LITERATURE REVIEW

BioBrowser: Establishing a biodiversity baseline for the Australian goat industry

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Abstract

The project BioBrowser: Establishing a biodiversity baseline for the Australian goat industry (B.GOA.0003), is the first stage of developing a sustainability framework for the Australian goat industry. The first step in the project is this literature review, with the objective being to gather sufficient information to design an on-farm pilot to test shortlisted biodiversity measures in goat production systems, and feed into a cost-benefit analysis. This BioBrowser literature review is intended to provide insights into:

- how biodiversity is currently assessed and monitored within livestock production systems
- how feed supply (biomass) is estimated in Australian rangelands environments (focusing on goat production)
- current methods of assessing rangeland condition and how these relate to biodiversity
- how total grazing pressure is estimated, and managed, in the Australian rangelands
- the ecological role and impact of goats in landscapes where they are extensively grazed (e.g. Australian rangelands).

Goatmeat production is the largest goat industry in Australia, although goats are also used for dairy and fibre (mohair and cashmere) production. Rangeland goats are the major source for the goatmeat processing industry, accounting for approximately 90% of total goat meat production. Rangelands include all those environments where natural ecological processes predominate and where values and benefits are based primarily on natural resources, which have not been intensively developed for primary production.

The interaction between goats and biodiversity in Australia is complex. Competition and land degradation by feral goats is listed as a key threatening process under the federal EPBC Act. There is increasing consumer pressure on the red meat and fibre industries to demonstrate continuous environmental improvement, and justify their social licence to operate (Hacker et al 2019). Given the reliance of the Australian goat industry on unmanaged rangeland goats, and the significant implications of this production system for biodiversity, this literature review concentrates on rangelands production systems. Additionally, the sheep industry, through the SSF and Nature Positive Farming (AWI) are actively developing measures for biodiversity in southern Australia. These measures are likely to also be a good fit for goat production in these landscapes.

Whilst risk management for the industry (climate change adaptation and social licence), is a key imperative for measuring biodiversity within the Australian goat industry, other drivers include:

1. Basis for industry-level sustainability reporting (e.g. Goat Industry Sustainability Framework).
2. Increase industry readiness to participate in new markets (e.g. nature repair, biodiversity credits).
3. Supply chain (consumer) demands (particularly in growing the domestic market).
4. Support producer decision-making (increased data regarding the resource base).
5. Meet needs for farm businesses to report sustainability (e.g. finance sector, insurance sector).



The long-term use of rangelands for livestock production, combined with feral herbivores and exotic species have led to widespread decline in ecosystem condition (Landsberg et al 2003). However, making a direct link between resource condition, biodiversity and livestock production in the rangelands is problematic (Fensham et al 2010 and 2011; Waters et al 2018), and there is no evidence that well-managed goats (in the same way as cattle or sheep), are negative for the environment (Waters et al 2018). Total grazing pressure (TGP) is the combined grazing pressure exerted by all managed and unmanaged herbivores on vegetation, soil and water resources (Fisher at al 2004). Current industry best practice encourages pastoralists to account for, and manage, the grazing pressure from non-domestic herbivores, as well as domestic livestock, to protect from over-grazing and impacts on land condition (MLA 2023; Campbell and Hacker 2000). Attempting to differentiate the grazing impacts of different species of herbivore is problematic and unlikely to yield meaningful information. A focus on TGP is therefore recommended in establishing a biodiversity baseline in the pastoral rangelands.

Rainfall is the principal driver of change in the rangelands (Bastin 2008). It has been observed that changes in ground cover due to management changes are dwarfed by changes due to seasonal conditions. Research consistently shows that stocking rate and the intensity and duration of grazing are the strongest drivers of floristic diversity, rather than the grazing system itself (Hacker and McDonald 2021; Hunt et al, 2014; Stafford-Smith et al, 2007). There is considerable evidence to support the beneficial effect of including rest periods on production and environmental sustainability (Hacker and McDonald, 2021). The once widely accepted view that grazing pressure should be spread over the landscape as evenly as possible, is now thought to reduce biodiversity because it leaves little of the landscape unaffected by grazing (Fisher et al 2004). Supporting landscape heterogeneity is now encouraged as industry best practice (MLA, 2023), with the importance of maintaining some areas remote from water promoted in a number of rangelands monitoring programs (e.g. SA's rangelands assessment method).

Failure to adequately separate the different drivers of rangeland condition can lead to misinterpretation of grazing effects. Well-functioning rangelands are both productive and resilient, able to support grazing systems while sustaining ecological health. A rangeland in good condition is one where the fundamental ecological processes of water infiltration, nutrient cycling, energy capture, and species interactions are working effectively, and resources (particularly water and nutrients) are retained within the local system rather than being lost through runoff. Hence, some aspects of rangeland condition are correlated with biodiversity, in some ecosystems.

There are a number of tools and approaches currently used by industry to assess rangeland condition. All of these tools incorporate measures of ground cover (litter, cryptogams, erosion) and coverage of perennial, palatable plants. While formal recording by producers does not appear to have been widely adopted, there are pastoral monitoring programs in SA and WA, and industry monitoring via organisations such as LLS in NSW and QDAF in Queensland. There is an opportunity to leverage these industry-supported rangeland condition monitoring approaches in measuring biodiversity. This may also generate benefits of de-mystifying biodiversity, and positively engaging producers.

Eleven approaches relevant to measuring biodiversity at a property scale in the rangelands, were reviewed:

1. Farming for the Future (FftF) and Nature Positive Farming (AWI)
2. Accounting for Nature (methods NV-03, NV-07 and NV-10)
3. Clean Energy Regulator nature repair market – replanting native forest and woodland ecosystems (rangelands ineligible for this method)
4. Climate Friendly rangelands nature repair method (under development)
5. Native Vegetation Council (SA) rangelands assessment manual (RAM)
6. Ecological Outcome Verification (EOV)
7. Green Collar / Farming for the Future rangeland natural capital assessment (under development)
8. Australian Collaborative Rangeland Information System (ACRIS)
9. Clean Energy Regulator Human Induced Regeneration carbon project method
10. Biodiversity assessment method (BAM), NSW.
11. BioCondition, Queensland.

