on the land manager's management, illustrated by a quote from one respondent "*Impacts depend on management i.e. the amount of time the plants are exposed to grazing pressure and the length of the recovery period*". In contrast, unmanaged herbivores impact on soils cannot be easily or readily managed.

Respondents stated that livestock (managed herbivores) and unmanaged herbivores have negative impacts on pastures, although a greater proportion of respondents said unmanaged herbivores can have a larger negative impact on pastures than livestock. However, the nature of the impact of unmanaged herbivores on pastures depends on the on the level of management, and particularly the capacity to control unmanaged herbivores. Respondents described the negative impact on pasture as the inability to provide pasture rest and recovery time, as a result of an inability to prevent unmanaged grazing pressure by unmanaged herbivores on areas being spelled by removing livestock.

4.4.4 Business profitability

More than 60 percent of respondents said the unmanaged herbivores have a negative impact on livestock productivity, and more than 65 percent of respondents said that unmanaged herbivores (kangaroos, camels, donkeys and rabbits) have a negative impact on business profitability. Kangaroos had the greatest impact. The most common impacts reported were:

i. land managers had to reduce stocking rates due to competition from unmanaged herbivores;

ii. difficulties with grazing management e.g. unable to incorporate critical growing season rest; and

iii. competition for water or fouling of water (reduced quality).

In contrast, the role of unmanaged goats on business profitability varied with over 40 percent of respondents indicating that goats have a positive impact on business profitability, but a similar proportion (45%) said unmanaged goats have a negative impact on business.

4.4.5 TGP management influences – current and future

Respondents indicated that they can more easily adjust livestock and unmanaged goat numbers relative to feed-supply than managing kangaroos and 'other' grazing animal numbers.

Practices that have resulted in the best improvements in TGP management include: exclusion fencing, grazing management, adjusting stocking rate, water management and harvesting/culling. Land managers are more likely to use a combination of management practices for management of TGP, with 85 percent of responses listing more than three practices.

Factors survey respondents (n = 197) most frequently identified that would make a substantial difference to their ability to manage TGP in the next 10 years were:

i. improving kangaroo management;

ii. fencing;

iii. pest control;

iv. technology and

v. funding/incentives.

Detailed responses are shown in Table 4-3.

Improving kangaroo management

Nearly half (49%) of the responses indicated that improved kangaroo management would make a difference to TGP management. The most common approach suggested for reducing kangaroo numbers was industry/market development. Changes to government policy or industry regulation and planning rated highly as mechanisms for managing kangaroo numbers. However, as shown in Table 3-4 above, commercial kangaroo harvesting has almost no impact on overall kangaroo numbers in any state.

Fencing

Fencing was identified as making a future difference to TGP management in 40 percent of responses. The main type of fencing mentioned was exclusion fencing. In most cases, the respondents did not specify what species the fencing would be used to manage, but where this was specified, kangaroos were the most frequently mentioned species.

As described by one respondent: "*We live in NSW and are planning on trying to do our own exclusion fence to help control grazing pressure from the increased number in population of kangaroos and emus, as it is impossible to spell pasture in paddocks due to the grazing pressure from them. We are also hopeful that the exclusion fencing will help control the continued increase of wild dogs*."

Pest control

The pest control response in making a difference to TGP management related to maintaining or improving control efforts for a range of pest animals. Often the respondents referred to controlling unmanaged animals, pests or vermin without mentioning a specific species. Pigs were the most frequently referred to pest species in relation to pest control, followed by rabbits and wild dogs.

Technology

The technology response in this section included general comments such as new technology or improved access to technology. Improvements in fencing (including virtual fencing and trap yards) and water management were specifically mentioned. Access to real-time information about pasture, soils, weather and grazing pressure for decision-making was also important. The responses included the importance of emerging technologies such as drones, auto-drafting and weighing, and tracking animals via satellite.

As described by one respondent: "Access to real time data on climate, weather tools to readily calculate pasture biomass for more [accurate] feed budgeting. Increased ability to rapidly [manipulate] livestock numbers (stocking rate) and other grazing animals numbers in [response] to data on climate and pasture production".

Funding/incentives

The majority of the responses relating to the funding and incentives theme were to support fencing or other infrastructure (e.g. trap yards) in order to make a difference to TGP management.

4.5 Implications for managing TGP

The numbers of unmanaged herbivores reported by land managers match regional monitoring reports (Section 3). The survey respondents regard unmanaged herbivory as a significant problem affecting the performance of their pastoral businesses – in both environmental and financial terms (Table 4-3). Unmanaged herbivores commonly include goats and kangaroos. However, camels, donkeys and pigs need to be also included when referring to unmanaged herbivores, with pigs increasing in importance.

Although, land managers and service providers are prepared to tolerate some forage demand from Macropods and unmanaged goats, they see current levels as being too high. Further, they believe unmanaged herbivory is costing them more than the estimates provided by responsible state agencies and the literature.

Land managers responding to the survey would like to see a reduction in unmanaged herbivory but recognise that some current control technologies are not cost-effective or payback periods are unknown. They would like to see improved technologies – especially in being able to control unmanaged herbivores and wild dogs spatially – and some financial assistance with implementing these methods.

Table 4-3: Unedited survey respondents (number of respondents, NR) suggested approaches to managing TGP

Theme	NR.	Sub-theme	Quotes from respondents
Improving kangaroo management	96	Industry/market development Changed Government policy or regulation/planning Unspecified reduction/ increased control Culling Increased ability to manage Source of income, profit, value Technology/new methods Public perception	• Government policy to mitigate kangaroos on a permit of 5,000 at a time reducing paperwork and time for both government and land managers. • More markets for roos and better ways of processing. • Kangaroo shooters to be brought together with land managers to help each other for a win win and a good business model. • Red tape on shooting kangaroos to decrease technology to muster and load kangaroos to harvest and use them effectively. • This is a chance to collectively put a picture together maybe to build a kangaroo/ wallaby management plan... • Kangaroos are the biggest issue on my farm in relation to TGP pressure so increased measures to control them would be key. • Ability to manage kangaroo numbers in line with available feed and water resources, the same as we do now with our livestock. • Better kangaroo markets or cull laws.

Theme	NR.	Sub-theme	Quotes from respondents
Fencing	79	Type: • Exclusion • Unspecified • TGP • Cluster • Smaller Paddocks • Virtual • Higher • Hinge-joint	• Exclusion fencing for unmanged animals would be the main one in our area. • The continuation of exclusion fencing projects and kangaroo mitigation. • Exclusion fencng. • Virtual fencing. • Sustained funding for exclusion fencing - perhaps in a different style to clusters, make it applicable to individuals... • Increased fencing infrastructure...
		To manage: • Unspecified • Kangaroos • Livestock • TGP • Pest animals • Goats • Emus • Unmanaged animals • Dogs	• More secure fencing (higher) to stop influx of kangaroos after storm rains etc. e.g. cluster fence. • Exclusion fencing is proving the best measure as you have some hope of keeping other pest animals out. Without it, you could trap/bait/shoot wild dogs, harvest goats/kangaroos and new ones will move into the cleaned out territory, especially after rainfall so does not allow for pasture to develop... • We live in NSW and are planning on trying to do our own exclusion fence to help control grazing pressure from the increased number in population of kangaroos and emus, as it is impossible to spell pasture in paddocks due to the grazing pressure from them. We are also hopeful that the exclusion fencing will help control the continued increase of wild dogs...
Pest control	31	Ferals/pests Pigs Rabbits Wild dogs/ Dingoes Unmanaged goats Foxes Donkeys Camels Emus	• Not having anyone bait or kill the dingoes here. Having a way of detecting and killing donkeys and camels. • Easier feral animal control... • Mandatory pig control... • Conversion from unmanaged to managed goat farming. • New forms of biological control for rabbits • Continue feral herbivore shoots alternative to 1080 baits for dingos for organic properties... • More control of camels and donkeys. • Cull vermin (donkeys/ rabbits/ camels... • Try to reduce all other pest animals...

Theme	NR.	Sub-theme	Quotes from respondents
Technology	26	Technology (Unspecified) Fencing innovation (e.g virtual and trap yards) Access to information for decision making Water control/ management Auto-drafting/ weighing Drones Pest management (new methods) Kangaroo management (new methods) Labour saving Animal tracking via satellite	• New technology will also have a major impact on things such as remote monitoring of waters, automatic weighing and drafting of stock in the paddock as they come into water and improved efficiency water pumping and other equipment… • Labour saving technology… • Virtual fencing. • Access to real time data on climate, weather tools to readily calculate pasture biomass for more accurate feed budgeting. Increased ability to rapidly manipulate livestock numbers (SR) and numbers of other grazing animals in response to data on climate and pasture production. • Technology. Better design trap yards for multi-species control. • Access to new technology (especially where it can improve efficiency.
Funding and incentives	25	Fencing and Infrastructure (e.g. trap-yards) Funding for education, training and networking Payments for managing kangaroos Stewardship payments Changes to drought subsidies Giving wildlife a dollar value	• More funding available to assist with fencing costs… • Giving wildlife a dollar value for me as a landholder, as seen USA + Africa! Long term goal… • Any help that MLA may be able to do in assisting with erecting fences. Alike the front end loader initiative that AWI has in Longreach. perhaps facilitating clusters mediation in T&C's, cost/acre etc… • Exclusion cluster fencing subsidies in NSW similar to QLD. • Establishment of market mechanisms that provide an economic incentive, possibly via stewardship payments to manage for improved sustainable production outcomes.
Water management	24		• Increased fencing infrastructure and water points to increase grazing opportunities elsewhere… • More work on waters - ability to shut off watering points… • remote monitoring of waters…improved efficiency water pumping and other equipment…
Training and education	20		• Networking to spread good ideas is essential… • Greater priority given to funding management training in the skills required to increase ground-cover and maintain it during poor seasons… • Always new skills and knowledge

Theme	NR.	Sub-theme	Quotes from respondents
Grazing management	20		• Continue to monitor all forms of grazing pressure and regulate domestic numbers… • Increased ability to rapidly manipluate livestock numbers (SR) and other grazing animals numbers in responce to data on climate and pasture production. • Hingejoint-type fencing has to be combined with good grazing management in order to make a positive change…
Season / rainfall			• A return to some better years of rainfall… • Good consistence wet seasons, tell me how to achieve this please. • Rain…
Profitability / market conditions			• Markets and prices… • As an enterprise becomes more profitable many limitations are removed, animal welfare, grazing management, spelling, fencing and water infrastructure, employment opportunities… • Maintaining markets to current levels or higher bringing more money into the farm gate will help grazier's meet the costs of building exclusion fencing, managing vegetation, improving country and growing production grasses and crops which will all in turn make a substantial difference in managing TPG. They wont have to run more animals if the grasses become more productive with less competition…
Policy change	8		• Change drought subsidies to follow the same rules as other natural disasters & apply them to townspeople as well as rural producers • Being not so constrained by Pastoral Board Regulations, to be able to conduct other farming type practices on a pastoral lease e.g. feed lotting, irrigation. • Keep the government (particularly Qld state govt and Federal too if they go down the vegetation laws path), out of the way of graziers trying to manage their vegetation and making their properties more productive…
Control woody weeds	5		• Controling woody weeds… • Vegetation management - to have the ability to control regrowth. • Control method for woody weeds…

5. Relationship between TGP management, production and resource condition

5.1 Summary - key messages and knowledge gaps

Key messages

The quantity and quality of forage available for all herbivores within the Southern Rangelands is frequently low, during which time animal performance (both domestic and non-domestic herbivores) can be poor and forage risks being degraded. This is most apparent when high densities of herbivores coincide with periods of low rainfall. However, an imbalance between forage supply and forage demand may also occur under a range of seasonal conditions.
Most non-domestic herbivores are not managed in proportion to the feedbase they consume, and are not harvested for economic return as efficiently as domestic herbivores.
Increasingly, various forms of rotational grazing and pasture spelling are being practiced by land managers, but grazing by Macropods reduces any benefits (e.g. increased ground cover) they may gain from spelling pastures and rotationally grazing livestock.
Macropod numbers are higher now that at the time of European settlement, and current commercial harvesting has no impact on numbers.
Competition for pasture occurs when biomass falls below 300 kg/ha, while other studies suggest this occurs when biomass falls below 400 to 500 kg/ha.
When compared on a per kg metabolic body weight basis, the daily dry matter intake by macropods appears to be around 75% of that of sheep when fed a low fibre forage such as young grass leaf. However, when forage contains high levels of fibre, such as grass stems, macropods and sheep consume similar amounts daily.
At any one time, the dietary composition of livestock, Macropods and unmanaged goats is often quite different. However, all species of herbivore appear to rely on the same broad groups of forages (annual and perennial grasses, ephemeral and perennial forbs) for the large majority of their feed.
Overlap in the diets of livestock, Macropods and goats appear to occur sequentially over a range of climatic conditions.
The cost to land managers from supporting kangaroos is estimated between $2 and $3.40 per kangaroo/annum.

Knowledge gaps

Early identification of an imbalance between feed supply and feed demand that would enable land managers to take action to manage total grazing pressure.
Quantification of the impact on resource condition, forage availability and financial returns by unmanaged herbivores.
Ability to identify when livestock density approaches thresholds of an imbalance between feed supply and demand at landscape and patch scales.
Would it be possible to maintain pasture yields above 300 kg-500kg/ha and would this limit competition between livestock and macropods for forage? Or, do macropods reduce forage quality and thus potentially reduce livestock productivity even when pasture yields exceed 300-500 kg/ha?

5.2 The production system in the Southern Rangelands

Pastoral enterprises in the Southern Rangelands graze predominantly sheep or cattle, or sheep and cattle. Managed goats are becoming more common, but goat enterprises primarily rely on sheep and/or cattle production. Enterprises tend to be low input and extensive, where stocking rates are much lower and property size much larger compared to higher rainfall zones.

5.2.1 The dynamics of semiarid and arid rangeland grazing systems

Much as has been written on underlying principles which describe interactions between grazing herbivores and vegetation in semi-arid and arid rangelands. Two broad, contrasting principles are those of 'equilibrial' or 'non-equilibrial' systems. The assumption of an equilibrial system, which implies a state of balance, can be achieved between herbivores and vegetation but carries the risk of inappropriate recommendations of a fixed stocking rate or carrying capacity. A contrary view, which arose from work in Africa in the 1980s and 1990s, is that rangeland systems are 'non-equilibrial' due to considerable environmental temporal and spatial variability. Illius and O'Connor (1999) provided a robust review, critiquing the proposition that populations of plants and animals are governed by 'non-equilibrial' processes. The non-equibrial proposition argues, as stated by Illius and O'Connor (1999), that "*plant production in highly variable climates is largely determined by rainfall and is [relatively] unaffected by animal population density*". We contend that this statement is more likely to be true where the herbivores are native and have to fend for themselves, such as Macropods. Where herbivores are livestock, and where management decouples them from the environment, it is less likely to be true. An over-reliance on the assumption of non-equilibrial processes would imply that grazing has a relatively negligible impact on plant populations, and clearly that is not the universal case in Australian rangelands. Relying on either equilibrial or non-equilibrial processes to explain the balance between grazing herbivores and vegetation is inadequate.

The conclusion of *Illius and O'Connor (1999)*, which appears consistent with experiences in Australian rangeland systems is that, depending on the spatial and temporal scale, there are elements of both equilibrial and non-equilibrial processes at work, and that perhaps the best way to view the semi-arid and arid grazing systems is that they can be – and perhaps more are often than not – in a state where equilibrium is not reached (i.e. in a state of 'disequlibrium'). This is because environmental fluctuations and random variation in other parameters are "*constantly redefining the equilibrium point, sometimes at a faster rate than the system can respond*". In other words, the system is in a permanent orbit around a moving point. It is also conceivable that when certain thresholds are passed, the system moves into a new 'orbit'. This might occur when grasslands morph into shrub or woodlands, or when erosion removes topsoil, organic matter and nutrients. We suggest that the concept of a changing equilibrium is important to grasp when trying to describe or predict the consequences of TGP. The scale and direction that the system responds to an intervention can depend on where the system is on its orbit. This has implications to the degree of management effort and financial resources that should be allocated to controlling TGP.

At any given point in time, the relationship between vegetation and herbivores can be considered as a point on a trajectory that orbits, but may never reach, a point of equilibrium. The trajectory would only reach the point of equilibrium if all the abiotic and biotic factors remained constant, but of course they do not. Over time and space, the system experiences variation in abiotic factors such as rainfall and fire, and biotic factors (e.g., plant phenology (new shoots, seed set, maturation, dormancy or senescence) and animal physiology (e.g. pregnancy, lactation, growth, behaviour and health status)).

The position in the landscape adds another level of variability and complexity, largely by how it changes the accessibility to water by plants (e.g. drainage lines, riparian areas, or low-lying plains that have access to soil moisture versus elevated rocky areas that are drier) and by animals (naturally occurring water or artificial watering points). The provision of shade and the thermal environment is yet another factor influencing habitat selection (see Section 5.4).

5.2.2 Domestic herbivore management

Continuous grazing of livestock, with little change in stocking rates except when drought forces land managers to markedly reduce numbers of sheep or cattle, is the most common grazing management strategy in the Southern Rangelands (Fisher *et al*. 2004). This is particularly the case in the chenopod shrublands and mulga woodlands / shrublands where annual and perennial grasses and forbs provide the bulk of forage for livestock during average and above average rainfall years, and where shrubs and trees supplement this during dry years.

In the grasslands, inter-annual variation in forage quantity and quality is high, and there is a lack of palatable shrubs and trees which supply dry-season or dry-year forage reserves. Hence, land managers more often need to adjust sheep and cattle stocking rates in response to high inter-annual variability in forage conditions. Adjusting stocking rates annually is also recommended for less arid parts of the Southern Rangelands. While they have more regular growing seasons, there is still considerable inter-annual variability. Land managers are encouraged to adjust stocking rates at the end of the growing season or in response to atypical seasonal conditions to avoid over-grazing and subsequent pasture degradation and poor animal performance.

Increasingly, various forms of rotational grazing and pasture spelling are being practiced by land managers. These may occur systematically in accordance with weekly, seasonal or annual rules. However, it is more common for pasture spelling to occur opportunistically, after rain when there is sufficient forage to enable one or more paddocks to be rested. Opportunistic spelling may also occur during drought following destocking, but is much less effective at regenerating pastures compared with spelling actively growing plants. Some land managers will also spell paddocks so that they have a feed reserve to be used during dry seasons or dry years, or for young growing livestock, or for building up fuel supplies for a controlled burn.

5.2.3 Unmanaged and native herbivore management

Unmanaged goats

Unmanaged goats are widely believed to reduce the forage supplies available to sheep and cattle, and on some occasions to the extent this reduces the rates of growth, reproduction and survival of sheep and cattle. They compete with sheep and cattle for forage resources in the rangelands. Unmanaged goats are mustered and sold when numbers and prices are favourable, and hence is an opportunistic enterprise. Prices for goats have often been low, during which time harvesting rates decline and their numbers build up. Recent reviews have shown that unmanaged goats have provided an important source of income for land managers in areas where they are abundant (URS 2015).

Macropods

Densities of kangaroos and euro/wallaroo can be high following a sequence of years of average or above average rainfall, and at these times they can be a substantial component of unmanaged total grazing pressure. Numbers are considered to be higher now than at the time of European settlement, particularly in the ‘sheep rangelands’, where dingo numbers are low due to exclusion fencing or intensive control activities (Pople and Grigg 1999).

Macropods rarely provide income for land managers. Hence, much of the debate about the role of Macropods in pastoral enterprises concerns their costs. In this respect, there is a major divergence of views between the scientific literature and land managers concerning the extent that large Macropods compete for forage with livestock and subsequently reduce the productivity of livestock enterprises.

The scientific literature tends to conclude that competition between Macropods and livestock, particularly sheep, seldom occurs, because food is often not limiting, because food choices or feeding sites differ, and because kangaroos often contribute little to total grazing pressure (Dawson and Ellis 1994, Edwards *et al*. 1996, Pople and Grigg 1999, Olsen and Low 2006, Dawson and Munn 2007).

This is in marked contrast to the views of land managers, who believe that kangaroos are a major constraint to the productivity of sheep and cattle (Collins and Menz 1986, Gibson and Young 1987, Sloan *et al*. 1988). A survey of land managers by Gibson and Young (1987) reported that the estimated annual costs of kangaroos per property varied from $3,800 to $15,000, that the costs of kangaroos per hectare ranged from $0.06 to $0.43 per annum, and that the cost per kangaroo ranged from $2.00 to $3.40 per annum. Land managers also state that grazing by kangaroos reduces the benefits they may gain from resting pastures and rotationally grazing livestock. Evidence of this was found during the 10 year 'Boolathana Grazing Trial' in the Gascoyne, WA. Here, kangaroos preferentially grazed conservatively stocked sheep paddocks with dung counts showing 50-100 percent more kangaroos in lightly stocked paddocks compared to heavily grazed paddocks (Holm 1994, Watson *et al*. 1988).

Populations of the large Macropod species are harvested annually for meat and skins in accordance with annual quotas of between 10 and 20 percent of estimated population size (Department of Environment and Energy 2017). As described in Section 3, only around 20 to 50 percent of annual quotas have been harvested and consequently the commercial Macropod industry is likely to have little impact on the size and density of Macropod populations.

In addition to the commercial harvest of Macropods, land managers can acquire permits that enable them to shoot Macropods for the purpose of limiting their impacts on infrastructure, pastures and livestock production, but limited use is made of this facility, which is recognised as an activity with no immediate commercial return for the land manager.

5.2.4 Implications of Macropods and unmanaged goats for livestock productivity – an introduction

This section of the review is entirely based on a review of literature which provides insights into the extent that large species of Macropods and unmanaged goats compete with livestock, and thus, reduce the productivity and profitability of pastoral enterprises in those parts of Southern Rangelands where they occur in significant numbers (being areas protected from wild dog predation). It is noted that other species of non-domestic herbivore – camels, donkeys and rabbits also contribute to TGP when in high densities.

There is considerable consensus that unmanaged goats do compete with sheep and cattle. It is widely accepted that they do reduce the profitability of pastoral enterprises by reducing the number of livestock that can be carried and by damaging fences. However, harvesting unmanaged goats and selling them directly to markets, or using unmanaged goat stock to establish domestic goat herds, can create significant income for land managers (URS 2015). This scenario concerning unmanaged goats is very different to that involving the large Macropods, such as red, eastern and western grey kangaroos and the euro/wallaroo.

As noted in the previous section, there is a major divergence of views about the extent that large Macropods compete with livestock and subsequently reduce the productivity and profitability of livestock enterprises. As Descovich *et al*. (2016) wrote, '*the kangaroo is perceived as both a national icon and as a pest species*.'

We have attempted to address this divergent opinion by examining the characteristics of livestock and Macropods which determine the potential for interspecific competition. First of all, it was assumed that potential competition between livestock and Macropods would mainly involve their use of shared forage resources, and the extent that use of these limit availability for each other. There is little evidence that Macropods and livestock compete for water, as this is rarely limiting in the rangelands. Likewise, there is no evidence that competition occurs because they share sites used for resting, or for shelter or for reproduction, again because supply of these does not appear to be limited.

While populations of Macropods may eat similar or even greater amounts of available forage compared with livestock, does this imply they reduce the carrying capacity for livestock by equivalent amounts? For this to occur, Macropods would need to eat similar forages in similar places as livestock. While the diets of Macropods can be quite different to those of sheep and cattle on occasions, and while they may graze different parts of the landscape on occasions, over time, there appears to be considerable overlap in what they eat and where they eat it. Even assuming there is substantial overlap in diet composition and grazing distributions, reductions in livestock carrying capacity and performance will only occur when the quantity and quality of shared forages are inadequate for livestock. This certainly occurs on some occasions, such as during droughts, when forage biomass is very low and herbivore intakes do not satisfy maintenance requirements. Some studies indicate this occurs when pasture biomass falls below 300 kg/ha (Short 1985 and 1986), while other studies suggest this occurs when biomass falls below 400 to 500 kg/ha (Dawson and Ellis 1994 and Edwards *et al*. 1995). How often do these circumstances occur within the Southern Rangelands, and what are the impacts on livestock enterprises at these times?

Furthermore, relationships between species of herbivores and between herbivores and pastures are density dependent. Livestock are often maintained in significant numbers, while numbers of unmanaged and native herbivores vary enormously with seasonal variation. Numbers of livestock, unmanaged goats and Macropods all increase during sequences of years with average and above average rainfall. Invariably, when drier conditions return and all forage supplies are exhausted, livestock are supplemented, agisted or sold, over half of the Macropods die of starvation and goats relocate. At these times, what is the bio-physical and financial impact of unmanaged and native herbivores?

Generally, forage quality limits livestock productivity more than forage quantity. In the Southern Rangelands, quality is closely related to the phenology of pastures, being highest after rain when grasses and forbs are growing. It is these periods of pasture growth that are critical to periods of herbivore growth, body condition and reproduction. At these times, the diets of all species of herbivores are largely green grasses and newly grown forbs, and there appears to be considerable overlap in diet composition. However, the extent that they eat the same or different species of grasses and forbs is not known, and neither is the extent that grazing of these forages by one species of herbivore reduces their availability to others. This probably does not occur in seasons of high rainfall and high pasture production, but these conditions occur infrequently within the rangelands. There are many occasions when rainfall is both low and patchily distributed, when it is likely that Macropods and unmanaged goats reduce the availability of high quality young foliage for livestock. While this is likely to occur, how often and to what extent does this occur, and what impact does this have on livestock performance and enterprise profitability?

5.3 Interactions between vegetation and herbivores

Two concluding statements from Jonzén *et al.* (2005) relate directly to these current considerations on the interactions between vegetation and herbivores:

i. *"Rainfall is not always an adequate indicator or resource availability, and we still do not know how to approximate resource availability. The model that used rainfall as a surrogate for resources appears to have missed an aspect of resource dynamics."*

ii. *"The results indicate that we must think more carefully about mechanistic relationships between sheep, cattle, kangaroos and their resources. Hence, if we are ever to understand how demographic processes interact with environmental fluctuations, we need to go much further that simply model patterns in data. This calls for rigorous treatment of the problems, an understanding of the stochastic [random] nature of the phenomena."*

Clearly, using fixed rules to predict feeding behaviour is not possible. The nutritional characteristics of the plant species, the presence of secondary plant compounds, and relative abundance of different species all influence selective behaviours. Whilst it is tempting to classify cattle, sheep, goats and Macropods in some way to better gauge their likely impact on vegetation, relying on fixed categorisation not only oversimplifies reality, but also can be misleading. The different classes of animals may tend towards being grazers or browsers if given the choice, but the relative availability (abundance) and digestibility of different plant types and the past experiences of the animals will be dominant factors in determining plant composition in the selected diet.

5.3.1 Herbivore diets - factors which affect daily dry matter intake

While the field metabolic rate (FMR) of a herbivore, which is a measure of its energy use, has a significant influence on digestible dry matter intake (DDMI), so do the characteristics of forages, water requirements, ambient temperatures, differences in digestive tracts, and the abundance and quality of forages. Feeding trials which measure DDMIs provide a more direct method for comparing the intakes of similarly sized Macropods and sheep, and take into account some of the other factors which influence feed intake.

The livestock grazing trials reviewed in this report showed that DDMI of young grass leaf by herbivores is considerably higher than that of old grass leaf, and DDMI of grass leaves is considerably higher than that of grass stems of the same age (Laredo and Minson 1973, Thornton and Minson 1973, Poppi *et al*. 1980, Hendricksen *et al*. 1981, Poppi *et al*. 1981a, Poppi *et al.* 1981b, McLeod *et al*. 1990, Archimeade *et al*. 2000, and Drescher *et al*. 2006). The DDMI of sheep or cattle feeding on young grass leaves is around 30 percent higher compared with feeding on old grass leaves. Also, DDMI of sheep or cattle feeding on grass leaf is between 30-120 percent higher than when feeding on grass stems of the same age.

Bite size and bite rate also have a large influence on DDMI, although these also appear closely related to the amount of leaf present in forages. Drescher *et al*. (2006) observed that the bite size of cattle increased at a rapid rate with increases in the availability of a 100 percent leaf diet, but only increased marginally or not at all with increases in availability of 45 and 25 percent leaf diets (55 and 75% stems respectively). Bite rate was similarly affected, but not to the same extent as bite size. Hence, bite size limited forage intake rate much more than bite rate. For these reasons, Drescher *et al*. (2006) concluded that changes in the functional response curve were mainly caused by the response of bite size to forage quality. Due to increases in bite size and also bite rate, forage intake rate of cattle increased from around 10 g/min at a forage availability of 20 g/m^2, to 45 g/min at a forage availability of 100 g/m^2. Drescher *et al.* (2006) then proposed that changes in the foraging behaviour was not simply due to the decreased availability of high-quality leaves, but was at least in part caused by the interference of stems with the foraging process.

A number of studies have found that DDMI is often negatively related to the mean retention times (MRTs) of forage (Laredo and Minson 1973, Thornton and Minson 1973, Poppi *et al.* 1980, Hendricksen *et al*. 1981, Poppi *et al*. 1981a, Poppi *et al*. 1981b, Lechner-Doll *et al*. 1990), and that MRTs often differ between herbivores with different types of digestive systems.

Macropods also have a capacity to substantially increase their DDMI without causing appreciable declines in MRTs. They are able to do this by greatly expanding their gastro-intestinal tracts. In comparison, ruminant sheep and cattle had less ability to expand the gastro-intestinal tracts and thus any increase in DDMI is accompanied by a rapid decrease in MRT and probably digestive efficiency (Clauss *et al*. 2007). Hume (1984) also refers to the colon-like tubular morphology of the kangaroo stomach which allows them to excrete fluid much faster than particles (23 vs. 40 hrs for 90% excretion). This is shorter than that in sheep fed the same diet (38 and 44 hrs for 90% excretion). Food intake rates of kangaroos such as the wallaroo and red kangaroo fall less slowly with increases in the fibre content of forage than it does in ruminants. This is due to longer passage times in ruminants, which can exceed 60 hours on high fibre diets. On a high fibre diet, intake of wallaroos fell by 17 percent while that of sheep fell by 58 percent.

Munn *et al*. (2010) also referred to the difficulties faced by sheep associated with particle outflow from the rumen. In particular, a major consequence of the ruminant system is a potential limit to food intake resulting from bulky plant material filling the gut (Stevens and Hume 1995). Flow of material from the tubiform forestomach of kangaroos is not restricted by particle size as it is in sheep, and numerous haustrations of the kangaroo forestomach support gut expansibility (Munn and Dawson 2006), which probably assist kangaroos in sustaining food intakes during long feeding bouts.

Low pasture biomass may also limit intakes of forage by herbivores. Short (1985, 1986) monitored the food intakes of Merino sheep and red and western grey kangaroos as they progressively depleted arid zone pastures from 1000-1,200 kg/ha to an ungrazable residue. This author observed that daily dry matter intakes did not decline until pasture biomass fell below 300 kg/ha, and that these herbivores could not compete with each other at biomasses greater than this.

5.3.2 Influence of dietary fibre content on intake

The review of over 30 studies were reviewed which measured the DDMIs of sheep when fed low fibre diets such as lucerne hay and high fibre diets such as oaten straw. Of these, only a small number of studies measured intakes of Macropods and goats, and even fewer compared intakes of several species when fed the same forage. The live body weights of animals used in these studies were converted to metabolic body weights by raising live weights to the power of 0.73 for the eutherian mammals (sheep, goats) and 0.60 for marsupial mammals (Macropods). These power values are referred to as allometric exponents, and in general, are used to relate variation in body weight with associated variation in physiological and morphological traits of mammals, such as metabolism and gut volume respectively. Using these allometric components accounts for the decrease in metabolic rate per kg of body weight which occurs as total body weight increases, and therefore provides a better estimate of the absolute energy requirements of an animal. The allometric exponent values were derived by Capellini *et al*. (2010), and used by Munn *et al.* (2013) and Munn *et al.* (2016) in their comparisons of the field metabolic rates of sheep and Macropods. In this literature review, the forage intakes of sheep and goats were calculated in units of g/kg$^{0.73}$/day, and the forage intakes of Macropods were calculated in units of g/kg$^{0.73}$/day and g/kg$^{0.60}$/day. This enabled the intakes of sheep, goats and Macropods to be compared on a metabolic body weight basis.

The mean DDMIs of *low fibre forage*, for sheep, unmanaged goats and Macropods are presented in Table 5-1. These DDMIs were then used to derive total daily intakes for 35 kg animals, again on a metabolic body weight basis.

Table 5-1: Mean DDMI of a low fibre diet such as lucerne hay for sheep, unmanaged goats and Macropods

Herbivore	Mean DDMI g/kg$^{0.73}$/d		Mean DDMI g/kg$^{0.6}$/d		Total DDMI g/35 kg$^{0.73}$/d			Total DDMI g/35 kg$^{0.6}$/d		
	N	Mean	N	Mean	N	Mean	Ratio	N	Mean	Ratio
Sheep	26	73.4			26	984	1.00			
Unmanaged goat	4	65.1			4	872	0.89			
Red	20	55.2	19	85.5	20	739	0.75	19	722	0.73
Eastern grey	9	52.2	7	76.6	9	700	0.71	7	646	0.66
Euro	4	55.2	2	81.9	4	740	0.75	2	691	0.70
Western grey[1]	4	56.5	4	83.1	4	757	0.77	4	698	0.71

In g/kg$^{0.73}$/d for sheep and goats and in g/kg$^{0.73}$/d and g/kg$^{0.6}$/d for Macropods, and the corresponding total DDMI in grams for 35 kg animals (N = sample size, Ratio is the ratio of intake of goats to sheep, and Macropods to sheep when all weigh 35 kg).

[1] Values for western grey kangaroos based on Powell and Arnold (1984). In their study, the DDMI of four western greys was 0.77 that of sheep. Using the average intake of sheep above, then the intake of western greys is 56.5 g/kg$^{0.73}$/d. The DDMIs in g/kg$^{0.6}$/d for red kangaroos, eastern greys and euros were on average 1.47 times their intakes in g/kg$^{0.73}$/d. Based on this ratio, the intake of western greys is 83.1 g/kg$^{0.6}$/d.

The same comparisons were made when these animals were fed a *high fibre diet* such as oaten straw (Table 5-2).

Table 5-2: Mean DDMI of a high fibre diet such as oaten straw for sheep, unmanaged goats and Macropods

Herbivore	Mean DDMI $g/kg^{0.73}/d$		Mean DDMI $g/kg^{0.6}/d$		Total DDMI Intake $g/35\ kg^{0.73}/d$			Total DDMI Intake $g/35\ kg^{0.6}/d$		
	N	Mean	N	Mean	N	Mean	Ratio	N	Mean	Ratio
Sheep	16	39.5			16	529				
Unmanaged goat	3	42.4			3	568	1.07			
Red	10	31.4	9	45.1	10	420	0.79	9	381	0.72
E. grey	4	33.7	4	50.9	4	452	0.85	4	430	0.81
Euro	4	46.7	2	63.9	4	625	1.18	2	539	1.02
W. grey[1]	4	47.4	4	69.7	4	635	1.20	4	585	1.11

In $g/kg^{0.73}/d$ for sheep and goats and in $g/kg^{0.73}/d$ and $g/kg^{0.6}/d$ for Macropods, and the corresponding total DDMI in grams for 35 kg animals (N = sample size, Ratio is the ratio of intake of goats to sheep, and Macropods to sheep when all weigh 35 kg).

[1] Values for western grey kangaroos based on Powell and Arnold (1984). In their study, the DDMI of four western greys was 1.20 that of sheep. Using the average intake of sheep above, then the intake of western greys is 47.4 $g/kg^{0.73}/d$. The DDMIs in $g/kg^{0.6}/d$ for red kangaroos, eastern greys and euros were on average 1.47 times their intakes in $g/kg^{0.73}/d$. Based on this ratio, the intake of western greys is 69.7 $g/kg^{0.6}/d$.

The data in the tables show clear differences between sheep, unmanaged goats and Macropods in how they handle fibre in their diet. Sheep are greater consumers of low dietary fibre forage – as in growing seasons and when fresh leaf and forbs are available. However, they are lower consumers than the other classes of herbivore when dietary fibre increases – as when feed dries off, or becomes scarcer.

5.3.3 Gut morphology, plant architecture and diet selection

There have been numerous studies aiming to relate feed intake and diet selection of herbivores to their gut morphology. An animal's anatomy and physiology is an important factor influencing what is chooses to eat, but the characteristics of the plants also influence the animal behaviour and physiology (Shipley, 1999). In the context of this review, the gut morphology differences are greatest between ruminants (sheep, cattle, goats) and Macropods, which are non-ruminant, foregut fermenters (e.g. Clauss *et al.* (2010)). Indeed, considerable effort has been directed to understanding how characteristics of gut morphology and digestive processes might lead to different patterns of diet selection. The most common comparison in relation to TGP in the Southern Rangelands has been between sheep and kangaroos, either with free-ranging animals (e.g. Munn *et al.*, 2010; Munn *et al.*, 2014), in enclosed areas of natural vegetation (e.g. Parsons *et al.* 2006) or with pelleted or chopped prepared diets (e.g. Freudenberger and Hume, 1992). The results across studies are not consistent, probably due to differences between studies in the diets fed to the animals, and the species of Macropod involved, and, an oft-ignored feature, the previous feeding experiences of the animals, which is either not known or not described.

The main distinguishing features of grasses and browse are listed in Table 5-3. Evolutionary strategies to deal with the limitations of consuming grasses or browse are many and varied, and not restricted to gut morphology, but can also include differences in saliva (e.g. more tannin-binding proteins in the saliva of browsers), teeth structure, mouth structure (which influences bite size), and muzzle shape and size (browsers tend to have narrower muzzles allowing them to be more easily select new growth from plants).

Table 5-3: Distinguishing characteristics of grasses and browse (trees, shrubs and sub-shrubs) that can affect how herbivores can use them

Morphological features	Grasses	Browse
Cell walls	Thicker	Thinner
	Consist mainly of slowly-digestible cellulose	Contains more relatively indigestible lignin
Nutritive value (NV)	New growth high NV?, but can change quickly due to season and plant maturity	Generally low-moderate NV, but more consistent over time.
	Can be low in crude protein	Moderate-to high protein content
Secondary plant compounds	Silica, which increases tooth wear and reduces fibre digestion	Phenolics such as tannins – reduce protein digestibility in rumen but can increase the amount of 'by-pass protein' available at the small intestine.
		Terpenes – reduce DM digestibility
		Alkaloids – can be toxic
Re-growth	New tillers added at the base of the plant	New growth on the tips
Architecture	Relatively uniform	Heterogeneous mix of plant parts that differ in nutritive value

adapted from Shipley (1999).

Perhaps most pertinent to the discussion of TGP management is the dispersion of the different plant types in the landscape. Grazers that rely mostly on grasses tend to select patches where there is relative abundance of the most nutritious grasses, and move across these patches as feed is consumed. Browsers tend to choose bites more carefully, e.g. selecting specific leaves from heterogeneous shrub architecture. A high level of bite selectivity can also occur in grazers as well, although grazers may show more patch selectivity that bite selectivity.

5.3.4 Learned behaviours and diet selection

An alternative approach to broaden diet selectivity and habitat selection of domestic herbivores other than relying on the potentially risky approach of increasing stocking rate (which, it should be pointed out, is only risky if forward feed budgeting is inadequate). The alternative, or complementary, approach is to change animal behaviour so they do not form ingrained habits, but instead choose to incorporate more plants and more locations into their patterns of diet selection and habitat use (Revell *et al.* 2015). Where rotational grazing has successfully broadened diet selection (i.e. reduced selectivity), it may not necessarily be due to higher competition between animals as is usually assumed, but rather because moving animals to new areas provides the animals with repeated, positive experiences of the nutritional and anti-nutritional characteristics of a range of forages. Through positive nutritional and metabolic experiences, grazing animals are able to learn to successfully mix and match different plant species to meet their metabolic requirements (Ginane *et al.* 2015, Revell 2017). In cases where animals learn through repeated, stress-free movement – either guided by animal leaders in their group, by experienced shepherds (Meuret and Provenza 2016), or with Rangelands Self Herding methods (Revell *et al.* 2016; see later) – the animals' diet can be broadened by choice, rather than them being forced to be less selective because of high animal-animal competition or because of an outright lack of herbage biomass.

Grazing herbivores experience fluctuating seasonal conditions yet still need to select a diet that best meets their metabolic requirements (Ginane *et al.* 2015), which can change depending on physiological state, ambient conditions and health status. To cope with this variability, grazing herbivores must continuously assess how well their nutrient requirements are being met and modify their selection of forages as required (Provenza, 1995; Provenza *et al.* 2003).

Ginane *et al.* (2015) recently reviewed the complex interaction between sensory characteristics of plants and the metabolic demands of the animals that consume them. The initial decision-making process of an animal to seek and procure feed is strongly influenced by 'reward expectancy' (i.e. what an animal expects to receive by consuming the forage), which, in turn, is shaped by previous experiences. Whether a particular feeding behaviour continues is influenced by metabolic signals that relay information to the animal's central nervous system. Hence, information is nearly continuously collected and interpreted by the grazing herbivore – information about the characteristics of the plants on offer and the animal's own metabolic state.

Learning requires animals to associate specific signals or cues (e.g. sight, smell and taste) of forages to post-ingestive signals that arise in the body (Provenza, 1995). The post-ingestive signals feed back to the central nervous system to provide information on the physical load in the digestive tract and on the metabolic state of the animal (Ginane *et al.*, 2015). In complex situations where dietary choices are large and variable, dietary learning may take longer to occur (Ginane *et al.* 2009). Early life experiences can have a profound influence on later diet selection of grazing herbivores. An implication for TGP management is that the plant species on offer when animals are young – especially during the period where they are still interacting with their mother – can strongly shape the selection of different plants later in their life. This may go some way to explaining the lack of consistency across experiments that have quantified diet composition of livestock or wildlife (discussed earlier in this review). For example, a lack of diversity in plant species in the landscape when animals are young – e.g., after a drought when most of the preferred plants have been eliminated – may limit diet diversity thereafter. Animals fed a monotonous diet in early life are more reluctant to consume a variety of feeds later in life (Villalba *et al*. 2012).

The power of learning feeding behaviours from an individual's mother is shown by the data of Vu Hai *et al.* (2016). When a leaf material of a unpalatable shrub (*Chromonaela odorata* – a plant native to the Americas) was offered to weaned kid goats, their voluntary consumption of plant material nearly doubled over a four-week period, but only if the kids' mothers had consumed the plant during pregnancy. Consumption of the plant did not increase for kid goats whose mothers had not consumed it during pregnancy.

Management systems are often not designed to allow animals to learn about the functional attributes of different forages during their life cycle, from gestation onwards. Low stocking rates with abundant feed allow animals to consume only a subset of species from the full range on offer (‘eating the best and leaving the rest’), while high grazing pressure may broaden the diet through competition and necessity, but does not provide a good learning experience about the relative attributes of different components of the diet (‘eating the rest but not learning the best’).

Whilst the research discussed above has been in respect to livestock species, the underlying principles associated with diet selection, learnt behaviours, and interactions between a ‘reward system’ and a ‘homeostatic system’ (Ginane *et al.* 2015) will almost certainly hold for other herbivore species as well. If animals have not been managed to consume a diverse diet, or if seasonal conditions have not allowed them to experience a diverse range of plants – especially if this occurs during critical developmental windows in early life – then it is conceivable that there will be an elevated level of competition between animal species for a limited range of plants. A diversity of plants at a given point in time is not enough on its own to guarantee a diverse diet. Animals must have had the opportunity to experience the range of plants in the past and learnt how to incorporate different species into their diet. This potential adaptability of animals and the plasticity of behavioural patterns mean that the degree of competition for feed resources between animals should not be viewed as fixed, and perhaps not even predictable when we have incomplete knowledge of the animals’ circumstances and experiences.

5.3.5 Access to water

Access to water is a dominant factor affecting livestock distribution, especially in the arid ad semi-arid rangelands (Ganskopp 2001; Bailey 2016; Revell 2016). Cattle often remain within about 2 km of watering point, but can travel much further when required; e.g., 4 km in the Chihuahuan Desert (Bailey *et al.* 2010), which is consistent with GPS tracking data of cattle in Western Australian rangelands (D.K. Revell, personal communication).

Numerous studies of native animal and livestock herbivory show that DDMI and water intake are linearly related, and as such, water restriction reduces voluntary feed intake (McDowell 1985, Silanikove 1992, Freer *et al.* 2007). Several studies have also shown that Macropods have much lower daily water requirements than livestock and hence do not show the same water-focussed grazing patterns as livestock (Dawson *et al.* 1975, Munn *et al.* 2013, Munn *et al*. 2014). Hence, water is less likely to limit intakes of Macropods, which allows them to graze further from waters at locations were food quality is higher. It follows that there are some examples with kangaroos where distance to watering points, has not been the dominant factor that describes utilisation patterns (Letnic *et al.*, 2015). Instead, the availability of forage (Fukuda *et al.* 2009), shade (Newsome 1965), tree-ed landscape (safety from predators) strongly influence the habitat use by arid zone Macropods.

Because kangaroos require less water than sheep and cattle, and can spend more time between drinking bouts, which means turning off artificial watering points may not cause a large effect on kangaroo distribution (Fukuda *et al.* 2009) if forage and shade are still available in the vicinity. This is consistent with the work of (Freudenberger and Hacker, 1997), which showed neither kangaroo or goat grazing pressure was substantially reduced by closing off water for several months.

5.3.6 Temperature and shade

Homeothermic animals use behaviour as a key mechanism to maintain body temperature, such as huddling or sun basking in cold weather or, in hot weather, seeking shade, sitting on moist ground or in green vegetation (which can be cooler due to the cooling effect of transpiration), wallowing or occupying a position with air movement to aid evaporative cooling. Behavioural modifications such as these are usually the most energy-effective strategies for the animals. Physiological adaptations, such as shivering or panting, require energy. Access to drinking water has a key influence on maintaining body temperature, especially in hot weather, because animals must conserve body water within tight limits; a loss of water equivalent to two percent of bodyweight is classified as dehydration.

Dry matter intake can also decline under conditions of high temperature, especially when combined with high humidity. McDowell (1985) reported that the feed intake of cattle at 40°C was around 70 percent of that at 18-20°C. Given that Macropods have much lower water requirements than livestock, lengthy periods of dry weather and high summer temperatures are less likely to constrain their DDMI. Furthermore, Macropods are able to maintain a higher proportion of green leaves in their diet than can sheep or cattle, which reduces their reliance on drinking water. Finally, Macropods predominantly graze at night, when it is cooler and humidity is higher.

The main mechanism for losing body heat in mammalian herbivores is via evaporative cooling from sweating or panting. In cattle, sweating contributes two thirds of the evaporative loss, with panting contributing one-third. The reverse proportions occur with sheep and goats (see review by Revell 2016). Kangaroos pant and lick their skin to increase heat loss. At rest they do not sweat, but they can sweat when exercising (Wallis 2013). Water lost from the body, including that lost by evaporation, must be replaced by drinking water to maintain water balance and prevent dehydration. Water can be conserved in the body by increasing the electrolyte concentration of urine. Generally, sheep have a greater capacity to concentrate their urine than cattle, and kangaroos are approximately the same as Merino sheep (Dawson and Denny 1969).

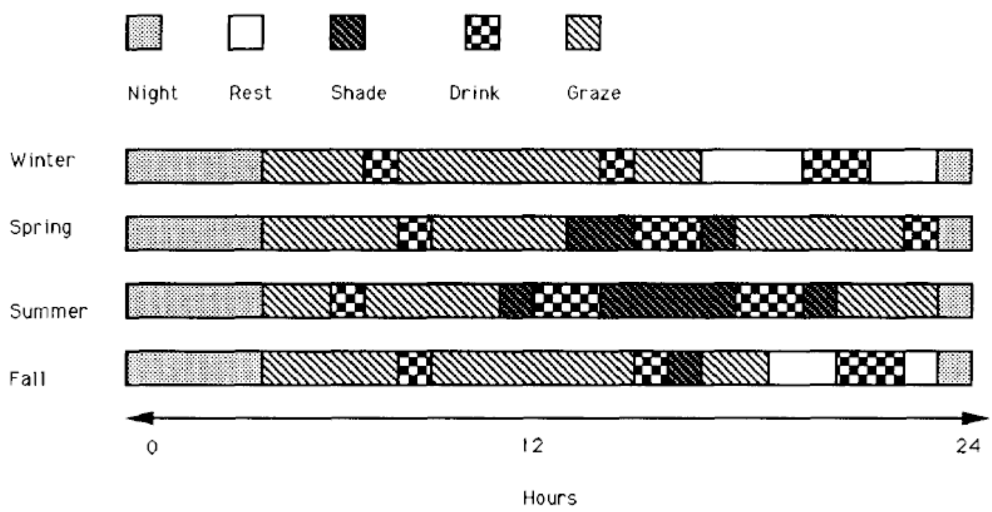
If behavioural and physiological responses are insufficient, animals will adjust feed intake; increasing feed intake to maintain body temperature in cold conditions, and reducing feed intake to reduce heat load in hot conditions. The efficiency of converting ingested feed into growth, pregnancy or lactation is reduced when feed intake is altered to maintain body temperature because a portion of gross energy is diverted toward body temperature regulation.

For all of the grazing herbivores being considered in TGP, habitat selection will be influenced by an interaction between:

1. ambient temperature, which affects the extent to which they need to lose (or gain) body heat;
2. the spatial distribution of provision of shade or other areas suitable for cooling; and
3. water availability, which is essential to replace water lost in evaporative cooling.

Loza *et al.* (1992) developed a physiologically-based model to predict patterns of landscape use of cattle as a function of environmental conditions, physiological needs, and the spatial distribution of water and shade. Simulations using this model in a relatively simple landscape predicted land-use patterns that fitted with expectations; for example, in winter, the modeled animals spent half of each day in the vicinity of the water regardless of the distance to shade but, in summer, the need for shade distributed animals more widely if shade and water were spatially separated from each other. The model was also used to predict the sequence of animal activities over a typical 24-hour period as influenced by season (Figure 5-1). A marked difference on shade-seeking behaviour in summer compared to winter was apparent.

Figure 5-1: Modelled animal activities during a typical day in different seasons



Source: After Loza *et al.* 1992.

5.3.7 Predation

In many locations around the world, including Africa, Europe and North America, the grazing and land use patterns by large herbivores is strongly shaped by predators. In the Australian rangeland contexts, there has been less attention paid to interactions between predation and patterns of vegetation use, although it is clearly recognised that predation by wild dogs and dingoes can:

i. have a large impact on productivity and profitability of managed livestock and unmanaged animals

ii. influence Macropod populations.