There was substantial consistency between the different methods and approaches to measurement. All methods use ecosystem benchmarks or reference condition to assess sites against, and all require field work to be conducted by an ecologist. The majority of methods utilise remote sensed data, to a greater or lesser extent. However, discussions with stakeholders conducted as part of this review strongly suggest that even for apparently simple measures such as ground cover, remote sensing is not yet reliable. Field assessments include tree/shrub cover, height and recruitment, weed cover, species richness, landscape context, etc. Ensuring consistency between goat industry biodiversity measures, and those used in other rangeland monitoring programs will enable value-adding rather than duplication; noting that the end use of data determines the level of rigour, independence and accuracy required.

Ten potential measures for establishing a biodiversity baseline for the Australia goat industry have been shortlisted. Some are not direct measures but are required to support interpretation of results, including trends. They are as follows:

- seasonal rainfall
- total grazing pressure
- remoteness from water (heterogeneity of grazing, and areas remote from water are important for biodiversity)
- locations of conservation significance (biodiversity hot spots) (landscape features important for biodiversity, and locations of threatened species or communities are identified and managed to protect biodiversity values)
- riparian tree cover (% waterways with tree cover)
- organic ground cover
- soil condition (cover, cryptogams, litter, soil roughness, erosion)
- biomass
- vegetation condition (vegetation structure, weed cover, shrub/tree recruitment, native plant cover, coarse woody debris, utilisation and presence of key shrub and ground cover species)
- management practices (assessing ground cover and forage condition and adjusting stocking rate in response; resting paddocks; in harvested rangeland situations, unsaleable animals are culled; targeted management of biodiversity hotspots; proactive control of feral animals; harvesting goats regularly to manage TGP; turning off water in paddocks not being grazed by livestock).

The 10 shortlisted measures being proposed for establishing a biodiversity baseline for the Australian goat industry are consistent with current industry methods, and will be suitable for all rangelands livestock enterprises (cattle, sheep and goats), as they are specific to the rangelands environment. By accounting for rainfall, the proposed approach can help separate climate from grazing impacts, enabling informed interpretation and decision-making. Collecting data on TGP is key to understanding grazing impacts.

What is proposed is consistent with other approaches that don't directly measure fauna, but assume a relationship between fauna populations and healthy habitat. Remote sensing is key to minimising costs of measurement, and only with further use will these tools become better calibrated and more useful. However, it is currently not considered reliable enough to be the sole measure. Field-based monitoring is included to improve the rigour of biodiversity assessments. Some of these leverage existing industry activities, while others specifically target biodiversity. All outcome-based measures should be compared to reference condition, as a means of assessing the results for biodiversity performance. The shortlisted biodiversity measures must be meaningful now, but should also include measures under development, with appropriate safeguards (e.g. ground cover assessment via remote sensing). The responsiveness of the measures to management, and the speed of change are also important considerations in enabling trends in condition over time to be determined.

While the focus for biodiversity measures is on outcome-based measures, combining them with carefully selected practice measures is recommended to help even out the noise associated with seasonal variation, account for the slow response times of the environment to changed management, and minimise data capture costs.

Using producers' knowledge of the country they manage, and building that knowledge, is an opportunity that should be embraced in establishing a method for biodiversity monitoring in the Australian rangelands. The proposed approach recommends using existing industry rangeland condition measures as a starting point. This will be less daunting for industry, and more likely to engage producers already familiar with these approaches. It also leverages the existing expertise in support and advisory networks.