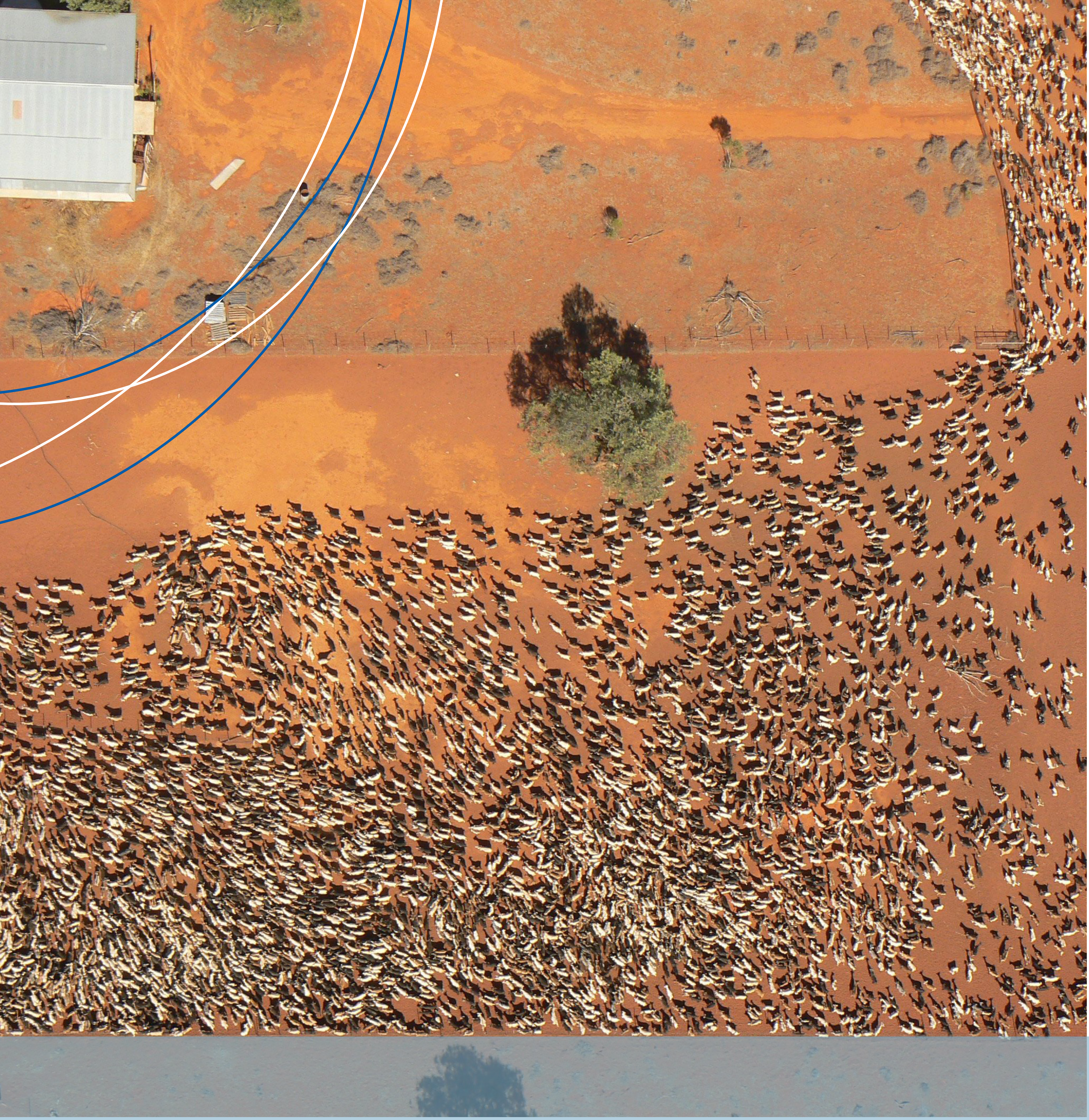
This role of dingoes in production environments is a vexed issue, with widely different views, perceptions and experiences, ranging from a strong desire to eliminate wild dog predation from areas grazed by livestock, especially when the production animals are small ruminants (sheep and goats), through to some reliance on wild dogs to control kangaroos to avoid large, uncontrolled populations reducing forage availability for livestock. It is beyond the scope of this review to attempt to resolve the issue, or indeed to seek clarity on a 'preferred option', as the role of wild dogs or dingoes in the landscape is as much a social issue as it is a biological or management issue. As Allen (2015) succinctly stated, "*Mammalian top-predators can have positive, negative and negligible effects on economic, environmental and social values, which vary spatially and temporally. Harnessing 'pros' while mitigating 'cons' of top-predators remains a key management challenge, particularly outside reserves in agro-ecosystems*."

The focus in this review is on the evidence that grazing herbivores avoid particular areas due to the presence of predators, and comment on how this could impact TGP management. The avoidance of areas due to chemical cues that act as foraging deterrents is generally well accepted, but the precise mechanisms are often poorly understood or are known to vary over time, either due to habituation of the prey animals or due to changes in the many other factors that influence patch selection.

Western grey kangaroos have been shown to persistently avoid areas that are close to experimentally deployed dingo scents, with urine causing a stronger aversive reaction than faeces (Parsons and Blumstein 2010). Interestingly, the kangaroos did not show any evidence of habituation to the olfactory cues despite the cues having never been paired with a negative consequence. In many other situations, including other studies with macropodid marsupials (Blumstein *et al.* 2002), olfactory cues are only effective with predator-experienced herbivores. Predator naïve individuals may need to learn about the olfactory signal for it to be a strong modifier of habitat or food selection.

Free-ranging domesticated goats show 'landscapes of fear' in their patch selection (Shrader *et al.* 2008). Aversion behaviours were based on both landscape features (preferring open, firm ground, good sightlines for predatory detection, and close proximity to preferred plants) and olfactory signals (avoiding predator faeces and urine). In the studies by Shrader *et al.* (2008), goats were habituated to eating from plastic trays. The amount of feed remaining after goats had abandoned an area (the 'giving up density' (GUD)) was used as an indicator of the relative preference of one patch over another. The influence of landscape variables on GUDs changed once predator cues were added. "*The goats no longer keyed off the surrounding vegetation, but continued to focus on whether the trays were visible from other trays. Goats achieved lower GUDs [i.e., higher feed utilisation] in trays that were visible compared to those that could not been seen from within the habitat*".

Other livestock are also known to avoid areas with faecal contamination (e.g. Cooper *et al.* 2000), but this is usually attributed to the avoidance of ingesting parasite larvae rather than a fear response. In such cases, they will avoid areas contaminated with faeces of their own species, rather than specifically avoiding areas with faeces or urine of their predators. Interestingly, parasite infected sheep will show a greater level of avoidance of faecally-contaminated patches than uninfected sheep, but all will avoid contaminated patches if possible.



5.3.8 Plant chemistry

Another mechanism affecting patch selection or avoidance is the concentration of plant secondary metabolites (PSMs). Understanding interactions between herbivore experiences and behaviour and plant nutrients and secondary metabolites (Provenza *et al.* 2003) can be very instructive in predicting or explaining changes in feed intake patterns. The precise balance of nutrients and PSM that influence habitat and diet selection will vary between animal species, animal experience, location and times. For example, the goats in the studies of Frye *et al.* (2013) selected for crude protein and against monoterpenes in sagebrush plants. Dairy cattle and horses fed hays selected for higher crude protein and water-soluble carbohydrate, and against neutral detergent fibre, but their preferences were also related to volatile compounds (Pain and Revell 2007).

5.4 Diets of different species – quality and quantity

There is extensive literature which describes the forage preferences and diet composition of livestock, Macropods and unmanaged goats in the Southern Rangelands (note: most references are provided at the end of each sub-section).

5.4.1 Individual species

Sheep

This review of sheep diet composition in the Southern Rangelands is for Merino sheep. While Dorpers, Damaras and other meat breeds are becoming increasingly common, no published studies of their diet composition in the rangelands of Australia were found. However, Alemseged and Hacker (2014) reported that studies of diet composition of Dorpers in South Africa indicated that their diet contained more browse and less grasses compared to Merino sheep. While this might suggest that the diet of Dorpers may be closer in composition to that of goats, this remains unknown until comparative studies have been conducted in Australia.

The most preferred forages of Merino sheep are fresh and green annual grasses and ephemeral forbs. When these are available, they will be the predominant forage for sheep. When annual grasses and ephemeral forbs are dry or unavailable, sheep consume large amounts of perennial grasses providing these are green. As perennial grasses become dry or are grazed out, sheep eat increasing amounts of perennial forbs providing they possess fresh growth. These are chenopod shrubs such as saltbush (*Atriplex spp.*) and burrs (*Scleroleana* and *Bassia spp.*), or non-chenopod perennial forbs such as legumes, *Calotis, Ptilotus, Sida*, *Abutilon* and *Hibiscus spp.* When the perennial forbs and palatable shrubs and trees stop growing or have been grazed out, sheep will revert to eating large amounts of dry perennial or annual grasses.

As the quantity and quality perennial grasses and perennial forbs deteriorate, and providing palatable shrubs and trees are present, sheep increasingly browse a narrow range of trees and shrubs such as *Acacia*, *Dodonea, Cassia*, *Eremophila* and *Heterodendrum spp.*). At this time, sheep will also eat less palatable perennial and annual grasses such as *Aristida, Eragrostis* and *Amphipogon spp.*

As the quantity and quality of perennial grasses and perennial forbs deteriorate, and when palatable shrub and tree species are not present, sheep increasingly eat dry burrs, dead grass stalks and dead matter (tree leaves, twigs, fruits) lying on the ground.

References: (Dawson *et al*. 1975, Dawson and Ellis 1994, Dawson and Ellis 1996, Downing 1986, Edwards *et al*. 1995, Ellis 1976, Ellis *et al*. 1977, Franco 2000, Graetz and Wilson 1980, Griffiths *et al.* 1974, Harrington 1986a and b, Leigh and Mulham 1966a and b, Leigh and Mulham 1967, Leigh *et al*. 1968, Loremer 1978, McMeniman *et al*. 1986, Munn *et al.* 2010, Munn *et al.* 2014, Robards *et al*. 1967, Squires 1980 and 1982, Storr 1968, Wilson *et al*. 1969, Wilson *et al.* 1975, Wilson 1979, Wilson and Mulham 1980 and Wilson 1991a and b).

Unmanaged goats

There have been fewer studies of diet composition of unmanaged goats, but these show they consume more browse from a wider range of shrubs and trees than do all other herbivores. However, like sheep and cattle, they also most prefer green annual grass and green ephemeral forbs, which make up the majority of their diet when these are readily available. When annual grasses and ephemeral forbs are dry or unavailable, goats eat large amounts of perennial grasses providing they were green.

As perennial grasses become dry or are grazed out, unmanaged goats eat large amounts of non-chenopod perennial forbs such as *Ptilotus, Hibiscus, Euphorbia,* and *Sida spp.* providing they are green, and some browse of trees such as *Heterodendrum, Casuarina, Geijera, Cassia, Dodonaea, Myoporum* and *Acacia spp*. However, some perennial chenopod forbs such as *Bassia* and *Scleroleana* are also consumed in large quantities. Furthermore, at Fowlers Gap (NSW), during a wet winter followed by a dry summer, chenopod shrub forage comprised 26 and 46 percent of the diet of unmanaged goats respectively.

As the quantity and quality perennial grasses and perennial forbs deteriorate, and providing palatable shrubs and trees are present, goats increasingly browse a wide range of trees and shrubs. When it is particularly dry, this can include species of trees and shrubs not eaten by sheep and cattle, and which were not previously browsed by goats. Also, goats are able to maintain a higher content of browse because they can access browse at greater heights than sheep, and forage in dense thickets that sheep and cattle do not penetrate. As the quantity and quality of browse falls to very low levels, goats will then mostly consume dry grass, and when this becomes scarce, they mainly eat fallen leaves, seeds, flowers, dead grass stalks and other dry litter lying on the ground.

References: (Dawson *et al*. 1975, Dawson and Ellis 1996, Downing 1986, Ellis 1976, Franco 2000, Harrington 1986a and b, Squires 1980 and 1982, Wilson *et al.* 1975, Wilson and Mulham 1980).

Cattle

While there are only a few studies of the diet composition of cattle in the Southern Rangelands, their most preferred forage also appears to be ephemeral forbs, which make up the majority of their diet when readily available. When ephemeral forbs are not available, green grass will be the predominant food of cattle. As with sheep, cattle also prefer annual grasses to perennial grasses. However, the amount of annual grasses, annual forbs and green perennial grasses in the diet of cattle is often much less than that of sheep, as cattle cannot efficiently harvest these forages when they are scarce.

When the availability of ephemeral forbs and green grass declines, cattle consume increasing quantities of perennial forbs such as saltbush when these are growing and readily available. When the perennial forb layer stops growing, or is grazed out, or is not present, cattle continue to eat large quantities of dry perennial grass. When perennial grasses and perennial forbs such as saltbush are not available, cattle eat large amounts or browse from shrubs and trees, and particularly mulga. At this time, cattle also increase their intake of less palatable grasses such as *Aristida*. When the supply of palatable browse runs out, they are forced to eat remaining dry grass stems and other dead materials on the ground.

References: (Chippendale 1962, Coates and Dixon 2006, Downing 1986, Graetz and Wilson 1980, Squires 1980 and 1982, Squires and Low 1987, Squires and Siebert 1983, Wilson 1979).

Red kangaroo

While there have been more studies of the diet composition of red kangaroos than other Macropods, most of these have occurred in the chenopod shrublands at Fowlers Gap research station in NSW.

As with sheep, unmanaged goats and cattle, red kangaroos most prefer ephemeral forbs and annual grasses. During wet winters when ephemeral forbs are abundant, these are often more than 50 percent of their diet. Similarly, green annual grasses appear to be preferred to green perennial grasses, and form high proportions of the diet of red kangaroos when they are available.

When green annual grasses and ephemeral forbs are scarce, such as during wet summers, the diet of red kangaroos is predominantly green perennial grasses. Red kangaroos appear to prefer the smaller perennial grasses, and consume smaller grasses than do sheep. During dry winters and summers, even when perennial forbs are available, perennial grasses are often 70 to 90 percent of the diet of red kangaroos. Red kangaroos, probably because of their lower absolute food requirements and highly developed capacity to selectively graze the green components of pastures, appear to maintain diets with a high composition of perennial grasses much longer than can sheep, which switch to perennial forbs such as chenopods much earlier.

Only when it has been dry for some time, and what little grass available is very dry, chenopods such as *Atriplex*, *Kochia*, *Bassia* and *Scleroleana spp.,* and other perennial forbs such as *Portulaca,* can be a high proportion (up to 80%) of the diet of red kangaroos. During droughts, when the more palatable chenopods, other perennial forbs and perennial grasses have been eaten out, the diet of red kangaroos is mainly the dry stems of perennial grasses, and foliage from the less palatable chenopods such as *Chenopodium spp*. and bluebush (*Maireana spp.*), and browse from prickly wattle, *Cassia spp.* and *Eremophila spp.*

References: (Bailey *et al.* 1971, Barker 1987, Chippendale 1968, Dawson *et al*. 1975, Dawson *et al*. 2004, Dawson and Ellis 1994, Edwards *et al*. 1995, Ellis 1976, Ellis *et al*. 1977, Griffiths *et al.* 1974, Griffiths and Barker 1966, Low *et al.* 1973, Munn *et al*. 2010, Newsome 1980, Storr 1968).

Western grey kangaroo

Only a small number of studies have recorded the composition of the diets of western grey kangaroos, in spite of the abundance and wide distribution of this species across the Southern Rangelands. Ephemeral forbs and annual grasses also appear to be their most preferred plants and make up the majority of their diet when they are readily available. During wet summers, when ephemeral forbs and annual grasses are not available, but green perennial grasses are abundant, then perennial grass is almost the exclusive diet of western grey kangaroos. If autumn and winter are dry, and ephemeral forbs disappear and perennial grasses are mature, perennial grasses will be the dominant food of western grey kangaroos. When it is particularly dry and perennial grass quantity and quality are low, western greys eat increasing amounts of perennial forbs, particularly chenopods When it remains dry for a long period of time, and perennial grasses and the palatable perennial forbs have been eaten out, the diet of western grey kangaroos is predominantly browse of shrubs such as prickly wattle, *Dodonea* and *Eremophila*.

References: (Barker 1987, Coulson and Norbury 1988, Dawson *et al.* 2004, Munn *et al*. 2014, Wilson 1991 a and b).

Eastern grey kangaroo

There have also only been a small number of studies of the diets of eastern grey kangaroos. These indicate that the eastern grey kangaroo consumes more grass than do the other herbivores except for the euro/wallaroo. Grasses are the major component of their diet at all times, and rarely drop below 70 percent. As with euro/wallaroos, ephemeral forbs were at most 35% of the diet of eastern greys, even when they were plentiful. However, it appears that the diet of eastern grey kangaroos more regularly consists of around 30 percent ephemeral forbs, which is more than what euro/wallaroos regularly consume. Regardless of seasonal conditions, perennial grasses are at least 70% of the diet of eastern grey kangaroos .Even under very dry conditions, when the small amount of perennial grasses present were of poor quality, only 16 percent of the diet of eastern grey kangaroos was chenopod shrub. The studies of eastern grey kangaroos show that they rarely eat browse from non-chenopod shrubs and trees and the studies cited here did not report any consumption of browse by eastern grey kangaroos, and Franco (2000) reported than the proportion of browse in their diet averaged only 2 percent over four seasons.

References: (Griffiths and Barker 1966, Griffiths *et al*. 1974, Kirkpatrick 1965).

Euro/Wallaroo

While very few studies have recorded the diet composition of euro/wallaroos, they appear to be more of a grass specialist than livestock, unmanaged goats and the red and western grey kangaroos. Even when ephemeral forbs are readily available, they are at most 25 percent of the diet of euro/wallaroos. As with the other herbivores, the euro/wallaroo also appears to have a high preference for annual grasses. These are almost their exclusive diet when they are abundant. During wet summers when perennial grasses are green and plentiful, these are almost the exclusive diet of euro/wallaroos. Even when ephemeral and perennial forbs are readily available, perennial grasses still appear to be their predominant food source. Even when it is dry, when the quantity and quality of perennial grasses has appreciably declined, but perennial forbs and other shrubs are available, perennial grasses are still the dominant forage of euro/wallaroos. However, euro/wallaroos also appear to increase their intake of chenopods and other perennial forbs to between 20-40 percent of their diet when perennial grass quantity and quality are very poor. In contrast to sheep, cattle, unmanaged goats, red kangaroos and western grey kangaroos, browse from non-chenopod shrubs and trees is usually less than 5 percent of the diet of euro/wallaroos, even when it is very dry.

References: (Dawson *et al*. 1975, Dawson and Ellis 1996, Ellis *et al.* 1977, Franco 2000, Storr 1968).

5.4.2 Species differences in forage intake

While fewer studies have compared DDMIs of Macropods, sheep and goats when fed the same forage (Foot and Romberg 1965, McIntosh 1966, Griffiths and Barker 1966, Forbes and Tribe 1970, Kempton 1972, Hume 1974, Kempton *et al*. 1976, Dellow and Hume 1982), they are likely to provide more accurate comparisons of intakes.

Short (1985 and 1987) measured the DDMIs of sheep and red kangaroos when grazing in small enclosures containing native pastures in Kinchega National Park (near Broken Hill). Pastures ranged in biomass from 500-1,200 kg/ha and these were progressively grazed down to an ungrazable residue. Consequently, these pastures are likely to be equivalent to a high fibre forage diet. Short (1985) observed that sheep intake was 61.1 g/kg$^{0.75}$/day, and that for red kangaroos was 62.3 g/kg$^{0.75}$/day. Under similar conditions, slightly higher intakes were reported by Short (1987) and that for sheep was 69.0 g/kg$^{0.75}$/day and for red kangaroo was 70.8 g/kg$^{0.75}$/day. These intakes are considerably higher than those reported for red kangaroos and sheep fed high fibre forage such as oaten straw. Short (1985) reported that the intake for sheep recorded in his trial was similar to that found by Leigh and Mulham (1966a, b), Wilson *et al*. (1969) and Noble (1975). These studies reported sheep intakes of around 60 g/kg$^{0.75}$/day when pastures yields were 600 kg/ha.

In a similar way, Short (1986) compared the intakes of red kangaroos and western grey kangaroos in Kinchega National Park. The DDMI of red kangaroos was 66 g/kg$^{0.75}$/day, while that for western grey kangaroos was 87 g/kg$^{0.75}$/day. The ratio of western grey kangaroo intake to red kangaroo intake is 1.32. This is similar to the greater intake of high fibre forage by western grey kangaroos compared with sheep recorded by Powell and Arnold (1984). In that case, it was 1.2 times that of sheep. Again, these intakes were considerably higher than those recorded for red kangaroos and western grey kangaroos fed high fibre forage such as oaten straw.

Perry (2016) recorded the DDMIs of 12 Brahman steers grazing tropical pastures in northern Australia. Their average body weight was 259 kg and their average daily intake over five days was 3,700 g. Accordingly, the DDMI of these steers was 64 g/kg$^{0.73}$/day, which is similar to the values recorded by Short (1985, 1986, 1987) for sheep and Macropods.

5.4.3 How much forage do individual animals eat?

The daily dry matter intakes (DDMI) of individual animals vary substantially with body size, growth rate and reproductive state. This can also vary with species of animal, as marsupials such as Macropods have low metabolic rates than eutherians such as sheep, and subsequently are predicted to have lower forage requirements. To enable the total demand for or offtake of forage to be calculated, equivalent animal units have been developed so that different species and classes of animals within a species can be combined. These equivalent animal units – expressed as 'dry sheep equivalents' have been presented in Section 3.

How much does each species of herbivore weigh?

The total amount of forage eaten by populations of different species of herbivores is substantially influenced by their average body size. Body sizes are often well known for different age classes of animals and for adult males and females of each species. However, little information is available on the proportions of each age class of males and females within populations of herbivores on properties. This is a major limitation in determining average body weights.

Average body weights of herbivores, taken from a range of sources, and corrected for flock/ mob structure are shown in Table 5-4.

Table 5-4: Average body weights in flocks/ herds/ mobs of herbivores

Species	Average weight (kg)	Comments and sources
Adult ewe	44	Suggested as 60% of a 'standard flock (Agsurf 2018)
Adult wether	42	11% of a 'standard flock (Agsurf 2018)
Lambs	10	27% of a 'standard flock (Agsurf 2018
Rams	80	2% of a 'standard flock (Agsurf 2018
*Sheep**	35	*Weighted average*, (Agsurf 2018, Auctions Plus 2018)
Goats	25	*Weighted average* (Dawson *et al*. 1975; Hoist *et al.* 1981)
Cattle	350	*Mixed herd - cows, steers, heifers, weaners* (AusVet Animal Health Services 2006)
Large male red kangaroo	62	Data from Fowlers Gap (Moss and Croft 1999)
Sub-adult male red kangaroo	24	
Female red kangaroo	25-26	
Small female red kangaroo	17	
Red kangaroo - Harvested population	19	*Weighted average* (A. Pople *pers comm.*)
Red kangaroo - Un-harvested populations	32	*Weighted average* (A. Pople *pers comm.*)
Western and Eastern Grey kangaroos - Harvested population	19	Insufficient specific data – assumed to be the same as for red kangaroos
Western and Eastern Grey kangaroos – Un-harvested population	32	
Euros/ wallaroos – Harvested populations	12	*Weighted averages* (Dawson *et al*. 1975, Arnold *et al.* 1994)
Euros/ wallaroos – Un-harvested populations	18	

The total daily dry matter intakes (DDMIs) of average-sized individuals of each species of herbivore were calculated by multiplying the DDMIs per kg of metabolic body weight ($BW^{0.73}$) by the average body size and then by the density or stocking rate of herbivores present at a location. DDMIs were calculated for high and low fibre diets. Intakes were also calculated using the allometric exponent of 0.6 for Macropods. Given this resulted in DDMIs for average-sized Macropods which were very similar to those calculated using an allometric exponent 0.73, these estimates are not shown in the following tables.

When consuming low fibre forage, average-sized cattle have by far the largest intake, followed by average-sized sheep, unmanaged goats and Macropods (Table 5-5). Under these conditions, the daily intakes of average-sized red, eastern grey and western grey kangaroos were 0.46 to 0.49 that of an average-sized sheep, whereas the intake of euro/wallaroos was 0.34 that of sheep. The daily intake of an unmanaged goat was 0.69 of sheep. The ratios of Macropod to sheep intakes in unharvested populations of Macropods were considerably higher. Ratios were between 0.67 and 0.72 for the three species of kangaroos, and 0.46 for the euro/wallaroo.

Table 5-5: The total daily dry matter intakes (g) of low fibre forage for livestock, goats and Macropods

Species	Macropods harvested		Macropods unharvested	
	Intake $BW^{0.73}$		Intake $BW^{0.73}$	
	(g)	Ratio	(g)	Ratio
Sheep	984		984	
Cattle	4534		4534	
Unmanaged goat	682	0.69	682	0.69
Red kangaroo	474	0.48	693	0.70
Eastern grey	448	0.46	655	0.67
Western grey	485	0.49	709	0.72
Euro/Wallaroo	339	0.34	455	0.46

Using average body weight (BW) and metabolic exponents of 0.73. Ratio is the ratio of herbivore intake to that of sheep.

Intakes of high fibre forage were 16 to 43 percent lower for Macropods and unmanaged goats, and 47 percent lower for sheep. DDMIs of Macropods were also calculated for populations with a high harvest rate and those which were not harvested. Average body size was lower in harvested populations.

The total DDMIs of high fibre forage of an average-sized individual of each species of herbivore are shown in Table 5-6. No data were found for cattle when fed high fibre diets similar to those fed to the other species. When Macropods are harvested, sheep had the highest daily intake followed by unmanaged goats. In this instance, the ratio of intake of unmanaged goats to the intake of sheep was 0.84. The intake of an average-sized western grey kangaroo was similar to that of unmanaged goats, while those of average-sized red and eastern grey kangaroos and euro/wallaroos were much lower. The ratios of intakes of the red kangaroo, eastern grey kangaroo and euro/wallaroo to intake of sheep were between 0.51 and 0.55. The intake ratio of western grey kangaroos and sheep was much higher at 0.77.

In unharvested populations of Macropods, due to their larger size, the ratios of Macropod to sheep intakes were also higher. The ratios of intakes of red kangaroos, eastern grey kangaroos and euro/wallaroos to intake of sheep were between 0.73 and 0.80. That for western grey kangaroos was even larger, at 1.12 times that for sheep.

Table 5-6: The total daily dry matter intakes (g) of high fibre forage for livestock, unmanaged goats and Macropods

Species	Macropods harvested		Macropods unharvested	
	Intake $BW^{0.73}$		Intake $BW^{0.73}$	
	(g)	Ratio	(g)	Ratio
Sheep	529		529	
Cattle				
Unmanaged goat	444	0.84	444	0.84
Red kangaroo	269	0.51	394	0.74
Eastern grey	289	0.55	423	0.80
Western grey	407	0.77	595	1.12
Euro/Wallaroo	286	0.54	385	0.73

Using average body weight (BW) and metabolic exponents of 0.73. Ratio is the ratio of herbivore intake to that of sheep.

To simplify calculations of total offtake and proportions due to different herbivores, the daily offtakes of the four species of Macropod were averaged. Table 5-7 shows the average daily intakes of Macropods when fed high and low fibre forages, when harvested or not, and using an allometric exponent of 0.73.

Table 5-7: The average total daily intakes (g) of average-sized sheep and unmanaged goats, and averaged-sized Macropods

Diet	Sheep	Goats	Macropods	
			Harvested population	Unharvested population
	$BW^{0.73}$	$BW^{0.73}$	$BW^{0.73}$	$BW^{0.73}$
High fibre	529	444	313	449
Low fibre	984	682	436	628

In harvested and unharvested populations, when fed high and low fibre forages.

5.4.4 Estimates of forage offtake by livestock

These intakes shown in Table 5-5 and Table 5-6 were then used to calculate total offtakes of forage by unmanaged and managed herbivores, and the proportions due to each type of herbivore, based on the animal densities presented in Table 5-8. This was undertaken for each State, for a range of geographic and time scales. The estimates are presented in Table 5-8.

Table 5-8: Percentage forage offtake by livestock

Year	**Location**	**Percentage forage offtake by livestock**	**Reference**
Queensland			
1996	Barcoo, Bulloo, Paroo, Murweh SLAs	82-92	Gutteridge *et al.* (2001)
1996	Balonne SLA	55-70	
1994-2011	Brigalow Belt	81-89	Bastin (2012); Pople and Froese (2012)
	Mulga lands	58-71	
1985	Longreach	84-91	Gibson and Young (1987)
New South Wales			
1996	Balranald SLA	64-75	Gutteridge *et al.* (2001)
1996	Central Darling, Cobar, Wentworth SLAs	35-50	
1994-2011	Brigalow Belt	84-91	Bastin (2012); Pople and Froese (2012)
1995-2011	Simpson Strzelecki Dunefields	28-42	
1985	Broken Hill Region	68-81	Gibson and Young (1987)
	Wanaaring Region	75-85	
1985-1987	Fowlers Gap (two paddocks)	30-90 18-92	Edwards *et al.* (1996)
1985	Broken Hill area	50-65	Bayliss (1985)
1980	Properties adjacent to Sturt National Park	32-47 16-27	Edwards (1989) Denny (1980)
South Australia			
1996	Pirie	35-49	Gutteridge *et al.* (2001)
	Far North	40-54	
	Flinders Ranges	58-71	
2012	Flinders Lofty	61-74	Bastin (2012) Pople and Froese (2012)
	Gawler	36-52	

Year	Location	Percentage forage offtake by livestock	Reference
1995	North East (4 properties)	23-37 14-20 47-60 29-42	Turner and Neagle (1996)
1996	North East (4 properties)	39-55 32-43 40-52 73-83	
Western Australia			
2001	Southern Rangelands	31-49	Gutteridge *et al*. (2001)
	Goldfields and Nullarbor	14-37	
2012	Coolgardie Bio region	95-97	Bastin (2012)
	Murchison Bio-region	55-66	Pople and Froese (2012)

Queensland

Based on the Queensland data sets, the proportion of total offtake by livestock in Queensland was high, often in the range of 80 to 90 percent. Even where Macropods were more common, the proportion of total offtake by sheep was still between 55 and 70 percent. Offtakes by livestock were lowest when calculated with high fibre diets and without any harvesting of Macropods.

New South Wales

Based on the studies above which provided densities of herbivores averaged over large areas, the proportion of total offtake due to livestock was often high, at 70 to 90 percent. However, in the large bioregion of the Simpson Strzelecki Dunefields, where livestock densities were low, offtake by livestock was only 28 to 42 percent of total offtake. The remainder was due mainly to Macropods.

At individual property and paddock scales, the proportion of total offtake by livestock was often much more variable, reflecting large spatial and temporal differences in herbivore densities which frequently occur within the rangelands. On some occasions, usually in the years of average to good rainfall, offtake by livestock is often 50 to 70 percent of total offtake. Offtake by livestock can also be high (approx. 90%) when forage conditions are very poor, when Macropods choose to graze elsewhere. Or, if rainfall is patchy during a dry season, then Macropods may congregate in paddocks with livestock to the extent they are responsible for over 80 percent of offtake.

South Australia

Individual herbivore densities for individual SLAs during 1996 in the rangelands of South Australia were estimated from maps provided by Gutteridge *et al.* (2001). Pirie and Flinders Ranges SLAs had relatively high densities of livestock and Macropods and few unmanaged goats, and the Far North had low densities of all herbivores. Bastin (2012) and Pople and Froese (2012) provided densities of livestock, Macropods and unmanaged goats for rangeland bioregions in South Australia. Offtakes were calculated for only two bioregions, being Flinders Lofty were livestock densities were relatively high, and Gawler were they were relatively low. Unmanaged goat densities were very low in both bioregions.

Western Australia

As in the other States, the proportion of total offtake by livestock was highly variable. In large areas such as the Coolgardie bioregion, livestock accounted for almost 100 percent of offtake. However, in bioregions containing more Macropods, offtake by livestock was more likely to be 60 percent of total offtake. At smaller scales, such as with SLAs, the proportion of total offtake by livestock was often between 30 to 50 percent. In some other SLAs, the proportion of offtake by sheep was only around 20 percent.

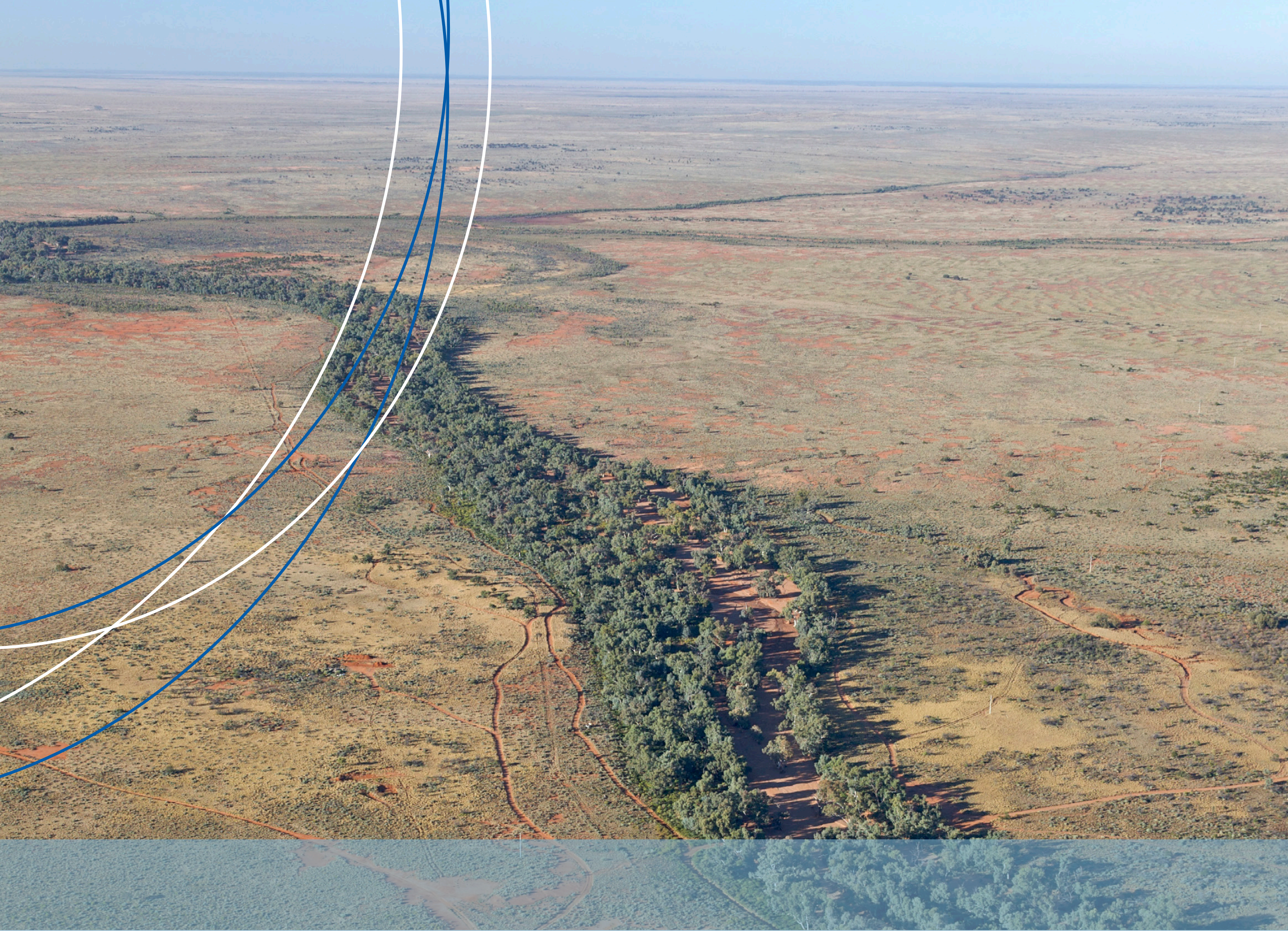
Variation in offtake across short distances and short time scales

Three studies examined in detail the variation in the populations (and hence percentage offtake) of livestock and unmanaged herbivores across relatively short distances and over short periods of time. The results are indicative of the temporal and spatial variations in densities of herbivores which regularly occur on pastoral properties. This spatial variation is not evident in the broader scale surveys referenced in the previous section which average densities over large areas.

Landsberg and Stol (1996) reported densities of sheep, unmanaged goats and kangaroos in two paddocks on a pastoral property south-east of Wanaaring, western NSW, on four occasions between 1991 and 1993. Densities of all three herbivores varied considerably over this short period of time. For example, sheep densities varied from 10 to 30 head/km^2, unmanaged goats from 7 to 43/km^2, and Macropods from one to 28/km^2. Accordingly, the proportion of total offtake that was sheep varied substantially over the period of this study. In Channel paddock, in December 1991, when densities of all herbivores were high, the proportion of total offtake by sheep ranged from 36 to 45 percent. In this paddock in April 1992, only four months later, densities of all herbivores had declined, and especially those of Macropods and unmanaged goats. At this time, the proportion of total offtake that was sheep ranged from 56 to 65 percent. In Channel paddock in February 1993, densities of sheep and Macropods had declined but that of unmanaged goats markedly increased. At this time, the proportion of total offtake by sheep ranged from 21 to 25 percent. Most of the remaining offtake was by unmanaged goats. At the same time, but in the nearby Crossroads paddock, densities of all herbivores were higher than those observed in Channel paddock. Sheep were dominant, and their proportion of total offtake ranged from 56 to 65 percent.

Browne (1995) provided data on the total number of herbivores on Bukulla, a 12,242 ha property in the north eastern floodplains of western NSW. Densities of Macropods and unmanaged goats were provided by an aerial survey of the property carried out by NSW Department of Agriculture in June 1992. In the previous year, Bukulla had 8,000 DSE of livestock, but because of poor seasonal conditions, this was reduced to 4409 DSE by June 1992. At this time there were 54 Macropods/km^2 and only 1.1 unmanaged goats/km^2. In 1991, the proportion of total offtake by livestock ranged from 58 to 72 percent, being lowest when eating a high fibre diet and if Macropods were not harvested. Even though livestock numbers were almost halved during 1992, offtake by livestock was still significant, ranging from 44 to 59 percent.

Wilson (1997) reported numbers of sheep and kangaroos on Mt. Mulya station near Louth in north western NSW during 1991 and 1992. At this time, sheep numbers had been reduced from 10,000 to 3,300. A helicopter survey at that time estimated there was 9,000 red and grey kangaroos on the property. Assuming a property area of 150 km^2, then the densities of sheep would have been 67 head/km^2 during 1991, and 22 head/km^2 in 1992. Macropod density would have been 60 head/km^2. On this basis, the proportion of total offtake by sheep during 1991, assuming 60 Macropods/km^2, ranged from 57 to 72 percent. In the following year, after sheep numbers were reduced, the proportion of total offtake by sheep ranged from 30 to 45 percent.



5.4.5 Numbers and distribution of animals

Animals select their habitat for a variety of reasons. Amongst the most dominant factors are: access to water (James *et al.* 1999), thermal environment, nutrients (Ganskopp and Bohnert 2009; Bjørneraas *et al.* 2012), phytochemicals (Frye *et al.* 2013), abundance/depletion (van Beest *et al.* 2010), and safety from predators (Laporte *et al.* 2010). All of these factors interact and vary across spatio-temporal scales.

The distribution of herbivores in the landscapes and patterns of forage utilisation are shaped by diet selectivity and animal habits. Habits form habitats. This is most noticeable under conditions of high herbage availability and low stocking rates, because animals have the opportunity to select their preferred plants and stay for an extended period at preferred sites (Burboa-Cabrera *et al.* 2003).

Attempts to overcome the problem of patch grazing and overutilisation of preferred plants and preferred areas by domestic stock are usually centred on rotational grazing. It is important to recognise the difference between stocking density (animal numbers per ha) and stocking rate (animal grazing days per ha), even though the two are often confused. The main advantages of rotational grazing are not, contrary to a commonly held view, due to an increase in *stocking density*. Rotational grazing can reduce diet selectivity or, to put it another way, broaden the diet because it can allow an increase in *stocking rate*. This is possible because allowing herbage to be rested from grazing, thus avoiding the repeated consumption of plants before they have the chance to regrow, can increase plant productivity. With more feed available, stocking rates can be increased, all other things being equal. (D.K. Revell, personal communication)

Most studies (see review by Bailey and Brown 2011) have shown that stocking density does not have a major effect on diet selectivity if stocking rate is held constant. For example, a higher stocking density can be achieved by using smaller paddocks or by increasing the number of animals, but if the paddocks are grazed for proportionately less time, stocking *rate* is unchanged. In such cases, there is surprisingly little evidence that stocking density *per se* affects diet selectivity or spatial utilisation.

The times when stocking density, as distinct from stocking rate, is expected to have a major effect on spatial distribution of grazing is with very high stock densities or very low herbage biomass. Under most southern Australian rangeland grazing systems, critical thresholds for high stock density should rarely be reached at the landscape scale if there is a sound understanding of a region's carrying capacity and there is widespread and uniform adjustment of stock numbers according to seasonal change. The evidence of landscape change and degradation, and unnecessary deaths of livestock in droughts, would suggest this situation does not always occur. Even if critical thresholds for livestock density are not reached at landscape scale, thresholds may be quite commonly exceeded at the patch scale. The thresholds for low herbage biomass are likely to be reached quite frequently, such as every dry season, especially if the grazing landscape has previously been heavily grazed.

Stocking rate can be increased in different ways:

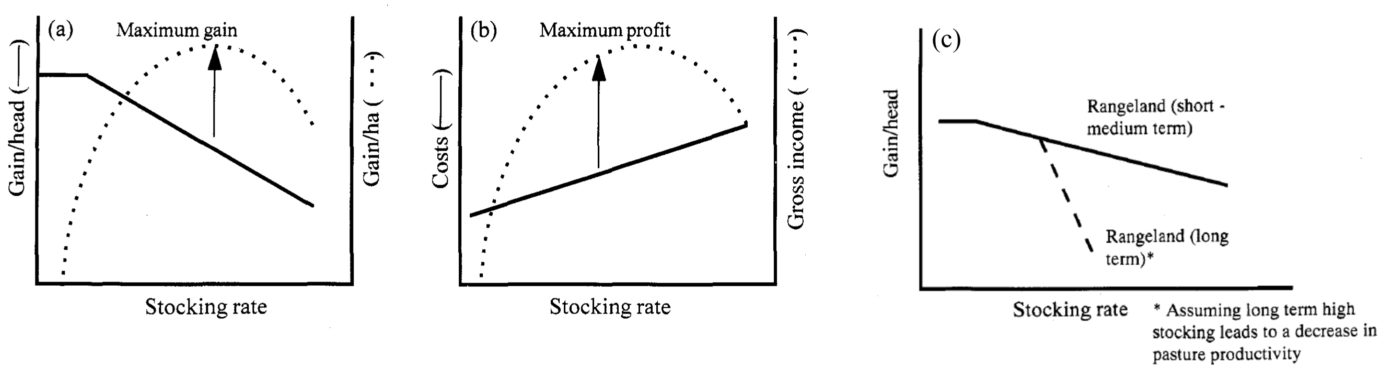
a. Paddock size is decreased, but animal numbers and the duration of grazing are left unchanged (in this case, both stocking density and stocking rate will be increased);

b. Paddock size and duration of grazing is unchanged, but more animals graze the area;

c. Paddock size and animal numbers are unchanged, but the animals graze the paddock for longer.

Ash and Stafford Smith (1996) questioned the relevance of stocking rate research to the complex and highly variable ecosystems that make up most rangeland enterprises. They concluded that the relationships between stocking rate and animal production that have been established from research using smaller paddocks or improved pastures (Figure 5-2) do not hold in variable rangeland environments. Further they hypothesised that the relationship between stocking rate and weight gain per animal in rangeland pastoral systems differs between the short- and the long-term.

Figure 5-2: The conventional relationship between stocking rate and productivity



(a) the relationships between gain per head and per ha with increasing stocking rate and

(b) the relationship between stocking rate and economic performance.

(c) describes the hypothesised short- and long-term relationship between stocking rate and animal production in rangelands.

From Ash and Stafford Smith (1996).

Due to highly variable seasonal conditions, it is not possible to be certain when the next growing season will commence, nor how long it will last or how much it will grow, which means having sufficient accumulated herbage as carry-forward feed is critical to risk management. In turn, it is essential to know the TGP in the landscape. If there are non-domestic herbivores in sufficiently high numbers, a grazing system might be closer than expected to a threshold of herbage biomass. In other words, the total number of animal grazing days per hectare needs to be known to avoid unexpected shortfalls in feed on offer (which will limit productivity) and ground cover (which will limit landscape function).

5.4.6 Where do livestock, Macropods and goats forage?

At bio-regional scales across the Southern Rangelands, the highest densities of Macropods and unmanaged goats tend to coincide with the highest densities of sheep and cattle (Storr 1968, Caughley *et al*. 1980, Short *et al*. 1983, Calaby and Grigg 1989, Cairns *et al.* 1981, Pople and Froese 2012, Department of Environment and Heritage Protection 2017). This is likely due to differences in the productivity or carrying capacity of bio-regions, where more productive lands support larger numbers of herbivores (Jonzen *et al*. 2005). Additionally, it is due to the provision of permanent waters, control of dingoes, tree-clearing and pasture improvement (Department of Environment and Heritage Protection Queensland 2013 and 2017, Lavery *et al*. 2018). Also, this may indicate that these species prefer similar environments. However, at a smaller scale, within paddocks, species of herbivore may graze or browse different areas due to differences in diets, different preferences for vegetation structures, and differences in distances they graze from water sources. Or, they may simply choose to avoid each other.

Sheep and cattle often prefer to graze in more open landscapes, particularly during plant growing seasons when ephemeral forbs and green grasses are readily available (Low *et al*. 1973, Dudzinski *et al.* 1982, Wilson and Harrington 1984, Terpstra and Wilson 1989). As grasses dry out and quantity and quality both decline, sheep and cattle venture into more wooded areas in search of browse and remaining grasses (Low *et al*. 1973, Dudzinski *et al*. 1982).

Unmanaged goats eat more browse than sheep and Macropods and appear to forage in shrubbed and wooded landscapes (Landsberg and Stol 1996). Also, more densely timbered areas, especially on rocky hills, provide unmanaged goats with shelter and affords them protection from predators, such as wild dogs, and from mustering by land managers. When forage is plentiful, and when drinking water is nearby or the weather is cool, unmanaged goats are likely to remain in highly timbered and hilly areas, and thus have distributions which do not overlap with sheep or cattle. However, when forage supplies become scarce in the timbered and hilly landscapes, unmanaged goats will move to parts of paddocks or to other paddocks which still contain forage. Like Macropods, the dispersion of unmanaged goats is generally not constrained by fences. Even so, as forage resources become increasingly limited in both quantity and dispersion, the grazing distributions of unmanaged goats are likely to increasingly overlap with livestock (Landsberg and Stol 1996, Witte 2002).

The grazing distributions of Macropods appear to follow a similar pattern to that of unmanaged goats, where they prefer wooded landscapes but move into more open areas when forage supplies become limiting. For example, grey kangaroos and red kangaroos prefer to graze in wooded areas after rain when pastures are green and plentiful, but as supply declines in quality and quantity, they graze in nearby open areas (Newsome 1965a and 1965b, Low *et al.* 1973, Dudzinski *et al*. 1982, Hill 1982, Terpstra and Wilson 1989), possibly because they are less visible to predators (Caughley 1964). Thus, while foraging distributions of sheep, cattle, unmanaged goats and Macropods are often different at any one point in time, they overlap considerably when considered over a number of seasons.

The foraging distributions of livestock and Macropods also appear to be focused to varying degrees around water points. Sheep, and to a lesser extent, cattle, appear to forage closer to water sources than do Macropods. When it is hot and dry, sheep mostly graze within 1 km of water (Squires 1974), and much of their time may be spent within 200 m from water (Andrew and Lange 1996). However, generally, the grazing distribution of sheep is largely confined to within 3 km of water (Wilson and Harrington 1984, James *et al*. 1999, Fensham and Fairfax 2008). Cattle may graze only 4 km from water in good seasons, but when it is dry and forage supplies around waters is low, they will graze up to 10 km from water (James *et al*. 1999). After reviewing a number of studies, Fensham and Fairfax (2008) concluded that cattle mainly graze up to 6 km from water.

Using the same methodology, Fensham and Fairfax (2008) reported that red kangaroos generally graze within 7 km from water. In comparison, Lavery *et al.* (2018) found that the largest numbers of red kangaroos were observed within 2 km of water points in Idalia National Park and a pastoral property in central western Queensland. However, the relationship between density and distance from waters was not significant. These authors also found that the densities of wallaroos were highest between 2 and 3 km from waters. Wallaroo densities were between 50 and 190/km^2 at distances of between 1 and 2 km from artificial water points, and less than 50/km^2 closer to waters or between 2 and 3 km from water.

Lavery *et al*. (2018) concluded that densities of red kangaroos and wallaroos were not influenced by distance to water, but instead were dictated by pasture quality. This is consistent with a number of studies that have recorded convergence of Macropods on areas from which sheep have been excluded (Andrew and Lange 1986, Watson *et al*. 1988, Terpstra and Wilson 1989, Norbury and Norbury 1993, Edwards *et al.* 1996).

In contrast to this, Gibson (1994, 1995) observed that eastern grey kangaroos, red kangaroos and wallaroos appeared to graze much closer to water point within conservation areas (e.g. National Park) in south west Queensland. Macropod faecal pellet numbers were highest at the bores, then declined sharply in number until 200 m from the bore. After 200 m, the abundance of faecal pellets remained constant with distance up to at least 1,000 m from the bore. In addition to this, Gibson (1994) tracked the movements of radio-collared red and eastern grey kangaroos at these bores. On average, eastern grey kangaroos travelled up to 2.25 km from one bore, and red kangaroos travelled up to 1.98 km from the same bore. At a second bore, on average, red kangaroos travelled 2.39 km from the water point.

No studies were found that report the distances that unmanaged goats graze from waters. However, given that they have much lower daily water requirements than sheep, and often browse foliage with a high water content, it is likely that they are able to graze further from waters than sheep.

Overall, the foraging distributions of sheep are likely to be constrained more by distance to water points than are those of cattle, Macropods and unmanaged goats. Hence, sheep mainly forage within 2 to 3 km of waters, resulting in high pasture utilisation rates in these parts of paddocks. Cattle can forage at distances up to 10 km from water, although they rarely graze further than 5 km, and most of the grazing, up to 80 percent, occurs within 2 km of water (Department of Agriculture and Food, Western Australia 2006; https://www.mla.com.au/research-and-development/Grazing-pasture-management/native-pasture/grazing-management/grazing-distribution/).

5.4.7 Diet overlap between herbivores

At any one time, the diet composition of livestock, Macropods and unmanaged goats is often quite different. However, all species of herbivore appear to rely on the same broad groups of forages (annual and perennial grasses, ephemeral and perennial forbs) for the large majority of their feed. Hence, overlap in diet appears to occur sequentially over a range of climatic conditions.

A considerable overlap has been observed in the diets of kangaroos and sheep; e.g. Munn *et al.* (2014) found a 'proportional similarity index' of 41 percent. As feed availability or herbage diversity declines, such as during an extended dry period, the degree of dietary overlap will, at least in theory, increase. Eventually, the diets must become nearly identical when opportunity for choice is removed.

The following summary reports dietary overlap through a sequence of seasonal conditions from very good (abundant annual and perennial forage) through to dry times when only perennial browse is available. The main references for this summary are:

- Sheep and Macropods – Dawson *et al.* (1975); Dawson and Ellis (1994 and 1996); Edwards *et al.* (1995), Franco (2000); Griffiths and Barker (1966); Griffiths *et al.* (1974); Munn *et al.* (2010): Munn *et al.* (2014): Storr (1968); Wilson (1991a) and Wilson (1991b).
- Sheep and unmanaged goats – Dawson *et al*. (1975); Downing (1986); Harrington (1986a, 1986b); Squires (1980, 1982); Wilson and Harrington (1984); Wilson and Mulham (1980);
- Cattle and Macropods – Chippendale (1962); Low *et al*. (1973);
- Cattle and sheep – Downing (1986); Squires (1980, 1982); Wilson and Harrington (1984).

When feed is plentiful and widely distributed

Green grass, particularly annual grasses, and green ephemeral forbs are the most preferred foods of sheep, cattle, unmanaged goats and the four species of Macropod. These are by far the dominant foods of these herbivores when supply is plentiful. However, the plentiful supply of these foods occurs for a short duration, perhaps two to three months at best. During this short period, when rainfall has been high and widespread, the low densities of herbivores present relative to the plentiful supplies of green grasses and green ephemeral forbs means that one species of herbivore is unlikely to deprive another of these foods. Also, as ephemeral forbs and annual grasses are short-lived, consumption of them by one herbivore during their growing period will have little impact on their long-term availability for other herbivores.

When feed is plentiful, but in patches

However, if the rains that resulted in the growth of grasses and ephemeral forbs were patchy and localised, then it is possible that the more mobile large Macropods which are able to pass through most paddock fences may to some extent deprive livestock of these foods. While densities of Macropods would need to be high and the bands of rainfall narrow, that is not be an uncommon set of circumstances in the Southern Rangelands.

Additionally, if densities of herbivores are high, consumption of perennial grasses when they are green and growing is likely to reduce the amount of mature grass that is available later in the year. If this occurs, then the consumption of green grass during the growing season by one species of herbivore may deprive another of dry grass during the following dry season.

As ephemeral forbs and annual grasses disappear

As the ephemeral forbs and annual grasses disappear, the diets of sheep and cattle will predominantly be perennial grasses and short-lived (facultative) grasses and herbs providing they are abundant and at least partly green. As they mature and dry off, sheep and cattle consume increasing amounts of perennial forbs such as chenopods, providing they have new growth and are readily available. However, sheep, due to their smaller size and lower daily intake requirements, are likely to graze green perennial grasses longer than cattle, and switch to chenopods later than cattle (Graetz and Wilson 1980). Hence, there is potential for cattle to deprive sheep of perennial forbs, which is more likely to occur if cattle stocking rate is high.

At this time, when the availability of green annual grasses and ephemeral forbs become limiting, the four species of Macropod also switch to eating perennial grasses. Their diet is likely to contain more perennial grasses than sheep and cattle, and for a longer period of time. When the availability of perennial grasses is limiting, red kangaroos, western grey kangaroos and euro/wallaroos switch to eating perennial forbs such as chenopods later than do sheep and cattle. As such, there is potential for sheep and cattle to deprive these Macropods of perennial forbs, especially when livestock stocking rates are high. Dawson and Ellis (1994) and Edwards *et al*. (1995), in different pastures and at a different time, concluded that competition between red kangaroos and sheep was likely when pasture biomass fell to 400-500 kg/ha.

Eastern grey kangaroos appear to eat small amounts of perennial forbs, and instead rely on perennial grasses during all climatic conditions. If their densities are high, they have potential to deprive other herbivores of perennial grasses when they come back to them after eating out the perennial forbs. In environments without perennial grasses, such as woodlands and shrublands in WA – western grey kangaroos browse on native shrubs (Department of Environment and Conservation 2009).

When the availability of green grasses and ephemeral forbs become limiting, and while some chenopods are consumed, unmanaged goats consume increasing quantities of browse from the larger shrubs and trees (Harrington 1986b). Browse can be the dominant food of unmanaged goats at this time. They do not deprive other herbivores of browse at this time, because the other herbivores are eating either perennial grasses or smaller perennial forbs. However, there is potential for them to deprive sheep and cattle of browse that they will eat later in the year, when the quality and quality of perennial grasses are very low (Harrington 1986b). They may also deprive red kangaroos and western grey kangaroos of browse they will eat when the perennial grass supply is exhausted later in the year. To a lesser extent, this also applies to euro/wallaroos.

When the more palatable perennial forbs such as chenopods and larger shrubs and trees have stopped growing or have been eaten out, sheep, cattle and unmanaged goats will switch back to perennial grasses, including seed heads, providing their quality and abundance is adequate. Consequently, there is potential for sheep, cattle, unmanaged goats and the four species of Macropod to deprive each other of perennial grasses, which is more likely to occur when seasons are dry and when densities of herbivores are high. This is more so for Macropods which are likely to have concentrated more on perennial grasses leading up to this situation. In much of the NSW rangelands, and in less productive shrublands in WA, because of the lack of perennial grasses, animals flux between consuming annual forbs (high quality/low stability) and browse (low quality/high stability) because of the lack of perennial grasses.

When browse is the main feed available

As the quality and quantity of the perennial grasses decline, and the perennial forbs have been grazed out, sheep, cattle and unmanaged goats eat increasing amounts of browse from shrubs and trees. Eventually, when grass quantity and quality are very low, their diets will be predominantly browse.

The red kangaroos and western grey kangaroos are likely to eat the dry stems of perennial grasses for longer than will sheep, cattle and unmanaged goats. They do this because browse is less attractive to them and because they have a greater capacity to efficiently harvest sparsely distributed grasses and access grasses under shrubs. Only when the supply of grasses is exhausted does their diet consist predominantly of browse.

In contrast to this, eastern grey kangaroos and euros/wallaroos continue to graze the dry stems of perennial grasses. Like the other species of Macropod, they have high capacity to eat small grasses, the better quality parts of large grasses, and grasses under shrubs. Also, browse is even less attractive to eastern grey kangaroos and euros/wallaroos than it is to the other Macropods, and is rarely more than 15 percent of their diet. Hence they continue grazing grasses until above ground supplies are depleted, and then they dig up and eat grass bases and roots. This is likely to deprive sheep, cattle and unmanaged goats of dry perennial grass stems that they will look for when browse is no longer available. However, given that eastern grey kangaroos and euros/wallaroos cannot substantially switch to browse, there are serious consequences for these species when perennial grasses become absent. The quantity and quality of their intake will decline, they will lose weight, and if this continues, they die of starvation, or succumb more readily to predators.

The sheep, cattle, unmanaged goats, red kangaroos and western grey kangaroos will continue to consume browse while it is available. At this time it is likely that the two species of Macropods will be deprived of browse by livestock and unmanaged goats which started consuming browse much earlier, and because the Macropods possibly eat browse from fewer species of shrubs and trees. If that is the case, then red kangaroos and western grey kangaroos are likely to be adversely impacted by a shortage of browse earlier than sheep, cattle and unmanaged goats. However, when browse is no longer available, red kangaroos and western grey kangaroos will also consume the remaining very poor quality dry grass stems, and then dig up and consume grass bases and roots. Again, this will deprive sheep, cattle and goats of grass stems that they will seek when their browse supply is depleted. Also, sheep, cattle and goats do not dig up grass bases and roots, and thus have one less food option than the Macropods.

Sheep eat browse from fewer shrubs and trees than do unmanaged goats and access browse up to one metre from the ground, whereas goats access browse to two metres (Wilson *et al*. 1975). Sheep are also less able than goats to access browse in thickets of shrubs and on rocky hillsides (Squires 1980). Furthermore, unmanaged goats commence browsing much earlier than sheep which has the potential to deprive them of acceptable and accessible browse. Consequently, sheep are likely to run out of browse earlier than unmanaged goats. When this occurs, they will consume the remaining dry stems of any perennial grasses present, but varying amounts of this will have already have been eaten by Macropods. When grass stems have been depleted, sheep will scavenge for fallen tree leaves and other dead materials on the ground. However, they have less capacity than unmanaged goats to scavenge for dead materials, seeds and flowers, and thus experience adverse impacts of food shortages earlier than unmanaged goats.

Cattle, due to their large size, are able to access higher browse than sheep and can break down branches and access browse beyond their reach. However, cattle also eat browse from fewer shrub and tree species than do unmanaged goats, and are much less able than goats to access browse in thickets and on rocky hillsides. Unmanaged goats are likely to have commenced browsing earlier than cattle, and thus have the potential to deprive them of browse. When browse supply is exhausted, cattle will then also eat dry grass stems, but due to their large size, probably have very poor capacity to scavenge sparse grass stems, fallen leaves and other dead materials on the ground. Consequently, they are also likely to be adversely impacted by food shortages before unmanaged goats and sheep.

Unmanaged goats eat leaves from a wide range of shrubs and trees, and when the more palatable species are eaten out, they will eat browse from some species of shrubs and trees that were previously unacceptable. Also, there are fewer parts of the landscape which are inaccessible to unmanaged goats (Wilson *et al.* 1975, Squires 1980). Furthermore, they continue to eat dead materials on the ground long after sheep and cattle have given up. Thus, unmanaged goats are likely to be the last of the herbivores to be adversely impacted by food shortages.

While there can be considerable overlap in the use of broad classes of plants, such as grasses, forbs and browse over the period of a year by sheep, cattle, unmanaged goats and Macropods, there is often less overlap during particular seasons, and there may be less overlap in the use of particular species of plants within these broad groups (Dawson 1989).

5.4.8 Evidence of competition between herbivores

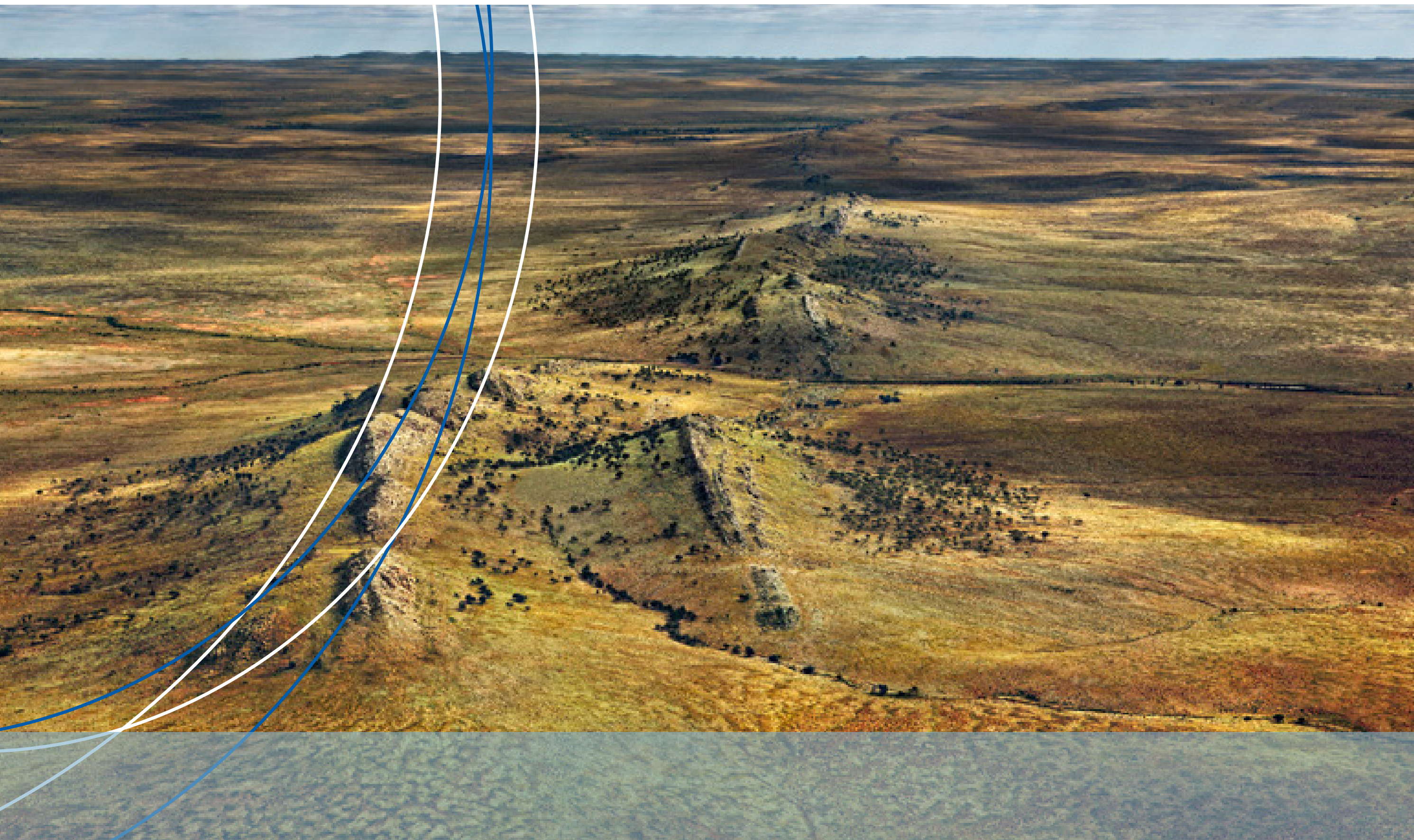
Competition between herbivores occurs when one animal interferes with or inhibits another to the extent this reduces the fitness of the other animal (Pianka 1981). Competition can occur when one animal physically reduces the access of another to resources, which is termed interference competition. Competition also occurs when one animal reduces the quantity or quality of a resource used by another animal, which is termed exploitative competition.

Intraspecific competition occurs when individuals of the same species deprive each other of resources. This is probably the most severe form of competition as animals within a species have the same resource requirements. Intraspecific competition is widespread and frequently occurring, particularly within herds or flocks of domestic herbivores which are maintained at relatively high stocking rates. Grazing trials have shown significant declines in body weights, live-weight gains, wool growth rates, and reproductive rates as the stocking rates or densities of individual species of livestock increase (Leigh *et al*. 1968, Wilson *et al*. 1969, Ash and Stafford Smith 1996, Freudenberger *et al*. 1999, Davies and Southey 2001, O'Reagain *et al*. 2009 and 2011).

Interspecific competition, between one or more different species, is often a lesser form of competition, as there is often little overlap of shared resources. However, interspecific competition is likely to occur when species of herbivore are accidentally or deliberately introduced by humans into natural communities. This has been the case with sheep, cattle and goats which have been introduced into the rangelands of southern Australia. These introductions are relatively recent, and there has not been sufficient time for introduced or native species to replace one another (Madhusudan 2004). Also, management of the domestic herbivores, such as provision of permanent waters, supplementary feeding, prevention of parasites and diseases, control of predators and constant reintroductions (livestock purchases) serve to maintain them in the landscape. Similarly, these same management practices aimed at improving the performance of livestock are also likely to increase the numbers of similar sized Macropods and unmanaged animals. Furthermore, the climate of the Southern Rangelands is highly variable, resulting in large swings in forage quantity and quality. Under these circumstances, herbivore biomass is often out-of-phase with forage biomass, which includes periods of over-grazing and decline in herbivore productivity. For these reasons, interspecific competition is more likely to occur between livestock, unmanaged goats, and native species of Macropod in the Southern Rangelands.

None-the-less, it has still proven difficult to demonstrate instances of competition between livestock and native or unmanaged herbivores. This requires demonstration of a decrease in the fitness of one species of herbivore due to habitat overlap and diet overlap with another species of herbivore, where the latter has limited the availability of resources for the former (De Boer and Prins 1990). This is often difficult to do in circumstances where these is also intraspecific competition and large swings in forage availability due to climate variability. However, interspecific competition between livestock and native herbivores has been inferred where the density of one species of herbivore increases as those of a co-existing herbivore decrease, and vice-versa, and especially when there is considerable overlap in their diets (Madhusudan 2004, Mishra *et al*. 2004). More convincing evidence of interspecific competition has been decreases in the body weights of cattle as the densities of a native herbivore increase (Howard *et al*. 1959).

In Australia, under conditions of set stocking within small paddocks of a grazing trial, Wilson (1991a and b) investigated the comparative effects of sheep and kangaroos at times when consumption of forage was more dominant than forage growth, being December 1987 and September 1989. In December 1987, one kangaroo had the same impact on green leaf biomass as 0.76 sheep, and the same impact on total forage biomass as 0.86 sheep. In September 1989, one kangaroo had the same impact on green leaf biomass as 0.71 sheep, and the same impact on total forage biomass as 0.75 sheep. In comparison, kangaroos had no impact on forage abundance during good seasons when pastures were growing rapidly. It was these circumstances that set the scene for competition between western grey kangaroos and sheep. In December 1987, the addition of a kangaroo to a paddock reduced wool growth by 0.62 times the addition of a sheep of the same weight. Two years later, in September 1989, the addition of one kangaroo to a paddock reduced wool growth by 0.44 times the addition of a sheep of the same weight. In the same years, the addition of one western grey kangaroo to the paddocks reduced live-weight gain of sheep by 0.57 and 0.22 times the addition of a sheep of the same weight. Wilson (1991a and b) concluded that both wool growth and sheep weight gain were reduced by increasing stocking rates of sheep or kangaroos, except when forage was abundant.



Edwards *et al.* (1996) also concluded that competition between sheep and red kangaroos were intermittent, occurring only during periods of climatically related food depletion, coinciding with high densities of the kangaroo. In this grazing trial, during a run of very dry months, sheep in paddocks containing kangaroos had lower live-weights relative to those in paddocks that were 'kangaroo-free'. At the same time, red kangaroos were not observed to have lost weight or condition.

Accordingly, a number of publications have proposed that competition does occur between livestock and Macropods, although this is limited to circumstances where pasture availability is low due to a succession of dry months, and when densities of Macropods are high (Dawson and Ellis 1994, Pople and Grigg 1999, Dawson and Munn 2007). Conversely, general opinion, such as that expressed by Pople and McLeod (2000) and Olsen and Low (2006), is that competition does not occur between sheep and Macropods when forage is abundant, because food choices or feeding sites differ, and because kangaroos often contribute little to total grazing pressure.

When interspecific competition between Macropods and livestock is acknowledged, it is believed that Macropods are impacted more than livestock, and that competition is asymmetrical. The reasoning for this is that livestock are able to rely on browse to keep them alive during very dry seasons or droughts, whereas Macropods cannot. Macropods are also at a competitive disadvantage because husbandry practices improve the performance and resilience of livestock. However, Macropods have characteristics which increase their competitive ability relative to livestock. They are not restricted by most livestock fencing and thus are able to graze areas infrequently grazed by livestock. Also, because of their much lower water requirements, they can forage greater distances than livestock from waters, again enabling them to access areas where grazing pressure is least. Additionally, their narrower jaws enable them to select higher quality forage, and their smaller body size allows them to survive longer under conditions of low pasture biomass. Macropods are also known to dig up butts of perennial grasses, providing them with an additional food supply compared to sheep and cattle.

The limited incidences of competition between livestock and Macropods reported in scientific literature are in marked contrast to the views of land managers. Sloan *et al*. (1988) reported that kangaroos were perceived as a major problem in 17 of 23 ABARES regions in which wool was grown. In particular, land managers considered kangaroos to be the major constraint on livestock production in the Gascoyne, North West Pastoral, Broken Hill and Longreach regions. They estimated that the total lost production due to kangaroos was around $200 million annually.

- Collins and Menz (1986), based on a survey of land managers in NSW, reported that the average cost of kangaroos per property was estimated to be $2,073, and the average cost per kangaroo was $1.47. Also, the value of carrying capacity foregone per kangaroo was $0.41. This was based on the pastoral-respondent estimated sheep equivalent of a kangaroo being 0.2 DSE, which is considerably lower than kangaroo DSEs of around 0.6 to 0.7 used in other studies.
- Gibson and Young (1987) surveyed land managers in five regions across Australia, as follows.:
    - In the Gascoyne region of Western Australia, the estimated cost of kangaroos per property was $11,000 and the cost per hectare was $0.06. The estimated cost per kangaroo was $3.40.
    - In the North West Pastoral Zone of South Australia, the cost per property was $15,000 and the cost per hectare was $0.09. The estimated cost per kangaroo was $2.07.
    - In the Broken Hill region of New South Wales, the cost per property was $7,400 and per hectare the cost was $0.18. The estimated cost per kangaroo was $2.00.
    - In the Wanaaring region of New South Wales, the cost per property was $3,800 and per hectare the cost was $0.19. The estimated cost per kangaroo was $2.75.
    - In the Longreach region of central western Queensland, the cost per property was $8,900 and per hectare the cost was $0.43. The estimated cost per kangaroo was $3.40.

Unmanaged goats are also believed to compete strongly with sheep, although empirical evidence is scant. Wilson and Mulham (1980) recorded interspecific competition between sheep and goats during a grazing trial on Ivandale Station, Ivanhoe, in western NSW. During the last three months of the trial, which was a period of low rainfall and very low pasture biomass, sheep grazing with goats lost weight sharply and produced less wool in contrast to sheep grazing without goats. In comparison, the goats grazing with sheep did not lose weight.

Parkes *et al*. (1996) claimed that economic losses attributable to unmanaged goats in Australia were around $25 million per annum. This consisted of a $17.8 million net loss caused by reduced stock production, $6 million contingency loss because of the threat of exotic disease, and $1.2 million direct cost expended by government agencies on goat control operations. In South Australia, Parkes *et al*. (1996) updated Henzell's (1989) calculations to give an estimate of a net average cost per unmanaged goat to sheep graziers of $8.15 per goat.

However, not all interactions between different species of herbivores are competitive. Many plants tolerate substantial levels of defoliation by herbivores by growing additional leaf and stems, a process known as compensatory growth (Hidding *et al*. 2009). This can diminish competition between herbivores, even to the extent where they facilitate one another (Arsenault and Owen-Smith 2002). Facilitation can occur through foraging by one species that result in higher quality grass regrowth, or through increased access to forage due to the removal of obstructing stems, for another species of herbivore.

Facilitation often involves a large herbivore which facilitates another smaller species by feeding on grass and thereby improving its quality (Mishra *et al*. 2004). This appears to be common in the grass swards on the Serengeti plains (McNaughton 1976, Arsenault and Owen-Smith 2002). Thomson's gazelle were attracted to areas where prior grazing by wildebeest improved the quality of grass. Similarly, Gordon (1988) found that areas grazed by cattle during winter had a significantly higher standing crop of green vegetation in spring, and had proportionately more green than dead material, than areas protected from cattle grazing. Red deer in spring preferred to feed in areas that had been grazed previously by cattle. Cattle are also known to benefit from prior grazing by native herbivores which enhanced the nitrogen content and digestibility of the forage available to cattle (Hobbs *et al*. 1996, du Toit 2011, Odadi *et al*. 2011). However, these positive interactions can turn negative under high stocking rates when forage biomass is greatly reduced (Hobbs *et al*. 1996). Arsenault and Owen-Smith (2002) noted that small species are more likely to benefit from the grazing impacts of larger species, and potentially out compete them when food supplies become reduced. Furthermore, by selectively grazing on green leaf in taller swards, smaller or narrow-muzzled species have the ability to deplete this component to the detriment of forage quality for larger species.

Facilitation has also been proposed as an outcome of interactions between kangaroos and cattle in Australia, where grazing by cattle stimulated perennial grasses to produce green shoots preferred by kangaroos (Newsome 1971). However, this is only likely to occur during the growing season, whereas consumption during the non-growing dry season can become competitive.

5.5 Implications for managing TGP

While land managers can influence the level, location and timing of grazing of livestock, they currently have only limited control over unmanaged goats, and almost no control over Macropods, with a result that TGP can vary significantly over relatively short time periods and small distances. This does not matter so much when forage supplies of all types are abundant – as during and immediately after years with well above average rainfall – but these situations are comparatively rare.

The quantity and quality of forage available for all herbivores within the Southern Rangelands is frequently low, which increases the prospects for direct competition between managed and unmanaged species for forage. When this occurs, animal performance (both domestic and non-domestic herbivores) can be poor and there is a risk of degrading the resource's productive potential. This is most apparent when high densities of herbivores coincide with periods of low rainfall. In addition, although various forms of rotational grazing and pasture spelling are being practiced by land managers, grazing by Macropods reduces the benefits they may gain from spelling pastures. Finally, land managers are obtaining no benefit from grazing Macropods, and there is disputation about the cost they impose upon the pastoral business.

Land managers need more real-time information and cost-effective technologies to be able to manage TGP. Firstly, they need to be able to identify early when an imbalance between forage supply and forage demand is imminent so that they can take action. There is also a need for quantification of the impact on resource condition, forage availability (and financial return) when unmanaged herbivores access spelled paddocks, which will allow land managers to determine how much to invest in control of unmanaged herbivores (as in Macropod proof fencing). Finally, a better ability to determine when forage supply is reaching critical levels (e.g. 300 kg-500kg/ha) will allow land managers to make more timely decisions about livestock numbers.

6. Impacts of resource condition

6.1 Summary - key messages and knowledge gaps

Key messages

Few published studies have directly addressed the impact of TGP on resource condition (ground cover, biodiversity and soil carbon)
While there are contested views in the literature regarding the impact of livestock on resource condition, on balance livestock grazing appears to have a neutral or negative impact on resource condition (including biodiversity)
Studies are generally limited to examining grazing impacts on floristic diversity; other components of biodiversity e.g. fauna impacts are less studied
There is a large body of literature which indicates livestock grazing systems that incorporate periods of rest can: 1. reduce herbivore selectivity 2. maintain higher levels of ground cover 3. have neutral to positive effect on plant species diversity 4. achieve desired pasture utilisation rates 5. enhance plant growth and survival 6. increase the perennial grass content and biomass 7. achieve a small improvement in soil organic carbon but this may occur over long timeframes (>10 years) 8. reduce rates soil erosion
Prolonged, intense livestock grazing will reduce biomass; change pasture composition from productive, perennial plants and towards annual plants
Negative effects of livestock grazing intensity will be exaggerated under drought conditions
Grazing intensity is a more important driver of resource condition than the type of grazing system e.g. rotational grazing vs. set stocking
Considerable research on grazing systems has occurred. However, a clear understanding of the temporal and spatial impacts of grazing intensity on resource condition is not known

Knowledge gaps

How does managing TGP affect resource condition (ground cover, biodiversity and soil carbon)?
When does private vs public interest in maintaining resource condition diverge?
An understanding of the performance of TGP management options (e.g. cluster fencing) on resource and economic outcomes
A dynamic assessment of grazing impacts is required, that takes into account multiple landscape factors and their interactions
Development of an ‘estimated environmental value’ of rangelands or a carbon ‘neutrality’ index to meet changing consumer preferences for carbon and land degradation neutrality

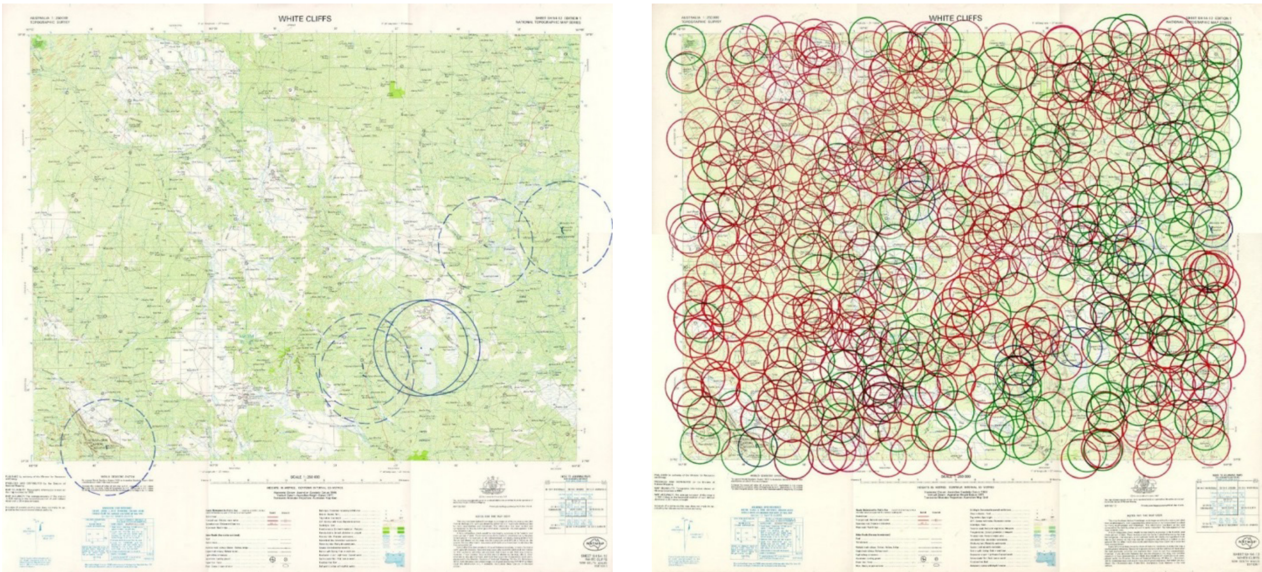
6.2 The current state of the rangelands

Across Australia, grazing occurs on 356 million hectares of native pastures, or 46 percent of the land surface (State of the Environment 2011). There is no argument that a substantial proportion of the land and vegetation resources of the grazed rangelands have been altered as a result of more than a century's grazing by domestic livestock, and related perturbations associated with fire frequencies, weed infestations, and feral animal grazing. These issues occur to a greater or lesser extent across all rangeland regions (Bastin 2008). The impact of these issues on animal production will be compounded in some regions by increased seasonal variability and declining rainfall over recent decades.

In Australia, following pastoral settlement in the latter half of the 19th century, vegetation responses to changes in total grazing pressure have been linked to woody thickening and livestock production decline in western NSW (Anon 1901; Anon 1969; Hodgkinson *et al*. 1984).

Pastoralism has increased access to watering points which has fundamentally changed managed and unmanaged animal populations and limited the amount of water remote areas which are not grazed (Figure 6-1).

Figure 6-1: Distribution of permanent and semi-permanent waters on the White Cliffs 1:250 000 topographic map sheet before settlement (left) and at the present time (right)



The solid and dashed circles in the top figure represent 10 km radii from permanent waters (including mound springs) and semipermanent water holes, respectively. Only areas within the solid circles would have been permanently habitable for kangaroos. In the bottom figure red and green circles represent sheep grazing radii (5 km) from earth tanks (407) and bores and wells (155), respectively. Virtually all of the landscape is permanently accessible to both sheep and kangaroos.

Source: Hacker and McLeod (2003) in Waters and Hacker (2008).

‘Good’ rangeland resource condition is identified as having sustained biophysical and socio-economic functions relative to some reference state (Friedel *et al*. 2000; Pyke *et al*. 2002). Loss of biodiversity is often used as an indicator of declining rangeland resource condition but there are difficulties in determining a valid benchmark or reference state. There is evidence that while rangelands are characterised by instability, these environments also have an intrinsic resilience (Abel and Blaikie 1989). Trends in multiple indicators across Australian rangelands also suggest that generally, changes in range condition are driven more by seasonal conditions than by grazing (Bastin 2008).

It is difficult to separate effects of seasonal conditions from those due to grazing herbivores, either directly as a loss of perennial grass cover or in-directly through woody regrowth (Archer *at al*. 1995; Donohue *et al*. 2013; Golubiewski and Hall-Beyer 2007; Silcock and Fensham 2013; Zhu *et al.* 2016; Walker and Steffen 1992). Further, an interpretation of the 2008 ACRIS data (Bastin 2008) suggest the rangelands are not highly dynamic.

However, there remains a negative narrative surrounding the rangelands which supports ‘*entrenched prevailing paradigms despite a lack of empirical evidence’* (Silcock *et al*. 2015). Recent changes in management of total grazing pressure through exclusion fencing in the Southern Rangelands is allowing unprecedented opportunities to manage total grazing pressure, however little direct evidence has been published. Combined with change in pastoral land-use driven by the adoption of carbon farming in some regions, this is providing the opportunity to reverse the negative narrative for the Southern Rangelands.

Development of an ‘estimated environmental value’ of rangelands or a carbon ‘neutrality’ index or a ‘sustainability’ metric akin to an estimated breeding value (EBV) for livestock could recognise sustainable pastoral land-use practise. Reliable data, collated in national recording schemes to recognise good stewardship is lacking. While an extensive review of possible mechanisms to measure and verify possible indicators is beyond the scope of this review there are a number of projects in NSW and QLD in the context of carbon farming that are attempted to develop metrics.

6.2.1 Approaches to assessing grazing impacts

Three approaches have traditionally been employed to assess the impacts of grazing intensity; examining piosphere effects (Lange 1969); controlled grazing experiments and paddock contrasts (which includes both comparisons between grazing systems and contrasts between grazing and grazing exclusion). While each approach provides insights there are limitations to each which makes both interpretation and application of results problematic.

Piosphere effects

The dispersal, distribution and abundance of herbivores is influenced by artificial water points which act as focal points for water-dependent herbivores such as goats (Letnic *et al*. 2014) and domestic livestock compared with kangaroo populations which are less dependent on water. Studies utilising a piosphere approach have shown that grazing in close proximity to water points (high grazing intensity) has resulted in shifts from palatable perennial species to increased annual species (Friedel *et al.* 2003; Landsberg *et al.* 2003; Hendricks *et al.* 2005) and accompanied by decreased species diversity (Hendricks *et al.* 2005; Todd 2006) as well as increased soil erosion (Tongway *et al.* 2003; Tabeni *et al.* 2014). However, the results of this experimental approach can be dependent on the size of the paddock relative to the number of water points as well as the number of herbivores.

Controlled grazing experiments

Such experiments do not generally assess the impacts of grazing at large scales but examine small-scale impacts often at patch and/or area-specific responses (Archibald *et al.* 2005; McDonald *et al.* 2017). The frequent rotation of livestock and resting of paddocks have been shown to achieve positive ecological outcomes (see Teague *et al.* 2015; Waters *et al*. 2016 and 2017 for more recent studies and references within) and socio-economic outcomes (Teague *et al.* 2015). However, in a review of global experimental grazing experiments, Briske *et al.* (2008) argue the opposite, suggesting complexities with ecological variability (amount, seasonality and intra-annual variability in rainfall; past grazing; vegetation structure, composition and productivity; type of herbivore, prior condition, soil variability) combined with complexities in grazing system make deriving a clear, coherent interpretation of results from the global literature difficult.

Paddock contrasts

The long term (18 year), Wambiana grazing experiment (near Charters Towers in Queensland) contrasted a range of grazing systems, including continuous set stocking at different stocking rates, flexible stocking with annual variation in stocking rate and pasture resting in a tropical, northern Australian beef production system. Here, the greatest negative impacts of heavy grazing were manifest during droughts and particularly evident when rates of pasture utilisation were high (O'Reagain *et al.* 2009). In this study, high levels of long-term pasture utilisation led to accelerated declines in perennial, productive and palatable pasture species. While this study also suggested that pasture responses to periods of rest may be slow and therefore not necessarily translate into subsequent increased stocking rates, declining soil quality indicators, increased runoff and reduced activity of soil fauna (e.g. termites) were each linked to continuous, heavy grazing.

More recently, remotely sensed data has been used to assess grazing impacts. For example, Normalised Difference Vegetation Index (NDVI) has been utilised to provide an additional set of data complementary to the ground measurements obtained via the Western Australian Rangeland Monitoring System (WARMS). Here, the relative differences between actual and potential carrying capacity can provide an indication of trends in resource availability but are provided at a regional or major vegetation community scale over 3-5 year time periods (Watson *et al.* 2007; Novelly *et al.* 2008). A range of GIS-based data sources are being utilised by state and federal agencies to monitor and report on changes in ground cover and resource condition at regional and finer scales.

For example TERN Auscover provides seasonal ground cover (green and bare) but has uncertainties with tree cover greater than 15 percent[1] as well as a seasonal persistent green product primarily used for woody vegetation (trees and shrubs)[2]. SLATS woody change is a Queensland Government product that is used for reporting on loss of woody vegetation[3]; VegMachine® is a tool for summarizing long term, spatial and temporal changes in total and ground cover from decades of satellite imagery. It provides fractional cover at a range of scales[4]. Total standing dry matter (TDSM) can be derived from simulations in AussieGRASS[5]. However, finer scale remotely sensed products have been more recently developed to assess changes over shorter timeframes (see Figure 6-2 and Figure 6-3).

[1] http://data.auscover.org.au/xwiki/bin/view/Product+pages/Seasonal+Ground+Cover
[2] http://data.auscover.org.au/xwiki/bin/view/Product+pages/Landsat+Seasonal+Persistent+Green
[3] https://data.qld.gov.au/dataset/statewide-landcover-and-trees-study-queensland-series
[4] https://vegmachine.net/
[5] https://longpaddock.qld.gov.au/aussiegrass/

6.3 Rangeland responses to grazing

6.3.1 Ground cover responses

The amount of bare ground is associated with erosion and loss of landscape function (Freudenberger *et al.* 1997; Bartley *et al.* 2006; Muñoz-Robles *et al.* 2011). Specifying minimum ground cover targets (e.g. 50%, below which wind erosion occurs) are broadly promoted across rangeland NRM regions, however land managers do not always manage to achieve ground cover targets. There are a number of reasons for this.

i. The application of a blanket target of is not realistic as different range types or Land Systems innately support varying levels of ground cover (or bare soil) but there is little information to underpin setting of locally specific targets.

ii. There is little economic incentive to do so (Moss *et al*. 2012; Hacker *et al*. 2010).

iii. Groundcover has a spatial and temporal component that will require seasonal adjustment to account for climatic variability (Bastin *et al*. 2014).

iv. Difficulties in identifying when ground cover trends are due to a management effect from those due to seasonal conditions.

The use of Landsat derived, seasonal fractional ground cover to monitor changes in management has been developed collaboratively between Western Local Land Service, NSW Office of Environment and Heritage and the NRM Spatial Hub (FarmMap4D). Here, the performance of a paddock or property is gauged against the surrounding local area. While the method requires broader field validation, it provides a cost-effective method to monitor changes due to grazing management. In addition, it also avoids setting a ground cover target, as the relative performance of an area is adjusted to prevailing seasonal condition as well as providing timely (3 months, Figure 6-2 or weekly, Figure 6-3) indication of seasonal trends which can inform grazing management decisions (Figure 6-2). An alternative method to monitor changes and trends has been proposed by Bastin *et al*. (2014). This 'dynamic reference-cover' method also employs remotely-sensed ground cover, assessing trends in persistent (perennial) ground cover in the interval between a set of sequential dry years. While this has been used to assess change in condition of ~640,000 km^2 in Queensland between 1988 and 2005, this method is less applicable to monitoring changes within short timeframes and is of limited utility value for informing management decisions (Bastin *et al.* 2014).

The amount of bare ground will increase and cover of cryptogram and litter will decline with high grazing intensity (Tongway *et al.* 2003; Tabeni *et al.* 2014; Waters *et al*. 2017). However, there is also evidence that grazing which incorporates periods of rest can maintain ground cover and increased the perennial pasture component (Kahn *et al.* 2010; Sanjari *et al.* 2009: Teague *et al*. 2011) as well as reducing soil erosion (Sanjari *et al*. 2009).

A meta-data analysis using 75 studies (Argentina, Australia, Canada, US and Zimbabwe) compared grazing system impacts on ground cover and livestock production (Hawkins 2017). Holistic Planned Grazing™ (HPG) (high intensity/short duration grazing) was compared to continuous grazing in temperate and tropical grasslands, savannas and shrublands but no differences in groundcover (basal plant cover) or livestock production were found between grazing systems (Hawkins 2017). However, while this author notes a high level of variation in study results, higher productivity areas (generally higher rainfall) tended to have positive effects but overall stocking rate and grazing pressure were found to be more important than the grazing system in achieving a balance between plant and animal production. Where the grazing pressure is significant and controlled through partial exclusion fencing, and/or long periods of rest are incorporated into the grazing system, between 6-16 percent increases in perennial ground cover have been reported in western NSW (Waters *et al*. 2017, Table 6-1).

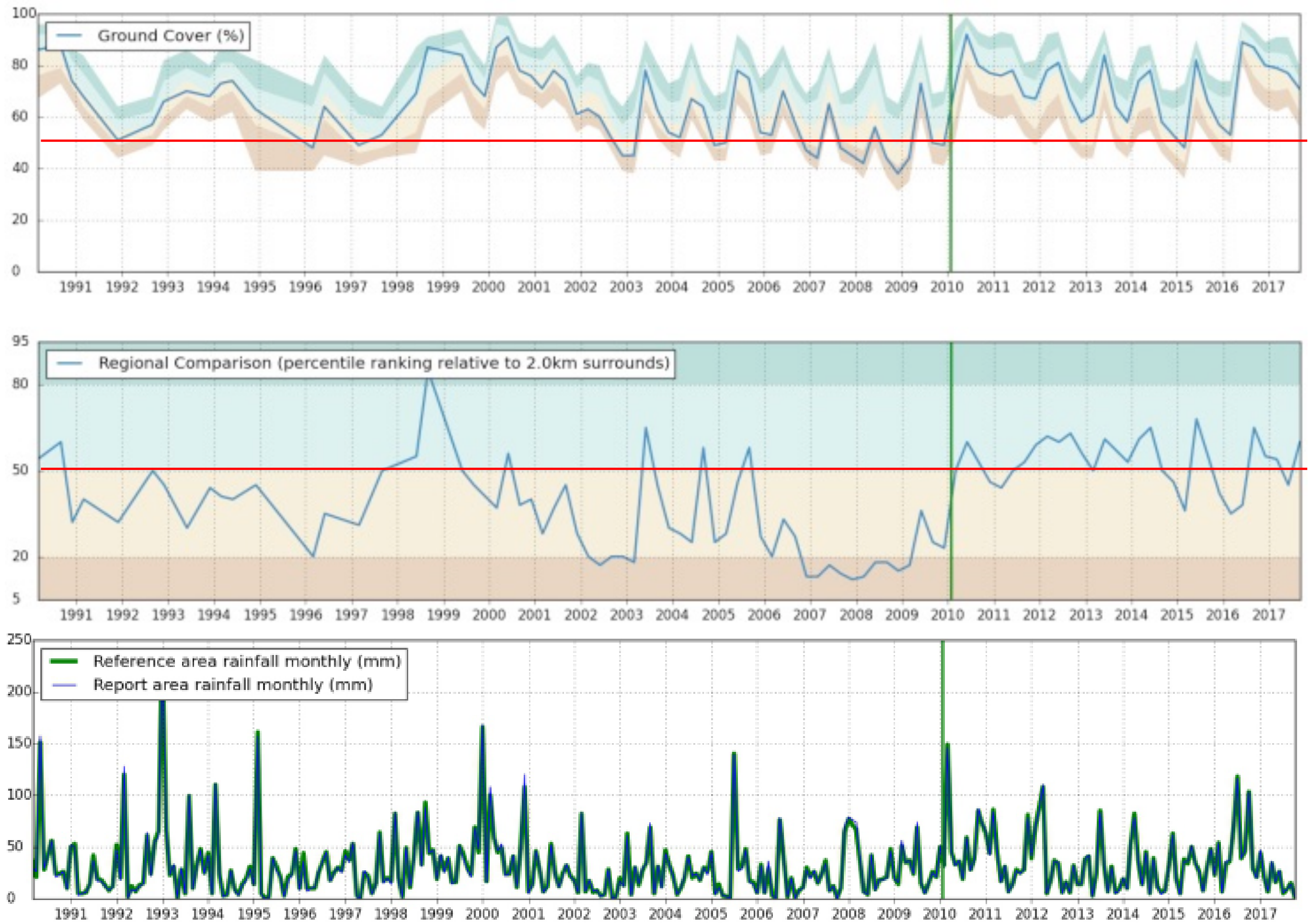
Table 6-1: Predicted means (se) for significant ground cover components (percentage ground cover within 0.25m^2 quadrat)

		Treatment	Perennial	Litter	Cryptogam	Dung	Rock	Bare	CWD	Annuals
Location 1	Claypan	Rotational grazing	16.0^{b} (3.9)	25.7^{b} (4.0)	ns	ns	-	51.0^{b} (6.2)	-	ns
		Continuous grazing	5.0^{a} (4.4)	7.2^{a} (4.5)	ns	ns	-	82.1^{c} (6.9)	-	ns
	No Claypan	Rotational grazing	29.7^{c} (2.6)	33.4^{b} (2.7)	ns	ns	-	29.7^{a} (4.1)	-	ns
		Continuous grazing	20.8^{bc} (2.6)	26.7^{b} (2.7)	ns	ns	-	46.7^{b} (4.2)	-	ns
Location 2	Box	Rotational grazing + TGP fence	30.5^{d} (3.6)	20.6^{ab} (4.1)	16.3^{ab} (4.8)	0.8^{ab} (0.5)	3.5^{a} (3.91)	31.6^{ab} (4.7)	1.1^{a} (1.0)	ns
		No stock + high TGP	14.7^{abc} (4.2)	13.2^{ab} (4.5)	34.3^{b} (5.0)	1.6^{b} (0.5)	8.7^{a} (3.91)	36.0^{ab} (4.9)	0.4^{a} (1.0)	ns
	Yarran	Rotational grazing + TGP fence	23.6^{cd} (3.7)	19.4^{ab} (2.9)	15.5^{a} (3.5)	0.4^{ab} (0.4)	2.3^{a} (2.9)	45.2^{b} (3.5)	1.3^{a} (0.7)	ns
		No stock + high TGP	8.4^{a} (4.1)	22.1^{b} (4.8)	37.1^{b} (5.1)	0.0^{a} (0.5)	0.3^{a} (3.91)	26.1^{a} (5.0)	4.2^{b} (1.0)	ns
	Ridges	Rotational grazing + TGP fence	19.9^{bc} (4.5)	11.9^{ab} (4.3)	37.6^{b} (4.9)	0.2^{ab} (0.5)	9.2^{a} (3.91)	32.2^{ab} (4.7)	1.4^{ab} (1.0)	ns
		No stock + high TGP	13.4^{ab} (4.6)	5.4^{a} (4.0)	30.8^{bc} (4.8)	1.1^{ab} (0.5)	31.3^{b} (3.91)	29.5^{a} (4.7)	0.0^{a} (1.0)	ns
Location 3	Pine/Belah	No stock + high TGP	2.5^{a} (2.8)	ns	31.8^{b} (3.6)	3.2^{b} (0.8)	ns	30.8^{b} (2.8)	5.7^{b} (1.45)	39.8^{a} (5.8)
		No stock + low TGP	17.7^{b} (2.7)	ns	33.9^{b} (3.4)	0.6^{a} (0.7)	ns	15.0^{a} (2.7)	1.1^{a} (1.4)	42.1^{a} (5.5)
		Rotational grazing + TGP fence	15.0^{b} (2.8)	ns	6.3^{a} (3.6)	1.9^{ab} (0.8)	ns	16.8^{a} (2.8)	1.1^{a} (1.5)	66.8^{b} (4.3)

Grazing management treatments are shaded and contrasting treatments unshaded. Locations represent different soil types/ enterprise types comparing rotational grazing with/without the use of total grazing pressure (TGP) fencing. Rotational grazing is consistently associated with higher levels of perennial ground cover. Predicted values, within location, not sharing the same superscript are significantly different ($p<0.05$)

Source: Waters *et al.* 2017

Figure 6-2: Time series analysis of ground cover for a Western LLS incentive project area over a 26+ year time period (1991 to 2017)



a. Indicates the percentage ground cover (vegetation, rock, litter) based on Landsat Fractional Ground cover. The blue line indicates the value for the project area while the green-brown bands correspond to the percentile ranges of fractional cover values recorded within a 2 km reference buffer zone surrounding the project area. It is assumed that the buffer zone is of similar land types to the project area. The red line indicates a 50% ground cover threshold (the proportion 30m pixels), below which soil is exposed to wind and water erosion. Ground cover generally remains above this threshold during the Millennium drought (2003-2010 c.), falling below 50% on 5 occasions (2003, 2005, 2007, 2009). Coincident with the post-Millennium drought breaking rainfall in 2010, project fencing was completed (green line indicates final inspection date) and the area subject to different management compared to the 2km buffer area surrounding the incentive project area. Without analysis, segregation of the rainfall response from the seasonal response is difficult.

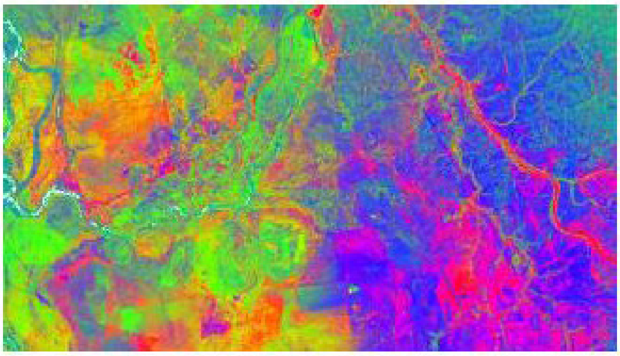
b. The seasonal response is removed from the analysis and the project area groundcover is assessed solely in relation to the percentile range of the buffer zone. In this case, a management response is visible following the intervention date (green line). The incentive area consistently maintained higher levels of ground cover after fencing, and demonstrates a greater capacity to respond to rainfall.

There may be differences in soil type and vegetation between the project area and reference buffer zone. However, the relative trend of groundcover in relation to a reference receiving the same seasonal conditions provides evidence of a management response. This illustrates the utility value of using remote sensed fractional ground cover data to provide trends in ground cover resulting from management.

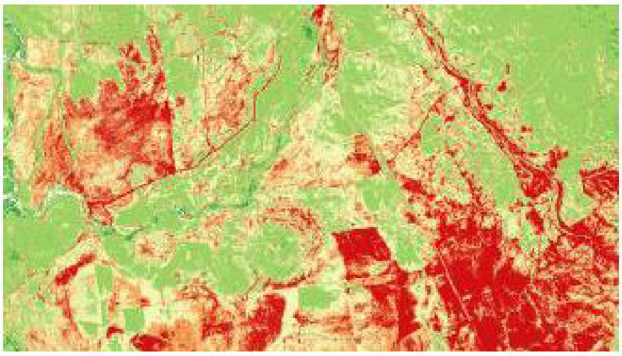
Source: Western Local Land Service.

Figure 6-3: Near real-time in ground cover and pasture biomass can be provided using 10 m resolution every five days from remotely sensed Sentinel data

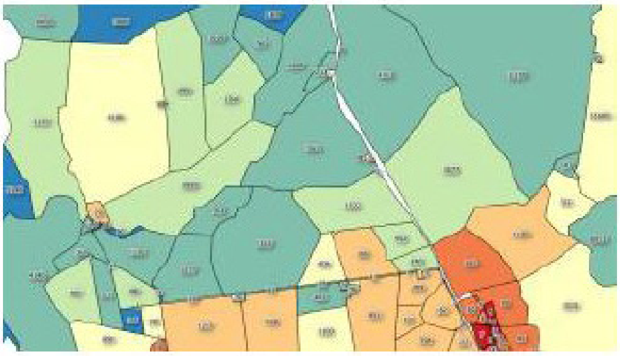
5 daily, paddock scale imagery



Fractional ground cover



Kg of pasture biomass per ha



Total kg in the paddock

Products to determine net food on offer at a paddock scale are currently being developed and pilot studies undertaken in Western Australia and Queensland. Ground validation for grasslands has yielded promising results but is yet to be tested for woodlands. There is potential to integrate these products with livestock production data at the farm scale.

Source: Phil Tickle and Peter Scarth (Cibo Labs).

6.3.2 Soil carbon responses

Carbon stores in the rangelands

Relative to high rainfall grazing systems, comparatively low levels of soil organic carbon (SOC) are found in rangeland soil surface layers, but the extensive areas occupied by rangelands represent a significant potential sink for greenhouse gas emissions (Powlson *et al*. 2011).

While rates of organic matter (OM) accumulation will influence carbon (C) input to soils, OM is most useful when it transforms to humus (stable carbon), little information on the environmental conditions that optimise biological transformation within rangeland grazing systems exists (Janzen 2006). The storage of C in soil is influenced by multiple factors, but the productivity of vegetation and OM decomposition are the two most important factors which can be regulated by grazing management.