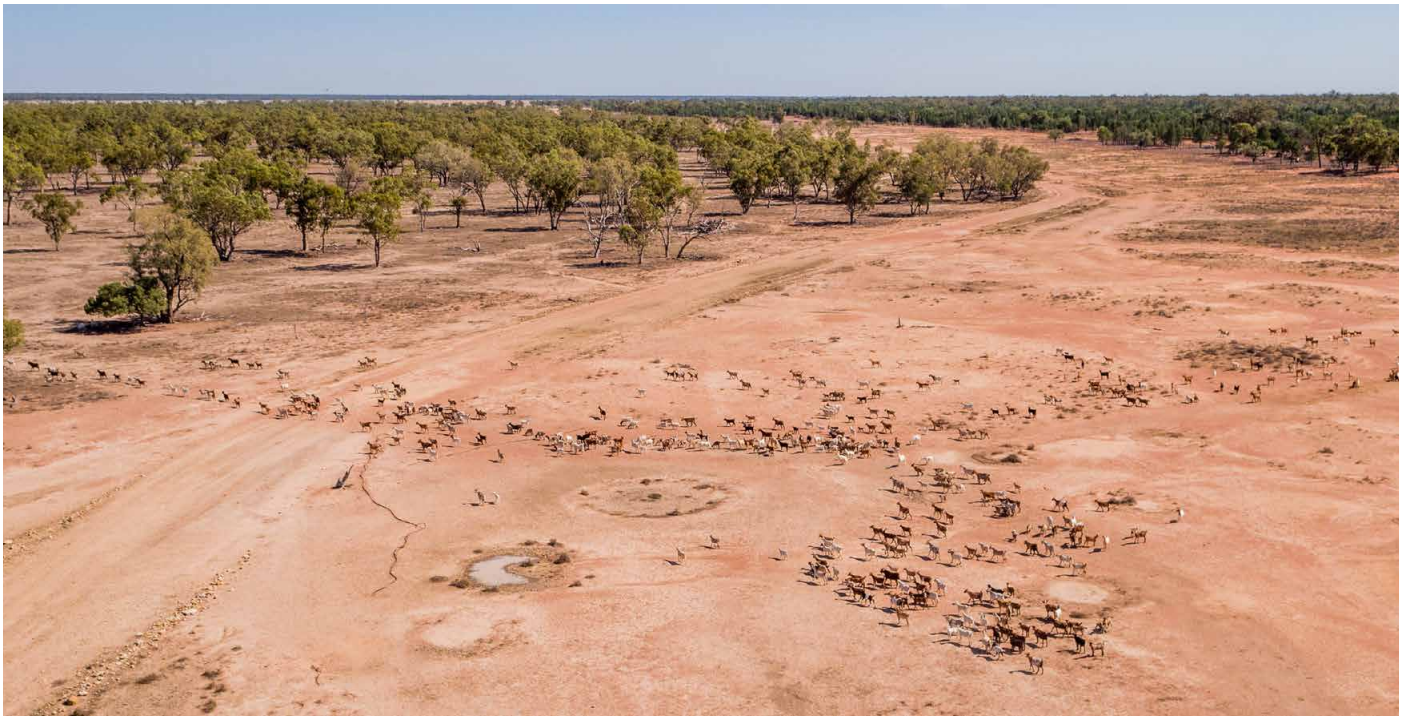


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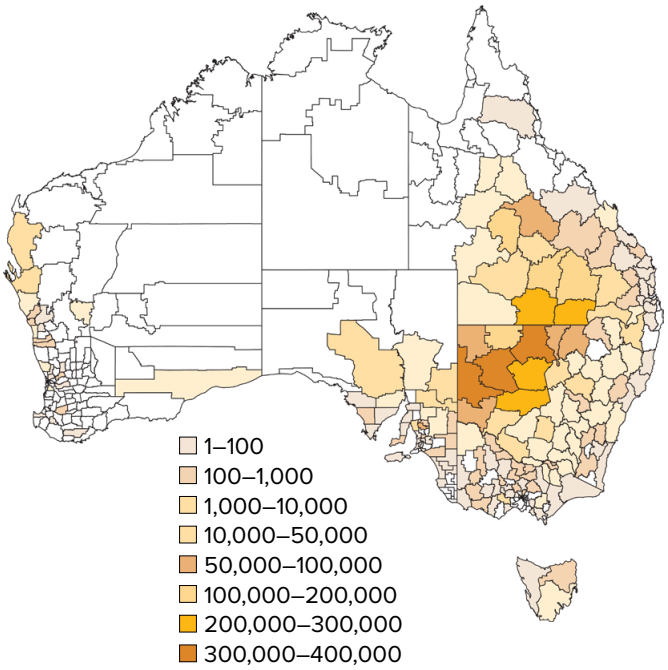
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1 Introduction

The importance of goat production to the Australian red meat industry has significantly increased in recent years, with a 248% production increase between 2020 and 2024 (MLA Industry insights, global snapshot May 2025). Globally, Australia is a minor producer of goatmeat but the largest exporter (48% of global goatmeat exports in 2023) (MLA Industry insights, global snapshot May 2025).

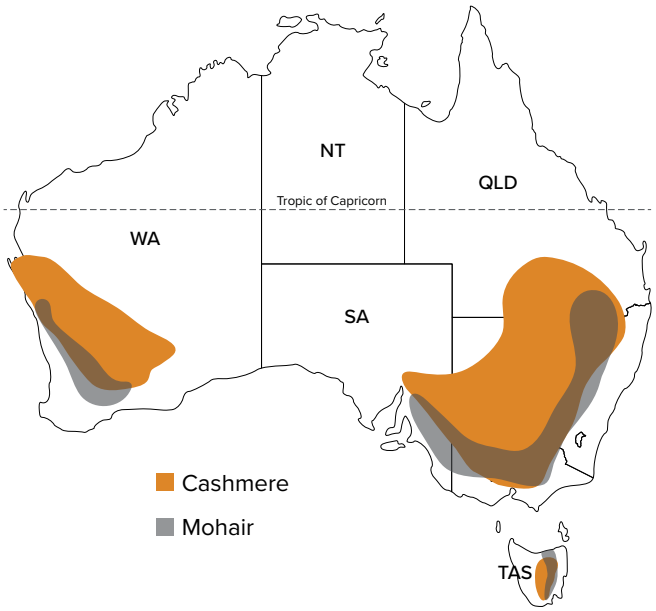
Rangeland goats are the major source of goats for the goatmeat processing industry, accounting for approximately 90% of total goat meat production (goatindustrycouncil.com.au/goats-in-australia/rangeland-goats/). The rangeland goat is a composite breed, which is naturalised throughout Australia's rangelands. There has been a long-term shift from opportunistic harvesting of rangeland goats to managed production systems (Atkinson et al 2021, MLA 2025). This contributes to a more consistent goatmeat supply (MLA 2025), higher yielding and quality carcass (goatindustrycouncil.com.au/goats-in-australia/rangeland-goats/), opportunity to value-add (by meeting grid requirements), and enables more control of grazing pressure (Atkinson et al 2021). These are all positive for long-term industry viability and sustainability.

Figure 1: Number of goats supplied for processing from each NLIS region in Australia (MLA global snapshot 2025)



As well as goatmeat production, goats are also used for dairy and fibre (mohair and cashmere) production. Production in the southern rangelands of Australia underpins the goatmeat industry (Atkinson et al 2021), and fibre production (**Figure 2**). Goats are also farmed in the high-rainfall and sheep-wheat zones of NSW, Queensland, South Australia, Western Australia, Victoria and Tasmania. Industry development is occurring in NSW and Queensland (Atkinson et al 2021), particularly north-western New South Wales and southern Queensland (MLA Industry insights, global snapshot May 2025). Industry development in the pastoral zones of South Australia and Western Australia has been comparatively restricted by factors including reliance on wild harvesting, state legislation, the lower relative abundance of goats, and a lower level of infrastructure development (Atkinson et al 2021).

Figure 2: Approximate locations of cashmere and mohair production throughout Australia (source: Agrifutures)



The interaction between goats and biodiversity in Australia is complex. Competition and land degradation by feral goats is listed as a key threatening process under the federal EPBC Act (invasives.org.au/media-releases/new-national-feral-goat-plan-welcomed-but-requires-funding/). As a species, goats are not governed under federal law, regulation falls to states and territories (e.g. in Victoria and South Australia they are declared animals). In 2023, a draft threat abatement plan for competition and land degradation by unmanaged goats was released for public comment (DCCEEW, 2023). This plan has not progressed since submissions closed in February 2024, however, its release put the goat industry on-notice to demonstrate environmental credentials, particularly in relation to biodiversity. As a maturing, high-value export commodity reliant on opportunistic harvest of wild rangeland goats, the Australian goat industry seeks to demonstrate its environmental credentials to international and domestic markets.

This BioBrowser literature review is intended to provide insights into:

- how biodiversity is currently assessed and monitored within livestock production systems
- how feed supply (biomass) is estimated in Australian rangelands environments
- current methods of assessing rangeland condition and how these relate to biodiversity
- how total grazing pressure is estimated, and managed, in the Australian rangelands
- the ecological role and impact of goats in landscapes where they are extensively grazed (e.g. Australian rangelands).

The approach used was to review published and unpublished literature, and gather further information via interviews with key industry and technical experts. The overall objective is to gather sufficient information to design an on-farm pilot. The pilot will test shortlisted biodiversity measures in goat production systems, developing a methodology that is defensible in terms of the parameters chosen, site selection, data collection protocols and analytical/interpretation approaches. Given this process will test the suitability of the proposed metrics, which may be further refined post-pilot, it may not be able to deliver a definitive baseline figure. The project will prepare industry to undertake this task, at both farm and regional scales, feeding into the development of biodiversity goals and indicators for the goat industry sustainability framework.

1.1 Industry frameworks and reporting

A key objective of this project is to feed into the development of a Goat Industry Sustainability Framework biodiversity goals and indicators. The beef and sheep industries have had industry-level sustainability frameworks in place for some years. The Australian Beef Sustainability Framework (ABSF) inaugural annual update was released in 2017, while the Sheep Sustainability Framework (SSF) was launched in 2021. The Australian Agricultural Sustainability Framework (AASF) is led by the National Farmers Federation to meet sustainability needs across sectors, with development beginning in 2020. The ABSF and SSF provide annual reports (Australian Beef Sustainability Framework 2023; Sheep Sustainability Framework 2024), with the data reporting period for different metrics ranging from annual to five-yearly. Both provide the outcome (data) and the status (baseline, steady, improving, declining). The AASF has not finalised biodiversity metrics, or commenced reporting.

All three industry frameworks have environmental stewardship themes (enhancing the environment and climate (SSF), and environmental stewardship (ABSF and AASF), and within this theme all have indicators or criteria relating specifically to biodiversity (**Table 1**). The ABSF uses a qualitative practice-based measure against indicator 6.1 (measured via producer surveys), and a quantitative outcome-based measure for indicators 9.1–9.4 (remote-sensed).

The SSF has not finalised metrics for measuring biodiversity indicators. It is still to settle on a definition of biodiversity, and metrics and measures will be difficult to confirm until this is done. As part of this, the SSF is reviewing adopting, or aligning with, the ABSF balance of tree and grass cover indicators (**Table 1**) (C Nelson, pers comms). The SSF is currently measuring biodiversity performance indirectly via adoption of conservation-friendly practices, (which are broad ranging, from ground cover to riparian management, and collected via the qualitative biennial national sheep producer survey) (C Nelson, pers comms).

Table 1: Summary of the biodiversity indicators of key industry sustainability frameworks relevant to goats

Australian Beef Sustainability Framework	**Sheep Sustainability Framework**	**Australian Agricultural Sustainability Framework**
Environmental stewardship Goal: By 2030, the Australian beef industry will demonstrate its net positive contribution to nature	Enhancing the environment and climate	**Environmental stewardship**
Biodiversity Indicator 6.1 Percentage of cattle-producing land managed for biodiversity outcomes through active management	**Priority: Improve Natural Resource Management** Indicator 3.1.2 Conservation practices Metric to be determined	**Biodiversity** Principle 5 Biodiverse ecological communities are protected and enhanced
Balance of tree and grass cover Indicator 9.1 Percentage of national forest cover gain on grazing properties Indicator 9.2 Percentage of national forest cover loss on grazing properties Indicator 9.3 Percentage of national woodland cover gain on grazing properties	**Priority: Encourage biodiversity** Indicator 3.3.1 Maintaining and increasing biodiversity Specific metrics to be identified	Criteria 9. Farms support a diverse range of beneficial flora and fauna species
Indicator 9.4 Percentage of national woodland cover loss on grazing properties		
		Criteria 10. Farm-related ecosystems are functioning and thriving

2 Methodology

There are two components to this literature review:

- desktop search for scholarly articles and industry and other publications
- interviews and further research, informed by the networks and industry knowledge of the project reference group, MLA staff and the authors.

2.1 Literature review

The literature review involved conducting key word searches using Google and Google scholar. It began with a review of known industry sources including MLA goat industry snapshots, the Australian Beef Sustainability Framework, Sheep Sustainability Framework and Australian Agricultural Sustainability Framework, as well as final report from MLA-funded projects. Key words included:

- total grazing pressure Australian rangelands
- measuring Australian rangeland condition
- livestock and biodiversity
- goats and biodiversity
- Australian rangelands biodiversity.

2.2 Interviews and desktop research

Meetings were held with the following people/organisations:

- Trudie Atkinson, NSW Department of Primary Industries and Regional Development
- Mitchell Plumbe, Meat & Livestock Australia
- Courtney Nelson, Meat & Livestock Australia
- Ron Hacker, Ron Hacker Rangeland Consulting Services
- John Falkenhagen, Goat Industry Council of Australia
- Krystie Bremer, Gascoyne Catchment Group
- Jay Hender, Hafiz Stewart, Ben Symons, Climate Friendly
- Sarah McDonald, NSW Department of Primary Industries and Regional Development
- Cathleen Waters, Green Collar
- Paris Capell, Western Local Land Services, NSW
- John Maconochie and Matthew Humphrey, Department Environment and Water, SA
- Brian Allport, Grassland Goats
- Christine Plummer, Western Local Land Services, NSW
- Louw Hoffman, University of Queensland
- Angela Hawdon, Farming for the Future.
- Jess Mitchell, HW Greenham
- Ian McConnel, Bush Heritage Australia
- Phil Tickle, CiboLabs
- Robert Hassett, Department of Primary Industries, Queensland
- Steven McLeod, Department of Primary Industries and Regional Development, NSW
- Charlie Eager and Elisa Sparrow, South Australian Arid Lands Landscape Board
- Cassia Paragnani, South Australian Arid Lands Landscape Board.