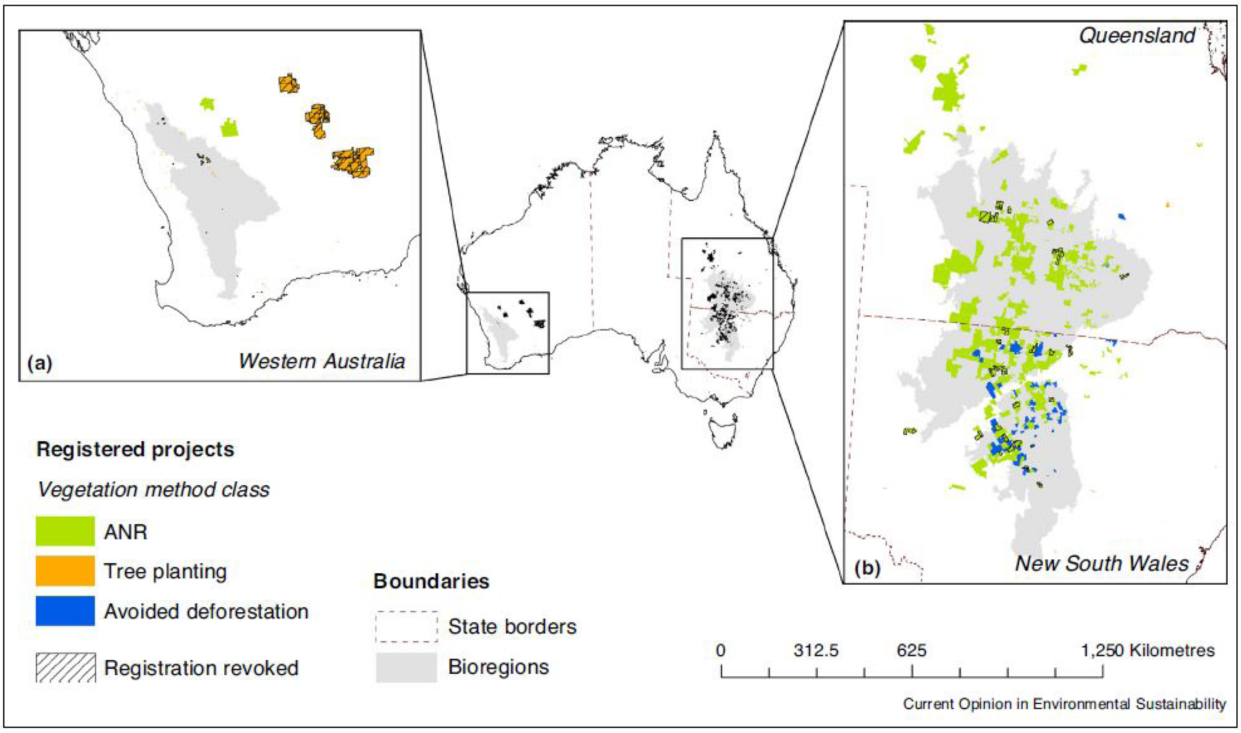
The theoretical potential for rangelands to provide a sink for soil C has resulted in a considerable number of recent publications examining the impacts of grazing on SOC. The literature supports a general recognition that long-term, high intensity grazing will result in losses in soil organic carbon (Powlson *et al*. 2011; Janzen 2006). However, there are contested views for the effects of livestock grazing on soil carbon. Some recent studies show a decrease (Su *et al.* 2004; Zuo *et al.,* 2008; Mofidi *et al.* 2012; Hawkins 2017), no significant change (Sanjari *et al.* 2008; Aynekulu *et al*. 2017; Allen *et al.* 2013 McCalla *et al*. 1984; Booker *et al*. 2013, Sanderman *et al*. 2015) or an increase in soil C (Reid *et al*. 2004; Reeder & Schuman 2002; Teague *et al.* 2011; Li *et al.* 2011; Yong-Zhong *et al*. 2005; Waters *et al*. 2017; Orgill *et al.* 2017). These inconsistencies may be due to differences in plant species composition (Piňeiro *et al.* 2010), the carry-over effects from previous management and interactions between these factors. McSherry and Richie (2013) found that with increasing grazing intensity, C4 dominated tropical grasslands increased soil C by 6 to12 percent but decreases of up to 18 percent occurred with C3 dominated grasslands. In addition, soil type and rainfall show that the effects of grazing are highly context dependent (Waters *et al.* 2017). In a recent global meta-analysis (Abdalla *et al*. 2018), using the results from 83 global studies and normalising SOC values to a common soil depth, grazing was found to decrease SOC, but for dry environments, an increase in SOC by 5.8 to 16.1 percent was found with the greatest increased associated with C4 dominated grasslands. In another study in the semi-arid rangelands of eastern Australia, the effect of grazing intensity were found to be mediated by ground cover and high OM supply and/or reduced erosion (Waters *et al*. 2017).

As rangeland systems are characterised by large fluctuations of relatively low levels of net primary productivity (NPP), limited temporal opportunities to rapidly increase the input of organic matter (OM) or to derive benefits from OM and sequester carbon may occur. The ability to recognise these opportunities will therefore be of central importance in increasing SOC under rangeland grazing systems. However, to the best of our knowledge, no understanding of temporal changes in SOC, under Australian rangeland pastoral systems exists. Other abiotic factors such as grazing intensity will also modify soil structure, function and the capacity for SOC storage at a site scale, as well as innate climatic and soil characteristics.

Carbon farming in the rangelands

Carbon farming has transformed the south-eastern Australian rangelands over recent years with extensive areas of semi-arid Southern Rangelands managing vegetation for carbon (Figure 6-4). In many of the areas of South East Australia, these carbon areas are being surrounded by TGP control fencing representing an opportunity to examine the impacts of grazing control on co-benefits of soil carbon and resource condition. In addition, approaches to integrate carbon farming with livestock production may provide a pathway that allows livestock industries to achieve net zero emission targets (Mayberry *et al.* 2018).

Figure 6-4: The distribution of vegetation projects registered under the Australian governments Emissions Reduction Fund (ERF) across southern semi-arid rangelands



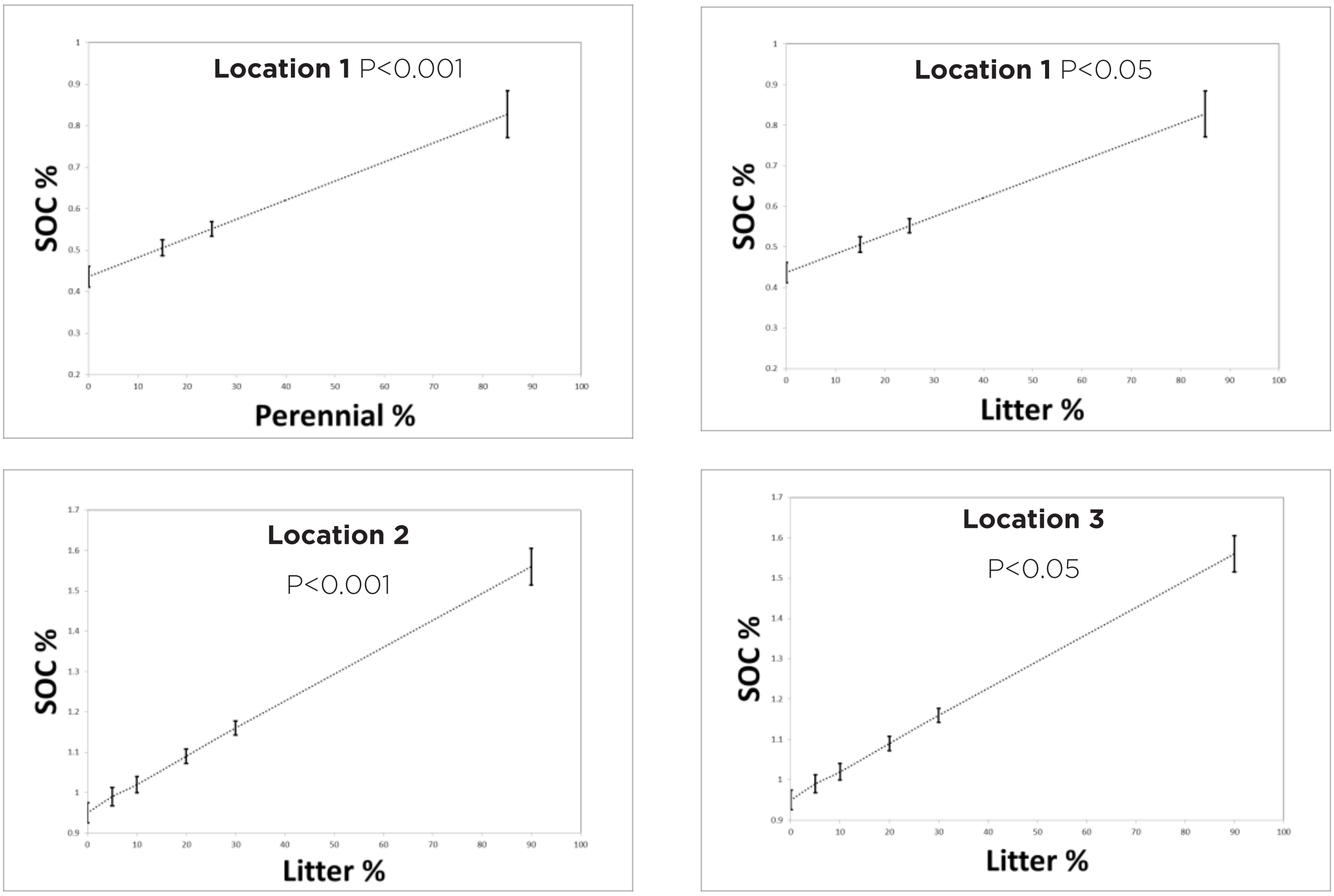
There has been a large uptake of cost effective methods, assisted natural regeneration (ANR) and avoiding clearing of native vegetation in SE Australia. In Western Australia most registered projects are associated with tree planting (a single, 1.5 million hectare project was revoked in February 2018) but there are relatively few active projects due to high costs.

Source: Evans (2018).

Strong relationships between ground cover (perennial and litter) have been shown for both Vertisols (fine textured grey soils) and Kandasol (course textured red soils) soil (Figure 65). These ground cover components are influenced by grazing management and trends or changes may be monitored using remotely sensed methods such as Landsat fractional ground cover (Muir *et al.* 2011; Guerschman *et al.* 2012).

The use of remotely sensed data (including fractional ground cover) is proving useful in providing an efficient and accurate method for the indirect measurement of soil carbon in rangelands (Wang *et al*. 2017; Wang *et al*. 2018).

Figure 6-5: Significant relationships between ground cover and soil organic carbon percentage (SOC %) for three study locations (1 = Vertisol; 2 & 3 = Kandosol) .in western NSW



Points represent predicted means with standard errors (bars). Source: Waters *et al.* (2017).

Differences in intensity and patterns of grazing may also help to explain inconsistent effects of grazing on soil C (Dumont *et al.* 2007). The continuous removal of plant biomass with grazing will negatively impact soil OM (Mofidi *et al.* 2012) by reducing the amount of litter (Schuman *et al.* 1999; Rutherford *et al.* 2012; Shengjie *et al*. 2017), reducing root exudation and lowering microbial biomass (Mofidi *et al.* 2012). The quality of litter may also be altered for affecting soil microbial life (Shengjie *et al*. 2017) and can be associated with reducing water soluble C (Larreguy *et al.* 2017) and decreasing quality of organic C stock as well as increased soil pH (Cui *et al*. 2005).

In addition, reduced plant cover can also make soil more vulnerable to wind and water erosion, increasing losses in soil C (Pulido *et al*. 2016). Where grazing intensity increases, shifts from native to a greater proportion of annual and exotic plant species can occur (Díaz *et al*. 2007). However, other studies have shown that long-term (>40 years) removal of grazing can result in lower levels of soil C and nitrogen (Schuman *et al*. 1999), but short-term increases in soil N under grazing may also occur (Lu *et al.* 2015). Some reports of short duration grazing followed by long periods of pasture rest have shown increases in SOC (Waters *et al.* 2017; Talore *et al.* 2016), reduced soil compaction and reduced risk of erosion even within relatively short time frames (<5 years; Sanjari *et al*. 2008; Teague *et al*. 2011; McSherry and Ritchie 2013). Shengjie *et al*. 2017 contrasted grazed and non-grazed Mongolian steppe grasslands and found that the long term effect of intensive grazing on SOC may carryover for more than 20 years. While these authors report 20 to 35 percent more biomass in non-grazed sites, no differences on SOC were found.

6.3.3 Biodiversity responses

It has been suggested that livestock grazing impacts alone are having limited impact on in situ biodiversity except in extreme cases of over-utilisation, in particularly vulnerable environments (e.g. riparian areas) and where grazing animals are vectors for weed seed distribution (e.g. mesquite, prickly acacia) (URS 2014). However, globally, livestock grazing has been implicit in the loss of biodiversity (Steinfeld *et al.* 2006; Lunt *et al*. 2007a and b; Eldridge *et al.* 2016) and there is general agreement in the literature that biodiversity is negatively impacted as grazing intensity increases (Lunt *et al*. 2007a and b; Díaz *et al.* 2007; Rutherford *et al.* 2012). The 2008 ACRIS Reports (Bastin 2008) suggest a downward trend in biodiversity throughout the rangelands (citing declines in bird numbers as the main evidence), although this could result from many factors apart from grazing impacts, including weed and pest infestations and loss of habitat in some more closely settled areas.

There is an extensive body of literature which examines how grazing systems and the frequency and duration of grazing influences biodiversity but generally stocking rate and prolonged, high intensity grazing have been found to be a more important driver of floristic diversity than the grazing system (O'Reagain and Turner 1992; Provenza *et al*. 2003; Vermeire *et al*. 2008, Hawkins 2017).

Prolonged defoliation through continuous high grazing intensity reduces the longevity and distribution of plant roots (Hodgkinson and Bass Becking 1977) and negatively impacts plant growth and mortality (Hacker *et al.* 2006; Briske *at al*. 2008). Perennial grass mortality rates can be further increased when high grazing intensity occurs under drought conditions (Hodgkinson and Mueller 2005).

A number of studies have shown low intensity, continuous grazing to increase plant diversity (Lunt *et al*. 2007a and b; Borer *et al*. 2014) due to increased structural and compositional heterogeneity resulting from patch-grazing which leaves some parts of the landscape over or under-utilised by herbivores (Teague *et al*. 2004). However, others argue that continuous grazing will result in a decline in desirable perennial grasses which are selectively grazed, over-utilised without recovery periods from grazing (Norton 1998a); here over-grazed patches may expand as less desirable areas are continually avoided (Teague *et al*. 2008). It is then argued that the negative effects of patch and selective grazing can be avoided by employing high intensity grazing in a rotation which allows for a more even grazing impact across a paddock and incorporates a sufficient recovery period. There are a number reports which suggest no additional benefit from rotational grazing compared to continuous grazing (Hacker and Richmond 1994; Briske *et al.* 2008; Bailey and Brown 2011; Hall *et al.* 2014). There is considerable evidence to support the beneficial effect for including relatively long rest periods within grazing systems on biodiversity. However, prolonged, high grazing intensity is recognised as a continuing threatening process as it depletes habitat, reduces plant population sizes and increased population isolation (DEWAHA 2009). These conflicting results may be due to carryover effects of past grazing history, how the grazing systems is described and/or interactions with grazing systems and livestock type.

While there are numerous studies which examine changes in plant species diversity, abundance and composition under grazing, examination of other components of biodiversity occur less frequently. For example, in a systematic review and meta-data analysis of 250 global studies, less than 10 percent of studies examined birds, mammals and invertebrates and the overwhelming number were focused on livestock production and feed-base issues (McDonald, 2017b; Table 6-2).

Table 6-2: Results from a trend analysis undertaken as part of a meta-data analysis of 250 grazing studies

Variable (n)	SRG-CG			SRG-UG		
	Lesser (%)	Greater (%)	Neutral (%)	Lesser (%)	Greater (%)	Neutral (%)
Plant richness (39)	12 (3)	34.5 (9)	54 (14)	17 (4)	39 (9)	44 (10)
Plant diversity (26)	6 (1)	41 (7)	53 (9)	26.5 (4)	26.5 (4)	47 (7)
Mammal richness (3)	0 (0)	0 (0)	100 (2)	0 (0)	100 (1)	0 (0)
Mammal diversity (2)	0 (0)	100 (1)	0 (0)	0 (0)	100 (1)	0 (0)
Bird richness (6)	20 (1)	20 (1)	60 (3)	0 (0)	0 (0)	100 (4)
Bird diversity (2)	0 (0)	0 (0)	100 (1)	0 (0)	100 (2)	0 (0)
Invertebrate richness (10)	0 (0)	86 (6)	14 (1)	29 (2)	14 (1)	57 (4)
Invertebrate diversity (4)	0 (0)	50 (2)	50 (2)	50 (1)	0 (0)	50 (0)
Biomass (117)	4 (4)	48 (51)	48 (51)	34 (11)	25 (8)	41 (13)
Ground cover (52)	6 (3)	48 (22)	46 (21)	40 (10)	4 (1)	56 (14)
Weight gain (82)	31 (25)	17 (14)	52 (43)	n/a	n/a	n/a
Animal production per unit area (38)	16 (6)	47 (18)	37 (14)	n/a	n/a	n/a

Trends (% of total papers) in response variables that compared strategic rest grazing (SRG) with continuous grazing (CG) and in studies that compared strategic rest grazing to un-grazed (UG) areas. Response variable is listed with overall number of studies beside it in parentheses (n). For each individual contrast the number of studies is shown in parentheses beside the parentheses.

Source: McDonald 2017.

In this same meta-data analysis, strategic rest resulted in greater or neutral invertebrate, bird and mammal diversity than continuous grazing but invertebrate diversity and richness tended to be less or neutral with livestock grazing compared to ungrazed studies. A negative effect on invertebrates diversity has been reported Waters *et al*. (2017) under high, continuous grazing, but neutral effects on bird diversity. It is possible that areas grazed by livestock have lower invertebrate forage availability associated with reduced litter compared to un-grazed areas which may allow higher capture rates associated with higher invertebrate diversity and abundance.

Grazing may create vertical and structural complexities capable of supporting greater biodiversity (Peco *et al*. 2006; Dumont *et al.* 2007; Wallis De Vries *et al.* 2007) particularly for plant and mammal diversity (Table 6-2), and some types of grazing management in the semi-arid rangelands can maintain (Dostálek and Frantík 2008; Lewis *et al.* 2009; Fensham *et al.* 2010; Fensham *et al.* 2014; Oñatibia and Aguiar 2016) or improve resource condition as well as plant diversity and species composition (Dorrough *et al.* 2004; Waters *et al.* 2017) but this grazing management requires significant periods rest from grazing to allow pasture recovery.

In summary, it has been suggested that grazing impacts alone are having limited impact on *in situ* biodiversity except in extreme cases of over-utilisation, in particularly vulnerable environments (e.g. riparian areas) and where grazing animals are vectors for weed seed distribution (e.g. mesquite, prickly acacia) (URS 2014).

6.3.4 Summary

Making a direct link between resource condition, biodiversity and livestock production is problematic. This is due to innate high spatial heterogeneity in rangeland vegetation and soil as well as interactions between stocking rate and livestock productivity. Many studies only tend to examine pasture and livestock productivity, with little emphasis on biodiversity or resource condition, beyond and examination of floristic diversity. There is also a distinct lack of empirical temporal and spatial data which can help to understand these interactions.

The approaches used in determining the impact of grazing on resource conditions include examining piosphere effects; controlled grazing experiments and paddock contrasts. The reported findings are not unanimous in being able to recommend standard strategies for avoiding degradation or encouraging improvement in the resource base. However, it is clear that managing total grazing pressure is a key factor influencing the condition of the resource.

Despite considerable research, obtaining a clear understanding of temporal and spatial impacts on biodiversity with increasing grazing intensity to support tangible management recommendations is not available. General thresholds of 30 percent utilisation of perennial grasses may prevent the mortality of perennial grasses and lead to greater levels of ground cover but studies that make a direct link between ground cover and biodiversity (particularly fauna) are rare. Studies which examine changes in plant species diversity and abundance and composition under grazing are more common. Further, the impression from a review of the available information from the 2008 ACRIS Reports (Bastin 2008) is that the rangelands are not highly dynamic, which acts as a disincentive to managers seeking to manage for sustained improvement in the resource.

Land managers generally have a good understanding for a need to manage ground cover, soil erosion, pests and weeds because of clear linkages to livestock production and enterprise profitability. While at times, farm resources may restrain best management of these environmental issues, there is a general lack of an appreciation of the value of biodiversity at a property scale and its regional significance.

6.4 Implications for managing TGP

Given that large areas of the Australian rangelands are now less productive than prior to the introduction of livestock, an objective for land managers and responsible agencies is to affect a gradual improvement on the base rangeland resource. How to manage the rangelands responsibly has been the subject of numerous studies. These have investigated the links between livestock grazing, animal and resource production, and resource condition, but there has been very little attention paid to how TGP affects these outcomes at paddock or property scale. In summary, the work has shown that grazing intensity is a more important driver of resource condition than the type of grazing system e.g. rotational grazing vs. continuous grazing; and there is no consensus about the value of short duration intense grazing.

The value of removing livestock from rangeland vegetation for periods of time – spelling or resting – has been reported frequently, although these studies have not necessarily considered the added impact of unmanaged herbivory during these rest periods. Further investigation is required to provide a clear understanding of the temporal and spatial impacts of TGP on resource condition, and hence on short-term and long-term productivity. This will assist in determining the performance of TGP management options (e.g. cluster fencing) on resource and economic outcomes.

There are still unknowns about the impact of grazing on biodiversity, although the general view is that biodiversity is only reduced under conditions of very heavy grazing pressure. The move into carbon farming which is occurring in Western NSW and South West Queensland requires special management to ensure maximum rates of carbon sequestration. There is a need for more information in how TGP – in particular unmanaged herbivory – affects above and below ground carbon stores. This could be complemented by the development of an 'estimated environmental value' of rangelands or a carbon 'neutrality' index to meet changing consumer preferences for ethical and environmental agricultural production systems as well as meeting emission reduction and land degradation neutrality targets.

7. Management of TGP

7.1 Summary - key messages and knowledge gaps

Key messages

Exclusion fencing – to protect livestock from wild dogs and to limit Macropod movement is being adopted in South West Queensland and Western NSW. It is also being used to protect areas used for carbon farming from unmanaged herbivory.
The uptake of both cluster and TGP style fencing in South Eastern Australia represents an unprecedented opportunity to manage grazing pressure in these semi-arid regions.
Over the past four years, practical methods to positively influence livestock grazing distributions have been developed, principally in Western Australia. The methods are collectively referred to as Rangelands Self Herding.
While experimental designs have been proposed to examine the role of the dingo in rangeland restoration, the ability of wild dogs (dingoes) to benefit native wildlife is contested.
There is a large and increasing number of data sources and technology products from both public and private sector organisations that support the management and monitoring of extensive grazing systems. Most of these are available on-line but few specifically address the imbalance between feed supply and demand.
Technology products for management of the non-domestic herbivore component of TGP are largely restricted to introduced/feral animals. Very few or no technology products for the management of native herbivores (e.g. kangaroos) are currently available.
Past monitoring of pastures (particularly ground cover) have provided information on regional scale changes over time, however, real time data is required for decision making, rather than historic data. Recent GIS-based products provide an opportunity to derive real-time, paddock scale monitoring.

Knowledge gaps

A range of control options for management of unmanaged animals in rangelands are available but a systematic evaluation of their cost effectiveness has not been undertaken.
Despite wide spread adoption of exclusion and TGP fencing in Southern Australian rangelands, the biophysical and economic impacts as well as opportunities has not been evaluated.
The long-term administration of fenced 'clusters' and the case for public and private investment has not been evaluated.
Determining a role for wild dogs (dingoes) in managing unmanaged herbivory while at the same time limiting or avoiding predation on livestock.
Further information is needed on a possible role for guardian animals in livestock management.
It is not known how the large number of available information sources and technologies are used in managing grazing businesses, and their effectiveness in generating environmental and financial benefits.
Further development of products for pasture systems in the Southern Rangelands particularly shrub based systems at the property level is required. Few technology products integrate information on all herbivores trends in feedbase.
Technology products for the monitoring of populations and the management of native unmanaged animals (e.g. kangaroos) are currently unavailable.

7.2 Current TGP management options

This section reviews the 'newer' TGP management options available to land managers in the Southern Rangelands. Five management options are reviewed.

7.2.1 Exclusion fencing

Over the past five years, exclusion (total or partial) fencing for management of TGP in southern Australian rangelands (Figure 7-1) has been implemented. Driven initially by incentive funding programs run through e.g. NRM bodies (Western Local Land Services in Western NSW and South West NRM in Queensland) but more recently, more extensive uptake has occurred as a result of income from carbon farming and private investment (area fenced has not been verified). Exclusion fencing is recognised as a viable option for total grazing pressure management but little published information on benefits is available.

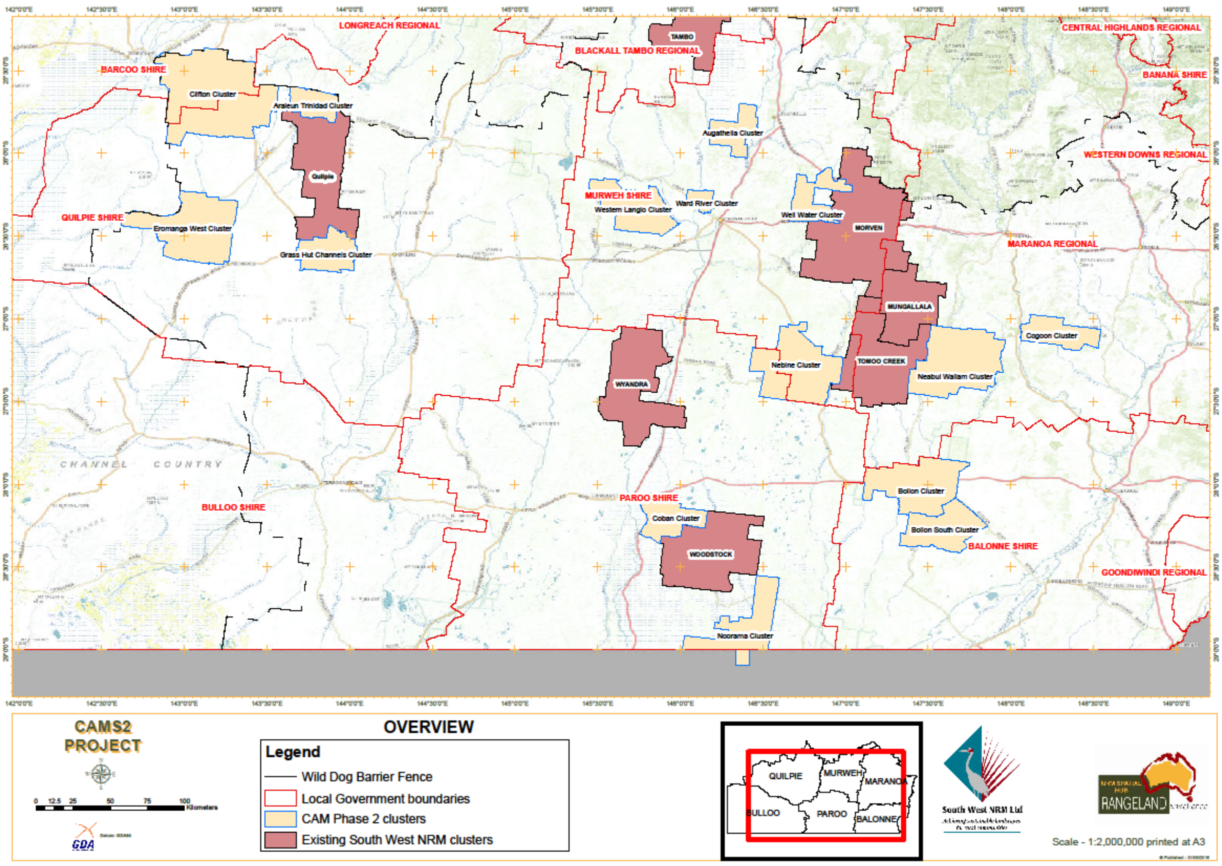
Figure 7-1. Exclusion fencing designs

Left: Exclusion fencing: fence height 1.6 m (30 cm apron), 7 m post spacing, hinge-joint suitable to prevent movement of wild dogs, predominantly used in boundaries to surround multiple properties (e.g. 360-200,000 ha); Right: TGP fencing: partial exclusion (effective for goat exclusion), fence height 1.1 m (top and bottom barb), 10 m post spacing, predominantly used as boundary fences (e.g. 4-40,000 ha).

Five Collaborative Area Management projects were co-funded by land managers and the Australian/Queensland Governments over the period 2013-2016 to erect exclusion fencing (cluster fencing) across a total of 3.2 million hectares (800,000 hectares annually). Recent projects have resulted in an additional 4 million hectares being fenced with cluster fencing in southwest Queensland (Figure 7-2).

The fencing has been motivated by land manager biosecurity goals - primarily wild dog exclusion – and other economic, social and environmental outcomes have also been promoted. However, little direct quantification of environmental and social benefits has been published but anecdotal evidence suggested wild dog exclusion supports sheep enterprises which maintain higher regional employment rates than cattle enterprises (J. Grant personal communication). Economic benefits of cluster fencing report an increase in gross margin by up to 345 percent from $5.04/ha to $22.42/ha, generating an additional $25.67 million in annual agricultural production (South West NRM 2017). Exclusion fencing is not a new concept, but improved fence design and materials along with high livestock prices (sheep and goats), government incentives and formal agreements designed to ensure the maintenance of fences have renewed interest in exclusion fencing (Crowden and Allen 2016). Fence design details specifically for wild dog exclusion (Australian Wool Innovation 2017), exclusion fencing generally (Kondinin Group 2016) as well as through commercial fencing suppliers (Clipex 2017) are available.

Figure 7-2: Extent of Cluster Fencing in south west Queensland as at January 2018

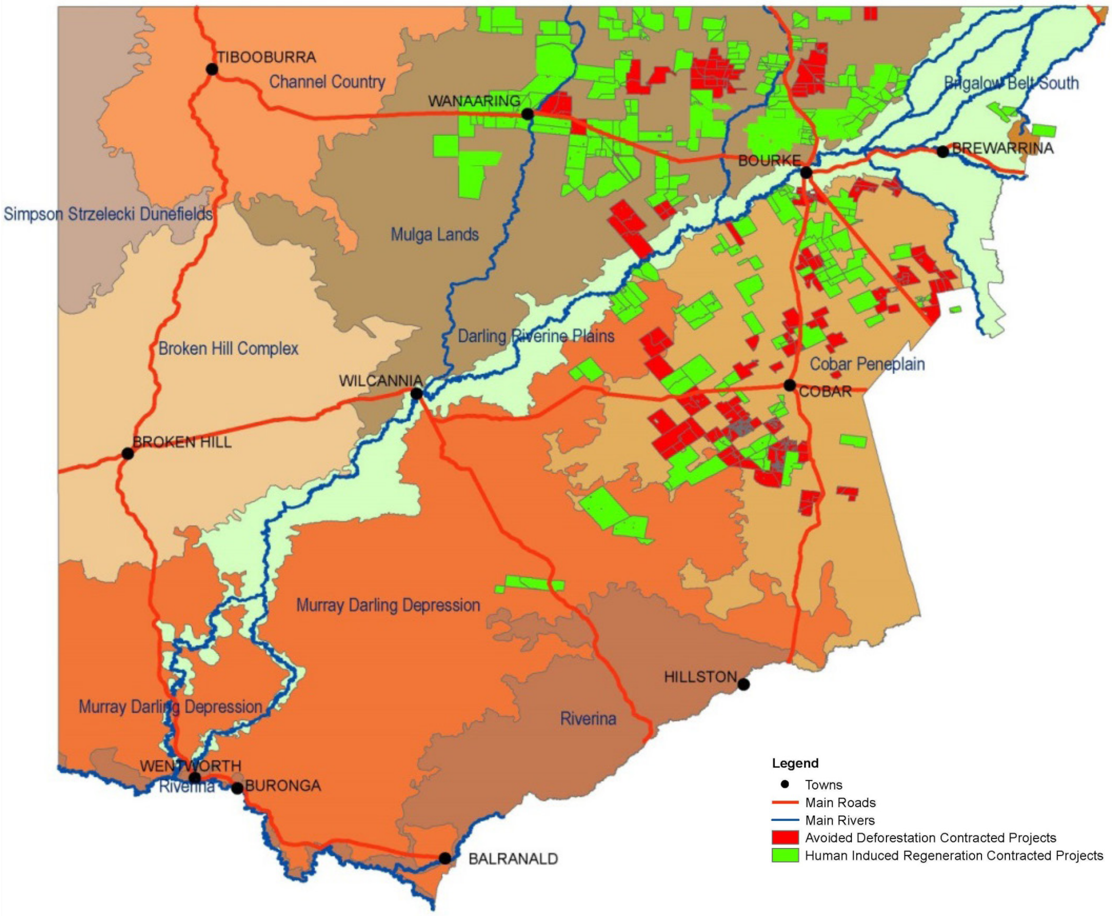


Source: SW NRM http://www.southwestnrm.org.au/collaborative-area-management

Total grazing pressure (TGP) fencing has also been widely adopted in Western NSW, primarily for the exclusion of goats and partial exclusion of kangaroos. The carbon market in Western NSW has also seen, conservatively, more than half the projects use TGP fencing as a boundary around carbon management areas (J. Sinclair personal communication) while carbon farming covers extensive areas in NSW (see Figure 7-3), it is likely that comparable carbon areas in SW Queensland are also being managed with TGP fencing. TGP fencing design details have been published (WLLS 2017; MLA 2017c).

The uptake of both cluster and TGP style fencing in South Eastern Australia represents an unprecedented opportunity to manage grazing pressure in these semi-arid regions. Comparisons of the different approaches to TGP management are given in Table 7-1.

Figure 7-3: Approximate area under carbon farming in Western NSW



More than 3.3 million ha of Western NSW are currently managed for carbon farming under two vegetation methods; (HIR – Human induced regeneration, >2.5M ha and AD – Avoided deforestation, >816K ha). Locations and size of projects shown are derived from the mapping files taken directly from the Clean Energy Regulator website February and are a slight overestimate of the carbon areas.

Source: Western Local Land Service.

7.2.2 Rangelands self-herding

Over the past four years, practical methods for positively influencing livestock grazing distributions have been developed, principally in Western Australia. The methods are collectively referred to as Rangelands Self Herding (Revell *et al.* 2015). The practices are based on behavioural and nutritional science, and there are seven underlying principles:

- people-animal interactions
- internal feedback for animals to trigger feeding behaviour
- animal experiences
- diet diversity
- livestock and other herbivores grazing behaviours
- individuals and groups of animals interact
- broad consequences of animals directly and indirectly affect the system.

Applying Self Herding methods has led to observable changes in grazing patterns, for example: 'tighter' retention of livestock in locations such as new watering points; the broadening of grazing distributions further from watering points; the addition of new grazing 'loops' from watering points watering points; and the inclusion of new watering points into grazing circuits (*D.K. Revell personal communication*). Ongoing studies are designed to quantify these responses to support a growing body of experiential and anecdotal evidence. Specific studies to determine the effectiveness of self-herding to manage grazing without fencing are being undertaken https://rangelandswa.com.au/trials-begin-to-demonstrate-effectiveness-of-self-herding/.

7.2.3 Low-stress herding and supplement placement

There have been several studies (see review by Bailey 2016) in the USA testing the effectiveness of combining low-stress herding and low moisture block (LMB) protein supplements to target cattle grazing to particular areas or plants. It is considered a viable management option to increase utilisation in topographically diverse rangelands (e.g. upland areas) although the efficiency appears to depend on herding to trigger the movement of the animals (Bailey *et al*. 2008) and also on the relative availability and quality of forage in different areas (Stephenson *et al.* 2017). The reliance on herding means it will be impractical for many stations in Australia that are typically large and with low number of labour units. Nevertheless, there is potential for herding to alter the land use patterns of livestock, resulting in a range of benefits including improved livestock productivity and enhanced natural resource management (Meuret and Provenza 2015).

7.2.4 Re-introduction of the dingo

There have been conflicting scientific views as to the potential benefit of reintroducing populations of apex predators (dingoes, *Canis lupus dingo*) to areas of livestock production in a bid to restore degraded rangelands (Fleming *et al*. 2012a and b; Johnson and Ritchie 2013; Allen 2011; Allen *et al*. 2011a and b). These arguments revolve around the positive impact of the dingo and its role in suppressing medium and large-sized prey herbivores e.g. red foxes (*Vulpes vulpes*) and unmanaged cats (*Felis catus*) that prey on threatened native species (Moseby *et al*. 2012). However, there is also evidence across the Southern Rangelands that dingos or wild dogs supress unmanaged goats and kangaroo populations in (e.g. cattle only enterprises may rely on dingoes to provide some control of kangaroo populations) The reduction in dingo numbers has been linked to increased herbivore populations and reduced plant biomass (Letnic *et al*. 2011) but it has also been shown that the dingo has no effect (Morrant *et al.* 2017) or a negative effect (Allen and Fleming 2012) on populations of native fauna. Allen *et al.* (2013) review concluded that the scientific evidence for the positive impact of the dingo was both unreliable and inconclusive. While experimental designs have been proposed to examine the role of the dingo in rangeland restoration (Newsome *et al*. 2015) the role of the dingo in the regulation of unmanaged herbivore populations and native wildlife is largely unproven.

7.2.5 Guardian animals

Guardian animals include the use of donkeys, dogs and alpacas to protect livestock from predation. However while we found little rangeland specific information, guardian dogs have been found to be an effective control option in situations where there is at least one dog per 100 head of livestock as well as being cost effective (1-3 year payback period) (Van Bommel 2012).

7.2.6 TGP Management impacts

A summary of the economic, ecological and social implications of the currently employed approaches for TGP management is provided in Table 7-1 and highlight uncertainties around:

- investment costs (including the degree of government co-investment)
- within-fence grazing management practices and changes in distribution of grazing pressure both inside and outside exclusion areas
- the nature and success of long-term collaborative agreements
- a distinct lack of published data on resource condition and biodiversity changes.

Table 7-1: Comparison of different approaches to management of total grazing pressure and the key uncertainties

Method	Approach	Target species	Economic impacts	Economic uncertainties	Ecological impacts	Ecological uncertainties	Social impacts	Social uncertainties
Cluster Fencing: Collaborative area management (CAM)	Exclusion	Wild dogs	Fencing cost currently subsidised through incentive funding from state and federal governments Immediate productivity return through 80-100% increased lambing/ kidding Ongoing, coordinated control of wild dogs required Kangaroo control required Producers provided with enterprise flexibility (managed goats, sheep, cattle)	Self-funding of internal cluster fencing occurring which places questions over the future role of public funding of cluster fencing Current high livestock prices may justify building of internal exclusion fences but in more marginal areas ongoing incentives may be required Divergent priorities for dog/kangaroo control between sheep and cattle producers places uncertainty over permanent reduction in kangaroo/dog numbers at regional scale	Controls immigration and migration of dogs, kangaroos, goats, emus, rabbits, foxes Limited monitoring data available or undertaken. No trends in increase/ decrease of kangaroos inside/outside cluster fences Some inconsistent results in terms of changed in perennial species and biodiversity but generally increases in ground cover despite a run of poor seasonal conditions Evidence dogs outside provide some kangaroo control	Whole of landscape impact on ground cover dependent on livestock grazing management Will removal of wild dogs result in increases in kangaroo and goat populations within the cluster Uncertainty over employing goats to control INS within clusters	General optimism in ability and willingness to invest in future farm development Within cluster relationships difficult to build and retain in the long term Properties outside clusters wanting to join	Mechanisms to support, facilitate ongoing biosecurity control Collaborative area management support

Method	Approach	Target species	Economic impacts	Economic uncertainties	Ecological impacts	Ecological uncertainties	Social impacts	Social uncertainties
TGP: partial exclusion fencing	Partial exclusion	Unmanaged goats and Macropods	Cost of fencing subsidised through funding incentives Generally single property boundary fences Little widespread uptake of internal fencing Increased resilience to seasonal fluctuations in income and reduced drought susceptibility	Unlikely large scale uptake without incentive funding but appears a trend for some carbon farming income in W NSW to be redirected into TGP fencing Competing economic opportunity to harvest unmanaged goats at low input cost despite resource degradation	Controls movement of goats (male goats can be problematic) and partial control of kangaroos Higher perennial ground cover inside TGP fenced areas (approximately 9-15%) Potential restoration tool for degraded areas	Impact contingent on removal of unmanaged animals and ongoing internal grazing management	Increased awareness and desire to obtain incentive funding Provides an avenue for increased drought resilience	Ability of managers to persist with management change especially in periods of duress. Resistance to change from traditional enterprise model
Self-herding	Behavioural	Principally livestock	Low cost Can bring more areas into the grazing range Higher productivity through improved nutrient acquisition by livestock and higher intake associated with diet diversity Reducing/ eliminating lag times when animals are relocated Increased resilience to seasonal fluctuations because animals have a broader set of experiences Improved mustering efficiency	Financial benefits not yet fully quantified across a range of systems Potential benefits to reduced shrinkage and meat quality yet to quantified	Alteration in grazing habitat selection and diet selection	Potential impact of altered dietary patterns Potential to use self-herding tools to influence other (non-livestock) animals	Improves human-animal interactions, making it easier and safer to work with livestock in the paddock and yards	Willingness to continually improve management capacity to implement full suite of Self Herding tools Benefits to public perceptions by improving animal behaviour

Method	Approach	Target species	Economic impacts	Economic uncertainties	Ecological impacts	Ecological uncertainties	Social impacts	Social uncertainties
Reintroduction of the dingo	Behavioural	Unmanaged herbivores (goats and Macropods)	Precludes sheep or goat enterprises and a reliance on cattle which limits flexibility in livestock enterprise	The levels of predation of goats and Macropod on feedbase Dingo populations thresholds which result in a shift from goat and kangaroo to livestock predation	Predation of foxes and cats	Contested views on the indirect impacts on native wildlife	Attitudes to dingo or wild dog control are contingent on enterprise type	Social conflicts over inability to control Dingo or wild dog populations
Guardian animals	Behavioural	Wild dogs	Costs returned in 1-3 years Fenced areas provide optimal effectiveness	Cost effectiveness in extensive rangeland areas	In unfenced areas, guardian animals may roam resulting in injury and mortality of native populations	Harassment, injury and death of wildlife	None identified	None identified

Source: Adapted from Waters *et al.* 2017; R. Grant personal communication

7.3 Traditional approaches to TGP management

Since European settlement land managers have been managing TGP in a range of ways. Many of these are summaries in the section below.

7.3.1 Rabbit proof fencing

In the 1880s, 300 miles of the NSW - SA boundary was netted to prevent rabbits spreading to NSW from SA. At about the same time a 100 mile section of the South Australian – Queensland border was netted (Rolls 1969). Rabbit fencing continues to this day e.g. Darling Downs–Moreton Rabbit Board Fence (Queensland).

The State Barrier Fence of Western Australia, formerly known as the Rabbit Proof Fence, the State Vermin Fence, and the Emu Fence, is a pest-exclusion fence constructed between 1901 and 1907 to keep rabbits and other agricultural pests, from the east, out of Western Australian pastoral areas (Department of Primary Industries and Regional Development 2018).

Unfortunately, the original rabbit proof fences, which extended from the Pilbara to the south coast were ineffective in preventing rabbit infestation. Part of the fencing was converted into the state's current barrier fence, which lies along the boundary between the pastoral and agricultural areas (see below).

7.3.2 Wild dog fencing

Construction of dog-proof fencing to protect sheep grazing districts from wild dogs and dingoes was established in SA under the *Dog Fence Act* 1946. Dog fences continue to be one management options with the Wild Dog Barrier Fence (Queensland) and Dog Fence (South Australia).

Western Australia's current State Barrier Fence – 1,170 km long - plays an important role in preventing animal pests such as emus and wild dogs from moving into the State's agricultural areas from pastoral areas in the east. The fence is a state asset set within a 20 metre reserve, which is managed by the Department of Agriculture and Food, Western Australia (now Department of Primary Industries and Regional Development).

As at 2018, the Department of Primary Industries and Regional Development (DPIRD) proposes to extend the State Barrier Fence eastwards from its current termination point near Ravensthorpe, extending north around Salmon Gums and terminating east of Esperance near Cape Arid National Park.

source: https://www.agric.wa.gov.au/invasive-species/state-barrier-fence-overview

7.3.3 Macropod barrier fencing

There are various fence and gate designs which can reduce damage to pastures by excluding Macropods: sloped fencing, double fencing and electric fencing e.g. McCutchan fence (Department of Environment and Conservation 2018).

7.3.4 Destruction of animals and habitat

Methods including warren/den ripping, warren fumigation, shooting (including commercial Macropod harvest) and 1080 poisoning have and continue to be utilised as TGP management options.

7.3.5 Controlling access to watering points

The controlled access to watering points is aimed at encouraging herbivores particularly Macropods to find alternative sources of water and therefore reducing the grazing impact around the water source. Two primary methods of control at watering points are:

- turning off/closing water points
- restricting access to watering point through fencing.

Kangaroo access to water can be restricted through strategically placed electric fences; one such method the 'Finlayson electrified trough', however this method is not recommended.

7.3.6 Mustering and trapping

Mustering and trapping, and subsequent offtake of goats, camels and donkeys.

7.3.7 Introduction of viral vectors

The introduction of viral vectors/biological control agents for managing introduced herbivore populations, in particular rabbits include: Myxomatosis and rabbit haemorrhagic disease.

7.4 Non-traditional approaches to TGP management

7.4.1 Fertility treatments

Through the use of fertility control techniques, long-term control of Macropod populations may be possible. Various methods of fertility control have been tested including the use of hormonal contraceptives and immuno-contraception – vaccinating the animal against its own eggs, sperm or reproductive hormones.

The use of hormones to inhibit reproduction has generally been found to be successful. With contraceptives such as Levonorgestrel (currently used by human females), has been found to be a suitable long-term contraceptive in eastern grey kangaroos. However, the chemical has been implicated in some side effects associated with the reproductive tract and some metabolic changes.

Other contraceptives (e.g. Deslorelin, a non-steroidal contraceptive) have been trialed in female tammar wallabies and found to be effective. However, some hormones have the potential to alter social behaviour, including dominance hierarchies, which can influence access to food.

The use of contraceptives is currently limited to small populations of kangaroos rather than broad-scale control. As the use of contraceptives is expensive and in some cases cannot be applied without first anaesthetizing the animal. Contraceptives such as Deslorelin will become cheaper and more easily applied if methods can be developed for darting animals from a distance.

The use of the immuno-contraception fertility control method has been found to have both practical and ethical issues, and has not been advocated as a fertility control method. An alternative to hormonal or immuno-contraception is surgical sterilisation, however such methods are very expensive, invasive and have been found to be not always effective.

7.4.2 Predator urine to deter Macropods

Macropods have been found to avoid and flee areas where dingo (*Canis lupus dingo*) urine was present. Macropod avoidance behaviour of historic predators such as the Dingo are usually inherited and then reinforced through experience. It is not known whether over time, Macropods may become accustomed to the odour of Dingo urine and therefore declines in effectiveness of the predator urine may result.

7.5 Review of technology products for TGP Management

7.5.1 Introduction

A total of 53 technology products of practical application to land managers (not technology products for researchers or government reporting) in the Southern Rangelands relevant to TGP were reviewed, categorised as follows: pastures, livestock, non-domestic herbivore, natural resource management, climate and weather, and 'other' technology products. Not all technology products were available at the time of review or are suitable for land managers in the Southern Rangelands but are included as part of an overview of the technology products available. This paper follows from Leigo *et al*. (2012) who reviewed 60 technology products, although those technology products were not included in this review.

The technology products were reviewed as part of a desktop study and based on information available from websites, play store, published journals, reports or articles. Where suitable information was not available, authors or resellers of the technology products were contacted to gather information required for the review. Technology products were reviewed in the period October – December 2017. The products presented are not intended to be a comprehensive list of all technologies available, nor do the authors endorse any of the products.

The criteria used for the review included cost, uses, features, requirements and commentary related to the relevance to use in management of TGP or availability of the technology product.

7.5.2 Overview

Table 7-2 presents a summary of the 53 technology products reviewed which may be of practical application to land managers managing TGP (note – not technology products for researchers or government reporting). Technology products were categorised as follows: pastures, livestock, unmanaged herbivory, natural resource management, climate and weather, and 'other' technology products.

The reviewers found i) no one individual technology product, nor a simple amalgamation of technology products could be recommended to land managers for use in managing TGP; and ii) development of 'new' technology products may benefit from the amalgamation or modification of existing technology products.

Any future development of technology products must be underpinned by consultation and analysis of land managers in the Southern Rangelands, specifically:

i. regarding the technology products they currently use, their feedback and experiences;
ii. the type, functionality and potential usefulness of any 'new' technology product/s to manage TGP; and
iii. the practicality of any technology product/s; iv) the land managers' ability to use 'technology products'; and v) connectivity/reliability of internet.

Table 7-2: Overview of technology products

Technology product categories and rational for development	Technology products reviewed	Use/uses of technology product	Value for providing information for TGP management	Limitations of the technology product for management of TGP
Pasture technology product				
Remote pasture monitoring technology product – monitor pastures via satellite technology for vegetation greenness or cover	FarmMap4D(2017) (formally Spatial Hub)	Mapping, assessing and monitoring properties	+	• The monitoring of pastures provides information regarding pasture changes over time however, real time data is often required for decision making, rather than historic data.
Pasture production – based on climate information pasture production is estimated	The Long Paddock: Rainfall and Pasture Growth (Dept of Science, Information Technology and Innovation 2017)	Estimates of pasture production on a state basis	+	• Further development of technology product for pasture systems in the Southern Rangelands particularly shrub based systems at the property level is required.
	MLA Rainfall to Pasture Growth Outlook Tool (RPGOT) (MLA 2017d)	Estimating pasture growth based on climatic conditions		
Feed budgeting – technology products to calculate feed requirements of livestock	Grazclock v 2.4.2 (Alcock 2011)	Whole farm feed budget	+	• Technology products have been developed for specific locations and pasture types, and require modification for application in the Southern Rangelands
	Feed demand calculator (MLA 2013)	Calculation of feed demand and compares demand to monthly supply		

A qualitative assessment of technology products value in informing the management of TGP was undertaken.

Key: (0 = nil: no value in informing management of TGP + = low value in informing management of TGP; ++ = moderate value in informing management of TGP; +++= high value in informing management of TGP).