Following the interview, most stakeholders provided additional materials or links, and/or names and contact details of people they believed would be helpful to speak with.



3 Results

3.1 Defining biodiversity

Before biodiversity can be measured, it is critical to ensure there is agreed and common understanding. Biodiversity means biological diversity (at the levels of ecosystems, species and genes), and the definitions proposed are those used by the Australian Beef Sustainability Framework and the Australian Agricultural Sustainability Framework.

The variety of different plants, animals and micro-organisms, and the ecosystems they are part of, found in a specified place. It encompasses species richness, genetic variation within species and ecosystem diversity (AASF).

Ensuring the conservation and enhancement of plant and animal species, genetic diversity, and natural ecosystems (ABSF).

3.2 Livestock production and biodiversity

The Australian livestock industry is highly heterogeneous, in terms of the environments where they operate and the production systems utilised. This applies equally to cattle, sheep and goats. Goat production occurs from intensively managed dairy, goatmeat or fibre enterprises in the higher rainfall zones (>500mm) through to unmanaged and managed rangeland enterprises (predominantly goatmeat). In the higher rainfall zones, agricultural production is predominantly in converted landscapes, with separate areas of remnant native vegetation. In the rangelands, livestock production is fully integrated with the natural environment, and based on native vegetation and naturalised exotic pasture.

Rangelands include all those environments where natural ecological processes predominate and where values and benefits are based primarily on natural resources, which have not been intensively developed for primary production. The rangelands of the semiarid and arid zones cover approximately 75% of the Australian continent (Nielsen et al 2020 after ARS 2019). Ninety-percent of Australia's goatmeat is produced from rangelands environments.

Figure 3: Map of the rangelands of Australia (source: Outback Australia - the rangelands - DCCEEW)



Globally, livestock grazing has been associated with the loss of biodiversity (Steinfeld et al. 2006; Lunt et al. 2007; Eldridge et al. 2016). Waters et al (2018) noted that there are contested views in the literature regarding the level of impact of livestock production on resource condition, and that livestock grazing appears to have a neutral or negative impact on resource condition (including biodiversity). There is general agreement in the literature that biodiversity is negatively impacted as grazing intensity increases (Lunt et al 2007). The 2008 Australian Collaborative Rangeland Information System (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. Fisher et al (2004) highlighted impacts of grazing management (and in particular total grazing pressure) on biodiversity across Australia's rangelands, observing that excessive grazing has both direct and indirect negative impacts. Direct impacts include soil erosion, fouled water supplies and weed invasion. Indirect impacts are through the loss of potential productivity, biodiversity, and the ecosystem services provided by native flora and fauna (Fisher at al 2004).

There is increasing consumer pressure on the red meat and fibre industries to demonstrate continuous environmental improvement, and justify their social licence to operate (Hacker et al 2019). Despite the fact there is no evidence that well-managed goats (in the same way as cattle or sheep), are negative for the environment (Waters et al 2018), the goat industry is under external pressure to demonstrate it is not negatively impacting biodiversity (goat threat abatement plan, DCCEEW, 2008). This imperative for the goat industry is largely due to the presence and impact of unmanaged goats (e.g. in South Australia goats are treated as a pest species (J Maconochie pers comms).

In addition to managing risk for the goat industry, establishing industry standards for measuring biodiversity also creates opportunity. The livestock industry's focus on reducing carbon emissions (CN30) closely connects with biodiversity and nature, as there is a strong link between carbon and nature (Thomas et al 2013). Additionally, there are increasing opportunities for livestock producers to participate in nature repair and/or biodiversity credit projects; and stacking onto existing carbon projects has potential.

Given the reliance of the Australian goat industry on unmanaged rangeland goats, and the significant implications of this production system for biodiversity, this literature review concentrates on rangelands production systems. Additionally, the sheep industry, through the SSF and Nature Positive Farming (AWI) are actively developing measures for biodiversity in southern Australia. These measures are likely to also be a good fit for goat production in these landscapes.

In summary, the imperatives for measuring biodiversity within the Australian goat industry are:

1. risk management for the industry (climate change adaptation and social licence)
2. increase industry readiness to participate in new markets (e.g. nature repair, biodiversity credits)
3. supply chain (consumer) demands (particularly in growing the domestic market)
4. support producer decision-making (increased data regarding the resource base)
5. meet needs for farm businesses to report sustainability (e.g. finance sector, insurance sector)
6. basis for industry-level sustainability reporting (e.g. Goat Industry Sustainability Framework).

The rigour and required evidence for monitoring data will differ depending on the end use (e.g. a lower level of rigour is required for producer decision-making compared to supply chain reporting). Given the scope of this project is focused on point six, the data integrity required for this will underpin the selection of biodiversity measures.

3.2.1 Biodiversity in a rangelands context

A number of studies have suggested that careful grazing management can achieve dual conservation and production outcomes, and play a role in increasing biodiversity in agricultural landscapes (Curry and Hacker, 1990; Dorrough et al 2004; Fensham et al 2011; Silcock and Fensham 2019; McDonald et al 2019). The impact of grazing on biodiversity will vary depending on location, herbivore type, grazing intensity and grazing system. While some authors have considered the impact of grazing on biodiversity in the southern rangelands to be generally negative (Eldridge et al 2016), it can be argued that well managed grazing can be compatible with conservation of rangelands biodiversity (Hacker and McDonald 2021).