Technology product categories and rational for development	Technology products reviewed	Use/uses of technology product	Value for providing information for TGP management	Limitations of the technology product for management of TGP
Other pasture technology products –examine effects of variable weather and test management options	GrassGro™ 3 (Horizon Agriculture n.d.)	Decision support/ planning technology products for sheep and beef enterprises producing predictions of the variability in pasture and animal production.	0/+	• Technology products may assist land managers to plan grazing management over seasons/years, utilising this information land managers would be able to make decisions regarding management of the livestock component of TGP. However accurate site descriptions and interpretation of results requies expertise and no account of herbivores other than livestock is made.
Other pasture technology products –to identify pasture plants	Weed ID: The Ute Guide (GRDC 2013b)	Reference guide to most common paddock weeds	0/+	• Technology products reviewed are mostly developed for wildflowers, weeds or gardens plants, further development of information for southern rangeland species including identification, nutrition value, etc. is required • Information about identification and nutrition of pasture species may play a role in informing land managers pasture production and feed budgeting
	SA Weed Control (PIRSA 2017)	Information about the control of weeds declared in SA		
	The Native Plant Guide (Yau and Langdon n.d.)	Information on Australian native flora		
	Wildflowers WA Photo ID (n.d.)	Web based technology product to identify Western Australia wildflowers		
	Plant identification applications	Primarily identification of garden plants or overseas plants		
	Plant identification books	Identification of trees, shrubs, perennial grasses and annual grasses and forbs in the Southern Shrublands	++	• See Table 7-4

Technology product categories and rational for development	Technology products reviewed	Use/uses of technology product	Value for providing information for TGP management	Limitations of the technology product for management of TGP
Livestock technology products				
Livestock/grazing management – to record and monitor livestock related information including numbers, grazing management activities – plans, movements	Maia grazing (Maia Technology 2017)	Managing and planning grazing management	+	• Technology products only generally relate to the livestock component of TGP. Few technology products combine with pasture management – feed budgeting and livestock production.
	Farmware (2017)	Record keeping of activities for livestock, paddocks and storage inventories		
	PocketPAM2 (Fairport Farm Software 2017)	Record keeping of farm activity details		
	Phoenix (AGDATA Australia 2017)	Record keeping of financial and farm management details		
	AgriWebb (2017)	Record keeping of farm and livestock information details		
	Various overseas applications to record farm and livestock records	Record keeping of farm and livestock details		

Technology product categories and rational for development	Technology products reviewed	Use/uses of technology product	Value for providing information for TGP management	Limitations of the technology product for management of TGP
Monitoring of livestock – to monitor livestock, weight, location or condition either remotely or directly	eShepherd (Agersens 2017)	The App with a livestock collar allows virtual fencing, moving or monitoring of livestock	0/+	• Technology products relate only to aspects location or condition of livestock component of TGP.
	Remote WOW System	Remote weighing, tracking and drafting of cattle		
	MiHub™ Livestock Management software Tru-test 2017)	Analyses weighing data from portable or fixed readers to monitor animal weight.		
	Weigh systems	Weighing livestock		
	Electronic identification (EID) readers	Identifying individual animals		
	Livestock computer management software	Matching EID with relevant information to the animal and its performance		
	Lambing Planner (DPIRD 2017a)	App mapping the breeding cycle for sheep and provides key recommendations on management options		
	Sheep Condition Scoring (DPIRD 2017b)	Recording sheep body condition scores		

Technology product categories and rational for development	Technology products reviewed	Use/uses of technology product	Value for providing information for TGP management	Limitations of the technology product for management of TGP
Livestock nutrition – to calculate and compare cost and/or nutrition of pasture and supplementary feeding	GrazFeed (Horizon Agriculture n.d.)	Decision support technology product used to calculate energy and protein requirements of sheep and cattle grazing for temperate and tropical pastures and supplementary feeding	0/+	• Technology products relate particularly to the nutrition of feed, predominately in tropical and temperate pastures, or supplementary feed rather than pastures of Southern Rangelands
	Feed cost calculator (WA)	Calculate and compare nutrition and costs of livestock feeds: protein, energy, and dry matter		
	Feed cost calculator (NSW) (Department of Primary Industries 2017 and n.d.)	Calculate and compare nutrition and costs of livestock feeds: protein, energy, dry matter		
	Supplementary feeding calculator for pregnant and lactating ewes	Calculating supplementary feed for pregnant and lactating ewes when low levels of green feed		
	Drought Feed Calculator (Digital Services NSW 2017)	App for sheep and cattle producers to determine the minimum feed requirement for a range of animals with different nutritional needs		
	Ration Book (Coorong Tatiara Local Action Plan Committee n.d.)	Calculating least cost diets for sheep and cattle		

Technology product categories and rational for development	Technology products reviewed	Use/uses of technology product	Value for providing information for TGP management	Limitations of the technology product for management of TGP
Marketing livestock – to inform land managers of prices and numbers of livestock being sold or slaughtered	MLA Market Reports and Prices (MLA 2015 and 2016)	Market reports for sheep, cattle and goats	0	• Technology products are simply informing land managers of livestock prices and numbers of livestock being sold or slaughtered, which may be of assistance when adjusting through sales or purchase the livestock component of TGP
Remote water monitoring – to inform land manager of water related information remotely through a range of transfer mechanisms	Remote watering monitoring - Various companies have different technology products	Monitoring tank and trough levels and water usage	0	• Technology products provide important information for the land manager about water use and tank levels. It is assumed that livestock are utilising the water, rather than non-domestic animals.
Other livestock technology products	AskBill (Sheep CRC 2017)	Predictions of climate patterns (for main sheep producing regions) and implications for grazing livestock (sheep only)	0	• Applicability of these 'other' technology products to the Southern Rangelands is unknown.
	LTEM Lifetime Ewe Management (AWI 2017)	A digital extension of the Lifetime Ewe Management course		

Technology product categories and rational for development	Technology products reviewed	Use/uses of technology product	Value for providing information for TGP management	Limitations of the technology product for management of TGP
Non-domestic herbivores technology products				
Non-domestic herbivores – to inform land managers about locations, control activities and SOP for introduced non-domestic animals	Pestsmart: Pest Animal Toolkit (Centre for Invasive Species Solutions 2017)	Toolkits for a range of pest including: • Wild dog • European rabbit • Unmanaged goat • Unmanaged horse • Unmanaged deer • Unmanaged camel	+	• Technology products only relate to introduced non-domestic animals.
	WildDogScan (FeralScan 2017d)	Record and map sightings of wild dogs, their impacts and control activities undertaken		
	CamelScan (FeralScan 2017a)	Record and map sightings of unmanaged camels, damage and control activities undertaken		
	Unmanaged Goat Scan (FeralScan 2017b)	Record and map sightings of unmanaged goats, damage and control activities undertaken		
	RabbitScan (FeralScan 2017c)	Record and map rabbits activity, warrens, damage and control activities undertaken		

Technology product categories and rational for development	Technology products reviewed	Use/uses of technology product	Value for providing information for TGP management	Limitations of the technology product for management of TGP
Natural resource management technology products				
Natural resource management – technology products can inform the land manager and Government authority of the rangeland condition, ground and vegetation cover	Ground Cover (Namoi Catchment Management Authority 2017)	Assess ground cover of paddock	+	• Technology products importantly relate to aspects of natural resource management which are important for managing TGP, however the cause of any impacts on the natural resource are unknown
	LandPKS (Land-Potential Knowledge System 2017)	LandInfo - Characterising soil and site topographic information to determine land potential LandCover- a technology product for recording vegetation cover and structure to assess and monitor major changes in plant community composition and wind and water erosion risk		
	Monitoring App (Gascoyne Catchments Group 2017)	A self-assessment monitoring and reporting technology products for rangeland condition for the Gascoyne region of WA		
	Rangeland monitoring systems for shrublands and grasslands (Pastoral Lands Board of WA n.d. – a and b)	A system of Rangeland Condition Monitoring (RCM) based upon permanent photographic monitoring sites and plant counts – for use in southern shrublands and northern grasslands		

Technology product categories and rational for development	Technology products reviewed	Use/uses of technology product	Value for providing information for TGP management	Limitations of the technology product for management of TGP
Climate/weather technology products				
Climate/weather – technology products relate to climate and weather and may be useful in assisting land managers decision making in relation to pasture and livestock management	BOM Weather App (Bureau of Meteorology 2017a)	Details of current weather conditions, forecasts, radar, warnings	0/+	• Technology products need to be used in conjunction with other aspects of management particularly pasture production, livestock and non-domestic herbivore numbers
	BOM website – MetEye, Agriculture Services – water and land, Climate and past weather, Climate watch, Climate videos, Climate model forecasts (BOM 2017a, b and c)	Short-term forecasts and latest weather, ENSO; drought statements; rainfall and temperature outlooks; cyclone outlooks, POAMA – long-range outlook.		
	Climate Kelpie website (GRDC 2016)	Rainfall forecasts, seasonal forecasts, decision support tools, what drives climate and weather in your region, future projected climate		
	Australian CliMate website or App Commonwealth of Australia 2017)	Climate analysis to information decision making		
	BOM Weather App (Bureau of Meteorology 2017a)	Details of current weather conditions, forecasts, radar, warnings		
	MEA – Free Weather Data (Measurement Engineering Australia 2017)	Regional and specific locational weather readings		

Technology product categories and rational for development	Technology products reviewed	Use/uses of technology product	Value for providing information for TGP management	Limitations of the technology product for management of TGP
Climate/weather – technology products relate to climate and weather and may be useful in assisting land managers decision making in relation to pasture and livestock management	Long Paddock - Rainfall and pasture growth (Dept of Science, Information Technology and Innovation 2017)	Rainfall and pasture growth	0/+	• Technology products need to be used in conjunction with other aspects of management particularly pasture production, livestock and non-domestic herbivore numbers
	Long Paddock - SILO Climate Data (Dept of Science, Information Technology and Innovation 2017	Australian climate data from 1889 (current to yesterday)		
Other technology products				
	Insect ID: The Ute Guide (GRDC 2013a)	Reference guide to insect pests commonly affecting broadacre crops and growers across Australia	0/+	• Technology products for soils, insects and mapping may play in a role in management of TGP but need to be incorporated with the other aspects of TGP.
	SoilMapp (CSIRO 2015)	Accessing soil data information for any location in Australia		
	NatureMaps (Dept of Environment, Water and Natural Resources 2017)	Access to maps and geographic information about SA		
	Websites and applications to undertake mapping	Mapping paddocks determining area, measuring distance		

7.5.3 Pasture technology products

Remote pasture monitoring technology products

Remote pasture monitoring technology products which monitor pastures via satellite technology using either vegetation greenness (e.g. NDVI), used to estimate pasture biomass and availability; and/or cover used to inform landscape health, and inferences about pasture production (Leigo *et al.* 2012). Remote pasture monitoring can provide a snapshot of pasture at a point of time; show pasture spatial variability; present time series images of pasture changes over time and allow land managers to plan grazing management of livestock. This information can be used to assess areas of increasing or decreasing pasture (biomass or cover); landscape health and stability.

Only one product, *FarmMap4D* (FarmMap4D 2017) formally NRM Spatial hub, is reviewed in this section (Table 7-1), see Leigo *et al*. (2012) for a review of other products on this topic. *FarmMap4D* is a technology products that uses high resolution imagery (Digital Globe), land type mapping with access to government datasets, monitoring of changes in ground cover and vegetation with 30 years of historic data and time series data (10 m resolution, updated weekly), design infrastructure (fences, water points). Training, support and specialist mapping services are available. A range of pasture technology products is presented in Table 7-3.

Pasture production and feed budgeting technology products

Technology products for estimation of pasture production based on climate data and feed budgeting provide the land manager with information to factor into their pasture and grazing management decisions, including planning grazing, determining stocking rates, pasture growth rates, stock rations and current and predicted feed. Two technology products for modelling pasture growth were reviewed. The technology products provide estimates of pasture production – growth rates and biomass estimates based on climatic information.

The Long Paddock: Rainfall and Pasture Growth (Department of Science, Information Technology and Innovation 2017) provides rainfall, rainfall percentile maps, estimates of pasture production for all states of Australia. Data has been presented at the 'locality' level and is therefore not suitable for decision-making at the property level.

MLA Rainfall to Pasture Growth Outlook Tool (Meat & Livestock Australia 2017b) estimates, covers southern Australian pasture growth based on climatic conditions. The tool provides pasture growth, soil moisture and rainfall outlooks for up to 3 months based on a local weather station (3,300 weather stations available); and annual data on rainfall, soil moisture and pasture growth.

Three technology products for feed budgeting *Grazclock*, *Feed Demand Calculator*, and *Stocktake Plus* were reviewed. The first two technology products use Excel spreadsheets to calculate feed requirements, *Grazclock* (Alcock 2011) provides whole farm feed budgets based on supplied data for 9 NSW regions, where users can enter pasture growth data for their property. The *MLA Feed demand calculator* (Meat & Livestock Australia 2013) calculates feed demand of livestock and compares demand to monthly supply for a limited range of locations and is primarily focused on the agricultural zones.

Stocktake Plus (Future Beef 2017) is a decision support App based on Stocktake (see Leigo *et al.* 2012 for further information). The App can be used to undertake short term feed budgeting and allows the user to monitor land condition.

Technology products focused specifically on livestock production and other farm records are discussed in the section *Livestock management technology products.*

Other pasture technology products reviewed include a product for land managers to analyse effects of variable weather on animal and pasture production, which may provide important information for land managers to manage pastures and livestock sustainably and profitably (see Table 7-1). *GrassGro 3* (Horizon Agriculture, n.d.-a) is a decision support tool for sheep and beef managers to examine variability in plant and animal production over seasons or years, assess risks from variable weather and test management options. Training in its use is recommended.

Table 7-3: Pasture technology products

Product name	Owner/Author	Cost	Uses/Used for	Features	Requirements	Comments
Remote pasture monitoring technology products						
FarmMap4D (formally Spatial Hub)	FarmMap4D	$300-750 annually, depending on number of properties	Mapping, assessing and monitoring properties	Time series remote sensing and analysis technology products: • Satellite imagery: to 30cm refreshed every 12-18 months; to 10m weekly • National digital elevation model (25m resolution) • Ground and fractional cover monitoring • Shares code with FORAGE and VegMachine • Estimate carrying capacity • Natural Capital Accounting	Computer with internet connection	
Pasture production and feed budgeting technology products						
The Long Paddock: Rainfall and Pasture Growth	Queensland Government	Information free to download	Estimates of pasture production on a state basis	State based maps of • pasture biomass • relative pasture growth • pasture curing index • pasture fire risk • relative rainfall	Computer with internet connection	Information is not sufficiently detailed to allow for decisions at the property scale. Data has not been validated from areas outside Queensland.
MLA Rainfall to Pasture Growth Outlook Tool (RPGOT)	Meat & Livestock Australia (MLA)	Information free to download	Estimating pasture growth based on climatic conditions	Climatic conditions including rainfall and soil moisture are used to estimate pasture growth. Provides rainfall, soil moisture and pasture growth outlook for up to 3 months. Data available for 3300 weather stations.	Computer with internet connection	Only southern Australia is covered by the MLA tool.

Product name	Owner/Author	Cost	Uses/Used for	Features	Requirements	Comments
Grazclock v 2.4.2	Alcock, D (NSW Department of Industry and Investment)	Free	Whole farm feed budget, graphically illustrating animal feed requirements with pasture supply curve	Allows to choose (9 NSW regions) or supply pasture growth (up to 10 pasture types) for a range of pastures; six livestock enterprises are available e.g. self-replacing merinos.	Computer with internet connection and Excel (2003)	Pasture data only supplied for 9 NSW regions, however pasture growth data can be added
Feed demand calculator	Meat & Livestock Australia (MLA)	Free	Calculates feed demand of livestock and compares demand to monthly supply	Product allows specification of location, enterprise type, growth rates, soil types, slope, pasture wastage, pasture quality	Computer with internet connection and Excel (2003)	Limited applicability to pastoral areas
Other pasture technology products						

GrassGro™ 3	Horizon Agriculture	$825
		additional $121 for locality sets and weather upgrade.
		Training costs $250 (2-day course).
			Decision support/ planning tool for sheep and beef enterprises producing predictions of the variability in pasture and animal production and assessment of the risks from variable weather over seasons and years	• Developed by CSIRO Plant Industry
				• Assessment of land capability and production benchmarking
				• Review of management tactics during the current season
				• Resource sustainability:
				  • Ground cover
				  • Water balance
				  • Nutrient deficiency
				• Drought management and climate variability scenarios
				• Financial testing – tactical and strategic:
				• Supply chain analysis
					Computer with internet connection	Predictions only available for temperate pastures in southern NSW, Victoria, Tasmania, South Australia and Western Australia.
						Training in use the product is recommended.

Product name	Owner/Author	Cost	Uses/Used for	Features	Requirements	Comments
Weed ID: The Ute Guide	Grains Research and Development Corporation	Free	Reference guide to most common paddock weeds in southern Australia	Photographs of each stage of the weed's lifecycle. Plants characterised by plant type. Filter by state, lifecycle, native, flowering or have a smell.	Android 2.2 +	
SA Weed Control	Primary industries and Regions SA	Free	Information about the control of weeds declared in SA	• Photographs and descriptions of the 139 declared plants • Information about control treatments • Information on the safe use of herbicides	Android 4.2 and up	
The Native Plant Guide	Peter Yau and Tim Langdon	Unknown	Information on Australian native flora	Database of 440 Australian native plants.	iOS 7.0 or later	Cannot find further information. Application not available
Wildflowers WA Photo ID	Wildflowers WA – John and Margaret English, Libby Mattiske and Cameron Blackburn	$25/annum	Web based technology product to identify Western Australia wildflowers	Search to identify plants using 12 search criteria including location, flower colour, flowering time, plant size and habit, leaf shape and size, flower type	Computer or smart phone/ device with internet access	Western Australian based technology product

Plant identification sources

Other technology products were primarily related to plant identification, particularly the identification and/or control of weeds, rather than the identification of native plants – shrubs, grasses and herbs, the primary feed base of the Southern Rangelands. Knowledge and understanding of the plants that make up the feed base is important for performance of livestock; overall management of the resource; the plants in the feed base, which may cause adverse reactions in livestock, or plants declared as weeds. Land managers are therefore reliant on books, or other similar publications or expert advice to identify the plants of the feed base.

Technology products related to plant identification include two weed based products: *The Weed ID: The Ute Guide* (Grains Research and Development Corporation, 2013b) is an App designed to assist in the identification of the most common weeds found in paddocks. *The SA Weed Control* App (Primary Industries and Regions South Australia, 2017) has photographs and descriptions of declared plants, control treatments for weeds declared in South Australia.

7.5.4 Livestock monitoring technology products

Livestock monitoring technology products provide land managers options to undertake checks on livestock either remotely or directly, for weights, locations or livestock condition. Monitoring of livestock technology products is divided into two sub-sections: 'remote' and 'other' livestock monitoring technology products. Remote livestock monitoring technology products are categorised as those products which require no or minor human intervention to operate, in comparison 'other livestock' products require more human intervention for their operation. A range of livestock technology products are presented in Table 7-5.

For remote monitoring of livestock, two products were reviewed: *eShepherd* (Agersens, 2017) is a collar and an App for virtual fencing. The technology product can be used from a smart phone, tablet or computer where a land manager can (virtually) fence a paddock, muster livestock, and locate livestock. Only suitable for cattle. *MiHub™ Livestock Management software* (Tru-test, 2017) is a product which uses weighing data from portable or fixed readers to monitor animal weight. Data can be compared to target weights and used to monitor animal weight gain.

Other livestock technology products include a range of weigh systems (data collector and load bar) for weighing livestock; Electronic identification (EID) readers for recording individual animal identifying number; and livestock computer management software which matching EID with relevant information to the animal and its performance. A number of different companies sell these products.

- *Lambing Planner* (Department of Primary Industries and Regional Development 2017a) is an App for sheep producers where the breeding cycle can be mapped and recommendations regarding management at different stages of the breeding cycle are provided.
- *Sheep Condition Scoring* (Department of Primary Industries and Regional Development 2017b), scores are recorded on the App, which calculates average flock condition score, and graphs body condition score ranges and skews in data.

Livestock nutrition technology products

Four Apps or websites were reviewed which are able to calculate and compare nutrition of feeds, cost of feed and/or supplementary feeds. These include the *GrazFeed* (Horizon Agriculture, n.d.-b), a decision support tool which analyses energy and protein requirements of sheep and cattle grazing tropical and temperate pastures and calculates supplementary feeding requirements and costs to reach livestock production targets. Feed cost calculators produced by Western Australia and NSW Governments (Department of Primary Industries and Regional Development 2017c, Department of Primary Industries NSW n.d.-a) are web based technology products which calculate and compare nutrition (protein, energy, dry matter) and costs of livestock feeds. Western Australia also has a product - Supplementary feeding calculator for pregnant and lactating ewes ((Department of Primary Industries and Regional Development 2017d) which is also a web based product used to calculate supplementary feed for pregnant and lactating ewes.

Two technology products were reviewed which are primarily aimed to determine diets for livestock during dry times and drought. The first the *Drought Feed Calculator* (Digital Services NSW 2017) is an App for sheep and cattle producers to determine the minimum feed requirement for a range of animals with different nutritional needs during drought and dry seasons. The minimum feed requirement for a range of animals can be determined. The second is a software program *Ration Book* (Coorong Tatiara Local Action Plan Committee, n.d.) that calculates least cost diets for sheep and beef cattle.

Marketing livestock technology products

Land managers options for sale of livestock (beef, sheep and managed goats) can be informed by information regarding prices and numbers of livestock being sold or slaughtered. MLA have two products; the website (Meat & Livestock Australia, 2016) and App (Meat & Livestock Australia 2015) available for marketing and intelligence on livestock – beef, sheep and goats, both products are free. Information provided includes the latest prices for saleyard, over the hook, skins and store reports; numbers for weekly slaughter, saleyard throughput and saleyard indicators.

Remote water monitoring technology products

Remote monitoring of water utilises a number of mechanisms for transfer of data including satellite, mobile phone, or line of sight. Products not only provide the land manager with water usage data and tank water levels but also has accompanying software, which can plot water use and water levels over time, alert land managers to abnormal uses or low levels. A number of different companies sell these products. Technology in this space is improving see section on *Developing technology products*.

Other livestock technology products

Two technology products are reviewed:

- *AskBill* (Sheep CRC 2017) is an App which provides land managers predictions for livestock (sheep) and pastures based on information provided by the user regarding climate, health and productivity.
- *LTEM (Lifetime Ewe Management)* (Australian Wool Innovation 2017) is a App to support the Lifetime Ewe Management course. App functions include budgeting supplements and guides on nutritional management, using assessments of condition score of animals and feed on offer.

Table 7-4: Livestock technology products

Product name	Owner/Author	Cost	Uses/Used for	Features	Requirements	Comments
Livestock/grazing management technology products						
Maia grazing	Maia Technology	From $100/ month + GST (annual commitment)	Managing and planning grazing management	• Livestock inventory • Allows scenario based forecasting based on historic grazing records and climatic conditions • Development of grazing plans and charts • Livestock movements • Paddock, stock and rainfall analysis • Production and margin analysis	Cloud based App Can be used on a range of devices and off line.	
Farmware	Farmware	Free version available with limited functionality $22-77/per month	Recording activities for livestock, paddocks and storage inventories	Records the following information: • Mobs and numbers of livestock • Animal treatment records • Paddock usage by livestock • Paddock/crop treatments • Analysis of: • Livestock performance, including stocking rates • Paddock and crop performance • Storage inventories	Cloud based App (Android and Apple devices) Can be used off line	

Product name	Owner/Author	Cost	Uses/Used for	Features	Requirements	Comments
PocketPAM2	Fairport Farm Software	Free to download (product subscriptions costs)	Collection of farm records	Multiple modules - only those related to Southern Rangelands are listed: • Mapping • Weather • General purpose diary • Livestock and consumable inventory • Inventory stocktake • Time keeping – recording events • Pasture – cover, growth rates and composition • Water meter readings	Android and Apple iPhone /iPad	
Phoenix	Agdata	Production modules $29/month (desktop) per module Financial module $39/month (discount for multiple modules)	Record keeping of financial and farm management records	Production modules: • Mapping - property maps, from a range of information types • Livestock module – production and decision support systems • Weather – weather records • Financial modules for records and budgeting	Computer with internet connection Cloud based App (Phoenix Live) requires strong internet connectivity)	
AgriWebb	AgriWebb	$550-$2000/ annum Training and support services available	Farm and livestock record keeping	• Livestock recording e.g. numbers, movements, wright gains, livestock treatments. • Pasture and crop records e.g. pasture types, input costs. • Inventory e.g. feed, chemicals. • Mapping	Cloud based App (Android and Apple devices) Can be used off line	

Product name	Owner/Author	Cost	Uses/Used for	Features	Requirements	Comments
Applications to record farm and livestock records	Various Apps available including: • farmGRAZE – UK • Farm IQ – New Zealand • Pro Grass Rotation – Ireland • FarmBoss – New Zealand • Agrimap – New Zealand	Free - $$ depending on the App	To record farm and livestock records	• Apps vary in the features available	Depends on the App	Primarily for overseas based grazing systems
Monitoring of livestock - remote						
eShepherd	Agersens®	Estimated cost per cow $100 (includes base station and installation)	App together with a collar allows fencing, moving or monitoring of livestock	• Can be controlled from smart phone, tablet or computer. • Virtual fence created, instructions send wirelessly to each animal's collar.	Internet connection required for wireless base station	Released planned for Australia in late 2017. Only available for cattle.
Remote WOW System	Tru-Test	Unknown	Remote weigh, track and drafting of cattle	• Data processed and sent via online software – MiHubb Livestock Management • Weekly reports • Remote camera, photos cattle and water trough	Requires 3G or satellite connection	

Product name	Owner/Author	Cost	Uses/Used for	Features	Requirements	Comments
MiHub™ Livestock Management software	Tru-Test	Base plan $25/month Enterprise plan POA – included training	Analyses weighing data from portable or fixed readers to monitor animal weight.	• Data can be compared to target weights, used to monitor animal weight gain.	Computer with internet connection - MiHub™ is cloud based	Requires software to transfer data from readers to computer. Can be used off line.
Monitoring of livestock – Other technology products						
Weigh systems	Various companies	POA	Weighing livestock	Systems include data collector and load bars	Depends in the system	
Electronic identification (EID) readers	Various companies	POA	Identifying individual animals	Reads the individual animals identifying number	Tags with microchip	
Livestock computer management software	Various companies	POA	Matching EID with relevant information to the animal and its performance	Individual animal records, which may include: • Genetics/bloodlines • Breeding history • Weight gain • Vaccine and parasite control history and relevant withholding periods • Supplement history • Fibre diameter measurements • Pregnancy scanning data	Computer management software	Used mainly by stud producers
Lambing Planner	Department of Primary Industries and Regional Development, WA	Free	App for sheep managers to map the breeding cycle for sheep and provides key recommendations on management options.	The Lambing Planner sets out key management operations that make up the breeding cycle, providing information on: • Ewe and ram nutrition • Condition score targets at different stages • Reproductive management • Lambing guidelines.	Android 4.05 and up	

Product name	Owner/Author	Cost	Uses/Used for	Features	Requirements	Comments
Sheep Condition Scoring	Department of Primary Industries and Regional Development, WA	Free	Recording of sheep body condition scores	• Calculates average flock condition score • A histogram is produced showing range of scores and any skew in data • Records can be saved for a mob and tracked over time	App in both Android and iOS formats	
Livestock nutrition technology products						
GrazFeed	Horizon Agriculture	$423.50 (as at Nov 2017). Training course costs unknown	Decision support tool used to calculate energy and protein requirements of sheep and cattle grazing for temperate and tropical pastures and supplementary feeding	• Developed by CSIRO Agriculture and Food • Requires information on pasture quantity and quality to undertake analysis • Calculates live weight change and stocking rate • Suitable for any breed of sheep and cattle	Standard PC with Windows™ operating system	Pasture component limited applicability to pastoral producers. Training through attendance at Prograze course is recommended.
Feed cost calculator (WA)	Department of Primary Industries and Regional Development, WA	Free	Calculate and compare nutrition and costs of livestock feeds: protein, energy, and dry matter	• Allows comparison of up to three feed types and feed mix	Computer with internet connection	
Feed cost calculator (NSW)	Department of Primary Industries (NSW)	Free	Calculate and compare nutrition and costs of livestock feeds: protein, energy, dry matter	• Allows comparison of up to four feed types and feed mix	Computer with internet connection	

Product name	Owner/Author	Cost	Uses/Used for	Features	Requirements	Comments
Supplementary feeding calculator for pregnant and lactating ewes	Department of Primary Industries and Regional Development, WA	Free	Calculating supplementary feed for pregnant and lactating ewes when low levels of green feed	• Product allows specification of: size of sheep, gestation details, flock composition (percentage dry, singles, twins), livestock targets, paddock details, supplementary feed types	Computer with internet connection	Limited applicability to pastoral areas as based on legume-based pastures
Drought Feed Calculator	Digital Services NSW	Free	App for sheep and cattle producers to determine the minimum feed requirement for a range of animals with different nutritional needs	• Allows comparison of feed values, 71 different feeds available. • Calculates: • The amount of feed per head • The cost per head • The cost for a period • The amount for a mob/herd • The total cost for a mob/herd	Smart Andriod phone 4.0 and up	
Ration Book	Coorong Tatiara Local Action Plan Committee	$27.50	Calculating least cost diets for sheep and cattle	• Rations for livestock can be formulated in drought, maintenance, pregnancy or lactation and growth. • Gross margin spreadsheet to determine financial feasibility of feed lotting.	Windows computer with CD/DVD ROM drive	
Marketing livestock technology products						
Market Reports and Prices Website and App	Meat & Livestock Australia	Free	Market reports for sheep, cattle and goats	• Allows selection of: • Livestock type (sheep, cattle and goats) • State/region (NSW, SA, Tas, Vic and WA) • Reports and data include saleyard reports and data, over the hook indicators, store reports and data, weekly slaughter, saleyard throughput, saleyard indicators and skin report	Website: Computer with internet connection App: Android 2.3.3	

Product name	Owner/Author	Cost	Uses/Used for	Features	Requirements	Comments
Remote watering monitoring						
Remote watering monitoring	Various companies	POA	Monitoring tank and trough levels and water usage	• Software can graph water use and levels. • Send warning signals to land manager when levels vary (beyond normal range), advise how long water will last.	Data can be transferred via satellite, mobile phone or line of sight.	
Other livestock technology products						
AskBill	Sheep CRC	Trial licences available $50 for six months. Launch commercial site Nov 2017	Predictions of climate patterns (for main sheep producing regions) and implications for grazing livestock (sheep only)	• Utilises farm data, information on weather (from BoM) 5x5 km grid. • Predict pasture growth, animal performance and risks of flystrike, worm infection and weather stress	Web based App, access to internet	Applicability to pastoral areas is unknown
LTEM Lifetime Ewe Management	Australian Wool Innovation Ltd	Free	A digital extension of the Lifetime Ewe Management course	• Manage nutrition of ewes based on assessment of • Condition scoring of animals and feed on offer.	Android 4.0.3 and up	Completion of Lifetime Ewe Management course is recommended

7.5.5 Non-domestic herbivores technology products

Technology products for management of non-domestic herbivores component of TGP are restricted to introduced non-domestic animals where five products were reviewed (Table 7-6). No technology products for native non-domestic animals (e.g. kangaroos) were available to be reviewed.

The website *Pestsmart* (Centre for Invasive Species Solutions 2017) has information on a range of pests including Wild dog, European rabbit, Unmanaged goat, Unmanaged horse, Unmanaged deer, Unmanaged camel, standard operating procedures for control, information about the unmanaged animal, details of where to get further information and links to record animal activity.

The Centre for Invasive Species Solutions has both a website and App - *FeralScan* for a range of species relevant to Southern Rangelands: camel (FeralScan, 2017a), goat (FeralScan, 2017b), rabbit (FeralScan, 2017c), wild dog (FeralScan, 2017d) and unmanaged pigs (FeralScan 2017e). The App supports only selected species relevant to Southern Rangelands: wild dog and rabbit. Information records and mapping of activity, damage and control activities undertaken. The website and app have the ability to create a local map of unmanaged animal activity, damage and control activities.

Table 7-5: Non-domestic animal technology products

Product name	Owner/Author	Cost	Uses/Used for	Features	Requirements
Pestsmart: Pest Animal Toolkit	Centre for Invasive Species Solutions	Information free to download	Toolkits for a range of pest including: Wild dog • European rabbit • Unmanaged goat • Unmanaged horse • Unmanaged deer • Unmanaged camel	Information on the particular pest, standard operating procedures for control, information about where to get further information and record animal activity	Computer with internet connection
WildDogScan	UnmanagedScan	Free to register	Record and map sightings of wild dogs, their impacts and control activities undertaken	Record and map wild dog activity, damage caused by wild dogs, control activities undertaken and the ability to create a local wild dog map	Computer with internet connection Smart phone (Apple and Andriod App)
CamelScan	UnmanagedScan	Free to register	Record and map sightings of unmanaged camels, damage and control activities undertaken	Record and map sightings, damage caused by unmanaged camels See mapped locations of unmanaged camel sightings	Computer with internet connection
Unmanaged Goat Scan	UnmanagedScan	Free to register	Record and map sightings of unmanaged goats, damage and control activities undertaken	Record and map sightings, damage caused by unmanaged goats See mapped locations of unmanaged goat sightings	Computer with internet connection
RabbitScan	UnmanagedScan	Free to register	Record and map rabbits activity, warrens, damage and control activities undertaken	Record and map sightings, and evidence of disease See mapped locations of rabbit activity and disease.	Computer with internet connection Smart phone (Apple and Andriod App)

7.5.6 Natural resource management technology products

The review of natural resource management technology products focussed on products related to rangeland condition, ground and vegetation cover (Table 7-7). Technology products specifically related to pastures such as pasture assessment through vegetation greenness and cover, and identification were reviewed in Table 7-3.

Five products were reviewed, the first Ground Cover (Namoi Catchment Management Authority 2017) App uses geo-location technology along with a standard step point monitoring process, supported by a photographic benchmark capability to assess the ground cover. The App has two components: 'Standard' for North West or the Hunter Region of New South Wales and 'Basic Assessment' for other users aiming to improve their grazing management by improving ground cover.

The Pastoral Lands Board of Western Australia has two simple ground-based photographic methods available for land manager use, loosely based on the Western Australian Rangeland Monitoring System (WARMS). The two methods can be used in (i) grasslands and (ii) shrublands. They are available at Pastoral Lands Board of WA (n.d. a and b).

The Monitoring App (Gascoyne Catchments Group 2017) is a self-assessment monitoring and reporting product for rangeland condition (plants, soils and erosion) in the Gascoyne Catchment (WA), applicability outside this region was unable to be assessed.

LandPKS (Land-Potential Knowledge System 2017) App has two components, first which collects basic soil and topographic information necessary to determine land potential (LandInfo) and the second collects soil and vegetation cover data necessary to assess and monitor major changes in plant community composition and wind and water erosion risk (LandCover). The App has limited applicability to Australia, with pilot sites in Kenya, Namibia, Malawi, Tanzania, Uganda, and Nepal.

Table 7-6: Natural resource management technology products

Product name	Owner/Author	Cost	Uses/Used for	Features	Requirements	Comments
Ground Cover	Namoi Catchment Management Authority	Free	Assess ground cover of paddock	Two components: 1. Standard Assessment is specifically designed for North West or the Hunter Region of New South Wales users 2. Basic Assessment is for users aiming to improve their grazing management by improving their ground cover. Information can be sent by email to a data base	Apple iOS 6.0 + devices only	
LandPKS	Land-Potential Knowledge System	Free	LandInfo - Characterising soil and site topographic information to determine land potential LandCover- recording vegetation cover and structure to assess and monitor major changes in plant community composition and wind and water erosion risk	LandInfo - Collection of data regarding soil texture, topography and soil properties. LandCover – collection of data including vegetation cover measured using point-intercept method, plant height, plant density and presence of inter-canopy gaps. User Guide information available	Andriod 4.1 and up Available to be used off line and then uploaded when internet connection available	Limited applicability to Australia, pilot sites include Kenya, Namibia, Malawi, Tanzania, Uganda, and Nepal. Further mobile Apps under development: Biomass (Biomass Monitor), Livestock body condition (Body Condition Score), and crops (Crop Monitor).
Rangeland condition monitoring - shrublands	Pastoral Lands Board of WA	Free	Self-assessment monitoring and reporting for rangeland condition in shrublands	Fixed ground sites involving photography and plant counts	Steel pickets, camera, 50 m measuring tape, 1 m^2 quadrat	

Product name	Owner/Author	Cost	Uses/Used for	Features	Requirements	Comments
Rangeland condition monitoring - grasslands	Pastoral Lands Board of WA	Free	Self-assessment monitoring and reporting for rangeland condition for grasslands	Fixed ground sites involving photography and assessment of perennial grass frequencies	Steel pickets, camera, 50 m measuring tape, 1 m^2 quadrat	
Monitoring App	Gascoyne Catchments Group	Free	Self-assessment monitoring and reporting for rangeland condition for the Gascoyne region of WA	Three components of rangeland health are assessed: plants, soils and erosion	iPhone or iPad compatible. Can be used off line	Need to obtain user name and password. Specific for the Gascoyne region of WA

7.5.7 Climate and weather technology products

There are a number of Climate/Weather technology products that can be used to assist land managers in decision making in relation to their livestock and pasture management (Table 7-3 and Table 7-5). Six products related to climate and weather were reviewed, a number of websites and Apps produced by various companies are listed in Table 7-8.

BOM Weather (Bureau of Meteorology 2017a) is an App providing details of current weather conditions, forecasts, radar, warnings for any location across Australia.

Bureau of Meteorology (Bureau of Meteorology 2017b) website provides users with climate and weather information including short term forecasts and the latest weather, ENSO (El Niño-Southern Oscillation); drought statements; rainfall and temperature outlooks; cyclone outlooks, POAMA – long range outlook and much more.

Climate Kelpie (Grains Research and Development Corporation 2016) website has a wide range of technology products (e.g. rainfall and seasonal forecasts) and comprehensive information about climate to help make farm business decisions.

Australian CliMate (Commonwealth of Australia 2017) provides analysis of long term climate records to inform land manager decision making. Analysis is structured around a number of questions such as 'Season's progress?' 'How's the drought?' and 'What trend?'

MEA – Free Weather Data (Measurement Engineering Australia 2017) provides regional and specific locational weather readings linked to weather station networks in South Australia, Victoria, New South Wales, Tasmania and Western Australia.

The Long Paddock (Department of Science, Information Technology and Innovation 2017) provides a range of climate and weather products including rainfall and pasture growth, SILO climate data and SOI dashboard.

Table 7-7: Climate and weather technology products

Product name	Owner/Author	Cost	Uses/Used for	Features	Requirements	Comments
BOM Weather App	Bureau of Meteorology	Free	Details of current weather conditions, forecasts, radar, warnings	View current conditions, forecasts, rain radar and warnings for your location or any location across Australia	Download App – Apple or Android 4.1 and up	
BOM website – MetEye, Agriculture Services – water and land, Climate and past weather, Climate watch, Climate videos, Climate model forecasts	Bureau of Meteorology	Free	Short-term forecasts and latest weather, ENSO; drought statements; rainfall and temperature outlooks; cyclone outlooks, POAMA – long-range outlook.	Many features see BOM website for details	Computer with internet connection	
Climate Kelpie website	Grains Research and Development Corporation	Free	Rainfall forecasts, seasonal forecasts, decision support tools, what drives climate and weather in your region, future projected climate	Climate adaption options – decisions about livestock business, profitable perennial plants (Everfarm)	Computer with internet connection	Requires skills to interpret information for decision making purposes
Australian CliMate website or App	Commonwealth of Australia	Free	Climate analysis to information decision making	Probabilities of future rainfall, temperature or radiation events, the risk of heat and cold stresses for a specified date Current season's rainfall, average temperature, heat sums and radiation, plant-available soil water for the current year, current state of the ENSO cycle	App - iOS and Android Website - Computer with internet connection Need to register	

Product name	Owner/Author	Cost	Uses/Used for	Features	Requirements	Comments
MEA – Free Weather Data	Measurement Engineering Australia	Free	Regional and specific locational weather readings	Daily record and 15 minute readings of air temp., relative humidity, dew point, solar radiation, wind speed, rain, and frost.	Computer with internet connection	
Long Paddock - Rainfall and pasture growth	Queensland Government	Free	Rainfall and pasture growth	Rainfall records and rainfall percentile maps to indicate pasture production Maps produced using techniques of Jeffrey *et al.* (2001)	Computer with internet connection	
Long Paddock - SILO Climate Data	Queensland Government	Free	Australian climate data from 1889 (current to yesterday)	Data available includes maximum and minimum air temperature; rainfall; evaporation; solar radiation; vapour pressure; mean sea level pressure; relative humidity, evapotranspiration	Computer with internet connection. Need to register Adobe reader	.
Long Paddock - SOI Dashboard	Queensland Government	Free	Southern Oscillation values – average, monthly averages and historically information	Southern Oscillation values available for the past 30, 90 days and monthly average values. Historical data from 1899 available	Computer with internet connection	

Product name	Owner/Author	Cost	Uses/Used for	Features	Requirements	Comments
Websites and applications to record climate/ weather data	Various websites/ Apps available including: • AUS Weather • DAFWA Weather Stations • Elders Weather • Pocket Weather Australia • RainLog • Rain Recorder • RainRadarAU • Sky News Weather • The Weather Channel • Weatherzone • Willy Weather • YR	Free - $$ depending on App / website	Locational weather readings, radar images, forecasts (short and long term)	Websites/Apps vary in the features available	Computer with internet connection for websites Requirements vary depending on the App	

7.5.8 Other technology products

A number of technology products classified as 'other' include: the *Insect ID: The Ute Guide* (Grains Research and Development Corporation 2013a) which provides users a guide to insect pests commonly affecting broadacre crops and growers across Australia. This guide may be useful for determining insect pests affecting pasture species in the Southern Rangelands. The products are shown in Table 7-9.

The CSIRO SoilMapp (Commonwealth Scientific and Industrial Research Organisation 2015), provides data and information about the soils at a particular location. This information may be useful for land managers in planning locations of infrastructure and management of land condition.

Mapping technology products have a range of uses including planning infrastructure and measuring paddock sizes, fence lines and pipelines, products that are of practical application to land managers in the management of TGP. A number of Apps are available in this space and were not reviewed. Mapping is also a component of *FarmMap4D* reviewed in Table 7-2 and in many of the livestock/grazing management technology products reviewed in Table 7-3.

NatureMaps (Department of Environment, Water and Natural Resources 2017), a web based product for accessing maps and geographical information for South Australia in an interactive online mapping format. *NatureMaps* includes a range of GIS databases including: Administrative Boundaries, Cadastral Information, Coast and Marine, Fauna and Flora, Fire, Heritage and Tourism, Landscapes, soils, Protected Areas, SA Most Likely Land Cover, Tenure and Landuse, Vegetation Mapping, Water (Ground and Surface), Wetlands, Graticules, Grids and Map Tiles and Photo Centres and Flight Lines.

Table 7-8: Other technology products

Product name	Owner/Author	Cost	Uses/Used for	Features	Requirements
Insect ID: The Ute Guide	Grains Research and Development Corporation	Free	Reference guide to insect pests commonly affecting broadacre crops and growers across Australia	Photos of life-cycle stages; detailed insect description with information on the crops they attack, how to monitor and other pests that they may be confused with	Android 2.2
SoilMapp	Commonwealth Scientific and Industrial Research Organisation	Free	Accessing soil data information for any location in Australia	Direct access to the Australian Soil Resource Information System (ASRIS) and APSoil, the database behind the agricultural computer model: Agricultural Production Systems sIMulator (APSIM).	iOS 7.0 or later
NatureMaps	Department of Environment, Water and Natural Resources (South Australia)	Free	Access to maps and geographic information about SA	Interactive online mapping. Access to a range of GIS databases including soils, cadastral information, vegetation mapping, and water – ground and surface.	Computer with internet connection
Websites and applications to undertake mapping	Various websites/ Apps available including: • GPS Area Calculator • Maps Distance Calculator	Free - $$ depending on App/website	Mapping paddocks determining area, measuring distance	Websites/Apps vary in the features available	Computer with internet connection for websites Requirements vary depending on the App

7.6 Evaluation

A qualitative assessment of the value of technology product for providing information for TGP management, and limitations of the products for the management of TGP is presented in Table 7-10. It should be noted that this assessment is based on the information available about the technology products obtained by the reviewers from product websites, rather than the actual use and application of the product for the Southern Rangelands.

Table 7-9: Evaluation of the technologies

Technology product categories / brief overview of product purpose	Value for providing information for TGP management	Limitations of the technology product for management of TGP
Pasture technology products		
Remote pasture monitoring technology products – monitor pastures via satellite technology for vegetation greenness or cover	+	• The monitoring of pastures provides information regarding pasture changes over time however, real time data is often required for decision making, rather than historic data.
Pasture production – based on climate information pasture production is estimated	+	• Further development of products for pasture systems in the Southern Rangelands particularly shrub based systems at the property level is required.
Feed budgeting – calculate feed requirements of livestock	+	• Technology products have been developed for specific locations and pasture types, and require modification for application in the Southern Rangelands
Other pasture technology products – examine effects of variable weather and test management options	0/+	• Technology products may assist land managers to plan grazing management over seasons/years, utilising this information land managers would be able to make decisions regarding management of the livestock component of TGP. However, other aspects of TGP need to be also accounted for.
Other pasture technology products – to identify pasture plants	0/+	• Technology products reviewed are mostly developed for wildflowers, weeds or gardens plants, further development of information for Southern Rangeland species including identification, nutrition value, etc. is required • Information about identification and nutrition of pasture species may play a role in inform land managers pasture production and feed budgeting

Qualitative assessment of the value of technology products for management of TGP.

Key: (0 = nil: no value in informing management of TGP ; + = low value in informing management of TGP; ++ = moderate value in informing management of TGP; +++= high value in informing management of TGP).

Technology product categories / brief overview of product purpose	Value for providing information for TGP management	Limitations of the technology product for management of TGP
Livestock technology products		
Livestock/grazing management – to record and monitor livestock related information including numbers, grazing management activities – plans, movements	+	• Technology products only generally relate to the livestock component of TGP. Few technology products combine with pasture management – feed budgeting and livestock production.
Monitoring of livestock – to monitor livestock, weight, location or condition either remotely or directly	0/+	• Technology products relate only to aspects location or condition of livestock component of TGP.
Livestock nutrition – to calculate and compare cost and/or nutrition of pasture and supplementary feeding	0	• Technology products relate particularly to the nutrition of feed, predominately in tropical and temperate pastures, or supplementary feed rather than pastures of Southern Rangelands
Marketing livestock – to inform land managers of prices and numbers of livestock being sold or slaughtered	0	• Technology products are simply inform land managers of livestock prices and numbers of livestock being sold or slaughtered, which may be of assistance when adjusting through sales or purchase the livestock component of TGP
Remote water monitoring – to inform land manager of water related information remotely through a range of transfer mechanisms	0	• Technology products provide important information for the land manager about water use and tank levels. It is assumed that livestock are utilising the water, rather than non-domestic animals.
Other livestock technology products	0	• Applicability of these 'other' technology products to the Southern Rangelands is unknown.
Non-domestic herbivores technology products		
Non-domestic herbivores – to inform land managers about locations, control activities and SOP for introduced non-domestic animals	+	• Technology products only relate to introduced non-domestic animals.
Natural resource management technology products		
Natural resource management – technology products can inform the land manager and Government authority of the rangeland condition, ground and vegetation cover	+	• Technology products importantly relate to aspects of natural resource management which are important for managing TGP, however the cause of any impacts on the natural resource are unknown

Technology product categories / brief overview of product purpose	Value for providing information for TGP management	Limitations of the technology product for management of TGP
Climate/weather technology products		
Climate/weather – technology products relate to climate and weather and may be useful in assisting land managers decision making in relation to pasture and livestock management	0/+	• Technology products need to be used in conjunction with other aspects of management particularly pasture production, livestock and non-domestic herbivore numbers
Other technology products		
Other technology products	0/+	• Technology products for soils, insects and mapping may play in a role in management of TGP but need to be incorporated with the other

7.7 Technology product development

This section identifies key organisations or groups working on or investing the research and development of technology products. Development of technology products is listed using the same categories as the review of technology products.

7.7.1 Pasture technology products

Development of technology products to monitor pastures in the agricultural zone include the use of drones to map paddocks such as a project by Seed Consulting[1] assessing pasture condition.

MLA in collaboration with Hitachi Consulting are piloting an on-farm project to evaluate and integrate data from weather stations, soil moisture probes and water trough monitors to support almost real time management decisions and forecasting (Meat & Livestock Australia 2017a).

7.7.2 Livestock tools

The *GrazingApp* (Department of Primary Industries (NSW) 2017) is still under development and focussed on feed budgeting and grazing management (W Badgery personal communication).

FarmBot (FarmBot 2017) is developing technology to enable remote water flow monitoring and pump control via satellite, release of these products is scheduled for early 2018 (Cameron Young personal communication[2]).

7.7.3 Non-domestic animals technology products

Unaware of any products being developed in this area.

7.7.4 Natural resource management technology products

Unaware of any products being developed in this area.

7.7.5 Climate and weather technology products

The current BOM long-range forecasting system POAMA-2, is low-resolution (250km) and will be replaced with a new seasonal forecasting system ACCESS-S (the seasonal prediction version of ACCESS) in mid-2018. ACCESS-S will operate at a 60 km resolution, compared to the 250 km resolution of POAMA-2, and will run on the Bureau's new supercomputer. This brings POAMA and seasonal prediction into the national ACCESS modelling framework, which utilises the latest local and overseas developments.

7.7.6 Other technology products

Enhanced drought information system (NSW Government, n.d.) is a project currently being developed by NSW Government to provide meteorological, agronomic and hydrological drought indicators to assist reporting of drought status and enhance drought policy planning.

Global Ag-Tech Ecosystem (GATE) (Department of Primary Industries (NSW), n.d.-b) is an initiative of NSW Department of Primary Industries (DPI) to fast track adoption of agricultural Research and Development, open to exploring the viability of agri-tech ideas. The initiative provides access to the long-term data sets held by DPI and will facilitate on-farm validation of new technologies on research properties and trial farms.

[1] Andy Chambers, Seed Consulting Services 106 Gilles Street, Adelaide, South Australia 5000. E andy.chambers@seedcs.com.au

[2] Warwick Badgery, NSW Department of Primary Industries, 1447 Forest Rd Orange NSW 2800 E: warwick.badgery@dpi.nsw.gov.au

7.8 Implications for managing TGP

Developing clusters of pastoral leases within fencing designed to exclude unwanted and unmanaged animals is an established approach in South West Queensland and Western New South Wales. Protection of small livestock from wild dog/ dingo predation is the objective in most cases, but a role for exclusion fencing to prevent Macropod and feral goat is also recognised. Partial exclusion (TGP fencing) is also being widely adopted in western NSW to provide control of feral goat and Macropod populations and areas being managed for carbon sequestration are continuing the adoption of this management option. Questions remain about the long-term administration of cluster fenced, collective projects, and the overall biophysical and economic impacts.

Over the past four years, practical methods for positively influencing livestock grazing distributions have been developed, principally in Western Australia. The methods, collectively referred to as Rangelands Self Herding require further investigation and experience in their use. How grazing systems that integrate wild dogs/ dingoes into cattle production with the aim of lowering Macropod numbers is also a 'work in progress'.

There has not been a systematic review of the cost-effectiveness of TGP management options but in particular excessive Macropod grazing. However, there is a large and increasing number of sources of GIS-based information and technologies, from both public and private sector organisations to support the management of extensive grazing systems, and most of these do not explicitly address all grazing herbivores. It is not known how well these are contributing to improved environmental and economic outcomes, and further development of products for pasture systems in the Southern Rangelands, particularly shrub based systems at the property level is required. Few technology products link TGP management with feed budgeting and livestock production.

8. References

Abdalla, M., Hastings, A., Chadwick, D.R., Jones, D.L., Evans, C.D., Jones, M.B., Rees, R.M. and Smith, P. (2018). Critical Review of the impacts of grazing intensity on soil organic carbon storage and other soil quality indicators in extensively managed grasslands. *Agriculture, Ecosystems & Environment* 253: 62-81

Abel, N.O.J., and Blaikie P.M. (1989). Land degradation, stocking rates and conversion policies in the communal rangelands of Botswana and Zimbabwe. *Land Degradation and Development* 1, 101-123.

AGDATA Australia. (2017). Phoenix Farm Management Software.

Agersens, (2017*). eShepherd*. https://agersens.com/eshepherd/.

AgriWebb, (2017). *AgriWebb*. www.agriwebb.com.

Agsurf, (2018). *Database*. Australian Government Department of Agricultural and Water Resource. http://apps.daff.gov.au/agsurf/

Alcock, D. (2011). *Grazclock V 2.4.2.* http://www.grazprophet.com.au/Downloads.php.

Alemseged, Y. and Hacker, R. B. (2014). Introduction of Dorper sheep into Australian rangelands: implications for production and natural resource management. *The Rangeland Journal* 36, 85–90.

Allen, B.L. (2011). A comment on the distribution of historical and contemporary livestock grazing across Australia: Implications for using dingoes for biodiversity conservation. *Ecological Management & Restoration* 12, 26–30.

Allen, B.L. (2015). More buck for less bang: Reconciling competing wildlife management interests in agricultural food webs. *Food Webs* 2, 1-9.

Allen, B. L., Engeman, R. M., and Allen, L. R. (2011*a*). Wild dogma: an examination of recent "evidence" for dingo regulation of invasive mesopredator release in Australia. *Current Zoology* 57, 568–583.

Allen, B.L., Engeman, R.M., and Allen, L.R. (2011*b*). Wild dogma II: the role and implications of wild dogma for wild dog management in Australia. *Current Zoology* 57, 737–740.

Allen, B.L., and Fleming, P.J.S. (2012). Reintroducing the dingo: the risk of dingo predation to threatened species in western New South Wales. *Wildlife Research* 39, 35–50.

Allen, B.L., Fleming, P.J.S., Allen, L.R., Engeman, R.M., Ballard, G., Leung, Luke K-P (2013). As clear as mud: A critical review of evidence for the ecological roles of Australian dingoes. *Biological Conservation* 159,158-174.

Allen, V.G., C. Batello, E.J. Berretta, J. Hodgson, M. Kothmann, X. Li, J. McIvor, J. Milne, C. Morris, A. Peeters and M. Sanderson (2011). An international terminology for grazing lands and grazing animals. *Grass and Forage Science*, 66, 2–28.

Andrew, M. and Lange, R. (1996). Development of a new piosphere in arid chenopod shruhland grazed by sheep. 1. Changes to the soil surface. *Australian Journal of Ecology* 11, 395-409

Anon, (1901). *Western Division of New South Wales. Royal Commission to Inquire into the Condition of Crown Tenants. Report and Summary of Evidence*. Department of Lands. Government Printer, Sydney.

Anon, (1969). *Report of the Inter-departmental Committee on Scrub and Timber Regrowth in the Cobar-Byrock District and other areas of the Western Division of NSW*. Department of Lands.

Archimeade, H., Bovala, M., Alexandrea, G., XandeÂa, A., Aumonta, G. and Poncet, C. (2000). Effect of regrowth age on intake and digestion of *Digitaria decumbens* consumed by Black-belly sheep. *Animal Feed Science and Technology* 87, 153-162.

Archer, S. R., Schimel D. S. and Holland E. A. (1995). Mechanisms of shrubland expansion: land use, climate or CO2? *Climate Change* 2, 91-9.

Archibald, S., W. J. Bond, W. D. Stock, and D. H. K. Fairbanks (2005). Shaping the landscape: fire-grazer interactions in an African savanna. *Ecological Applications* 15, 96–109.

Arnold, G., Steven, D. and Weeldenberg, J. (1994). Comparative ecology of western grey kangaroos (*Macropus fulginosus*) and euros (*M. robustus erubescens*) in Durokoppin Nature Reserve, isolated in the central wheatbelt of Western Australia. *Wildlife Research* 21, 307 – 321.

Arsenault, R. and Owen-Smith, N. (2002). Facilitation versus competition in grazing herbivore assemblages. *Oikos* 97, 313–318.

Ash, A. J. and Stafford Smith, D. M (1996). Evaluating stocking rate impacts in rangelands: Animals don't practice what we preach. *The Rangeland Journal* 18, 216-243.

AuctionsPlus, (2018). *AuctionsPlus Pty Limited*. Sydney, NSW, Australia. https://auctionsplus.com.au/

Australian Bureau of Statistics, (2017). *Australian Commodities 2015-16.* http://www.abs.gov.au/AUSSTATS/abs@.nsf/second+level+view?ReadForm&prodno=7121.0&viewtitle=Agricultural%20Commodities,%20Australia~2015-16~Latest~07/07/2017&&tabname=Past%20Future%20Issues&prodno=7121.0&issue=2015-16&num=&view=&

Australian Wool Innovation, (2017). *LTEM (Lifetime Ewe Management).* https://play.google.com/store/apps/details?id=com.ltem.main&hl=en.

AusVet Animal Health Services, (2006). A Review of the Structure and Dynamics of the Australian Beef Cattle Industry. http://www.agriculture.gov.au/SiteCollectionDocuments/animal-plant/animal-health/livestock-movement/beef-movement-ead.pdf

Aynekulu, E, Mekuria W, Tsegaye D, Feyissa K, Angassa A, Leeuw J, Shepherd K. (2017). Long-term livestock exclosure did not affect soil carbon in southern Ethiopian rangelands. *Geoderma* 307, 1–7.

Bailey, D. W. (2016). Grazing and animal distribution. In: Villalba, J.J., Manteca, X. (Eds.), *Animal Welfare in Extensive Production Systems*. 5M Publishing Ltd, Sheffield, UK, pp. 53-77.

Bailey, D. W., Brown, J. R. (2011). Rotational grazing systems and livestock grazing behavior in shrub-dominated semi-arid and arid rangelands. *Rangeland Ecology & Management* 64, 1-9.

Bailey, P., Martensz, P. and Barker, R. (1971). Red kangaroo, *Megaleia rufa* (Desmarest), in north-western New South Wales. 2. Food. *CSIRO Wildlife Research* 16, 29 – 39

Bailey, D. W., Thomas, M. G., Walker, J. W., Witmore, B. K., Tolleson, D. (2010). Effect of revious experience on grazing patterns and diet selection of Brangus cows in the Chihuahuan Desert. *Rangeland Ecology & Management* 63, 223-232.

Bailey, D. W., Van Wagoner, H. C., Weinmeister, R., Jensen, D. (2008). Evaluation of low-stress herding and supplement placement for managing cattle grazing in riparian and upland areas. *Rangeland Ecology & Management* 61, 26-37.

Barker, R. (1987). Diet of herbivores in the sheep rangelands. Pages 69-83. Kangaroos: their ecology and management in the sheep rangelands of Australia. Eds. G. Caughley, N. Shepherd and J. Short. Cambridge University Press. Cambridge.

Bartley, R. C., H. Roth, J. Ludwig, D. McJannet, A. Liedloff, J. Corfield, A. Hawdon, and B. Abbott. 2006. Runoff and erosion from Australia's tropical semi-arid rangelands: Influence of ground cover for differing space and time scales. *Hydrological Processes* 20, 3317-3333.

Bastin, G. (2008). *Rangelands — Taking the Pulse*, published on behalf of the ACRIS Management Committee by the National Land & Water Resources Audit, Canberra.

Bastin, G. (2012). ACRIS Kangaroo Density Update 2009-2012. Updated information to that provided in *Rangelands 2008 – Taking the pulse*. Gary Bastin, ACRIS Management Unit. http://www.environment.gov.au/system/files/resources/01aa82ce-d910-4a45-b98a-ea17c7269549/files/acris-kangaroo-density-update.pdf

Bastin, G., Denham, R., Scarth, P. Sparrow, A., and Chewings, V. (2014). Remotely-sensed analysis of ground-cover change in Queensland's rangelands, 1988–2005. *The Rangeland Journal* 36, 191-204.

Bayliss, P. (1985). The population dynamics of red and western grey kangaroos in arid New South Wales, Australia. I. Population trends and rainfall. *The Journal of Animal Ecology* 54, 111-125.

Bjørneraas, K., Herfindal, I., Solberg, E. J., Saether, B.-E., van Moorter, B., Rolandsen, C. M. (2012). Habitat quality influences population distribution, individual space use and functional responses in habitat selection by a large herbivore. *Oecologia* 168, 231.

Blumstein, D.T., Mari, M., Daniel, J. C., Ardron, J. G., Griffin, A. S. and Evans, C. S. (2002). Olfactory predator recognition: wallabies may have to learn to be wary. *Animal Conservation* 5, 87-93.

Booker, K, Huntsinger L, Bartolome J. W, Sayre N. F, Stewart W. (2013). What can ecological science tell us about opportunities for carbon sequestration on arid rangelands in the United States? *Global Environmental Change* 23, 240–251.

Borer, E. T., E. W. Seabloom, D. S. Gruner, W. S. Harpole, H. Hillebrand, E. M. Lind, P. B. Adler, J. Alberti, T. M. Anderson, J. D. Bakker, L. Biederman, D. Blumenthal, C. S. Brown, L. A. Brudvig, Y. M. Buckley, M. Cadotte, C. Chu, E. E. Cleland, M. J. Crawley, P. Daleo, E. I. Damschen, K. F. Davies, N. M. DeCrappeo, G. Du, J. Firn, Y. Hautier, R. W. Heckman, A. Hector, J. HilleRisLambers, O. Iribarne, J. A. Klein, J. M. Knops, K. J. La Pierre, A. D. Leakey, W. Li, A. S. MacDougall, R. L. McCulley, B. A. Melbourne, C. E. Mitchell, J. L. Moore, B. Mortensen, L. R. O'Halloran, J. L. Orrock, J. Pascual, S. M. Prober, D. A. Pyke, A. C. Risch, M. Schuetz, M. D. Smith, C. J. Stevens, L. L. Sullivan, R. J. Williams, P. D. Wragg, J. P. Wright, and L. H. Yang. (2014).Herbivores and nutrients control grassland plant diversity via light limitation.*Nature* 508, 517-520.

Briske, D. D., Derner J. D., Brown, J. R., Fuhlendorf S. D., Teague W. R., Havstad K. M., Gillen R. L., Ash A. J., Willams W. D. (2008). Rotational grazing on rangelands: reconciliation of perception and experimental evidence. *Rangeland Ecology and Management* 6, 3–17.

Browne, R. (1995). Exploring management options and considerations for land and kangaroo conservation in an economically and ecologically sustainable rural community. Pages 195-198 in *Conservation Through Sustainable Use of Wildlife.* Ed. G. Grigg, P. Hale and D. Lunney. Centre for Conservation Biology, University of Queensland.

Burboa-Cabrera, F. R., Schacht, W. H., Anderson, B. E. (2003). Utilization and grazing distribution of cattle at 4 stocking densities. *Journal of Range Management* 56, 328-333.

Bureau of Meteorology, (2017a). *BOM Weather*. https://play.google.com/store/apps/details?id=au.gov.bom.metview&hl=en.

Bureau of Meteorology, (2017b). *Bureau of Meteorology*. http://www.bom.gov.au/.

Bureau of Meteorology, (2017c). *Climate Glossary.* http://www.bom.gov.au/lam/glossary/.

Cairns, S., Pople, A. and Grigg, G. (1991). Density distributions and habitat associations of red kangaroos, *Macropus rufus*, and western grey kangaroos, M*. fuliginosus. Wildlife Research* 18, 377-401

Calaby, J. and Grigg, G. (1989). Changes in macropodoid communities and populations in the past 200 years, and the future. Pages 813-20. In *Kangaroos, wallabies and rat-kangaroos*. Ed. By G. Grigg, P. Jarman and I. Hume. Surrey Beatty and Sons. New South Wales, Australia.

Capellini, I., Venditti, C., Barton, R. A. (2010). Phylogeny and metabolic scaling in mammals. *Ecology* 91, 2783-2793.

Caughley, G. (1964). Density and dispersion of two species of kangaroo in relation to habitat. *Australian Journal of Zoology* 12, 238-249

Caughley, G., Grigg, G., Caughley, J. and Hill, G. (1980). Does dingo predation control the densities of kangaroos and emus? *Australian Wildlife Research* 7,1-12

Centre for Invasive Species Solutions, (2017). *Pestsmart: Pest Animal Toolkit.* https://www.pestsmart.org.au/pest-animal-species/.

Chippendale, G. (1962). Botanical examination of kangaroo stomach contents and cattle rumen contents. *Australian Journal of Science* 25, 21-22.

Chippendale, G. (1968). The plants grazed by red kangaroos, *Megalieia rufa* (*Desmarest*), in central Australia. *Proc. Linn. Soc. N.S.W.* 93, 98-110.

Clauss, M., Hume, I. D., Hummel, J. (2010). Evolutionary adaptations of ruminants and their potential relevance for modern production systems. *Animal* 4, 979-992.

Clauss, M, Streich, W., Schwarm, A., Ortmann, S. and Hummel, J. (2007). The relationship of food intake and ingesta passage predicts feeding ecology in two different megaherbivore groups. *Oikos* 116, 209-216.

Clipex, (2017). *Exclusion fencing.* https://clipex.com.au/media/wysiwyg/common/pdfs/exclusion-fence-brochure.pdf [Accessed: November 2017]

Coates, D. and Dixon, R. (2007). Faecal near infrared reflectance spectroscopy (F.NIRS) measurements of non-grass proportions in the diet of cattle grazing tropical rangelands. *The Rangeland Journal* 29, 51-63.

Collins, D. and Menz, K. (1986).An economic perspective to the population management of commercially harvested kangaroos. *Australian Rangeland Journal* 8, 103 – 109.

Commonwealth of Australia, (2017). *Australian CliMate.* https://climateapp.net.au/.

Cooper, J., Gordon, I. J. and Pike, A.W. (2000). Strategies for the avoidance of faeces by grazing sheep. *Applied Animal Behaviour Science* 69, 15-33.

Coorong Tatiara Local Action Plan Committee. (n.d.). *Ration Book.* https://www.coorong.sa.gov.au/page.aspx?u=1943.

Coulson, G. and Norbury, G. (1988). Ecology and management of western grey kangaroos (*Macropus fuliginosus*) at Hattah-Kulkyne National Park. Arthur Rylah Institute for Environmental Research Technical Report Series No. 72.

Crowden, C. and Allen, L. R. (2016). *Collaborative Area Management: the progress and the method behind the establishment of the cluster fencing project.* In: 5th Queensland Pest Animal Symposium, Townsville.

Cunningham, G.M., Mulham, W.E., Milthorpe, P.L. and Leigh, J.H. (2011) *Plants of Western New South Wales.* CSIRO Publishing, Melbourne.

Cui, X. Y., Wang, Y. F., Niu, H. S., Wu, J., Wang, S. P., Schung, E., Rogasik, J., Fleckenstein, J. and Tang, Y. H. (2005). Effect of long-tern grazing on soil organic carbon content in semiarid steppes in Inner Mongolia. *Ecological Research* 20, 519-527.

Dawson, T. (1989). Diets of macropodoid marsupials: General patterns and environmental influences. Pages 129-42. In *Kangaroos, wallabies and rat-kangaroos*. Ed. By G. Grigg, P. Jarman and I. Hume. Surrey Beatty and Sons. New South Wales, Australia.

Dawson, T. J. (1995). *Kangaroos: biology of the largest marsupials*. University of New South Wales Press: Sydney.

Dawson, T.J. and Denny, M.J.S. (1969). Seasonal variation in the plasma and the urine electrolyte concentration of the arid zone kangaroos *Megaleia rufa* and the *Macropus robustus*. *Australian Journal of Zoology* 17, 777-784.

Dawson, T. J., Denny, M. J. S., Russell, E. M. and Ellis, B. (1975). Water use and diet preferences of free ranging kangaroos, sheep and feral goats in the Australian arid zone during summer. *Journal of Zoology* 177, 1-23.

Dawson, T. J. and Ellis, B. A. (1994). Diets of mammalian herbivores in Australian arid shrublands: seasonal effects on overlap between red kangaroos, sheep and rabbits and on dietary niche breadths and electivities. *Journal of Arid Environments* 34, 491-506.

Dawson, T. J. and Ellis, B. A. (1996). Diets of mammalian herbivores in Australian arid, hilly shrublands: seasonal effects on overlap between euros (hill kangaroos), sheep and feral goats, and on dietary niche breadths and electivities. *Journal of Arid Environments* 34, 491-506.

Dawson, T. J., McTavish, K. J. and Ellis, B. A. (2004). Diets and foraging behaviour of red and eastern grey kangaroos in arid shrub land: is feeding behaviour involved in the range expansion of the eastern grey kangaroo into the arid zone? *Australian Mammalogy* 26, 169-178.

Dawson, T. J. and Munn, A.J. (2007). How much do kangaroos of differing age and size eat relative to domestic stock? Implications for the arid rangelands. Pp 96 - 101 in the *Animals of Arid Australia: out on their own?* 2007, Edited by Chris Dickman, Daniel Lunney and Shelley Burgin. Royal Zoological Society of New South Wales, Mosman, NSW, Australia.

Davies, H. L. and Southey, I. N. (2001). Effects of grazing management and stocking rate on pasture production, ewe liveweight, ewe fertility and lamb growth on subterranean clover-based pasture in Western Australia. *Australian Journal of Experimental Agriculture* 41,161–168.

De Boer, W. F. and Prins, H. H. T. (1990). Large herbivores that strive mightily but eat and drink as friends. *Oecologia* 82, 264–274.

Dellow, D. and Hume, I. (1982). Studies on the nutrition of Macropodine marsupials. I. intake and digestion of lucerne hay and fresh grass, *Phalaris aquatica*. *Australian Journal of Zoology* 30, 391-98

Denny, M. J. (1980). *Red kangaroo arid zone studies: final report*. Unpublished Final Report to Australian National Parks and Wildlife Service, Sydney

Department of Agriculture and Food, Western Australia, (2006).*The grazing of cattle in the northern pastoral areas of Western Australia: best management practice guidelines*. Department of Agriculture and Food, Western Australia.

Department of Environment and Conservation, (2009). Fauna Notes. No. 29. Western grey kangaroo. Government of Western Australia, Perth.

Department of Environment and Conservation, (2018). Fauna Notes No 32: *Fencing and gates to reduce kangaroo damage.* Government of Western Australia, Perth.https://www.dpaw.wa.gov.au/images/documents/plants-animals/animals/kangaroos/32_fencing_kangaroos.pdf). [Accessed 14 August 2018]

Department of Environment and Energy, (2017). Kangaroo and wallaby population, quota and harvest statistics. Macropod quotas and harvest by State – 2016. Australian Government, Canberra.

Department of Environment and Energy, (2018). Kangaroo Statistics. https://www.environment.gov.au/system/files/pages/d3f58a89-4fdf-43ca-8763-bbfd6048c303/files/kangaroo-statistics-new.pdf [Accessed 2 August 2018]

Department of Environment and Heritage Protection (2013). *Overview of the Queensland macropod industry*. Queensland Government, Brisbane.

Department of Environment and Heritage Protection Queensland, (2016a). *2017 Quota Submissions for Commercially Harvested Macropods in Queensland*. Government of Queensland, Brisbane, Queensland.

Department of Environment and Heritage Protection Queensland, (2016b). *Feral Goat.* Government of Queensland, Brisbane, Queensland.

Department of Environment and Heritage Protection Queensland, (2017). *Commercially Harvested Macropods 2018–22*. Government of Queensland, Brisbane, Queensland.

Department of the Environment, Water, Heritage and the Arts, (2009). *Assessment of Australia's Terrestrial Biodiversity 2008,* Report prepared by the Biodiversity Assessment Working Group of the National Land and Water Resources Audit for the Australian Government, Canberra.

Department of Environment, Water and Natural Resources South Australia, (2016). *2017 Quota Report for Commercial Kangaroo Harvest in South Australia*. Report prepared by Natural Resources South Australian Arid Lands Department of Environment, Water and Natural Resources. Government of South Australia, Adelaide, SA.

Department of Environment, Water and Natural Resources, (2017). *NatureMaps.* https://data.environment.sa.gov.au/NatureMaps/Pages/default.aspx.

Department of Parks and Wildlife Western Australia, (2016). *2017 Commercial Kangaroo Harvest Quota Submission for Western Australia*. Government of Western Australia, Perth, WA.

Department of Primary Industries, (no date). *Feed cost calculator*. https://www.dpi.nsw.gov.au/animals-and-livestock/nutrition/costs-and-nutritive-value/feed-cost-calculator.

Department of Primary Industries and Regional Development, (2017a). *Lambing Planner.* Government of Western Australia, Perth, WA. https://itunes.apple.com/au/app/lambing-planner/id1254318668?mt=8.

Department of Primary Industries and Regional Development, (2017b). *Sheep Condition Scoring.* Government of Western Australia, Perth, WA. https://itunes.apple.com/au/app/sheep-condition-scoring/id825370276?mt=8.

Department of Primary Industries and Regional Development, (2017c). *Feed cost calculator*. https://www.agric.wa.gov.au/feeding-nutrition/feed-cost-calculator.

Department of Primary Industries and Regional Development. (2017d). *Supplementary feeding calculator for pregnant and lactating ewes*. https://www.agric.wa.gov.au/feeding-nutrition/supplementary-feeding-calculator-pregnant-and-lactating-ewes.

Department of Primary Industries and Regional Development, (2018). *Invasive species – State Barrier Fence Overview*. https://www.agric.wa.gov.au/invasive-species/state-barrier-fence-overview.

Department of Science, Information Technology and Innovation, (2017). T*he Long Paddock: Rainfall and Pasture Growth*. https://www.longpaddock.qld.gov.au/rainfallandpasturegrowth/index.php.

Descovich, K., Tribe, A., McDonald, I. and Phillips, C. (2016). The eastern grey kangaroo: current management and future directions. *Wildlife Research* 43, 576-589.

Díaz, S., S. Lavorel, S. U. E. McIntyre, V. Falczuk, F. Casanoves, D. G. Milchunas, C. Skarpe, G. Rusch, M. Sternberg, I. Noy-Meir, J. Landsberg, W. E. I. Zhang, H. Clark, and B. D. Campbell. 2007. Plant trait responses to grazing - a global synthesis. *Global Change Biology* 13, 313-341.

Digital Services NSW, (2017). *Drought Feed Calculator.* https://play.google.com/store/apps/details?id=au.gov.nsw.agriculture.droughtfeedcalculator&hl=en.

Donohue, R. J., Roderick, M. L., McVicar, T. R., and Farquhar, G. D. (2013). Impact of CO_2 fertilization on maximum foliage cover across the globe's warm, arid environments*. Geophysical Research Letters* 40, 3031-3035.

Dorrough, J., A. Yen, V. Turner, S. Clark, J. Crosthwaite, and J. Hirth. (2004). Livestock grazing management and biodiversity conservation in Australian temperate grassy landscapes *Crop and Pasture Science* 55, 279-295.

Dostálek, J., and T. Frantík. (2008). Dry grassland plant diversity conservation using low-intensity sheep and goat grazing management: case study in Prague (Czech Republic). *Biodiversity and Conservation* 17,1439-1454.

Downing, B. H. (1986). Goat and sheep grazing in shrub-infested semi-arid woodlands of New South Wales. *The Australian Rangeland Journal* 8, 140–150.

Drescher, M., Ignas, Heitkonig, M., Raats, J. and Prins, H. (2006). The role of grass stems as structural foraging deterrents and their effects on the foraging behaviour of cattle. *Applied Animal Behaviour Science* 101, 10–26.

Dudzinski, M. L, Lowe, W., Muller, W. J. and Low, B. S. (1982). Joint use of habitat by red kangaroos and shorthorn cattle in arid central Australia. *Australian Journal of Ecology* 7, 69-74.

Dumont, B., Rook, A. J., Coran C., and Röver K. U (2007). Effects of livestock breed and grazing intensity on biodiversity and production in grazing systems. 2. Diet selection *Grass and Forage Science*, 62, 159–171

du Toit, J. (2011). Coexisting with cattle. *Science* 333 (6050), 1710-1711

Edwards, G. (1989). The interaction between macropods and sheep: a review. Pages 795-803. In *Kangaroos, wallabies and rat-kangaroos*. Ed. By G. Grigg, P. Jarman and I. Hume. Surrey Beatty and Sons. New South Wales, Australia.

Edwards, G. P., Croft, D. B. and Dawson, T. J. (1996). Competition between red kangaroos (*Macropus rufus*) and sheep (*Ovis aries*) in the arid rangelands of Australia. *Australian Journal of Ecology* 21, 165-172.

Edwards, G. P., Dawson, T. J. and Croft, D. B. (1995). The dietary overlap between red kangaroos (*Macropus rufus*) and sheep (*Ovis aries*) in the arid rangelands of Australia. *Australian Journal of Ecology* 20, 324-334.

Eldridge, D. J., Poore A. G., Ruiz-Colmenero M., Letnic M., and Soliveres S. (2016). Ecosystem structure, function and composition in rangelands are negatively affected by livestock grazing. *Ecological Applications* 26, 1273-1283.

Ellis, B. (1976). Diet selection in two native and two introduced herbivores in an Australian rangeland region. *The Australian Rangeland Journal* 1, 78-78.

Ellis, B., Russell, E., Dawson, T. and Harrop, C. (1977). Seasonal changes in diet preferences of free-ranging red kangaroos, euros and sheep in Western New South Wales. *Australian Wildlife Research* 4, 127–144.

Evans, M. C. (2018). Effective incentives for reforestation: lessons from Australia's carbon farming policies. Environmental Sustainability 32, 38-45

Fairport Farm Software, (2017). *PocketPAM2*. http://www.fairport.com.au/en/pam-process-analyse-manage/pocketpam2-data-capture-at-the-source.

FarmMap4D, (2017). *FarmMap4D Spatial Hub*. http://www.farmmap4d.com.au/.

Farmware. (2017). *Farmware*. https://www.farmware.net/.

Fensham, R. J. and Fairfax, R. J. (2008). Water-remoteness for grazing relief in Australian arid-lands. *Biological Conservation* 141, 1447-1460.

Fensham, R., R. Fairfax, and J. Dwyer (2010). Vegetation responses to the first 20 years of cattle grazing in an Australian desert. *Ecology* 9, 681-692.

Fensham, R. J., J. L. Silcock, and J. Firn (2014). Managed livestock grazing is compatible with the maintenance of plant diversity in semi-desert grasslands. *Ecological Applications* 24, 503–517.

FeralScan, (2017a). *Camel Scan*. https://www.pestsmart.org.au/pest-animal-species/camel/.

FeralScan, (2017b). *Feral Goat Scan*. https://www.pestsmart.org.au/pest-animal-species/feral-goat/.

FeralScan, (2017c). *Rabbit Scan*. https://www.pestsmart.org.au/pest-animal-species/european-rabbit/.

FeralScan, (2017d). *Wild Dog Scan*. https://www.pestsmart.org.au/pest-animal-species/wild-dog/.

FeralScan, (2017e) Wild Pig Scan. https://www.pestsmart.org.au/pest-animal-species/feral-pig/.

Fisher, A., Hunt, L., James, C., Landsberg, J., Phelps, D., Smyth, A., Watson, I (2004). *Review of total grazing pressure management issues and priorities for biodiversity conservation in rangelands: A resource to aid NRM planning.* Desert Knowledge CRC Project Report No. 3 (August 2004); Desert Knowledge CRC and Tropical Savannas Management CRC, Alice Springs.

Fleming, P. J. S., Allen, B. L., and Ballard, G. (2012a). Seven considerations about dingoes as biodiversity engineers: the socioecological niches of dogs in Australia. *Australian Mammalogy* 34, 119–131.

Fleming P. J. S., Allen, B. L., Ballard, G (2012b). Cautionary considerations for positive dingo management: a response to the Johnson and Ritchie critique of Fleming *et al*. (2012). *Australian Mammalogy* 35, 15 -22.

Foot, J. Z. and Romberg, B. (1965). The utilisation of roughage by sheep and the red kangaroo, *Macropus rufus* (Desmarest). *Australian Journal of Agricultural Research* 16, 429-435.

Forbes, D. K. and Tribe, D. E. (1970). The utilization of roughages by sheep and kangaroos. *Australian Journal of Zoology* 18, 247-25.

Franco, B. (2000). *The degree of dietary overlap between sheep, goats, red kangaroos, grey kangaroos and wallaroos in the south west Queensland mulgalands*. University of Queensland Study Project Report. Unpublished.

Freer, M., Dove, H. and Nolan, J. V. (2007). Water intake. In: *Nutrient requirements of domesticated ruminants* (ed. CSIRO), pp. 187–194. CSIRO Publishing, Collingwood, Australia.

Freudenberger, D. and Hacker, R.B. (1997). The effect of temporary closure of watering points on grazing intensity of red and grey kangaroos with related observations on feral goats. *Rangeland Journal* 19, 157-165.

Freudenberger, D.O., Hume, I.D. (1992). Ingestive and Digestive Responses to Dietary Fiber and Nitrogen by 2 Macropod Marsupials (*Macropus robustus erubescens* and *M. robustus robustus*) and a Ruminant (*Capra hircus*). *Australian Journal of Zoology* 40, 181-194.

Freudenberger, D., Wilson, A. and Palmer, R. (1999). The effects of perennial grasses, stocking rate and rainfall on sheep production in a semi-arid woodland of eastern Australia. *The Rangeland Journal* 21, 199 – 219.

Freudenberger, D., K. Hodgkinson, and J. Noble. (1997). Causes and consequences oflandscape dysfunction in rangelands. Pages 63-77 In J. Ludwig, D. Tongway, D. Freudenberger, J. Nobel, and K. Hodgkinson, editors. Landscape ecology, function and management: principles from Australia's rangelands, CSIRO publishing, Canberra, Australia.

Friedel, M. H., Laycock W. A. and Bastin G. N (2000). Assessing rangeland condition and trend. In: L.'t Mannetje and R.M. Jones (editors) *Field and Laboratory Methods for Grassland and Animal Production Research*. CABI, Wallingford, UK. pp. 227-262.

Friedel, M. H., A. D. Sparrow, J. E. Kinloch, and D. J. Tongway. 2003. Degradation and recovery processes in arid grazing lands of central Australia. Part 2: vegetation. Journal of Arid Environments 55, 327-348.

Frye, G. G., Connelly, J. W., Musil, D. D., Forbey, J.S. (2013). Phytochemistry predicts habitat selection by an avian herbivore at multiple spatial scales. *Ecology* 94, 308-314.

Fukuda, Y., McCallum, H. I., Grigg, G.C., Pople, A. R. (2009). Fencing artificial waterpoints failed to influence density and distribution of red kangaroos (*Macropus rufus*). *Wildlife Research* 36, 457-465.

Future Beef, (2017). *Stocktake Plus*. http://www.stocktakeplus.com.au/.

Ganskopp, D. (2001). Manipulating cattle distribution with salt and water in large arid-land pastures: a GPS/GIS assessment. *Applied Animal Behaviour Science* 73, 251-262.

Ganskopp, D. C., Bohnert, D. W. (2009). Landscape nutritional patterns and cattle distribution in rangeland pastures. *Applied Animal Behaviour Science* 116, 110-119.

Gascoyne Catchments Group, (2017). *Monitoring App*. http://www.ibc.com.au/gascoyne/installer.

Gibson, L. (1994). *The effect of artificial water exclusion on water usage, watering behaviour and movements from water of eastern grey kangaroos (*Macropus giganteus*) and red kangaroos (*Macropus rufus*).* Draft internal report to Queensland Department of Environment and Heritage.

Gibson, L. (1995). Concentration of eastern grey kangaroos (*Macropus giganteus*), red kangaroos (*Macropus rufus*) and wallaroos (*Macropus robustus*) in the vicinity of artificial waters and differences in artificial water usage. In: *Ecological Research and Management in the Mulgalands*. Ed. M. J. Page and T. S. Beutel. Conference Proceedings, pp. 75 - 84. Gatton, Qld: University of Queensland, Gatton College.

Gibson, L. M. and Young, M. D. (1987). *Kangaroos: Counting the Cost. The Economic Effects of Kangaroos and Kangaroo Culling on Agricultural Production*. CSIRO Division of Wildlife and Rangelands Research.

Ginane, C., Baumont, R., Duncan, A. J. (2009). Diet learning through post-ingestive consequences in sheep: the case of starch and casein variously combined in the same foods. *Animal* 3, 135-142.

Ginane, C., Bonnet, M., Baumont, R., Revell, D. K. (2015). Feeding behaviour in ruminants: a consequence of interactions between a reward system and the regulation of metabolic homeostasis. *Animal Production Science* 55, 247-260.

Golubiewski, N. E. and Hall-Beyer M. (2007). Woody Encroachment in the southwestern United States. In: *Encyclopaedia of Earth.* Eds Cutler, J. Cleveland (Washington DC: Environmental information Coalition, National Council for Science & the Environment).

Gordon, I. J. (1988). Facilitation of red deer grazing by cattle and its impact on red deer performance. *Journal of Applied Ecology* 25, 1-10.

Graetz, R. D. and Wilson, A. D. (1980). Comparison of the diets of sheep and cattle grazing a semi-arid Chenopod shrubland. *The Australian Rangeland Journal* 2, 67-75.

Grains Research and Development Corporation, (2013a). *Insect ID: The Ute Guide*. https://play.google.com/store/apps/details?id=au.com.grdc.ainsects.

Grains Research and Development Corporation, (2013b). *Weed ID: The Ute Guide*. https://play.google.com/store/apps/details?id=au.com.grdc.aweeds.

Guerschman, J. P., Oyarzábal, M., Malthus, T. J., McVicar, T. R., Byrne, G., Randall L. A., and Stewart, J. B. (2012). Evaluation of the MODIS based vegetation fractional cover product. (CSIRO Canberra)

Griffiths, M and Barker, R. D. (1966). The plants eaten by sheep and by Kangaroos grazing together in a paddock in South-western Queensland. *CSIRO Wildlife Research* 11, 145 – 167.

Griffiths, M., Barker, M. and Maclean, L. (1974). Further Observations on the Plants Eaten by Kangaroos and Sheep Grazing Together in a Paddock in South-Western Queensland. *Australian Wildlife Research* 1, 27–43.

Gutteridge, M. C., Stone, G. S., Hall, W. B., Hanna, A .L. and Kingston, J. V. (2001). National Rangelands Theme Project 1.5: Intensity of Land Use National Land and Water Resources Audit July 2001.

Hacker, R. (2011). Managing total grazing pressure in the rangelands – an overview. *National Total Grazing Pressure Workshop – Adelaide*, 16 February 2011.

Hacker, R. B., Hodgkinson, K. C., Melville, G. J., Bean, J. and Clipperton, S. P. (2006). Death model for tussock perennial grasses: thresholds for grazing-induced mortality of mulga Mitchell grass (*Thyridolepis mitchelliana*) *The Rangeland Journal* 28: 105-114.

Hacker, R. B., Jessop, P. J., Smith, W. J. and Melville, G. J. (2010). A ground cover-based incentive approach to enhancing resilience in rangelands viewed as complex adaptive systems *The Rangeland Journal* 32, 283-291.

Hacker, R. and Richmond, G. (1994). Simulated evaluation of grazing management systems for arid chenopod rangelands in Western Australia. *Agricultural Systems* 4, 397-418.

Hall, T. J., J. G. McIvor, D. J. Reid, P. Jones, N. D. MacLeod, C. K. McDonald, and D. R. Smith. (2014). A comparison of stocking methods for beef production in northern Australia: pasture and soil surface condition responses. *The Rangeland Journal* 36,161-174.

Harrington, G. N. (1986a). Herbivore diet in a semi-arid *Eucalyptus populnea* woodland. 1. Merino sheep. *Australian Journal of Experimental Agriculture* 26, 413-421.

Harrington, G. N. (1986b). Herbivore diet in a semi-arid *Eucalyptus populnea* woodland. 2. Feral goats. *Australian Journal of Experimental Agriculture* 26, 423-429.

Hawkins, H (2017). A global assessment of Holistic Planned Grazing™ compared with season-long, continuous grazing: meta-analysis findings. *African Journal of Range & Forage Science* 34, 65-75.

Hendricks, H. H, Bond, W. J, Midgley, J. J and Novellie, P. A (2005). Plant species richness and composition a long livestock grazing intensity gradients in a Namaqualand (South Africa) protected areas. *Plant Ecology* 176, 19-33.

Hendricksen, R., Poppi, D. and Minson, D. (1981). The voluntary intake, digestibility and retention time by cattle and sheep of stem and leaf fractions of a tropical legume (*Lablab purpureus*). *Australian Journal of Agricultural Research* 32, 389-98.

Henzell, R. P. (1989). Proclaimed animal research in South Australia – cost–benefits, future directions and related issues. Unpublished discussion paper. South Australia Animal and Plant Control Commission.

Hidding, B., Nolet, B., Boer, T. Pde Vries, P. and Klaassen, M. (2009). Compensatory growth in an aquatic plant mediates exploitative competition between seasonally tied herbivores. *Ecology* 90, 1891-1899.

Hill, G. (1982). Seasonal movement patterns of the eastern grey kangaroo in southern Queensland. *Australian Wildlife Research* 9, 373-87.

Hobbs, N. T., Baker, D. L., Bear, G. D. and Bowden, D. C. (1996). Ungulate grazing in sagebrush grassland: mechanisms of resource competition. *Ecological Applications* 6, 200-217.

Hodgkinson, K. C., Bass Becking, H. G. (1977). Effect of defoliation on root growth of some arid zone perennial plants. *Australian Journal of Agricultural Research* 29, 31-42.

Hodgkinson K. C., Harrington G. N., Griffin G. F., Noble J. C. and Young M. D. (1984). Management of Vegetation with Fire. In: *Management of Australia's Rangelands* (eds G. N. Harrington, A. D. Wilson and M. D. Young) pp. 141-56. CSIRO, Melbourne.

Hodgkinson, K. C and Muller, W. L. (2005). Death model for tussock perennial grasses: a rainfall threshold for survival and evidence for landscape control of death in drought *The Rangeland Journal* 27, 105-115.

Hoist, P. J. (1981). Age, hair colour, liveweight and fertility of two samples of Australian feral goat, *Capra hircus*. *Australian Wildlife Research* 8, 549-553.

Holm, A. (1994). *Boolathana Grazing Study, Carnarvon WA, 1983-1993*. Department of Agriculture, Western Australia.

Horizon Agriculture (n.d.-a). *GrassGro 3*. NSW, Horizon Agriculture.

Horizon Agriculture (n.d.-b). *GrazFeed*. NSW, Horizon Agriculture.

Howard, W., Wagnon, K. and Bentley, J. (1959). Competition between ground squirrels and cattle for range forage. *Journal of Range management* 12, 110-115.

Hume, I. D. (1974). Nitrogen and sulphur retention and fibre digestion by euros, red kangaroos and sheep. *Australian Journal of Zoology* 22, 13-23.

Hume, I. D. (1984). Principal features of digestion in kangaroos. *Proceedings of the Nutrition Society of Australia* 9, 76-81.

Illius, A. W., O'Connor, T. G. (1999). On the relevance of nonequilibrium concepts to arid and semiarid grazing systems. *Ecological Applications* 9, 798-813.

James, C. D., Landsberg, J., Morton, S.R. (1999). Provision of watering points in the Australian arid zone: a review of effects on biota. *Journal of Arid Environments* 41, 87-121.

Janzen, H. H. (2006). The soil carbon dilemma: shall we hoard it or use it? *Soil Biology and Biochemistry* 38, 419-424.

Johnson, C., and Ritchie, E. (2013). The dingo and biodiversity conservation: response to Fleming *et al*. (2012). *Australian Mammalogy* 35, 8-14.

Jonzén, N., Pople, A. R., Grigg, G. C., Possingham, H. P. (2005). Of sheep and rain: large-scale population dynamics of the red kangaroo. *Journal of Animal Ecology* 74, 22-30.

Kahn, L. P, Earl, J. M, Nicholls M. (2010). Herbage mass thresholds rather than plant phenology are a most useful cue for grazing management decisions in the mid-north of South Australia. *The Rangeland Journal* 32, 379–388.

Kempton, T. J. (1972). The efficiency of utilisation of a roughage diet and the rate of passage of digesta in the grey kangaroo, *Macropus giganteus* (Shaw) and the Merino sheep. Unpublished Thesis. University of New England, Armidale, NSW.

Kempton, T. J., Murray, R. M. and Leng, R. A. (1976). Methane production and digestibility measurements in the grey kangaroo and sheep. *Australian Journal of Biological Sciences* 29, 209-214.

Kirkpatrick, T. H. (1965). Studies of Macropodidae in Queensland. 1. Food preferences of the grey kangaroo (*Macropus major* Shaw). *Queensland Journal of Agricultural and Animal Sciences* 22, 89-93.

Kondinin Group, (2016). Research Report No 288; *Exclusion fencing – fighting ferals.* https://www.wool.com/globalassets/start/on-farm-research-and-development/sheep-health-welfare-and-productivity/pest-animals/wild-dogs-foxes-and-pigs/kondinin-exclusionfencing-jan2016.pd [Accessed November 2017).

Land-Potential Knowledge System, (2017). *LandPKS*. https://play.google.com/store/apps/details?id=org.landpotential.lpks.landcover.

Landsberg, J. and Stol, J. (1996). Spatial distribution of sheep, feral goats and kangaroos in woody rangeland paddocks. *Rangeland Journal* 18, 270-91.

Landsberg, J., C. D. James, S. R. Morton, W. J. Müller, and J. Stol. (2003). Abundance and composition of plant species along grazing gradients in Australian rangelands. *Journal of Applied Ecology* 40, 1008-1024.

Lange, R. T. (1969). The piosphere: sheep track and dung patterns. *Journal of Range Management* 22, 396-400.

Laporte, I., Muhly, T.B., Pitt, J. A., Alexander, M., Musiani, M. (2010). Effects of Wolves on Elk and Cattle Behaviors: Implications for Livestock Production and Wolf Conservation (Cattle & Elk Respond to Wolves). *PLoS ONE* 5, e11954.

Laredo, M. and Minson, D. (1973). The voluntary intake, digestibility, and retention time by sheep of leaf and stem fractions of five grasses. *Australia Journal of Agricultural Research* 24, 875-88.

Lavery, T. H., Pople, A. R. and McCallum, H. I. (2018). Going the distance on kangaroos and water: A review and test of artificial water point closures in Australia. *Journal of Arid Environments* 151, 31-40

Larreguy, C., Carrera, A. L. and Bertiller, M. B (2017). Reductions of plant cover induced by sheep grazing change above-below ground partition of chemistry of organic C stocks in arid rangelands of Patagonia Monte, Argentina. *Journal of Environmental Management* 199, 139-147.

Lechner-Doll, M., Rutagwenda, T., Schwartz, H., Schultka, W. and Engelhardt, W. (1990). Seasonal changes of ingesta mean retention time and forestomach fluid volume in indigenous camels, cattle, sheep and goats grazing a thornbush savannah pasture in Kenya. *The Journal of Agricultural Science* 115, 409-420.

Leigh, J. H., and Mulham, W. E. (1966a). Selection of diet by sheep grazing semi-arid pastures on the Riverine Plain. 1. A bladder saltbush (*Atriplex vesicaria*)-cotton bush (*Kochia aphylla*) community. *Australian Journal of Experimental Agriculture and Animal Husbandry* 6, 460-7.

Leigh, J. H., and Mulham, W. E. (1966b). Selection of diet by sheep grazing semi-arid pastures on the Riverine Plain. 2. A cotton bush (*Kochia aphylla*)-grassland (*Stipa variabilis*-*Danthonia caespitosa*) community. *Australian Journal of Experimental Agriculture and Animal Husbandry* 6, 468-74.

Leigh, J. H., and Mulham, W. E. (1967). Selection of diet by sheep grazing semi-arid pastures on the Riverine Plain. 3. A bladder salt bush (*Atriplex vesicaria*)-pigface (*Disphyma australe*) community. *Australian Journal of Experimental Agriculture and Animal Husbandry* 7, 421-5.

Leigh, J., Wilson, A. and Mulham, W. E. (1968). A study of Merino sheep grazing a cotton-bush (*Kochia aphylla*)–grassland (*Stipa variabilis–Danthonia caespitosa*) community on the riverine plain. *Australian Journal of Agricultural Research* 19, 947-961.

Leigo, S., G. Brennan, T. Beutel, A. Gray, D. Phelps, T. Driver and M. Trotter (2012). *Overview of technology products for the beef industry of remote Australia*. CRC-REP Working Paper CW009. Alice Springs Ninti One Limited.

Letnic, M., and Koch, F. (2010). Are dingoes a trophic regulator in arid Australia? A comparison of mammal communities on either side of the dingo fence. *Austral Ecology* 35, 167-175.

Letnic, M., Laffan, S., Greenville, A., Russell, B., Mitchell, B., Fleming, P. (2015). Artificial watering points are focal points for activity by an invasive herbivore but not native herbivores in conservation reserves in arid Australia. *Biodiversity & Conservation* 24, 1-16.

Lewis, T. O. M., N. Reid, P. J. Clarke, and R. D. B. Whalley. (2009). Resilience of a high-conservation-value, semi-arid grassland on fertile clay soils to burning, mowing and ploughing. *Austral Ecology* 35, 464-481.

Li, W, Huang H. Z, Zhang, Z. N and Wu, G. L (2011). Effects of grazing on the soil properties and C and N storage in relation to biomass allocation in an alpine meadow. *Journal of Soil Science and Plant Nutrition* 11, 27-3.

Loremer, M. S. (1978). Forage selection studies. 1. Botanical composition of forage selected by sheep grazing *Astrebla* spp. pasture in north-west Queensland. *Tropical Grasslands*, 12, 97-108.

Low, B., Birk, E., Lendon, D. and Low, W. (1973). Community utilization by cattle and kangaroos in mulga near Alice Springs, N.T. *Tropical Grasslands* 7, 149-156.

Loza, H. J., Grant, W. E., Stuth, J. W., Forbes, T.D.A. (1992). Physiologically based landscape use model for large herbivores. *Ecological Modelling* 61, 227-252.

Lunt, I. D., Eldridge, D. L., Morgan, J. W. and Witt, G. B. (2007a). A framework to predict the effects of livestock grazing and grazing exclusion on conservation values in natural ecosystems. *Australian Journal of Botany* 55, 401-415.

Lunt, I. D., A. M. Y. Jansen, D. L. Binns, and S. A. Kenny (2007b). Long-term effects of exclusion of grazing stock on degraded herbaceous plant communities in a riparian *Eucalyptus camaldulensis* forest in south-eastern Australia. *Austral Ecology* 32, 937-949.

Madhusudan, M. D. (2004). Recovery of wild large herbivores following livestock decline in a tropical Indian wildlife reserve. *Journal of Applied Ecology* 41, 858–869.

Maia Technology, (2017). *Maiagrazing*. http://maiatechnology.com.au/product/.

Mayberry, D., Bartlett, H., Moss, J., Wiedemann, S. and Herrero, M. (2018). *Greenhouse Gas mitigation potential of the Australian red meat production and processing sectors*. Final Report B.CCH.7714. Meat and Livestock Australia Limited, North Sydney.

McCalla, G. R, Blackburn, W. H, Merril, I. L. B. (1984). Effects of livestock grazing on infiltration rates, Edwards Plateau of Texas. *Journal of Range Management* 37, 265–269.

McDonald, S. (2017). Implications of grazing management systems incorporating planned rest for biodiversity conservation and landscape function in rangelands PhD, University of New England

McDonald, S. E., N. Reid, R. Smith, C. M. Waters, J. T. Hunter, and R. Rader. (2017b). Grazing management and biodiversity conservation in semi-arid rangelands.Unpublished.

McDowell, L.R. (1985). Nutrition of Grazing Ruminants in Warm Climates. Academic Press, New York.

McIntosh, D. L. (1966). The digestibility of two roughages and the rates of passages of their residues by the Red Kangaroo, *Megaleia rufa* (Desmarest), and the merino sheep. *CSIRO Wildlife Research* 11, 125 – 135.

McKeon, G., Hall, W., Henry, B., Stone, G. and Watson, I. (2004). Pasture Degradation and Recovery In: *Australia's Rangelands*. Natural Resources Sciences, Indooroopilly, Queensland.

McMeniman, N. P., Beale, I. F. and Murphy, G. M. (1986). Nutritional evaluation of south-west Queensland pastures. I. The botanical and nutrient content of diets selected by sheep grazing on Mitchell grass and Mulga/grassland associations. *Australian Journal of Agricultural Research* 37, 289-302.

McNaughton, S. J. (1976). Serengeti migratory wildebeest: facilitation of energy flow by grazing. *Science* 191, 92-94.

McSherry, M. E, Ritchie, M. E (2013) Effects of grazing on grassland soil carbon, a global review. *Global Change Biology* 19, 1347-1357.

Measurement Engineering Australia, (2017). MEA - *Free Weather Data*. http://mea.com.au/soil-plants-climate/weather/free-weather-data.

Meat and Livestock Australia,. (2013). *Feed demand calculator*. https://www.mla.com.au/extension-training-and-tools/tools-calculators/feed-demand-calculator.

Meat and Livestock Australia, (2015). *MLA Market Information*. https://play.google.com/store/apps/details?id=com.mla.mobile.

Meat and Livestock Australia. (2016). *Market Reports and Prices*. https://www.mla.com.au/prices-markets/market-reports-prices/.

Meat and Livestock Australia, (2017a). *Sheep numbers as at June 2016. Natural Resource Management Regions.* North Sydney, NSW

Meat and Livestock Australia, (2017b). *Cattle numbers as at June 2016. Natural Resource Management Regions.* North Sydney, NSW

Meat & Livestock Australia, (2017c). *Fact sheet 5, infrastructure for goats* https://www.mla.com.au/globalassets/mla-corporate/extensions-training-and-tools/documents/fs05-infrastructure-for-goats-final.pdf [Accessed November 2017].

Meat and Livestock Australia, (2017c). *Data-led innovation drives international award win*. https://www.mla.com.au/news-and-events/industry-news/data-led-innovation-drives-international-award-win/.

Meat and Livestock Australia, (2017d). *MLA Rainfall to Pasture Growth Outlook Tool*. http://rainfall.mla.com.au/Station/AllLocations.

Mitchell, A. A. and Wilcox D. G., with photographs by E. Laidlaw (2014). *Arid Shrubland Plants of Western Australia.* Nedlands, Western Australia UWA Publishing with the Department of Agriculture, Western Australia, 478 pp.

Milson, J. (2002). *Pasture Plants of North West Queensland*. Queensland Department of Primary Industries, Brisbane.

Milson, J. (2000). *Trees and Shrubs of North West Queensland*. Queensland Department of Primary Industries, Brisbane.

Meuret, M. and Provenza, F. D. (2015). When art and science Meet: Integrating knowledge of French herders with science of foraging behavior. *Rangeland Ecology and Management* 68, 1-17.

Mishra, C., van Wieren, S., Ketner, P., Heitkönig, I. and Prins, H. (2004). Competition between domestic livestock and wild bharal *Pseudois nayaur* in the Indian Trans-Himalaya. *Journal of Applied Ecology* 41, 344-354.

Mofidi, M. M. Rashtbari, H. Abbaspour, A. Ebadi, E. Sheidai, and J. Motamedi. (2012). Impact of grazing on chemical, physical and biological properties of soils in the mountain rangelands of Sahand, Iran. *The Rangeland Journal* 34, 297-303.

Morrant, D. S., Wurster, C. M., Johnson, C. N., Butler, J. R. A. and Congdon, B. C. (2017). Prey use by dingoes in a contested landscape: Ecosystem service provider or biodiversity threat? *Ecology and Evolution*. 7, 8927-8935.