Hacker and McDonald (2021) proposed that pastoralists have a greater duty of care to exercise stewardship of important or sensitive areas on their properties (e.g. mound springs, yellow footed rock wallaby habitat). Understanding where specific habitats, important for biodiversity, occur on pastoral leases, would enable pastoralists to differentially manage these areas.

Hacker and McDonald (2021) highlighted the opportunities for biodiversity conservation, and other ecosystem services, that are established and emerging, offering landholders financial rewards from management that delivers public good. The Australian Nature Repair Market Act aims to establish a national, voluntary biodiversity market to encourage private investment in ecosystem restoration and protection (Nature Repair Market Act 2023, aph.gov.au/Parliamentary_Business/Bills_LEGislation/Bills_Search_Results/Result?bId=r7014).

3.3 Goats in the Australian rangelands

The long-term use of rangelands for livestock production, combined with feral herbivores and exotic species have led to widespread decline in ecosystem condition (Landsberg et al 2003). However, making a direct link between resource condition, biodiversity and livestock production in the rangelands is problematic (Fensham et al 2010 and 2011; Waters, 2018), due to high spatial heterogeneity in rangeland vegetation and soil, as well as interactions between stocking rate and livestock productivity.

Waters et al (2018) observed that categorising sheep, goats, cattle and macropods to measure their impacts on vegetation is overly simplistic and misleading. Different species of herbivore may tend towards grazing or browsing if given the choice, but the relative availability and digestibility of plant species, as well as the past experience of the animals, is the dominant factor in the vegetation eaten (Waters et al 2018). There can be nearly as large a variation in forage selection between breeds of the same species, as between different species (Hacker and Alemseged, 2014). For example, the introduction of dorper sheep to the South Australian rangelands over the past 10–15 years has made differentiating sheep and goat browsing challenging (M. Humphrey pers comms). The degree of competition for feed resources between animals is not fixed, and perhaps not even predictable.

At a paddock scale, species of herbivore may feed in different areas due to differences in diets, different preferences for vegetation structures, and differences in distances they graze from water sources (Waters et al 2018). Unmanaged goats appear to prefer more densely timbered areas, especially on rocky hills (Waters et al 2018). There are a range of factors influencing the diet selection of goats, summarised by Hacker and Alemseged (2014), such as age, body condition score, reproductive status, as well as breed. Goat producers have observed the diet of wild rangeland goats to be 75–80% browse, compared with Boer goats at 30% browse. (B. Allport, pers comms).

When forage is plentiful, and drinking water is nearby or the weather cool, unmanaged goats are likely to remain in highly timbered and hilly areas, with limited overlap with sheep or cattle. However, when feed is scarce in the timbered and hilly landscapes, unmanaged goats will move to areas that contain better forage (Waters et al 2018).

Waters et al (2018) reviewed the diets of sheep, cattle, goats, and macropods. They found fewer studies on unmanaged goats compared with other herbivores, but the evidence shows goats consume a wider variety of shrubs and trees than any other species. This finding agrees with that of Hacker and Alemseged (2014). Like sheep and cattle,

goats prefer green annual grasses and ephemeral forbs when available. When these dry out, they switch to green perennial grasses, then to non-chenopod perennial forbs (e.g. *Ptilotus*, *Hibiscus*, *Euphorbia*, and *Sida*) and a range of trees (e.g. *Heterodendrum*, *Casuarina*, *Geijera*, *Cassia*, *Dodonaea*, *Myoporum*, and *Acacia*). They will also browse perennial chenopod forbs such as *Bassia* and *Scleroleana*. As pastures decline in quality and quantity, goats browse more heavily on trees and shrubs, including species not normally eaten by sheep or cattle. In extreme scarcity, they even consume dry grasses, fallen leaves, seeds, flowers, and bark. Unlike sheep and cattle, goats continue to eat dead plant material long after other herbivores have stopped. Macropods will make use of browse, but it is not a good food source for them, and goats can access food macropods can't (S. McLeod pers comm).

Goats also have greater foraging reach than other livestock. They can browse up to 2 metres high (compared with 1 metre for sheep), and move through dense thickets that cattle and sheep avoid (Waters et al 2018). A review by Hacker and Alemseged (2014) indicated that goats are 'top-down' grazers, selecting from the upper layers of the canopy or sward, while sheep are 'bottom-up' grazers, selecting preferentially from the ground storey or bottom of the sward. This difference, if able to be expressed, drives a difference in the selection patterns of each species.

Although no studies have measured how far goats graze from water, their lower daily water requirements, combined with their habit of browsing foliage with high water content, suggest they can forage further from water points than sheep, which typically remain within 2–3km. Russell et al (2011) noted data from an unpublished study from 2006 indicated goat activity was rare more than 4km from water.

Because of these traits, unmanaged goats are often the last herbivores to be adversely affected by food shortages (Waters et al 2018). This means their pressure on vegetation during dry periods can be especially severe. In their 2014 review, Hacker and Almseged challenged the prevailing view that goats are a major cause of rangeland degradation, and highlighted the importance of matching forage demand from all herbivores with forage supply. However, they also observed that the capacity of goats to maintain high reproductive rates in poor seasons has potential to result in forage demand rapidly exceeding supply, with adverse impacts on resource condition. In contrast, macropod numbers build up quickly in good conditions, and then populations crash during poor seasons (S. McLeod pers comm).

Given all herbivores overlap in their use of rangeland vegetation, the key to protecting biodiversity, and rangeland condition, is not to focus on goats alone, but for pastoralists to understand and proactively manage total grazing pressure (TGP).

3.4 Total grazing pressure and grazing management

In Australian livestock systems, domestic livestock share the forage resource with a range of non-domestic species (native and exotic) (Hacker et al 2019). Total grazing pressure (TGP) is the combined grazing pressure exerted by all managed and unmanaged herbivores on vegetation, soil and water resources (Fisher at al 2004).