Moseby, K. E., Neilly, H., Read, J. L., and Crisp, H. A. (2012). Interactions between a top order predator and exotic mesopredators in the Australian rangelands. *International Journal of Ecology* 2012.15 pages doi:10.1155/2012/250352

Moss, G. L. and Croft, D. B. (1999). Body condition of the red kangaroo (*Macropus rufus*) in arid Australia: The effect of environmental condition, sex and reproduction. *Australian Journal of Ecology* 24, 97-109.

Moss, J., Sinden, J., and Stayner, R. (2012). Estimating the cost of protecting groundcover on privately managed properties in the Australian rangelands: the case of the West 2000 Plus Enterprise-Based Conservation scheme. *The Rangeland Journal* 34, 75-87.

Muir, J., Schmidt, M., Tindal, I. D., Trevithick, R., Scarth, P and Stewart JB (2011). Field measurement of fractional ground cover: a technical handbook supporting ground cover monitoring for Australia. ABARES. http://adl.brs.gov.au/data/warehouse/pe_hbgcm9abll07701/HndbkGrndCovMontring2011_1.0.0_LR.pdf

Munn, A. and Dawson, T. (2006). Forage fibre digestion, rates of feed passage and gut fill in juvenile and adult red kangaroos *Macropus rufus* Desmarest: why body size matters. *The Journal of Experimental Biology* 209, 1535-1547.

Munn, A., Dawson, T., McLeod, S., Dennis, T., Maloney, S. (2013). Energy, water and space use by free-living red kangaroos (*Macropus rufus*) and domestic sheep (*Ovis aries*) in an Australian rangeland. *Journal of Comparative Physiology* B 183, 843-858.

Munn, A. J., Dawson, T. J., McLeod, S. R. (2010). Feeding biology of two functionally different foregue-fermenting mammals, the marsupial red kangaroo and the ruminant sheep: how physiological ecology can inform land management. *Journal of Zoology* 282, 226-237.

Munn, A. J., Dawson, T. J., McLeod, S. R. (2011). To: Feeding biology of two functionally different foregut-fermenting mammals, the marsupial red kangaroo (*Macropus rufus*) and the ruminant sheep (*Ovis aries*): how physiological ecology can inform land management. *Journal of Zoology* 283, 298-298.

Munn, A. J., Dawson, T. J., McLeod, S. R., Croft, D. B., Thompson, M. B., Dickman, C. R. (2009). Field metabolic rate and water turnover of red kangaroos and sheep in an arid rangeland: an empirically derived dry-sheep-equivalent for kangaroos. *Australian Journal of Zoology* 57, 23-28.

Munn, A., Dawson, T., McLeod, S., Dennis, T. and Maloney, S. (2013). Energy, water and space use by free-living red kangaroos *Macropus rufus* and domestic sheep *Ovis aries* in an Australian rangeland. *Journal of Comparative Physiology B* 183, 843-858.

Munn, A. J., Kalkman, L., Skeers, P., Roberts, J. A., Bailey, J. & Dawson, T. J. (2016). Field metabolic rate, movement distance, and grazing pressures by western grey kangaroos (*Macropus fuliginosus melanops*) and Merino sheep (*Ovis aries*) in semi-arid Australia. *Mammalian Biology* 81, 423-430.

Munn, A. J., Skeers, P., Kalkman, L., McLeod, S. R., Dawson, T. J. (2014). Water use and feeding patterns of the marsupial western grey kangaroo (*Macropus fuliginosus melanops*) grazing at the edge of its range in arid Australia, as compared with the dominant local livestock, the Merino sheep (*Ovis aries*). *Mammalian Biology* 79, 1-8.

Muñoz-Robles, C., N. Reid, M. Tighe, S. V. Briggs, and B. Wilson. (2011). Soil hydrological and erosional responses in patches and inter-patches in vegetation states in semi-arid Australia. Geoderma 160,524-534.

Namoi Catchment Management Authority. (2017). *Ground Cover.* https://itunes.apple.com/au/app/ground-cover/id539800027?mt=8.

Newsome, A. (1965). The distribution of red kangaroos, *Megaleia rufa (Desmarest*), about sources of persistent food and water in central Australia. *Australian Journal of Zoology* 13, 289-300.

Newsome, A. (1965a). The abundance of red kangaroos, *Megaleia rufa* (desmarest), in central Australia. *Australian Journal of Zoology* 13, 269-287.

Newsome, A. (1965b). The distribution of red kangaroos, *Megaleia rufa* (desmarest), about sources of persistent food and water in central Australia. *Australian Journal of Zoology* 13, 289-299.

Newsome, A. E. (1971). Competition between wildlife and domestic livestock. *Australian Veterinary Journal* 47, 577-586.

Newsome, A. E. (1980). Differences in the diets of male and female red kangaroos in central Australia. *African Journal of Ecology* 18, 27–31.

Newsome, T. M., Ballard, G.-A., Crowther, M. S., Dellinger, J. A., Fleming, P. J. S., Glen, A. S., Greenville, A. C., Johnson, C. N., Letnic, M., Moseb,y K. E., Nimmo, D. G., Nelson, M. P., Read, J. L., Ripple, W. J., Ritchie, E. G., Shores, C. R., Wallach, A. D., Wirsing, A. J. & Dickman, C. R. (2015). Resolving the value of the dingo in ecological restoration. *Restoration Ecology* 23, 201-208.

Noble, I. R. (1975). *Computer simulations of sheep grazing in the arid zone*. Unpublished PhD Thesis. University of Adelaide.

Norbury, G. L. and Norbury, D. C. (1993). The distribution of red kangaroos in relation to range regeneration. *The Rangeland Journal* 15, 3-11.

Norton, B. (1998) The application of grazing management to increase sustainable livestock production. *Animal production in Australia* 22,15-26.

Novelly, P.E., I. W. Watson, P. W. E. Thomas and N. J. Duckett (2008). The Western Australian Rangeland Monitoring System (WARMS) – operating a regional scale monitoring system. *The Rangeland Journal* 30, 271-281

O'Connor, J. (2016). *Australian goat industry summary 2016*. Meat & Livestock Australia Ltd April 2016, North Sydney, NSW.

Odadi, W. O., Karachi, M. K., Abdulrazak, S. A. and Young, T. P. (2011). African wild ungulates compete with or facilitate cattle depending on season. *Science* 333 (6050), 1753-1755.

Office of Environment and Heritage, (2017). *NSW Commercial Kangaroo Harvest Management Plan 2017. Quota Report*. Government of NSW, Sydney, NSW.

Olsen, P. and Low, T. (2006*). Situation Analysis Report. Update on Current State of Scientific Knowledge on Kangaroos in the Environment, Including Ecological and Economic Impact and Effect of Culling*. Prepared for the Kangaroo Management Advisory Panel March 2006, Australian Government, Canberra, ACT.

Oñatibia, G. R., and M. R. Aguiar. (2016). Continuous moderate grazing management promotes biomass production in Patagonian arid rangelands. *Journal of Arid Environments* 125,73-79.

O'Reagain, P., Bushell, J., Holloway, C. and Reid, A. (2009). Managing for rainfall variability: effect of grazing strategy on cattle production in a dry tropical savanna. *Animal Production Science* 49, 85-99.

O'Reagain, P., and Turner J. (1992). An evaluation of the empirical basis for grazing management recommendations for rangelands of southern Africa. *Journal of the Grassland Society of Southern Africa* 9, 38-49.

Orgill, S. E., C. M. Waters, G. Melville, I. Toole, Y. Alemseged, and W. Smith. (2017).Sensitivity of soil organic carbon to grazing management in the semi-arid rangelands of south-eastern Australia. *The Rangeland Journal* 39,153-167.

Pain, S.J. and Revell D.K. (2007) Natural odorants can influence the preference for lucerne hay exhibited by horses. *Recent Advances in Animal Nutrition in Australia.* 16, 27-33.

Parkes, J., Henzell, R. and Pickles, G. (1996). *Managing Vertebrate Pests: Feral Goats*. Australian Government Publishing Service, Canberra.

Parsons, M.,H. and Blumstein, D.,T. (2010). Familiarity Breeds Contempt: Kangaroos Persistently Avoid Areas with Experimentally Deployed Dingo Scents (Kangaroo Response to Dingo). *PLoS ONE* 5, e10403.

Parsons, M.,H., Lamont, B.,B., Davies, S.,J.J.F., Kovacs, B.,R. (2006). How energy and co-available foods affect forage selection by the western grey kangaroo. *Animal Behavior* 71, 765-772.

Pastoral Lands Board of Western Australia, (undated-a). *Method for rangeland condition monitoring: Shrubland.* Government of Western Australia, Perth.

Pastoral Lands Board of Western Australia (undated-b). *Method for rangeland condition monitoring: Grassland*. Government of Western Australia, Perth.

Peco, B., Sánchez, A.M. and Azcárate, F.F (2006). Abandonment in grazing systems: Consequences for vegetation and soil. *Agriculture, Ecosystems and Environment* 113, 284-294.

Perry, L. A. (2016). *Seasonal composition of tropical C4 grasses, and its influence on rumen prokaryotic diversity in relation to methane production from beef cattle in the northern Australian rangelands.* Unpublished PhD thesis, University of Queensland, St Lucia, Brisbane, Queensland.

Pianka, E. R. (1981). Competition and niche theory. *Theoretical Ecology; Principles and Applications* 8, 167-196.

Pinay, G., Paruelo, J.M., Jobaggy, E.G., Jaskson, R.B., Oesterheld, M. (2007). Impact of atmospheric CO_2 and plan life forms on soil microbial activities. *Soil Biology and Biochemistry* 39, 33-42.

Piňeiro, G., Paruelo, J.M., Oesterheld, M., Jobbágy, E.G., (2010). Pathways for grazing effects on soil organic carbon and nitrogen. Rangeland Ecology and Management 63, 109-119.

Pople, A. and Froese, J. (2012*). Distribution, abundance and harvesting of feral goats in the Australian rangelands 1984-2011*. Final report to the ACRIS Management Committee February 2012. Invasive Plants & Animals Science Biosecurity Queensland. Department of Employment, Economic Development & Innovation. Brisbane, Australia.

Pople, A. and Grigg, G. (1999). *Commercial harvesting of Kangaroos in Australia. Department of Zoology*, The University of Queensland. For Environment Australia, August 1999. Chapter 7: Kangaroos as pests, kangaroos as a resource.

Pople, A. R. and McLeod, S. R. (2000). Kangaroo management and the sustainable use of rangelands. In: P. Hale, A. Petrie, D. Moloney, and P. Sattler (Eds.). Management for Sustainable Ecosystems. Centre for Conservation Biology, University of Queensland, St Lucia, Brisbane, Queensland.

Pople, A, Phinn, S. Menke, N., Grigg, G., Possingham, H. and Mcalpine, C. (2007). Spatial patterns of kangaroo density across the South Australian pastoral zone over 26 years: aggregation during drought and suggestions of long distance movement. *Journal of Applied Ecology* 44, 1068-1079.

Poppi, D., Minson, D. and Ternouth, J. (1980). Studies of cattle and sheep eating leaf and stem fractions of grasses. I the voluntary intake, digestibility and retention time in the reticula-rumen. *Australian Journal of Agricultural Research* 32, 99-108.

Poppi, D., Minson, D. and Ternouth, J. (1981a). Studies of cattle and sheep eating leaf and stem fractions of grasses. 11 factors controlling the retention of feed in the reticulo-rumen. *Australian Journal of Agricultural Research* 32, 109-21.

Poppi, D., Minson, D. and Ternouth, J. (1981b). Studies of cattle and sheep eating leaf and stem fractions of grasses. 111 the retention time in the rumen of large feed particles. *Australian Journal of Agricultural Research* 32, 123-37.

Powell, J. and Arnold, G. (1984). Metabolism of sheep and western grey kangaroo fed pasture forages of different nutritive values. Pp. 570-571. In *Rangelands: a resource under siege. Proceedings of the second international rangeland congress*. Eds. P. Joss, P. Lynch and O. Williams. Cambridge University Press, Cambridge.

Powlson, D. S, Whitmore, A. P and Goulding, K. W. T (2011). Soil carbon sequestration to mitigate climate change: a critical re-examination to identify the true and false *European Journal of Soil Science* 62: 42-55

Primary Industries and Regions South Australia. (2017). *SA Weed Control*. https://play.google.com/store/apps/details?id=com.fusion.weedwhacker.

Provenza, F.D. (1995). Postingestive Feedback as an Elementary Determinant of Food Preference and Intake in Ruminants. *Journal of Range Management* 48, 2-17.

Provenza, F.D., Villalba, J.J., Dziba, L.E., Atwood, S.B., Banner, R.E. (2003). Linking herbivore experience, varied diets, and plant biochemical diversity. *Small Ruminant Research* 49, 257-274.

Pulido, M., S. Schnabel, J. F. L. Contador, J. Lozano-Parra, and F. González. (2016). The impact of heavy grazing on soil quality and pasture production in rangelands of SW Spain. *Land Degradation & Development* 29, 219-230.

Pyke D.A., Herrick J.E., Shaver P. and Pellant M. (2002). Rangeland health attributes and indicators for qualitative assessment. *Journal of Range Management* 55, 584-597.

Rangelands NRM (2018). *Achievements of Rangelands NRM in the National Landcare Program 1. 2014-2018.* Report prepared for the Australian Government. Rangelands NRM, South Perth, WA.

Reeder, J. D and Schuman GE (2002) Influence of livestock grazing on C sequestration in semi-arid mixed-grass and short-grass rangelands. *Environmental Pollution* 116, 457-469.

Reid, R.S., Thornton P.K., McCrabb G.J., Kruska R.L., Atieno F., and Jones P.G. (2004). Is it possible to mitigate Greenhouse Gas Emissions in pastoral ecosystems of the tropics? *Environment, Development and Sustainability* 6, 91-109.

Revell, D.K. (2016). Adaptive responses of rangeland livestock to manage water balance. In: Villalba, J.J., Manteca, X. (Eds.), *Animal Welfare in Extensive Production Systems*. 5M Publishing Ltd, Sheffield, UK, pp. 37-52.

Revell, D.K., Maynard, B., Erkelenz P.A., Thomas, D.T. (2015). Rangeland Self Herding' - positively influencing grazing distribution to benefit livestock, landscapes and people. *Proceedings of the Australian Rangeland Society Conference, Alice Springs, 12-17 April 2015*.

Robards, G. E., Leigh, J. H., and Mulham, W. E. (1967). Selection of diet by sheep grazing semi-arid pastures on the Riverine Plain. 4. A grassland (*Danthonia caespitosa*) community. *Australian Journal of Experimental Agriculture and Animal Husbandry* 7, 426-33.

Rolls, Eric. (1969). *They All Ran Wild*, Angus and Robertson. Sydney, NSW.

Rutherford, M.C., Powrie L.W., and Lusted, L.B. (2012). Herbivore-driven land degradation: Consequences for plant diversity and soil in arid subtropical thicket in south-eastern Africa *Land Degradation & Development* 25, 541-553.

Sanderman, J., Reseigh, J, Wurst, M., Young, M. and Austin J. (2015). Impacts of Rotational Grazing on Soil Carbon in Native Grass-Based Pastures in Southern Australia. *PLOS One* 10, 1-15.

Sanjari, G., Yu B., Ghadiri H., Ciesiolka C.A.A., Rose C.W. (2009). Effects of time-controlled grazing on runoff and sediment loss. *Soil Research* 47, 796–808.

Schuman, GE, Reeder JD, Manley JT, Hart RH, Manley WA. 1999. Impact of grazing management on the carbon and nitrogen balance of a mixed-grass rangeland. *Ecological Applications* 9, 65–71.

Sheep CRC, (2017). *AskBill.* https://www.sheepcrc.org.au/publications/websites-to-assist-you/askbill.php.

Shengjie, I.I.U., Xiaodong, Y., Ives, A.R., Zhili, A.R., Liqing, S.H.A. (2017). Effects of seasonal and perennial grazing on soil fauna community and microbial biomass carbon in the subalpine meadows of Yunnan, Southwest China. *Pedosphere* 27, 371-379.

Shipley, L.A. (1999). *Grazers and browsers: how digestive morphology affects diet selection. Grazing Behavior of Livestock and Wildlife*. Idaho Forest, Wildlife & Range Exp. Sta. Bull. #70. University of Idaho, College of Natural Resources, pp. 20-27.

Short, J. (1985). The functional response of kangaroos, sheep and rabbits in an arid grazing system. *Journal of Applied Ecology* 22, 435-447.

Short, J. (1986). The effect of pasture availability on food intake, species selection and grazing behaviour of kangaroos. *Journal of Applied Ecology* 23, 559-571

Short, J. (1987). Factors affecting food intake of rangelands herbivores. In "*Kangaroos: Their Ecology and Management in the Sheep Rangelands of Australia*" (Eds G. Caughley, N. Shepherd and J. Short.). pp.84-99. Cambridge University Press, Cambridge.

Shrader, A.M., Brown, J.S., Kerley, G.I.H., Kotler, B.P. (2008). Do free-ranging domestic goats show 'landscapes of fear'? Patch use in response to habitat features and predator cues. *Journal of Arid Environments* 72, 1811-1819.

Silanikove, N. (1992). Effects of water scarcity and hot environment on appetite and digestion in ruminants, a review. *Livestock Production Science* 30, 175-194.

Silcock, J. L., and R. J. Fensham. (2013). Arid vegetation in disequilibrium with livestock grazing: Evidence from long-term exclosures. *Austral Ecology* 38,57-65.

Silcock, J.L., Healy, A.J., Fensham R.J. (2015.). Lost in time and space: re-assessment of conservation status in an arid-zone flora through targeted field survey. *Aust. J. Botany*. 62, 674-688

Sloane, Cook and King Pty. Ltd, (1988). *The economic impact of pasture weeds, pest and diseases on the Australian wool industry*. Report to the Australian Wool Corporation. Sydney.

South West NRM (2017). *Economic Impact Analysis: Collaborative Area Management Phase 2*. South West NRM, Charleville.

Squires, V. R. (1974). Grazing distribution and activity patterns of Merino sheep on a saltbush community in south-east Australia. *Applied Animal Ethology Volume* 1, 17-30.

Squires, V. R. (1980). Chemical and botanical composition of the diets of oesophageally fistulated sheep, cattle and goats in a semi-arid *Eucalyptus populnea* woodland community. *The Australian Rangeland Journal* 2, 94-103.

Squires, V. R. (1982). Dietary overlap between sheep, cattle, and goats when grazing in common. *Journal of Range Management* 35, 116-119.

Squires, V. R. and Low, W. A. (1987). Botanical and chemical composition of the diet selected by cattle in three range types in central Australia. *The Australian Rangeland Journal* 9, 86-95.

Squires, V. and Siebert, B. (1983). Botanical and chemical components of the diet and liveweight change in cattle on semi-desert rangeland in central Australia. *The Australian Rangeland Journal* 5, 28-34.

Steinfeld, H.P., Gerber P, Wassenaar V.., Castek M, Rosales M, De Haan C. (2006). Livestocks long shadow. *Environmental Issues and Options*, FAO Rome.

Stephenson, M.B., Bailey, D.W., Bruegger, R.A., Howery, L.D. (2017). Factors affecting the efficacy of low-stress herding and supplement placement to target cattle grazing locations. *Rangeland Ecology & Management* 70, 202-209.

State of the Environment,(2011). *Australia. State of the Environment 2011*. Department of Sustainability, Environment, Water, Population and Communities, Canberra.

Stevens, C. E. and Hume, I. D. (1995). *Comparative Physiology of the Vertebrate Digestive Systems*, 2nd Ed. Cambridge: Cambridge University Press.

Storr, G. M. (1968). Diet of kangaroos (*Megaleia rufa* and *Macropus robustus*) and merino sheep near Port Hedland, Western Australia. *J. R. Soc. West. Aust*. 51, 25-32.

Su, YZ, Li YL, Cui HY, Zhao WZ (2005) Influences of continuous grazing and livestock exclusion on soil properties in a degraded sandy grassland, Inner Mongolia, northern China. *Catena* 59, 267-278.

Tabeni, S., I. A. Garibotti, C. Pissolito, and J. N. Aranibar. (2014). Grazing effects on biological soil crusts and their interaction with shrubs and grasses in an arid rangeland. *Journal of Vegetation Science* 25,1417-1425

Talore, D.G., Tesfamariam, E.H., Hassen, A., Du Toit, J.C., Klamppd, K. and Jean-Francoise, S. (2016). Long-term impacts of grazing intensity on soil carbon sequestration and selected soil properties in the arid Eastern Cape, South Africa. *Journal of Science Food and Agriculture* 96, 1945-1952.

Teague, W.R., Dowhower S.L., Baker S.A., Haile N., DeLaune P.B., Conover D.M. (2011). Grazing management impacts on vegetation, soil biota and soil chemical, physical and hydrological properties in tall grass prairie. *Agriculture Ecosystems and Environment* 141, 310–322.

Teague, W., Dowhower, S., and Waggoner J. (2004). Drought and grazing patch dynamics under different grazing management. *Journal of Arid Environments* 58, 97-117.

Teague, R., B. Grant, and H.H. Wang (2015). Assessing optimal configurations of multi-paddock grazing strategies in tallgrass prairie using a simulation model. *Journal of Environmental Management* 150, 262-273.

Teague, R., F. Provenza, B. Norton, T. Steffens, M. Barnes, M. Kothmann, and R. Roath. 2008. Benefits of multi-paddock grazing management on rangelands: limitations of experimental grazing research and knowledge gaps. Pages 41-80 In H. G. Schroder, editor. Grasslands: ecology, management and restoration. Nova Science Publishers, Hauppauge, NY, USA.

Terpstra, J. W. and Wilson, A. D. (1989). Grazing distribution of sheep and kangaroos in a semi-arid woodland. *Applied Animal Behaviour Science* 24, 343-352.

Thompson, J., Riethmuller, D., Kelly, D., Miller, E., and Scanlan, J. C. (2002). Feral goats in south-western Queensland: a permanent component of the grazing lands. *The Rangeland Journal* 24, 268 –287.

Thornton, R. and Minson, D. (1973). The relationship between apparent retention time in the rumen, voluntary intake, and apparent digestibility of legume and grass diets in sheep. *Australian Journal of Agricultural Research* 24, 889-898.

Todd, S. W. 2006. Gradients in vegetation cover, structure and species richness of Nama-Karoo shrublands in relation to distance from livestock watering points. *Journal of Applied Ecology* 43, 293-304.

Tongway, D. J., A. D. Sparrow, and M. H. Friedel. (2003). Degradation and recovery processes in arid grazing lands of central Australia. Part 1: soil and land resources. *Journal of Arid Environments* 55, 301-326.

Turner, C. and Neagle, N. (1996). Total grazing pressure management. Unpublished Progress report.

Tru-test. (2017). *MiHub™ LIvestock Management* https://mihub.tru-test.com/livestock/.

URS, (2014). *Investment plan for natural resource management within livestock production systems of Australian rangelands. A Draft R, D & E Business Plan*. Unpublished Report prepared for the Meat and Livestock Corporation. Project code: B.ERM.0094

URS, (2015). *WEST 2000 Plus Evaluation*. Unpublished Report prepared for Western Local Land Services, Dubbo, NSW.

van Bommel, L. and Chris N. Johnson, C.N. (2012). Good dog! Using livestock guardian dogs to protect livestock from predators in Australia's extensive grazing systems *Wildlife Research* 39, 220-229.

Vermeire, L.T., Heitschmidt, R.K and Haferkamp, M.R (2008). Vegetation response to seven grazing treatments in the Northern Great Plains. Agriculture*, Ecosystems & Environment* 125, 111-119.

Villalba, J.J., Catanese, F., Provenza, F.D. and Distel, R.A. (2012). Relationships between early experience to dietary diversity, acceptance of novel flavors, and open field behavior in sheep. *Physiology and Behaviour* 105, 181-187.

Vu Hai, P., Schonewille, J.T., Dam Van, T., Everts, H., Hendriks, W.H. (2016). Exposure to a novel feedstuff by goat dams during pregnancy and lactation versus pregnancy alone does not further improve post-weaning acceptance of this feedstuff by their kids. *Journal of the Science of Food and Agriculture* 96, 2215-2219.

Wang, B, Waters C, Orgill1 S, Cowie A, Gray J, Clark A**,** Liu DL (2018) High resolution mapping of soil organic carbon stocks using remote sensing variables in the semi-arid rangelands of eastern Australia. *Science of the Total Environment* 630, 367-378

Wang, B**,** Waters C, Orgill1 S, Cowie A, Clark A, Liu DL, Simpson M, McGowen I, Sides T (2018) Estimating soil organic carbon stocks using different modelling techniques in the semi-arid rangelands of eastern Australia. *Ecological Indicators* 88, 425-438

Walker, B. H. and Steffen W. L. (1992). Rangelands and Global Change. In: *Australian Rangelands in a Changing Environment*. Australian Rangeland Society, Cobar, NSW.

Wallis, R. (2013). Kangaroos*. The Victorian Naturalist* 130, 56.

Wallis De Vries, M., A. Parkinson, J. Dulphy, M. Sayer, and E. Diana. 2007. Effects of livestock breed and grazing intensity on biodiversity and production in grazing systems. 4. Effects on animal diversity. *Grass and Forage Science* 62,185-197.

Waters, C and Hacker, R. (2008). *Integration of biodiversity and primary production in northern and western New South Wales*. NSW Department of Primary Industries.

Waters, C. M., S. E. Orgill, G. J. Melville, I. D. Toole, and W. J. Smith. (2016). Management of grazing intensity in the semi-arid rangelands of southern Australia: effects on soil and biodiversity. *Land Degradation & Development* 28,1363-1375.

Waters, C.M., Revell, D.K., Grant, R., Pahl, L.I., Reseigh, J, Atkinson, T. (2017). Addressing feed supply and demand through total grazing pressure management in southern Australian rangelands: key issues and opportunities. *Proceedings of the 19th Australian Rangeland Society Biennial Conference. Australian Rangeland Society.* September 2017, Port Augusta.

Watson, I., Holm, A., Shackleton, K. and Allen, R. (1988). The effect of sheep stocking rate on red kangaroo grazing pressure. 62-65. *Australian Rangeland Society working papers, 5th Biennial Conference*, June 1988, Longreach.

Watson, I.W., P. E. Novelly and P. W. E. Thomas (2007) Monitoring changes in pastoral rangelands – the Western Australian Rangeland Monitoring System (WARMS) *The Rangeland Journal* 29, 191-205

Western Local Land Services, (2017) *Total grazing pressure projects – Revision and re-assessment of 2016 projects*. Dubbo, NSW. https://western.lls.nsw.gov.au/___.../DOC17-9941-Guidelines-Western-Region-TGP-Project

Wildflowers WA. (no date). *Wildflowers WA Photo ID*. http://www.wildflowerswa.net/#.

Wilson, A. (1997). Comment on the workshop: *The role of kangaroo management in the management of total grazing pressure. Total grazing pressure workshop*. Bourke, NSW.

Wilson, A. D. (1979). Management of the natural pastures of south-western New South Wales. *Australian Rangeland Journal* 1, 351-362.

Wilson, A. D. (1991a). The influence of kangaroos and forage on sheep productivity in the semi-arid woodlands. *The Rangeland Journal* 13, 69-80.

Wilson, A. D. (1991b). Forage utilization by sheep and kangaroos in a semi-arid woodland. *The Rangeland Journal* 13, 81-90.

Wilson, A.D. and Harrington, G.N. (1984).'Grazing ecology and animal production in *'Management of Australia's Rangelands'*, (eds. G.N. Harrington, A.D. Wilson and M.D. Young), CSIRO, Melbourne, 63-78.

Wilson, A. D., Leigh, J. H., and Mulham, W. E. (1969). A study of merino sheep grazing a bladder saltbush (*Atriplex vesicaria*)-cotton bush (*Kochia aphylla*) community on the Riverine Plain. *Australian Journal of Agricultural Research* 20, 1123-36.

Wilson, A. D., Leigh, J. H., Hindley, N. L. and Mulham, W. E. (1975). Comparison of the diets of goats and sheep on a *Casuarina cristata–Heterodendrum oleifolium* woodland community in western New South Wales. *Australian Journal of Experimental Agriculture and Animal Husbandry* 15, 45–53.

Wilson, A. D. and Mulham, W. E. (1980). Vegetation changes and animal productivity under sheep and goat grazing on an arid Belah (*Casuarina cristata*) - Rosewood (*Heterodendrum oleifolium*) woodland in western New South Wales. *Australian Rangelands Journal* 2, 183-188.

Witte, I. (2002). *Spatio-temporal Interactions of Mammalian Herbivores in the Arid Zone*. Unpublished PhD Thesis. University of New South Wales, Sydney.

Yau, P. and T. Langdon. (no date). *The Native Plant Guide*. http://econews.com.au/15910/australian-native-plants-now-on-your-ipad/.

Yong-Zhong S, Yu-Lin L, Jian-Yuan C, Wen-Zhi Z. (2005). Influences of continuous grazing and livestock exclusion on soil properties in a degraded sandy grassland, Inner Mongolia, northern China. *Catena* 59, 267–278.

Zhu, Z., Piao, S., Myneni, R.B. Huang, M., Zeng, Z., Canadell, J.G., Ciais, P., Sitch, S., Friedlingstein, P., Arneth, A., Cao, C., Cheng, L., Kato, E., Koven, C., Li, Y., Lian, X., Liu, Y., Liu, R., Mao, J., Pan, Y., Peng, S., Penuelas, J., Poulter, B., Pugh, T.A.M., Stocker, B.D., Viovy, N., Wang, X., Wang, Y., Xiao, Z., Yang, H., Zaehle, S. and Zeng, N. (2016). Greening of the Earth and its drivers. *Nature Climate Change*, 6, 791-795.

Zuo XA, Zhao HL, Zhao XY, Zhang TH, Guo YR, Wang SK, Drake S (2008) Spatial pattern and heterogeneity of soil properties in sand dunes under grazing and restoration in Horqin Sandy Land, Northern China. *Soil Tillage Research* 99, 202-212

9. Additional reading

The current situation

ABARES (2016). *Land Use in Australia. Australian land use profiles*. Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES), Canberra.

Bastin G (2014). Australian rangelands and climate change – remotely sensed ground cover. Ninti One Limited and CSIRO, Alice Springs.

Bastin, G. (2009). ACRIS Kangaroo Density Update 2004-2008. Updated information to that provided in *Rangelands 2008 – Taking the pulse*. Gary Bastin, ACRIS Management Unit. http://www.environment.gov.au/system/files/resources/6de4ab28-8fcf-4ea0-9379-bd1fd0f91f56/files/acris-kangaroo-update.pdf

Department of Environment and Science (2018). *2018 Quota Submissions for Commercially Harvested Macropods in Queensland*, Government of Queensland, Brisbane, Queensland.

Department of Environment, Water and Natural Resources Government of South Australia (2017). *2018 Quota Report for Commercial Kangaroo Harvest in South Australia*. Government of South Australia, Adelaide, SA.

MLA (2017a). How many goats are out there? 26 April 2017. North Sydney, NSW.

MLA (2017b). Fast Facts: Australia's sheep industry. North Sydney, NSW.

MLA (2017c). Fast Facts: Australia's beef industry. North Sydney, NSW.

Pople, A. R. (1996). *Effects of harvesting upon the demography of red kangaroos in western Queensland*. Unpublished PhD. Thesis. University of Queensland St Lucia, Brisbane, Queensland.

PWC (2011). *The Australian Beef Industry. The Basics*. PWC © 2011. PricewaterhouseCoopers, Sydney, Australia.

Southwell, C. and Pickles, G. (1993). Abundance, distribution, and rate of increase of feral goats in Western Australia. *The Rangeland Journal* 15(2), 334 – 348.

Southwell, C., Weaver, K., Sheppard, N. and Morris, P. (1993). Distribution and relative abundance of feral goats in the rangelands of eastern Australia. *The Rangeland Journal* 15(2), 331-333.

Management of TGP

Allen, B.L., and Leung, L.K.P. (2012). Assessing predation risk to threatened fauna from their prevalence in predator scats: dingoes and rodents in arid Australia. PLoS ONE 7, e36426.

Ballard, G., Fleming, P., Melville, G., West, P., Pradhan, U., Payne, N., Russell, B. and Theakston, P. (2011). Feral Goat Population Trends in Western New South Wales Rangelands. Unpublished final report to the Western Catchment Management Authority, May 2011 (NSW Department of Primary Industries: Orange) ISBN 978-0-7313-3931-0

Pattinson, R., Wilcox, C., Williams, S. and Curtis, K. (2015). NSW Wool Industry and Future Opportunities. A report to the NSW Department of Primary Industries from Miracle Dog, Poimena Analysis, Scott Williams Consulting and DAFWA.

Ritchie, E.G., Shores, C.R., Wallach, A.D., Wirsing, A.J., and Dickman, C. (2015). Resolving the value of the dingo in ecological restoration. Restoration Ecology 23, 201–208.

Roberts, J.A., Coulson, G., Munn, A.J., Kearney, M.R. (2016). A continent-wide analysis of the shade requirements of red and western grey kangaroos. Pub Med, Apr 5; 3(2): 340-353.

Relationship between TGP management and production

Barossa Improved Grazing Group. (2017). *The Barossa Improved Grazing Group* (BIGG). http://biggroup.org.au/

Bayliss, P. (1987). Kangaroo dynamics. Pages 119-134. *Kangaroos: their ecology and management in the sheep rangelands of Australia.* Eds. G Caughley, N. Shepherd and J. Short. Cambridge University Press. Cambridge.

Behrendt, R., van Burgel, A., Bailey, A., Barber, E., Curnow, C., Gordon, D., Hocking, J., Edwards, D., Oldham, C. and Thompson, A. (2011). On-farm paddock-scale comparisons across southern Australia confirm that increasing the nutrition of Merino ewes improves their production and the lifetime performance of their progeny. *Animal Production Science* 51, 805 – 812

Bonnet, O.J.F., Meuret, M., Tischler, M.R., Cezimbra, I.M., Azambuja, J.C.R., Carvalho, P.C.F. (2015). Continuous bite monitoring: a method to assess the foraging dynamics of herbivores in natural grazing conditions. *Animal Production Science* 55, 339-349.

Catanese, F., Distel, R.A., Rodríguez Iglesias, R.M., Villalba, J.J. (2010). Role of early experience in the development of preference for low-quality food in sheep. *Animal* 4, 784-791.

Cordova, F., Wallace, J. Pieper, R. (1978). Forage intake by grazing livestock: a review. *Journal of Range Management* 31(6), 430-438

Croft, D. (1985). Inter- and intraspecific conflict between arid-zone kangaroos at watering points. *Aust. J. Wildlife Research* 12, 337-348

CSIRO (2007). *Nutrient Requirements of Domesticated Ruminants*. CSIRO Publishing, Collingwood, VIC, Australia.

Dawson, T. J. and Hulbert, A. J. (1970). Standard metabolism, body temperature, and surface areas of Australian marsupials. *American Journal of Physiology* 218, 1233-1238.

Department of Agriculture and Food, Western Australia. (2006). *The grazing of goats in the pastoral areas of Western Australia: best management practice guidelines*. Department of Agriculture and Food, Western Australia.

Department of Primary Industries (2015). *Using DSEs and carrying capacities to compare sheep enterprises*. Government of NSW, Sydney, NSW.

Distel, R., Villalba, J., Laborde, H., Burgos, M. (1996). Persistence of the effects of early experience on consumption of low-quality roughage by sheep. *Journal of Animal Science* 74, 965-968.

Erickson, D.L., Reed, E., Ramachandran, P., Bourg, N.A., McShea, W.J., Ottesen, A. (2017). Reconstructing a herbivore's diet using a novel rbc L DNA mini-barcode for plants. AoB *PLANTS* 9.

Estell, R., Havstad, K., Cibils, A., Anderson, D., Schrader, T. (2014). The changing role of shrubs in rangeland-based livestock production systems: Can shrubs increase our forage supply? *Rangelands* 36, 25-31.

Evergraze (2013). *Understanding your stocking rate and feed supply demand profile*. http://www.evergraze.com.au/library-content/understanding-your-stocking-rate-and-feed-supply-demand-profile/

Fanning, F. D., and Dawson, T. J. (1989). The use of heart rate telemetry in the measurement of energy expenditure in free-ranging red kangaroos. In *Kangaroos, Wallabies and Rat Kangaroos* (Eds G. Caughley, N. Shepherd and J. Short). Pp. 129-142. Surrey Beatty and Sons, Chipping Norton, Australia.

Fletcher, I. (1971). Effects of nutrition, liveweight, and season on the incidence of twin ovulation in South Australian strong-wool merino ewes. *Aust. J. Agric. Res*. 22, 321-30.

Fogarty, N.M., McLeod, L. and Morgan, J. (2003). Variation among crossbred ewes in lamb productivity and profit on a feed unit basis. *Proc. Assoc. Advmt. Anim. Breed. Genet*. 15, 414-317.

Foose, T. J. (1982). Trophic strategies of ruminant versus non-ruminant ungulates. Ph.D. Dissertation. University of Chicago.

Fraser, M.D., Theobald, V.J., Griffiths, J.B., Morris, S.M., Moorby, J.M. (2009). Comparative diet selection by cattle and sheep grazing two contrasting heathland communities. *Agriculture, Ecosystems and Environment* 129, 182-192.

Green, B. (1989). Water and energy turnover in free-ranging Macropodoids. Pages 223-29. In *Kangaroos, wallabies and rat-kangaroos*. Ed. By G. Grigg, P. Jarman and I. Hume. Surrey Beatty and Sons. New South Wales, Australia.

Grice, A. C. and Beck, R.F. (1994). Kangaroos in Australian Rangelands. *Rangelands* 16(5), 189-192.

Hacker, R. and McLeod, S. (2003). Living with Kangaroos: A Guide to Kangaroos and their Management in the Murray-Darling Basin, Technical Report, NSW Agriculture, Orange, NSW.

Hatcher, S., Eppleston, C., Thornberry, K. and Watt, B. (2010). High Merino weaner survival rates are a function of weaning weight and positive post-weaning growth rates. *Animal Production Science* 50, 465 – 472.

Ho, K.W., Krebs, G.L., McCafferty, P., van Wyngaarden, S.P., Addison, J., 2010. Using faecal DNA to determine consumption by kangaroos of plants considered palatable to sheep. *Animal* 4, 282-288.

Holechek, J.L., Pieper, R.D., and Herbel, C.H (2010). *Range management: principles and practices.* 6th ed. Upper Saddle River, NJ, USA: Prentice Hall. 456 p.

Hollis, D. J. (1984). The ability of two macropods (Macropus eugenii and M. robustus robustus) of different body size to utilise diets of different fibre content compared with sheep. Unpublished Thesis, University of New England, Armidale, NSW.

Hume, I. D. (1999). Marsupial Nutrition. Cambridge University Press, Cambridge, UK.

Kartzinel, T.R., Chen, P.A., Coverdale, T.C., Erickson, D.L., Kress, W.J., Kuzmina, M.L., Rubenstein, D.I., Wang, W., Pringle, R.M., 2015. DNA metabarcoding illuminates dietary niche partitioning by African large herbivores. *Proceedings of the National Academy of Sciences of the United States of America* 112, 8019.

Khairo, S.A., Mullen, J.D., Hacker, R.B. & Patton, D.P (2008). Farming Systems in the Pastoral Zone of NSW: An Economic Analysis, Economic Research Report No.31, NSW DPI, Trangie, NSW.

Lodge, G. M. (2011). Developing pasture and livestock benchmarks for sheep production in northern New South Wales. Proceedings of the 26th Annual Conference of The Grassland Society of NSW. pp 115-118.

McLean, I. and Blakeley, S. (2014). Animal Equivalent Methodology. A methodology to accurately and consistently calculate cattle grazing loads in northern Australia. Published by Meat & Livestock Australia.

McLeod, M., Kennedy, M. and Minson, D. (1990). Resistance of leaf and stem fractions of tropical forage to chewing and passage in cattle. *British Journal of Nutrition* 63, 105 -119.

Moss, G. L. (1995). Home range, grouping patterns and the mating system of the Red Kangaroo (*Macropus rufus*) in the arid zone. PhD thesis, University of New South Wales, Sydney.

Murray, P. J., Dhanda, J. S., and Taylor, D. G. (1997). Goat meat production and its consequences for human nutrition. Proceedings of the Nutrition Society of Australia 21, 28-36.

Nagy, K. A. (1987). Field metabolic rate and food requirement scaling in mammals and birds. *Ecological Monographs* 57(2), 111–128.

O'Reagain, P. J., Bushell, J. J. and Holmes, B. (2011). Managing for rainfall variability: long-term profitability of different grazing strategies in a northern Australian tropical savanna. *Animal Production Science* 51(3), 210-224.

Pegard, A., Miquel, C., Valentini, A., Coissac, E., Bouvier, F., François, D., Taberlet, P., Engel, E., Pompanon, F. (2009). Universal DNA-based methods for assessing the diet of grazing livestock and wildlife from feces. *Journal of Agricultural and Food Chemistry* 57, 5700.

Restall, B. J. and Pattie, W. A. (1989). The inheritance of cashmere in Australian goats. 1. Characteristics of the base population and the effects of environmental factors. *Livestock Production Science* 21, 157-172.

Safari, E., Fogarty, N.M., Gilmour, A.R., Atkins, K.D., Mortimer, S. I., Swan, A.A., Brien, F.D., Greeff, C. and van der Werf, J.H.J. (2007). Across population genetic parameters for wool, growth, and reproduction traits in Australian Merino sheep. 1. Data structure and non-genetic effects. *Australian Journal of Agricultural Research* 58, 169–175.

Scarnecchia, D I. (1986). Viewpoint: animal-unit equivalents cannot be meaningfully weighted by indices of dietary overlap. *Journal of Range Management* 39(5), 471.

Searle, K.R., Hunt, L.P., Gordon, I.J. (2010). Individualistic herds: individual variation in herbivore foraging behavior and application to rangeland management. *Applied Animal Behaviour Science* 122, 1-12.

Short, J., Caughley, G., Grice, D. and Brown, B. (1983). The distribution and abundance of kangaroos in relation to environment in Western Australia. *Aust. Wildl. Res.*10, 435-51.

Sponheimer, M., Robinson, T., Roeder, B., Hammer, J., Ayliffe, L., Passey, B., Cerling, T., Dearing, D. and Ehleringer, J. (2003). Digestion and passage rates of grass hays by llamas, alpacas, goats, rabbits, and horses. *Small Ruminant Research* 48, 149–154

Stephenson, M.B., Bailey, D.W., Howery, L.D., Henderson, L. (2016). Efficacy of low-stress herding and low-moisture block to target cattle grazing locations on New Mexico rangelands. *Journal of Arid Environments* 130, 84-93.

Steuera, P., Südekuma, K., Müller, D., Franz, R., Kaandorpc, J., Clauss, M. and Hummel, J. (2011). Is there an influence of body mass on digesta mean retention time in herbivores? A comparative study on ungulates. *Comparative Biochemistry and Physiology Part A: Molecular & Integrative Physiology*. Volume 160, Issue 3, Pages 355–364.

The Forage and Grazing Terminology Committee (1992). Terminology for grazing lands and grazing animals. *J. Prod. Agric*. 5, 191-201.

Turner, B. W. and Alcock, D. (2000). The dry sheep equivalent - redefining a 'standard'. *Asian-Aus. J. Anim. Sci*. 13 Supplement July C, 215

van Beest, F.M., Mysterud, A., Loe, L.E., Milner, J.M. (2010). Forage quantity, quality and depletion as scale-dependent mechanisms driving habitat selection of a large browsing herbivore. *Journal of Animal Ecology* 79, 910-922.

Warn, L.K., Geenty, K.G. and McEachern, S. (2006). What is the optimum wool–meat enterprise mix? Wool Meets Meat (eds. P.B. Cronjé & D. Maxwell). Proceedings of the Australian Sheep Industry CRC Conference.

Xu, W., Taki, Y., Iwasawa, A., Yayota, M. (2016). Effects of early experience with low-quality roughage on feed intake, digestibility and metabolism in lambs. *Journal of Animal Physiology and Animal Nutrition* 100, 1023-1030.

Impacts on resource condition

Bai G, Bao Y, Du G, Qi Y (2013). Arbuscular mycorrhizal fungi associated with vegetation and soilparameters under rest grazing management in a desert steppe ecosystem. *Mycorrhiza* 23: 289–301.

Bedunah D.J., and Angerer J.P., (2012). Rangeland Degradation, Poverty and conflict: How can rangeland Scientists contribute to effective responses and solutions. *Rangeland Ecology and Management* 65: 606–612.

Briske D.D., Derner J.D., Milchunas D.J., Tate K.W (2011). An evidence-based assessment of prescribed grazing practices. In: Briske DD (ed.), *Conservation benefits of rangeland practices: assessment, recommendations, and knowledge gaps*. [Davis, CA]: United States Department of Agriculture, Natural Resources Conservation Service. pp 22–74.

Brown L. R. (2003). *Plan B Updates, China losing war with advancing deserts*. http://www.earth-policy.org/plan_b_updates/2003/update26 [Accessed 13/01/2017]

Chillo, V., Ojeda, R. A., Anand, M. and Reynolds J. F. (2015). A novel approach to assess livestock management effects on biodiversity of drylands. *Ecological Indicators* 50:69-78.

Commonwealth Scientific and Industrial Research Organisation. (2015). SoilMapp. https://itunes.apple.com/au/app/soilmapp/id578173447.

Cotrufo MF, Wallenstein M.D., Boot C.M., Denef K., Eldor P. (2013). The Microbial Efficiency-Matrix Stabilization (MEMS) framework integrates plant litter decomposition with soil organic matter stabilization: Do labile plant inputs form stable soil organic matter? *Global Change Biology* 19: 988–995.

Cotrufo MF, Wallenstein M.D., Boot C.M., Denef K., Eldor P., Bailey D.W., and J. R. Brown (2011). Rotational Grazing Systems and Livestock Grazing Behavior in Shrub-Dominated Semi-Arid and Arid Rangelands. *Rangeland Ecology & Management* 64: 1-9.

Doran-Browne, N.A., Ive, J., Graham, P., Eckard, R.J. (2016). Carbon-neutral wool farming in south-eastern Australia*. Animal Production Science* 56: 417-422.

Earl J.M. and Jones C.E. (1996). The need for a new approach to grazing management-is cell grazing the answer? *Rangeland J* 18, 327–350.

Guerin, G.R., Sparrow, B., Tokmakoff, A., Smyth, A., Leitch, E., Baruch, Z., and Lowe, A.J., (2017). Opportunities for Integrated Ecological Analysis across Inland Australia with Standardised Data from Ausplots Rangelands. *PLoS ONE* 12: 1-19.

McKeon, G., Flood, N. Carter, J., Stone, G., Crimp, S. and Howden, M. (2008). *Simulation of climate change impacts on livestock carrying capacity and production*. Garnaut Climate Change Review.

Munro, N. T., J. Fischer, J. Wood, and Lindenmayer, D.B. (2012). Assessing ecosystem function of restoration plantings in south-eastern Australia. *Forest Ecology and Management* 282: 36-45.

Nkonya E., Johnson T., Kwon H.Y., and Kato E (2016). Economics of Land Degradation in Sub-Saharan Africa. In: Nkonya E., Mirzabaev A., von Braun J. (eds) *Economics of Land Degradation and Improvement – A Global Assessment for Sustainable Development*. Springer, Cham.

Strohbach, B.J. (2018). Making more of vegetation classification results: A livestock farming suitability index as tool for land-use planning in Namibia. *Phytocoenologia* 48, 7-22.

Sun, D.S, Wesche, K., Chen, D.D., Zhang, S.H., Wu, G.L., Du, G.Z., Comerford, N.B (2011). Grazing depresses soil carbon storage through changing plant biomass and composition in a Tibetan alpine meadow. *Plant, Soil and Environment* 57: 271–278.

Teague, W. R., and S. L. Dowhower (2003). Patch dynamics under rotational and continuous grazing management in large, heterogeneous paddocks. *Journal of Arid Environments* 53: 211-229.

Teague, R., F. Provenza, U. Kreuter, T. Steffens, and M. Barnes. (2013). Multi-paddock grazing on rangelands: why the perceptual dichotomy between research results and rancher experience? *Journal of Environmental Management* 128: 699-717.

Tongway, D., and Hindley, N. (2004). Landscape function analysis: a system for monitoring rangeland function*. African Journal of Range and Forage Science* 21: 109-113.

Wessels K.J. Princea S.D., Frost P.E., and van Zylc D. (2004). Assessing the effects of human-induced land degradation in the former homelands of northern South Africa with a 1 km AVHRR NDVI time-series*. Remote sensing of Environment* 91: 47-67.

Technology products

Department of Primary Industries. (2017). *GrazingApp.* Government of NSW, Sydney. Government of NSW, Sydney. http://grazingapp.com.au/.

Department of Primary Industries (no date). *Global Ag-Tech Ecosystem (GATE)*. Government of NSW, Sydney, https://www.dpi.nsw.gov.au/about-us/science-and-research/gate.

Environmental Resources Information Network (2005). *Outback Australia - the rangelands. Introduction to Australia's rangelands*. Environmental Resources Information Network (ERIN) © Commonwealth of Australia, November 2005.

FarmBot. (2017). *FarmBot*. http://farmbot.com.au/

Government of NSW. (no date). *Enhanced drought information system*. Sydney, NSW. https://www.digital.nsw.gov.au/project-story/enhanced-drought-information-system.

Graham, P. (2017). *Prograze: profitable, sustainable grazing*. 9th Edition. NSW Department of Primary Industries, Government of NSW

Grains Research and Development Corporation (2016). *"Climate Kelpie."* Canberra, ACT.

Jeffrey, S. J., J. O. Carter, K. B. Moodie and A. R. Beswick (2001). "Using spatial interpolation to construct a comprehensive archive of Australian climate data." *Environmental Modelling and Software* 16: 309-330.

Making More From Sheep (2008). A joint initiative of Australian Wool Innovation and Meat & Livestock Australia.

Other

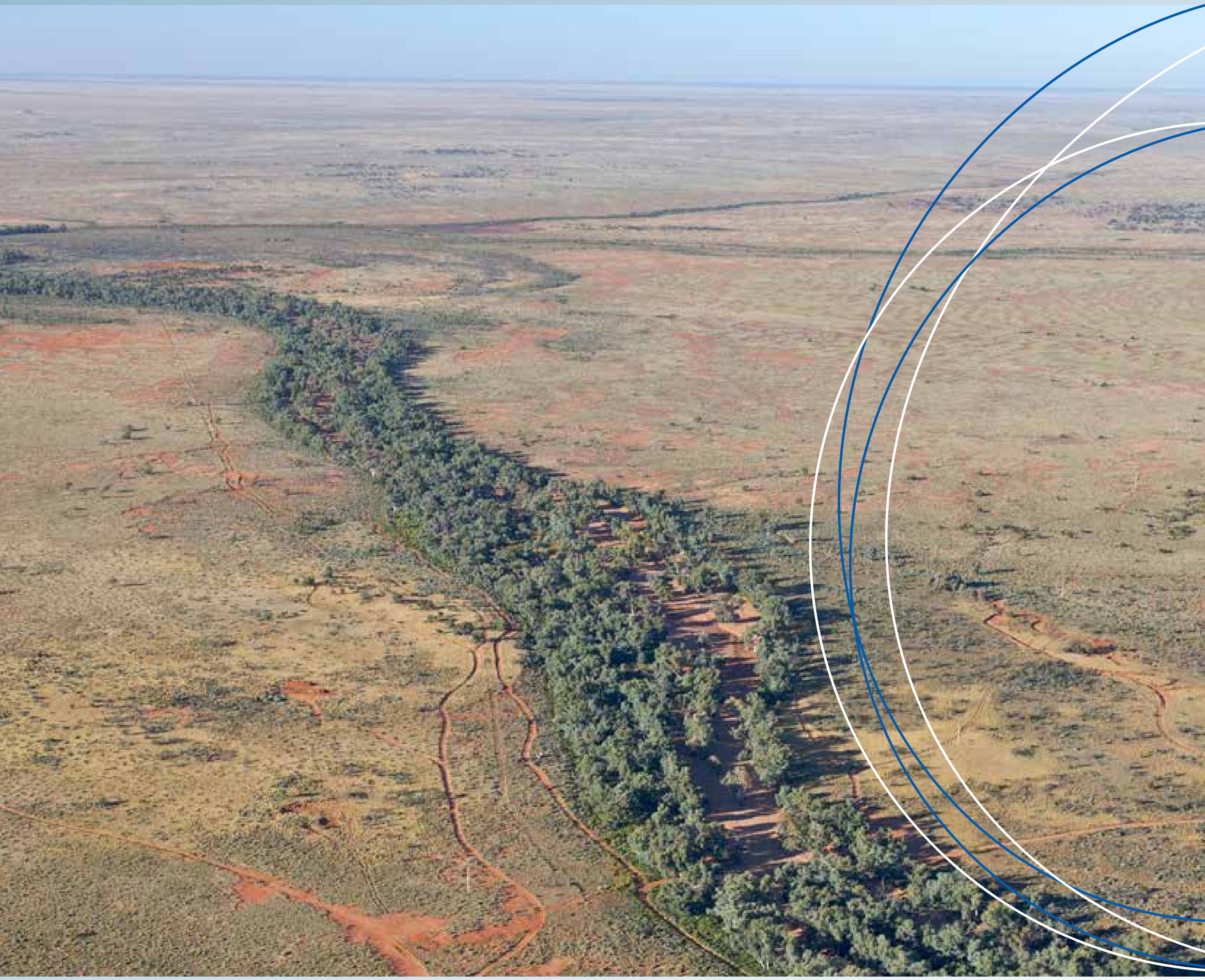
Snowden, D.J., Boone, M.E. (2007). A leader's framework for decision making. *Harvard Business Review*, November 2007.

Wester, J., 2013. Understanding the Cynefin framework – a basic intro. Everyday Kanban. Available at: http://www.everydaykanban.com/2013/09/29/understanding-the-cynefin-framework

Williams, J., Hook, R. and Hamblin, A. (2002). Agro-ecological regions of Australia – Methodology for their derivation and key issues in resource management. CSIRO Land and Water, Canberra, ACT.

Investment plan

Addressing feed supply and demand through total grazing pressure management



Authored by:

Cathy Waters - NSW Department of Primary Industries

Jodie Reseigh-O'Brien - Primary Industries and Regions – Rural Solutions

Lester Pahl - Department of Agriculture and Fisheries

Trudie Atkinson - NSW Department of Primary Industries

Don Burnside - D.G. Burnside & Associates

Dean Revell - Revell Science

MEAT & LIVESTOCK AUSTRALIA

Published by NSW Department of Industry

Investment plan Addressing feed supply and demand through total grazing pressure management

First published: September 2018.

More information: Cathy Waters (Livestock Systems, Orange) - cathy.waters@dpi.nsw.gov.au

Publication citation: Waters C, Reseigh-O'Brien J, Pahl L, Atkinson T, Burnside D and Revell D (2018). Addressing feed supply and demand through total grazing pressure management. NSW Department of Primary Industries.

Industry vision

Total grazing pressure management in the Australian Rangelands has delivered sustained productivity growth and has responded to changing market preferences and community expectations.

Industry is better equipped to adapt to drought and climate variability through the effective management of all herbivores.

Red meat production in the Southern Australian Rangelands is able to verify minimal negative environmental impacts and demonstrate continual environmental improvement. Over time, this will enable a defensible case for the increasing social licence of the red meat industry.

By 2024 this program of work will:

- Equip producers and jurisdictions with the means to quantify current total grazing pressure impacts and provide a predictive tool that identifies density/damage functions to inform proactive management decisions;
- Raise awareness of 1,500 land managers (~ 25 percent of the pastoral industry of Southern Australian Rangelands) of cost-effective total grazing pressure management;
- Directly engage 2000 landholders in co-learning and information exchange activities;
- Have 100 landholders contributing meta-data to the R&D program; and
- Establish at least 24 co-learning and monitoring sites within six nodes across three states (QLD, NSW, and SA).

Background

The need to manage total grazing pressure (TGP)

Total Grazing Pressure (TGP) has been defined as the combined grazing pressure exerted by all managed and unmanaged herbivores on the vegetation, soil and water resources of rangeland landscapes. TGP is important because it influences the demand for forage (feedbase) by all herbivores, relative to supply. A central tenet in TGP management is therefore achieving the balance between supply and demand for feed, and avoiding an imbalance occurring when feed demand exceeds feed supply. This imbalance can be detrimental to animal welfare, livestock productivity and damage resource condition.

Less than half the herbivory in Southern Australian Rangelands is managed by pastoralists. Recent estimates suggest that a total of 28.93 million DSE are currently grazing these areas, of which 15.57 million DSE are unmanaged Macropods and goats and 13.36 million DSE or about 45 per cent of this are livestock. The numbers of unmanaged herbivory is highest in areas protected behind the National Dog Fence, where most of the sheep in the Southern Australian Rangelands are now grazing. In areas beyond the National Dog Fence, there is still an issue in managing significant numbers of unmanaged Macropods which are competing with cattle for forage.

The quantity and quality of forage available for all herbivores within the Southern Rangelands is frequently low, and as seasonal conditions deteriorate, there is direct competition between managed and unmanaged species for forage. With an expected increase in the frequency of variable seasons, this issue will only increase, exacerbating the decline in the prerequisite natural resource base. This will subsequently impact on short and long term production and threaten the social licence to operate for livestock industries. This will be most apparent when high densities of herbivores coincide with periods of low rainfall.

Livestock management which rotationally graze paddocks and allows effective rest and recovery of pastures can maintain higher levels of ground cover, increase floristic diversity and perennial grass content as well as increasing long-term soil organic carbon levels. While various forms of rotational grazing and pasture spelling are being practiced by land managers, grazing by Macropods in particular may reduce the benefits pastoralists may gain from early destocking, and resting pastures to allow recovery. Finally, land managers are obtaining no benefit from grazing Macropods, and there are contested views on the cost they impose upon the pastoral business through both impacts on resource condition and feedbase.

Land managers and service providers views about TGP

Land managers (n=219) and service providers (n=47) across the Southern Rangelands responded to a survey about their approach to grazing management, and the challenges imposed by unmanaged herbivory. The numbers of unmanaged herbivores reported by land managers match regional government monitoring program results. Respondents regard unmanaged herbivory as a significant problem affecting the economic performance of their pastoral businesses as well as having environmental impacts. Unmanaged herbivores commonly include goats and kangaroos but respondents viewed that camels, donkeys and pigs also needed to be included when referring to unmanaged herbivores, with pigs being of increasing importance.

Although, land managers and service providers are prepared to tolerate some forage demand from Macropods and unmanaged goats, they see current levels as being too high. Further, they believe unmanaged herbivory is costing them more than the estimates provided by responsible state agencies and the literature.

Land managers responding to the survey would like to see a reduction in unmanaged herbivory but recognise that some current control technologies are not cost-effective or payback periods are unknown. They would like to see improved technologies – especially in being able to control unmanaged herbivores and wild dogs spatially – and some financial assistance with implementing these methods.

Key messages are presented as follows.

- Land managers and service providers in the Southern Rangelands indicated that a reduction in forage demand from unmanaged herbivores was required.
- Land managers were prepared to tolerate some forage demand from unmanaged herbivores but levels needed to be less than currently maintained.
- Unmanaged herbivores commonly include goats and kangaroos. However, importantly, camels, donkeys and pigs need to be also included when referring to unmanaged herbivores.
- Land manager perceptions of numbers of unmanaged herbivores match regional monitoring undertaken by government agencies.
- Land managers and service providers recognised that resource condition is impacted by managed and unmanaged herbivores.
- The management of livestock was reported as having both positive and negative impacts on resource condition, but this could be managed.
- Survey respondents indicated a negative impact on pasture resulted from an inability to provide pasture rest and recovery time due to unmanaged grazing pressure.
- Unmanaged herbivores were reported as having negative impacts on resource condition, but cannot be easily/readily managed.
- Land managers reported the impact of Macropods on business profitability is at odds with that reported in the scientific literature.
- Land manages and other stakeholder groups believe that kangaroo management and fencing will have the greatest impact on TGP management over the next five years.

Recent and current investment in TGP

From 2004 to September 2012, the Western CMA (NSW) invested approximately $9.4 million in some 284 projects involving TGP management (largely feral goat management). Western LLS has continued to invest in direct on-ground grants to landholders with the objective of improving natural resource outcomes.

The 2014 TGP incentive funding program committed $2.8 million to 58 landholders to erect 1005 km of TGP fencing, 42 trap yards and undertake grazing management plans. The project objective is to '... increase productivity, native vegetation and soil health by reducing total grazing pressure, particularly of unmanaged goats' (URS 2015). Conservative estimates suggest at least 1 million hectares in western NSW are currently being managed within TGP fencing either through incentive funding or within carbon farming areas.

Seven Collaborative Area Management or 'cluster' groups have been formed as part of a South West NRM (SWNRM), QLD state government funded initiatives. These groups of land managers came together and formed associations, allowing them to purchase fencing materials at a reduced cost. These groups then built exclusion fences surrounding their properties, helping each other and sharing fencing equipment. Once these fences are completed, the groups work to mitigate shared issues within the clusters. Some of these issues include unmanaged herbivores which apply an unsustainable grazing pressure and wild dogs that predate livestock.

The Collaborative Area Management project aims to increase diversity on properties, allowing land managers to continue with or return to sheep enterprises which anecdotally may benefit local towns through increased employment associated with the wool industry. Our best estimates suggest that approximately 7 million hectares in SW Queensland are now managed within cluster fencing.

Anecdotal evidence suggests both TGP and cluster style fencing continues to be erected independent of incentive programs in NSW, Queensland and WA. Motivation for exclusion fencing is primarily occurring to protect livestock from wild dogs but also excluding goats and Macropods.

Future needs

Despite the requirement for land managers to manage the natural resource on pastoral leases or freehold land to at least maintain resource condition, an inability to control the unmanaged herbivore populations precludes effective rest and recovery of pastures. Land managers are prepared to tolerate some forage demand from unmanaged herbivores, but in some areas, view the current populations of unmanaged herbivores is placing unprecedented demand for forage, which is negatively impacting pastoral businesses and the resource base. In addition, there is a view that this TGP exaggerates the effects of drought and accelerates the negative impacts on resource condition.

The uptake of exclusion fencing provides an unprecedented opportunity to manage TGP across extensive areas of SE Australia but as yet there is limited direct evidence of benefits to resource condition and primary production beyond financial benefits from reduced dog predation. Further, in recent years, practical non-lethal, non-fencing methods to influence livestock grazing distribution have been developed in Western Australia, referred to as Rangelands Self-herding and are currently being evaluated but is virtually unknown in SE Australia. The review identifies a range of other TGP management options and no immediate need for further research in developing new options is required. However, despite a range of other TGP management options (including re-introduction of the dingo and guardian animals) no comprehensive economic analysis of the cost-effectiveness of various TGP management options or the impacts on resource condition has been undertaken. Many of the TGP management options that have been recently adopted cross the Southern Australian Rangelands remain locally specific with little networking to share insights or coordination beyond state boundaries. This precludes the development of a community of practice to support rangeland pastoralists understanding the implications of and evaluating alternative management options available.

Government surveys on changes in Macropod and goat populations employ different methods as well as information being fragmented across jurisdictions making a defendable, reliable assessment of TGP for the Australian red meat industry difficult. These surveys are also undertaken at temporal and spatial scales that preclude land managers making timely decisions to respond to TGP. Southern rangeland land managers are vulnerable to the consequences of unmanaged TGP with an inability to identify temporal and spatial changes in herbivore distribution at a paddock scale and to assess the consequences to feedbase and resource condition. There is an absence of technology products for land managers to provide this information which can underpin management decisions.

Rangeland managers require real-time information and cost-effective technologies to be able to manage total grazing pressure. To improve management of existing enterprises, the rangeland pastoral industry need to be able to:

- Identify early when an imbalance between forage supply and forage demand is imminent so that they can take action;
- Quantify the impact on resource condition, forage availability (and financial return) from grazing herbivores and current grazing approach; and
- Quantify the impact of non-managed herbivores accessing spelled paddocks, allowing land managers to determine how much to invest in control of unmanaged herbivores.

Changing consumer preferences are dictating that the red meat industry is able to demonstrate production system practices that use natural resources wisely and show care and health of animals. Globally, expectations for sustainability development and addressing climate change impacts are also driving a need for the red meat industry to meet these expectations. The management of total grazing pressure provides an opportunity for southern rangeland pastoral industries to increase livestock productivity, meet changing consumer preferences for sustainably produced meat and fibre and maintain its social licence to operate.

Value proposition

By identifying early when an imbalance between forage supply and forage demand is imminent land managers can take action and be proactive in decision making optimising feedbase for livestock enterprises and ecological function.

Providing evidence of productive and sustainable practices that may be required in differing markets allows the red meat industry to meet market specifications of livestock products and commit to forward contracts. This will capture emerging market opportunities associated with land management (e.g. carbon and environmental services).

Investment plan

Investment themes

Three main themes were identified as sub-programs (Table 1). Over-arching each of these themes is a “Total Grazing Pressure Management Network” which will provide on-going program extension and delivery for the three sub-programs. A fourth sub-program will work to deliver policy reform and is considered necessary to support the investment plan but undertaken independently by Meat and Livestock Australia. Indicative budgets are provided and assume at least an additional 50 % in-kind contribution from collaborators.

<table>
<tr><th colspan="3">Overview of investment priorities for “Addressing feed supply and demand through total grazing pressure management” program</th><th></th></tr>
<tr><td colspan="3">Stakeholder Advisory Panel
Who: RD&A expertise, land manager representatives, wildlife managers, animal welfare adviser
Role: External program integration; Stakeholder an industry views</td><td></td></tr>
<tr><td colspan="3">Program Director
Role: RD&A Plan management and coordination; Program contractual protocols; Internal and external program integration; Engagement and communication; Succession and capacity building; Program monitoring and evaluation</td><td></td></tr>
<tr><td colspan="3">Total grazing pressure management network
Role: Development and delivery of stakeholder engagement and communication plan for each sub-program.</td><td rowspan="2">Peak Industry Councils and farmer organisations</td></tr>
<tr><td>Program Manager</td><td>Program Manager</td><td>Program Manager</td></tr>
<tr><td>Sub-program 1
Technical capacity for industry to manage all herbivores</td><td>Sub-program 2
Realising the production and environmental benefits of total grazing pressure management</td><td>Sub-program 3
Widespread adoption of evidence-based, effective total grazing pressure management</td><td>Sub-program 4
Legal capacity for industry to manage all herbivores</td></tr>
<tr><td>Outcomes
• Identification of herbivore density/ damage thresholds for TGP
• Industry verified tool for TGP management
• Industry pathways to manage TGP identified</td><td>Outcome
• Acceptable trade-offs between the environmental value of TGP management and farm profitability identified
• Identification of spatial and temporal impacts on resource condition
• Increased access to new markets</td><td>Outcome
• Locally relevant guideline to deploy TGP options
• Industry use of cost-effective TGP management options maximised
• Reduced risk of early adoption</td><td>Outcomes
• Policy framework which accommodates TGP management
• Community recognition of the impact of unmanaged herbivores
• Cross jurisdiction agreement for industry to responsibly manage Macropod populations</td></tr>
<tr><td>Projects
1.1 Assessing feasible solutions to identify an imbalance between feed supply and herbivore demand
1.2 Pilot and validate a tool to predict paddock scale hot spots and hot times for herbivore activity</td><td>Projects
2.1 On-farm benchmarking of environmental value of TGP management
2.2 Establishing a mechanism for trading and delivery of environmental services for the red meat industry</td><td>Projects
3.1 Establishing a network of co-learning sites.
3.2 Identification of cost effective TGP management options</td><td>Projects
4.1 National task force to co-ordinate and develop TGP management policy</td></tr>
<tr><td>$1,170,000</td><td>$490,000</td><td>$450,000</td><td>$150,000</td></tr>
<tr><td>Timeframe
1.1 Stage 1: Proof of concept: 6-9 months ($60,000)
Stage 2: Prototype development: 12 months ($450,000)
1.2 Stage 3: Pilot for tool prototype: 3-4 years ($360,000)
Stage 4: Implementation: 2 years ($300,000)</td><td>Timeframe
2.1 On-farm benchmarking: 4 years ($440,000)
2.2 Trading environmental services: 6-12 months ($50,000</td><td>Timeframe
3.1 Establish a network of co-learning sites: 6 months ($170,000)
3.2 Cost effective TGP management: 12 months ($280,000)</td><td>Timeframe
4.1 National TGP Task Force: 12-18 months ($150,000)</td></tr>
</table>

Stakeholders groups

Industry Research and Development Corporations	Government	Universities and Commercial Providers	Agricultural Sector Stakeholders	Finance & Commercial Sectors	Industry Lobby Groups	Philanthropic Investors
Meat & Livestock Australia • Sheepmeat Council of Australia • Australian Meat Industry Council Australian Wool Innovation (AWI) Goat Industry Council of Australia (GICA) Grains Research and Development Corporation (GRDC)	Federal (Department of Environment and Energy; Agriculture and Water Resources) State (NSW Department of Primary Industries (NSW DPI); Queensland Department of Agriculture and Fisheries (QDAF); Primary Industries and Rural Solutions South Australia (PIRSA))	University of Sydney (USyd) University of New England (UNE) University of Queensland (UQ) University of Southern Queensland (USQ) University of Adelaide (UoA) FarmMap4D Cibo Labs CSIRO	Producers and Land Managers NRM Bodies The Rangeland Alliance Kangaroo industry Retailers (Fencing)	Banks (NAB; Westpac; Rabo Bank) Retailers (Woolworths; Coles) Mining companies	NSW Farmers AgForce Queensland Livestock SA Pastoralists and Graziers Association of WA Animal Welfare groups	The PEW Charitable Trusts

Sub-Program 1. Stakeholders roles

Industry Research and Development Corporations	Government	Universities and Commercial Providers	Agricultural Sector Stakeholders	Finance & Commercial Sectors	Industry Lobby Groups	Philanthropic Investors
MLA seek and secure funding including co-investment from AWI and GICA MLA to convene project initiation workshop including detailed project scoping	State: NSW DPI, QDAF, PIRSA, co-development and pilot of "proof of concept"; management of research sites to support evidence-based understanding of achievable production and environmental targets Support and seek funding streams	Cibo Labs/ FarmMap4D UQ and USQ to co-develop "proof of concept" and participate in field evaluation Cibo Labs develop and identify temporal and spatial changes in biomass UNE, NSW DPI (Biosecurity), USQ and USyd to develop methods to monitor herbivore populations NSW DPI, QDAF and PIRSA to develop methods to monitor livestock movement and production Commercial software developers UoA (Australian Institute of Machine Learning) to develop methods to integrate on-farm and GIS derived data Support and seek funding streams	NRM bodies support ongoing communication and adoption programs NRM bodies and The Rangeland Alliance to identify and facilitate industry forums, determine location of core/technology transfer sites and producer group participants Land managers and groups to participate in core and technology transfer sites Land managers industry champions NRM bodies support and seek funding streams	Banks (NAB; Westpac; Rabo Bank) co-investors Retailers (Woolworths; Coles) co-investors		PEW Foundation to champion program sponsorship

Sub-Program 2. Stakeholders roles

Industry Research and Development Corporations	Government	Universities and Commercial Providers	Agricultural Sector Stakeholders	Finance & Commercial Sectors	Industry Lobby Groups	Philanthropic Investors
MLA seek and secure funding including co-investment from AWI and GICA	State: NSW DPI, QDAF, PIRSA, management of research sites to support benchmarking, risk profile tool and identify trade-offs between environment and livestock production Federal: co-investment in on-farm benchmarking and environmental risk profile tool Support and seek funding streams	Universities to review suitable environmental indicators Cibo Labs and commercial software developer to develop environmental risk profile tool USQ, UQ and USyd development of environmental risk profile tool and develop mechanism for trading of environmental services UoA (Australian Institute of Machine Learning) to develop methods to integrate on-farm and GIS derived data Support and seek funding streams	NRM bodies identify and facilitate locating research and demonstration (technology transfer) sites NRM bodies supporting and co-ordination of research extension and development activities to support integration of adaptive management and early warning signals Pastoralists and industry groups participation in co-learning research (core and technology transfer sites) Land managers industry champions NRM bodies to develop locally relevant guidelines for identification of ‘hot spots’ (biomass/ composition) NRM bodies support and seek funding streams	Banks (NAB; Westpac; Rabo Bank) and retailers (Woolworths; Coles) to provide funding support to identify environmental co-benefit indicators		PEW Foundation to champion program sponsorship

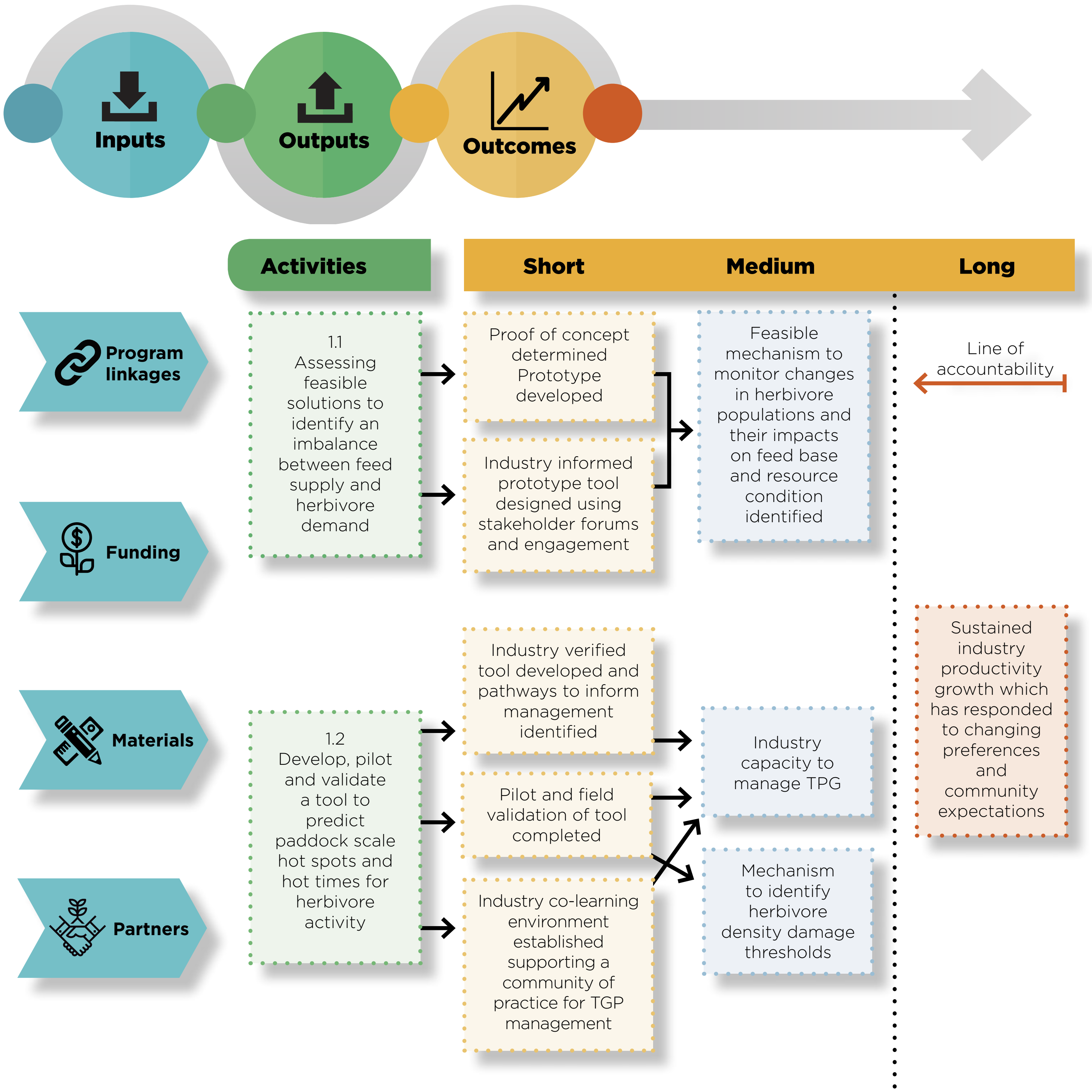
Sub-Program 3. Stakeholders roles

Industry Research and Development Corporations	Government	Universities and Commercial Providers	Agricultural Sector Stakeholders	Finance & Commercial Sectors	Industry Lobby Groups	Philanthropic Investors
MLA seek and secure funding including co-investment from AWI and GICA	State: NSW DPI, QDAF, PIRSA, management of research sites refinement and demonstration of TGP management options	USQ and UNE to undertake economic assessment (cost effective TGP management options) CSIRO to evaluate trade-offs (optimisation of land-use for pastoralism and TGP management	NRM bodies and The Rangeland Alliance to identify and facilitate locating research and demonstration (technology transfer) sites, support network of co-learning sites Land managers, adaptive management of research sites, refinement and demonstration of TGP management options in co-learning environment NRM bodies articulate the value proposition for TGP control methods	Banks and retailers to provide funding support to research TGP management options Fencing companies co-fund demonstration sites		PEW Foundation to champion program sponsorship

Sub-Program 4. Stakeholders roles

Industry Research and Development Corporations	Government	Universities and Commercial providers	Agricultural Sector Stakeholders	Finance & Commercial Sectors	Industry Lobby Groups	Philanthropic Investors
MLA seek and secure funding including co-investment from AWI, GICA and GRDC	State and Federal advice on legislative requirements		NRM bodies and the Australian Rangeland Alliance to co-convene national task force		Representation from all industry lobby groups	

Sub-program 1:
Technical capacity for industry to manage all herbivores



1.1 Assessing feasible solutions to identify an imbalance between feed supply and herbivore demand

There are four stages to be undertaken sequentially

Stage 1: Proof of concept

Technical workshop to scope the development of an early warning technology product or tool to identify an imbalance between feed supply and herbivore demand; the tool to capture spatial and temporal trends for diagnostic and predictive responses; applied at a paddock scale with capacity to be integrated at whole property scale; identify key GIS data sources (e.g. Sentinel products for near real-time pasture biomass) and other remotely sensed products to provide real time changes in feed supply (biomass and quality); field method to detect the density and distribution of all herbivores. The following three steps will develop the "Proof of concept"

i. **Development of a Primer document**: This will be informed by the review document B.TGP.1702 and detail the project scope, technical experts, industry networks, existing GIS data sources, State government kangaroo and goat regional monitoring, current research programs and management options to build a "straw man" diagnostic and predictive tool to identify an approaching imbalance between feed supply and demand. This Primer document will inform industry Stakeholder Forums.

ii. **Industry Stakeholder Forums**: Industry consultation using three (QLD, NSW and SA) regional forums to determine the needs and requirements from industry for data sharing and integration with pastoral management decisions. This will inform and refine tool design (e.g. visualisation of output/reporting and dashboard design) and also scope the inclusion of property scale collection of data (citizen science approach) and App development to support real-time, locally specific data sources for tool development.

iii. **Technical workshop**: A two-day workshop will be conducted bringing together technical expertise in data analytics, monitoring wildlife populations and livestock grazing management/behaviour, feed base and resource condition and to scope resourcing requirements for tool development and validation. Examples of scope of these expert groups include:

    a. Data analytics: uploading and analysing data (cloud based, on-line, App); requirement for additional derived data sources; real-time analytics using a mix of historical and local real-time data sources (qualitative and quantitative approaches).

    b. Wildlife populations and livestock grazing management/behaviour: Application of sensors/themography to remotely monitor paddock-scale herbivore location and behaviour; predictive modelling of population changes; remote weighing to measure livestock production (weight and growth).

Estimated timeframe for completion: 6-9 months

Estimated budget: $60,000

Stage 2: Prototype development:

Predictive analytics undertaken by independent software developer with multiple iterations validated with industry user groups across the network of sites; modification of existing platform such as FarmMap4D or MLA website used to house the tool.

Estimated timeframe for completion: 12 months

Estimated budget: $450,000

1.2 Pilot and validate a tool to predict paddock scale hot spots and hot times for herbivore activity

Stage 3: Pilot for tool prototype:

Field validation of prototype tool to be undertaken at multiple "Core" field sites (Figure 1) in a co-learning environment with land managers and researchers. A co-learning environment established with land managers and pastoralists to inform further tool design and refinement, delivery of an outreach program as well as supporting adaptive grazing management. Software developers finalise tool design, involving iterative modification using land manager groups. The ability for the tool to predict locally specific TGP 'imbalance' thresholds/trends will be assessed. The utility value of the tool to allow for a bespoke approach that accounts for local conditions (site condition, vegetation/soil and management) will also be assessed.

Estimated timeframe for completion: 3-4 years

Estimated budget: $360,000

Stage 4: Implementation:

A development program to demonstrate tool and link to adaptive grazing management across 24 co-learning sites (Figure 1). Demonstrate pathways for management options to respond to early warning signals of a feed supply/demand imbalance developed in an adaptive management framework.

Estimated timeframe for completion: 2 years

Estimated budget: $300,000

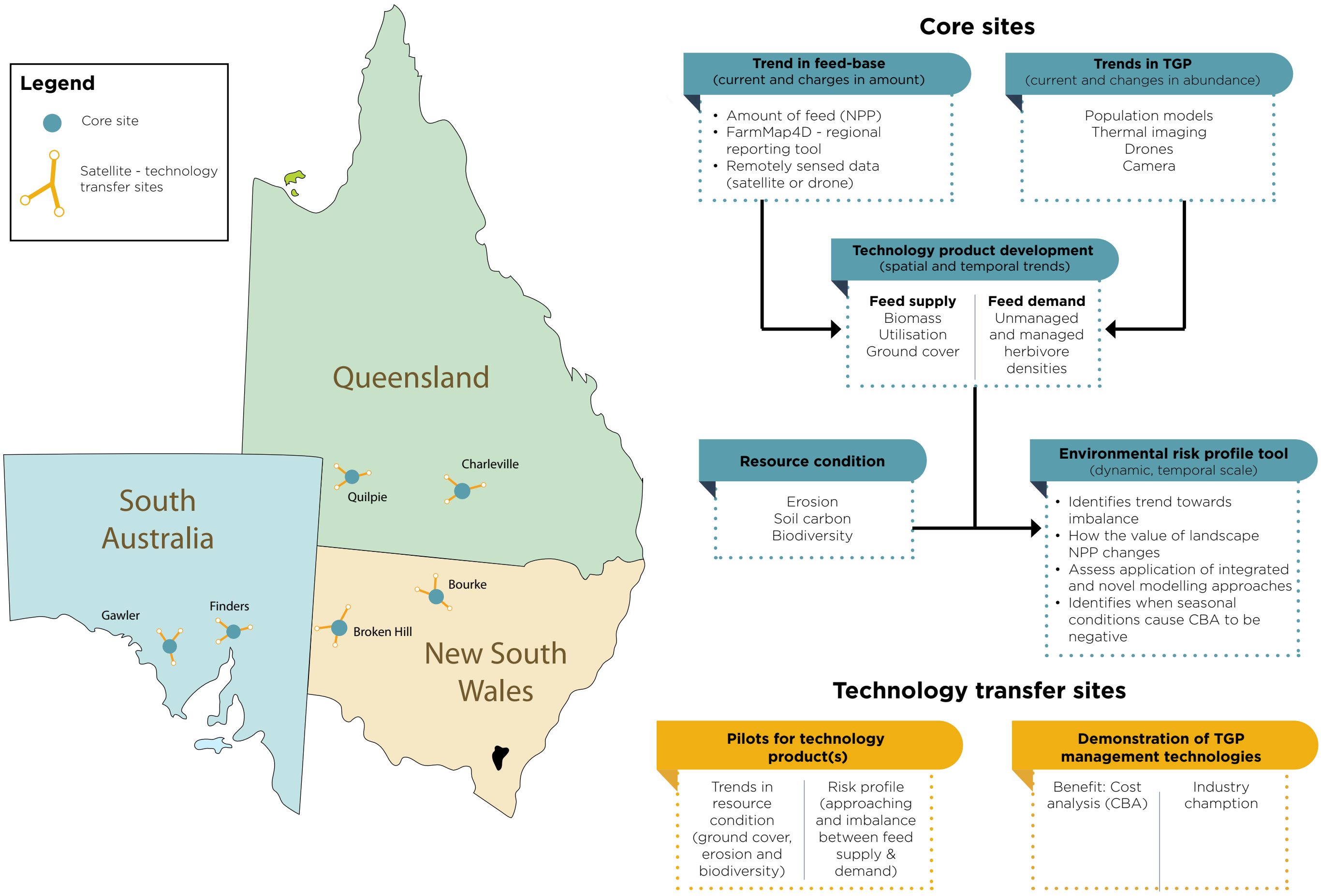
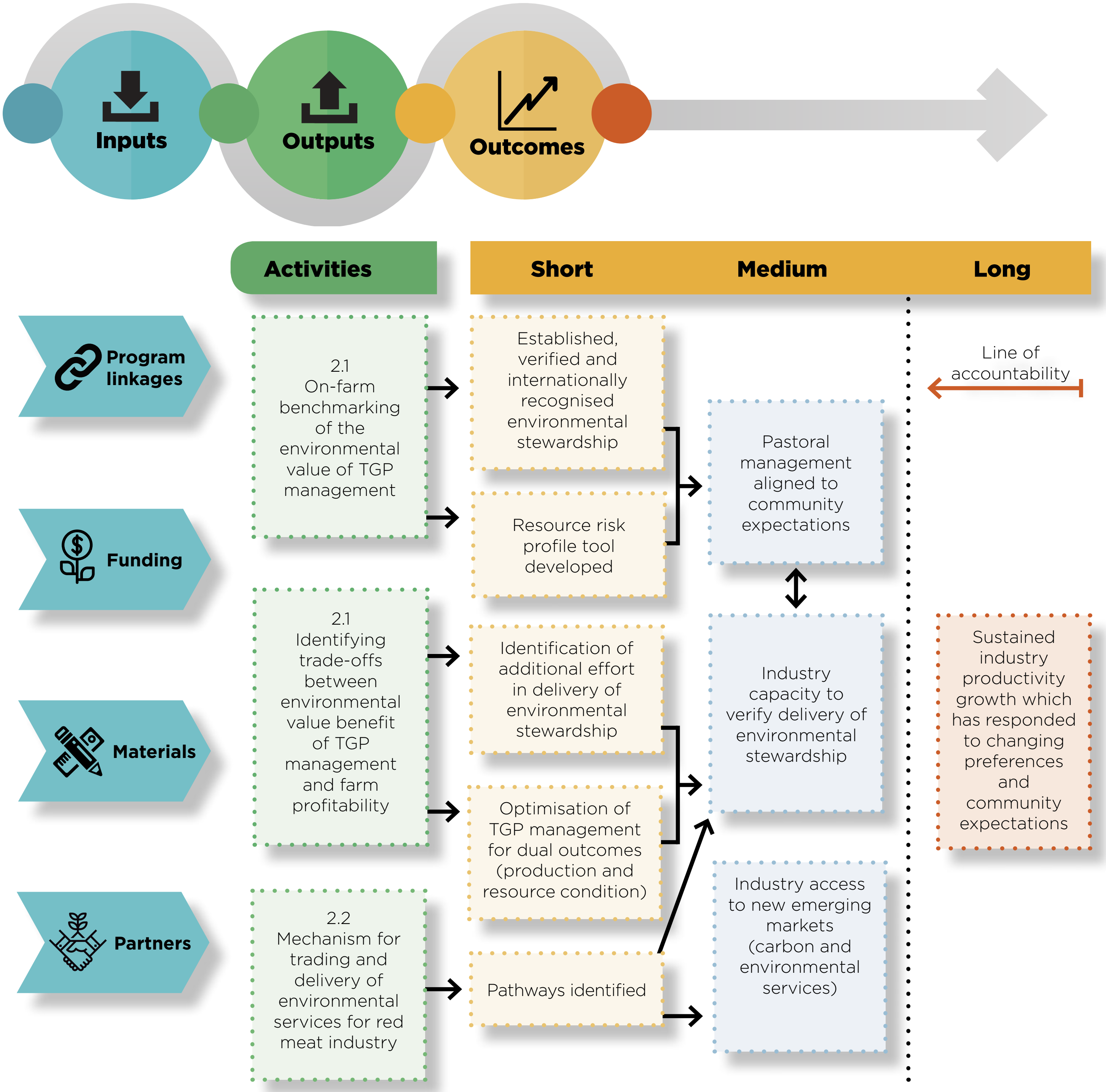


Figure 1. Location of core and satellite sites (technology transfer sites). Core sites are required to pilot, validate and demonstrate technology products (spatial and temporal trends tool and environmental risk profile tool). Satellite sites are required to demonstrate TGP management options in a co-learning environment which also allows adaptive grazing management to be supported through the integration of tools under regionally relevant conditions. Outreach programs will be supported through site networks. Location of sites chosen because they represent high total grazing pressure regions and/or adoption of TGP/exclusion fencing. These sites provide a network to support industry co-learning and a community of practice for TGP management.

Sub-program 2:

Realising the production and environmental benefits of TGP management



2.1 On-farm benchmarking of environmental value of TGP management

Evaluate through meta-data analysis and industry consultation, industry relevant indicators for resource condition (ground cover, perennial pasture composition, biodiversity, soil carbon). Initially, this will be underpinned by a literature review to assess practical rangeland environmental indicators. Develop a method to capture resource dynamics using integrated modelling which captures current landscape condition and changes over time. This may include a consideration of machine learning modelling rather than traditional statistical approaches. Here, opportunities to use locally specific information may be captured by land managers through e.g. purpose built App's to provide ongoing assessment of on-farm trends. This will be developed into an environmental "risk profile" tool which accounts for temporal and spatial impacts of land management to allow changes in management decisions to be considered in the context of farm economics. The "risk profile" benchmarking will be undertaken at 6 "Core" sites and efficiencies in delivering this project can be made by linkages with projects 1.2.

Estimated timeframe for completion: 4 years

Estimated budget: $440,000

2.2 Establishing a mechanism for trading and delivery of environmental services for the red meat industry

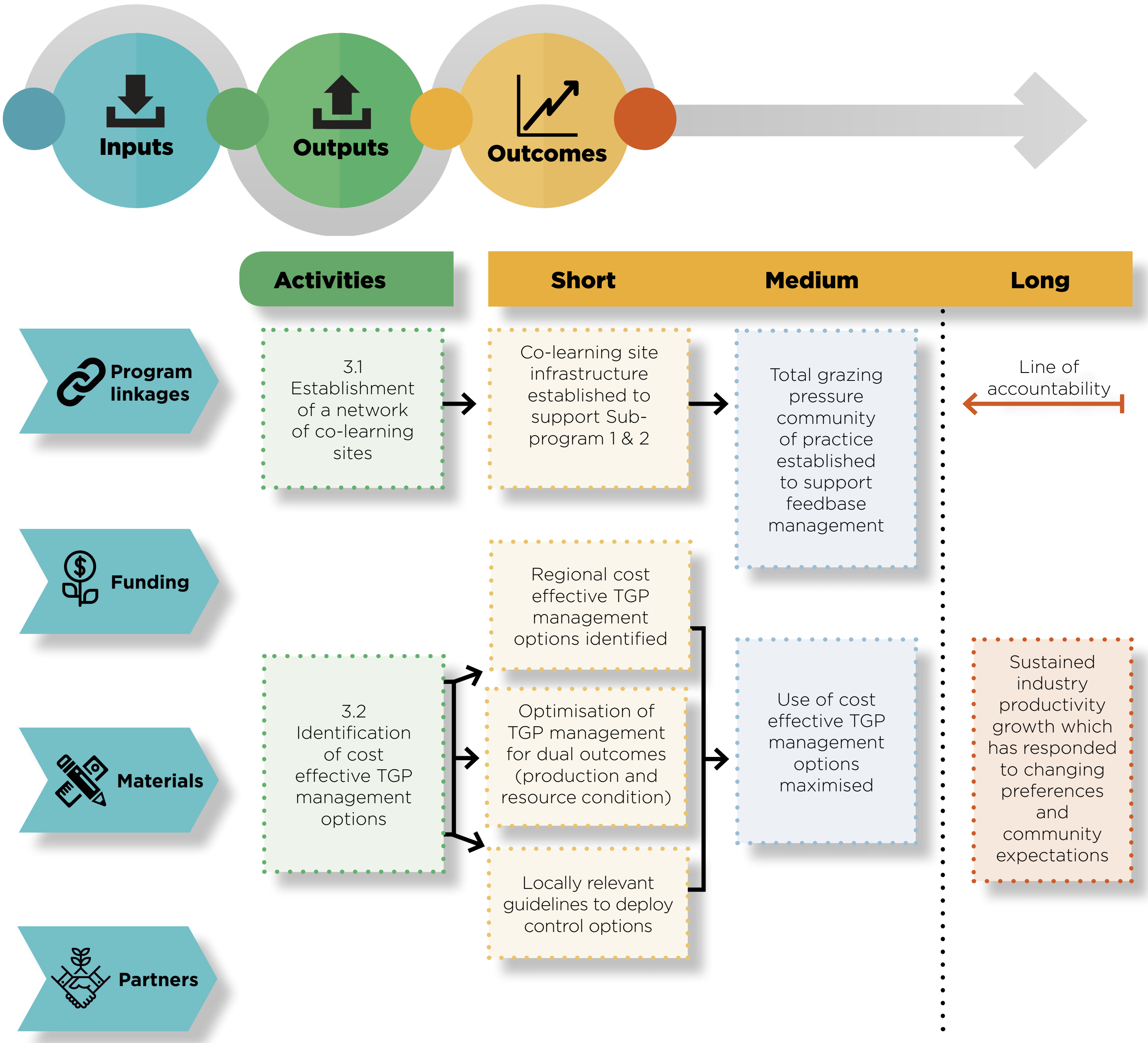
This is largely a desktop study to establish the rights and rules for TGP management that deliver environmental services and understand social and political constraints. Pathways to identify and label sustainable products demonstrating good stewardship will be identified. Economic analysis to determine the marginal benefits and costs to landholders to deliver environmental benefits will be costed and valued using a number of industry case studies. Established relationships and delivery pathways/channels for rangeland land managers to access environmental services markets will be identified. There are strong linkages to programs within the CRC High performing soils and The Sustainability framework for the red meat industry.

Estimated timeframe for completion: 6-12 months

Estimated budget: $50,000

Sub-program 3:

Realising the production and environmental benefits of TGP management



3.1. Establishment of a network of co-learning sites

Identify collaborative land managers and establish multiple co-learning sites (TGP fencing; cluster fencing/ collaborative area management and paired contrasts outside fenced areas). This funding will provide a dedicated coordinator, support field day/updates and establish infrastructure as required. The expectation is that local NRM bodies through the Rangeland Alliance will undertake the role of managing the network, once established. Infrastructure of 24 monitoring and evaluation sites established. Identify local interest in livestock grazing management and TGP management alternatives for producer groups at each of the 24 sites. Adaptive livestock management decisions within each of the paired contrast sites to be made collectively by producer groups at each site. Implications of management decisions to be evaluated in a co-learning environment. A network for communication and sharing of co-learning supported nationally through established links with NRM bodies by The Rangeland Alliance.

Estimated timeframe for completion: 6 months

Estimated budget: $170,000

3.2 Identification of cost effective TGP management options

At each of the satellite "technology transfer" sites a comprehensive (whole farm) economic assessment of TGP management options to be undertaken. Input data for these analyses to be developed using locally relevant on-farm values, identified through producer groups. The herbivore density thresholds which support economic management options identified. Locally relevant, TGP management guidelines to be developed and shared across the network of producers. Opportunities for co-investment in outreach programs and training in e.g. grazing management, animal health and welfare also need to be developed, adding value to the
co-learning sites.

Estimated timeframe for completion: 12 months

Estimated budget: $280,000

Sub-Program 4:

Legal capacity for industry to manage all herbivores

4.1 National task force to co-ordinate and develop TGP management policy

This sub-program recognises the requirement for TGP management to be formed within the context of a social licence to operate and aims to influence policy settings by

i. Obtaining recognition that Macropods are comparable to "livestock" and require management under certain seasonal conditions. This will require negotiation with animal welfare and state government environment reporting to modify or influence policy and legislation.

ii. An examination of animal welfare issues associated with TGP management options. This would include scoping and developing an 'industry code of practice' for animal welfare best practice.

iii. National coordination of TGP policy which is informed by a reliable, national TGP monitoring program (including the contribution of livestock, feral and native herbivores). This will require negation with state government agencies to report regional changes kangaroo and goat populations in an industry relevant, timely format. This material should be reported on the MLA website.

Estimated timeframe for completion: 12-18 months

Estimated budget: $150,000

Department of Primary Industries

Prospect statement

Addressing feed supply and demand through total grazing pressure management

MEAT & LIVESTOCK AUSTRALIA

Industry vision

Total grazing pressure management in the Australian Rangelands has delivered sustained productivity growth and has responded to changing market preferences and community expectations.

Industry is better equipped to adapt to drought and climate variability through the effective management of all herbivores.

Red meat production in the Southern Australian Rangelands is able to verify minimal negative environmental impacts and demonstrate continual environmental improvement. Over time, this will enable a defensible case for the increasing social licence of the red meat industry.

RD&A Program outcomes

By 2024 this program of work will:

- Equip producers and jurisdictions with the means to quantify current total grazing pressure impacts and provide a predictive tool that identifies density/damage functions to inform proactive management decisions;
- Raise awareness of 1,500 land managers (~ 25 percent of the pastoral industry of Southern Australian Rangelands) of cost-effective total grazing pressure management;
- Directly engage 2,000 landholders in co-learning and information exchange activities;
- Have 100 landholders contributing meta-data to the R&D program; and
- Establish at least 24 co-learning and monitoring sites within six nodes across three states (QLD, NSW, and SA).

The need to manage total grazing pressure (TGP)

Total Grazing Pressure (TGP) has been defined as the combined grazing pressure exerted by all managed and unmanaged herbivores on the vegetation, soil and water resources of rangeland landscapes. TGP is important because it influences the demand for forage (feedbase) by all herbivores, relative to supply. A central tenet in TGP management is therefore achieving the balance between supply and demand for feed, and avoiding an imbalance occurring when feed demand exceeds feed supply. This imbalance can be detrimental to animal welfare, livestock productivity and damage resource condition.

Less than half the herbivory in Southern Australian Rangelands is managed by pastoralists. Recent estimates suggest that a total of 28.93 million DSE are currently grazing these areas, of which 15.57 million DSE are unmanaged Macropods and goats and 13.36 million DSE or about 45 per cent of this are livestock. The numbers of unmanaged herbivory is highest in areas protected behind the National Dog Fence, where most of the sheep in the Southern Australian Rangelands are now grazing. In areas beyond the National Dog Fence, there is still an issue in managing significant numbers of unmanaged Macropods which are competing with cattle for forage.

The quantity and quality of forage available for all herbivores within the Southern Rangelands is frequently low, and as seasonal conditions deteriorate, there is direct competition between managed and unmanaged species for forage. With an expected increase in the frequency of variable seasons, this issue will only increase, exacerbating the decline in the prerequisite natural resource base. This will subsequently impact on short and long term production and threaten the social licence to operate for livestock industries. This will be most apparent when high densities of herbivores coincide with periods of low rainfall.

Livestock management which rotationally graze paddocks and allows effective rest and recovery of pastures can maintain higher levels of ground cover, increase floristic diversity and perennial grass content as well as increasing long-term soil organic carbon levels. While various forms of rotational grazing and pasture spelling are being practiced by land managers, grazing by Macropods in particular may reduce the benefits pastoralists may gain from early destocking, and resting pastures to allow recovery. Finally, land managers are obtaining no benefit from grazing Macropods, and there are contested views on the cost they impose upon the pastoral business through both impacts on resource condition and feedbase.

Rangeland managers require real-time information and cost-effective technologies to be able to manage total grazing pressure. To improve management of existing enterprises, the rangeland pastoral industry need to be able to:

- Identify early when an imbalance between forage supply and forage demand is imminent so that they can take action;
- Quantify the impact on resource condition, forage availability (and financial return) from grazing herbivores and current grazing approach; and
- Quantify the impact of non-managed herbivores accessing spelled paddocks, allowing land managers to determine how much to invest in control of unmanaged herbivores.

Changing consumer preferences are dictating that the red meat industry is able to demonstrate production system practices that use natural resources wisely and show care and health of animals. Globally, expectations for sustainability development and addressing climate change impacts are also driving a need for the red meat industry to meet these expectations. The management of total grazing pressure provides an opportunity for southern rangeland pastoral industries to increase livestock productivity, meet changing consumer preferences for sustainably produced meat and fibre and maintain its social licence to operate.

Value proposition

By identifying early when an imbalance between forage supply and forage demand is imminent, land managers can take action and be proactive in decision making optimising feedbase for livestock enterprises and ecological function.

Providing evidence of productive and sustainable practices that may be required in differing markets allows the red meat industry to meet market specifications of livestock products and commit to forward contracts. This will capture emerging market opportunities associated with land management (e.g. carbon and environmental services).

Overview of investment priorities for "*Addressing feed supply and demand through total grazing pressure management*" program			
Stakeholder Advisory Panel **Who:** RD&A expertise, land manager representatives, wildlife managers, animal welfare adviser **Role:** External program integration; Stakeholder an industry views			
Program Director **Role**: RD&A Plan management and coordination; Program contractual protocols; Internal and external program integration; Engagement and communication; Succession and capacity building; Program monitoring and evaluation			
Total grazing pressure management network **Role:** Development and delivery of stakeholder engagement and communication plan for each sub-program.			**Meat and Livestock Australia**
Program Manager	**Program Manager**	**Program Manager**	
Sub-program 1 *Technical capacity for industry to manage all herbivores*	Sub-program 2 *Realising the production and environmental benefits of total grazing pressure management*	Sub-program 3 *Widespread adoption of evidence-based, effective total grazing pressure management*	Sub-program 4 *Legal capacity for industry to manage all herbivores*
Outcomes • Identification of herbivore density/ damage thresholds for TGP • Industry verified tool for TGP management • Industry pathways to manage TGP identified	**Outcome** • Acceptable trade-offs between the environmental value of TGP management and farm profitability identified • Identification of spatial and temporal impacts on resource condition • Increased access to new markets	**Outcome** • Locally relevant guideline to deploy TGP options • Industry use of cost-effective TGP management options maximised • Reduced risk of early adoption	**Outcomes** • Policy framework which accommodates TGP management • Community recognition of the impact of unmanaged herbivores • Cross jurisdiction agreement for industry to responsibly manage Macropod populations
Projects **1.1** Assessing feasible solutions to identify an imbalance between feed supply and herbivore demand **1.2** Pilot and validate a tool to predict paddock scale hot spots and hot times for herbivore activity	**Projects** **2.1** On-farm benchmarking of environmental value of TGP management **2.2** Establishing a mechanism for trading and delivery of environmental services for the red meat industry	**Projects** **3.1** Establishing a network of co-learning sites **3.2** Identification of cost effective TGP management options	**Projects** **4.1** National task force to co-ordinate and develop TGP management policy
$1,170,000	**$490,000**	**$450,000**	**$150,000**