The management of the grazing pressure from all sources is critical for pastoral industries to maintain economic viability and conserve rangeland resources (Campbell and Hacker 2000; Hacker et al 2019). In more intensive grazing systems, non-domestic forage consumption is generally a background to animal production. However, in rangelands, the non-domestic component of forage consumption can be significant. Studies have estimated around 40–50% of the grazing pressure in the rangelands is unmanaged by pastoralists (i.e. kangaroo, or feral herbivores) (Fisher at al 2004; Waters et al 2018; Hacker and McDonald 2021). Unsurprisingly, unmanaged herbivory is highest in the areas protected behind the national dog fence (Waters et al 2018) since native and feral herbivores here are not subject to control by the dingo.

Fisher at al (2004) observed that managing the combined impacts of all animals is needed to ensure the sustainability of grazing industries, and conservation of biodiversity, in rangelands environments. However, there are challenges in managing total grazing pressure in the rangelands, including the large scale, variable and unpredictable climate, magnitude of pest populations, limited availability of labour, limited control over animals and their movements (Hacker et al 2019), and the typically low financial returns per land unit area (Fisher et al 2004). Another issue in managing TGP, identified by Fisher et al (2004) was a tendency to view feral species (including goats) as a 'cash crop' to be opportunistically harvested, even though these animals can reduce productivity of managed animals, and result in unsustainable use of the forage-base. However, a more contemporary view is that trapping/mustering and sale of unmanaged goats is socially acceptable, and can represent a significant source of income (Khairo et al. 2011). Hacker and McDonald (2021) promote trapping and sale of unmanaged goats with no release of animals of no commercial value, as a sustainable pastoral management activity. While there are some anecdotal observations that a combination of low goatmeat prices and seasonal conditions can create a perfect storm for unsustainable goat numbers in the rangelands, this is not supported by evidence (Atkinson, 2024). Atkinson (2024) noted that producers market goats, regardless of price to keep herd numbers in check and manage grazing pressure. M. Humphrey and J. Maconochi (pers comm) noted challenges with South Australian producers accessing processing space for goats can restrict timely destocking. This challenge is also true for Queensland and western NSW (B. Allport, pers comm). Atkinson (2024) also noted the potential for competition for kill space and extended wait times for bookings extending into 2025. The processing forecast for the 2024/25 financial year was for a record 3.3 million goats, despite low prices. Based on the first three quarters of 2024/25, this forecast looked like being exceeded (NSW Government, 2025).

Current industry best practice encourages pastoralists to account for, and manage (as best as possible), the grazing pressure from non-domestic herbivores, as well as domestic livestock, to protect from over-grazing and impacts on land condition (MLA 2023, Campbell and Hacker 2000). There are proven techniques available to minimise impacts from non-domestic herbivores, so that paddocks can be rested from continuous grazing (MLA 2023; Waters et al 2018; Hacker et al 2019; Hacker and McDonald 2021). Shifting from a wild-harvested to a managed goat enterprise reduces unmanaged grazing pressure, and enhances producer's capacity to manage stocking rates, resource condition thresholds (e.g. ground cover and perennial grass utilisation rates) and strategic rest. A recent survey of landholders in western NSW found 67% of pastoralists had incorporated TGP fencing or multi-species exclusion fencing, and 70% of those with no TGP fencing indicated they would consider incorporating it in future (Western Local Land Services, 2024 (unpublished)).

3.4.1 Grazing management

Research consistently shows that stocking rate and the intensity and duration of grazing are the strongest drivers of floristic diversity, rather than the grazing system itself (Hacker and McDonald 2021; Hunt et al, 2014; Stafford-Smith et al, 2007). Reviews of the impact of alternative grazing systems on biodiversity provide no clear evidence for the advantage of one system over another (e.g. Dorrough et al. 2004; McDonald et al. 2019). However, few studies examining biodiversity under contrasting grazing systems have been undertaken in the southern rangelands. There is considerable evidence to support the beneficial effect of including rest periods on production and environmental sustainability (Hacker and McDonald, 2021). However, how rest is applied can vary widely, including whether it is sufficient to enable recovery (C Waters, pers comms). Wild rangeland goats in Australia are used by producers to manage regrowth (invasive native scrub), with a typical rotation being goats followed by sheep or cattle, followed by a rest period (B Allport, pers comms).

In large paddocks at low stocking rates, livestock do not graze the landscape uniformly (Waters et al 2018). Selective grazing under a traditional continuous grazing model can result in over-utilisation and a loss of perennial grasses and other desirable species (Norton 1998), increasing the risk of land degradation and associated negative impacts on production. At the other end of the spectrum, rotational grazing systems promote using smaller paddocks at higher stock densities to increase uniformity of grazing, by reducing selective and patch grazing, which increases grazing pressure on less palatable species (Norton 1998).

Tactical grazing management (Campbell and Hacker 2000; Hacker and McDonald 2021; MLA 2023) is promoted as a technique to maintain or restore productive landscapes, by promoting favourable responses to seasonal opportunities while minimising the impact of seasonal hazards. It involves setting goals for management units, developing and implementing a strategy to achieve these goals (which include target thresholds for pasture utilisation or cover) and monitoring to assess if the goals are being achieved (Campbell and Hacker 2000; Hacker and McDonald 2021; MLA 2023).

The once widely accepted view that grazing pressure should be spread over the landscape as evenly as possible, is now thought to reduce biodiversity because it leaves little of the landscape unaffected by grazing (Fisher et al 2004). Fuhlendorf et al (2017) (in Hacker and McDonald 2021) argued that grazing management that promotes uniform, moderate grazing across the entire landscape fails to promote spatial and temporal heterogeneity. They highlighted the importance of large continuous tracts of rangeland, to enable disturbance processes to interact with landscape heterogeneity, forming multi-scaled mosaics, and enhancing biodiversity.

This approach of supporting landscape heterogeneity is now promoted as industry best practice (MLA 2023). The Grazing Fundamental EDGE (southern rangeland) producer manual highlights the importance of maintaining some areas remote from water, because of the benefit in providing refuges for species of flora and fauna, which are adversely impacted by pastoral development. Australian Collaborative Rangeland Information System (ACRIS) used distance from and distribution of water points as a measure for biodiversity (Bastin 2008).

The increase in grazing pressure close to water, resulting in a decrease in herbage cover is known as a grazing gradient (Bastin et al 1993). The 1993 research by Bastin et al demonstrated highly significant correlations between the field data and satellite indices of vegetation cover along transects moving away from water. They concluded that the grazing gradient method, when used with satellite data, is a suitable technique for assessing the extent of landscape recovery, following rainfall. In South Australia, the rangelands assessment method (RAM) uses grazing gradients bands of 0–3km, 3–5km 5–8km, 8–16km and 16–24km from a watering point (Native Vegetation Council, 2024). The grazing gradient layer is available via the SA Department for Environment and Water NatureMaps (spatial data layers for natural resources). The grazing gradient is determined by the location of natural waters and artificial water points, and landscape topography to account for variable movement of stock in different parts of the landscape (e.g. stock will not move as far if travelling uphill) (Native Vegetation Council, 2024).

3.4.2 Estimating total grazing pressure

Since management of TGP is such a fundamental issue for pastoralists in the southern rangelands, it is important that the contribution of the various species is understood (Hacker and McDonald, 2021). This requires comprehensive population estimates of all relevant herbivore species present within the landscape, however, in practice this can be a challenging exercise. The number of non-domestic animals on a property is usually underestimated. Kangaroo numbers can be much larger than expected and sightings of feral goats may account for only a relatively small fraction of the number present (Campbell and Hacker 2000).

Livestock populations are able to be quantified through property records, muster returns, or aerial surveys carried out by land managers or government agencies (the latter are typically at a regional scale). Non-domestic herbivores are often monitored via spotlighting surveys, camera trapping, pellet counts, and systematic transects (Hacker and McLeod, 2003). In NSW, Victoria, South Australia,

Western Australia and Queensland aerial surveys are used to generate population estimates for kangaroos (S. McLeod pers comm). The frequency of the survey varies from annual in NSW, Victoria and Queensland, every three years (SA) and different regions on rotation in WA. In NSW the aerial surveys also count goats, where a steady increase in numbers has been measured during the past 30 years (S. McLeod, pers comm). This data is used to establish kangaroo harvesting quotas and is publicly available (**Table 2**).

Table 2: Kangaroo population estimates for NSW, Queensland and SA

State	Link
NSW	environment.nsw.gov.au/publications/nsw-commercial-kangaroo-management-program-2025-quota-report
QLD	qld.gov.au/environment/plants-animals/wildlife-permits/macropods/macropods-quotas
SA	Department for Environment and Water – Quotas and harvest data

Western Local Land Services are developing a kangaroo predictive tool (lls.nsw.gov.au/regions/western/key-projects/you-cant-manage-what-you-cant-measure-kangaroo-predictive-tool-project). This tool downscales regional population estimates for kangaroos derived from aerial surveys, to the property level (based on modelled relationships between kangaroo density and population biology and environmental variables). The tool development is currently at a proof of concept stage.

Campbell and Hacker (2000) provide a simple method for estimating TGP, using the step point dung transect. This involves walking a transect and recording the dung from different species found at random points, which enables the proportion of each herbivore species in the total grazing pressure to be calculated (Campbell and Hacker 2000; Hacker et al 2022). Russell et al (2011) found goat dung indices to be correlated with ground cover estimates, after goats had been excluded from an area.

Population estimates are processed using models that standardize grazing pressure across species with differing body sizes, dietary preferences, and forage intake rates. A common approach involves converting herbivore numbers into dry sheep equivalents (DSE). This enables comparisons of grazing pressure across mixed herbivore assemblages (Hacker and McLeod, 2003). DSE ratings of most species are readily available (MLA 2023), including kangaroo, which Pahl (2019) has argued is 0.7 DSE on a population basis (a 50kg adult kangaroo is equivalent to 1 DSE).

3.5 The influence of rainfall

Arid and semi-arid environments (typical of the rangelands) are characterised by highly variable climates, especially rainfall, which strongly influences vegetation productivity and ecosystem resilience (Hacker and McLeod, 2003). Throughout most of the rangelands and for much of the time, rainfall is the principal driver of change (Bastin 2008). When it rains, how much falls and what follow up occurs have a profound effect on vegetation and animal population responses (Bastin 2008).

McDonald et al (2024) highlighted the importance of normalising indicators for seasonal conditions to account for management impacts against other external drivers of change. The Australian Collaborative Rangelands Information System (ACRIS) uses the term seasonal quality to describe the relative value of recent rainfall for vegetation growth. Its application helps filter the impacts of climate variability from those of grazing management (Bastin 2008).

The variability of rainfall complicates differentiating whether changes in vegetation condition arise from herbivory or climatic factors. Trends in multiple indicators across Australian rangelands suggest that generally, changes in range condition are driven more by seasonal conditions than by grazing (Bastin 2008). S. McDonald (pers comm) observed that changes in ground cover due to management changes are dwarfed by changes due to seasonal conditions. Failure to adequately separate these drivers can lead to misinterpretation of grazing effects.

To address the challenge of differentiating rainfall and grazing impacts, rain-use efficiency (RUE) has been adopted in rangeland ecology as a tool to normalise vegetation productivity against rainfall variability (Bastin et al 2012). RUE is defined as the ratio of vegetation production (proxied by above-ground net primary productivity or biomass), to the amount of rainfall received over a defined time period. Rain-use efficiency (RUE) is calculated by combining remotely sensed vegetation indices, such as NDVI, fractional cover, and woody vegetation extent, with gridded rainfall data (Bastin et al 2012).

While RUE is a fundamentally important concept of preserving land condition so it can respond to rainfall, it is not a widely used measure across the rangelands (R. Hacker pers comm). This is likely to be because other indicators will change before a response in biomass is observed (R. Hacker pers comm). However, many rangelands condition methods capture information about rainfall, as part of the assessment.

Stocking rate expressed in terms of DSE/ha/100mm rainfall is commonly used in livestock industries broadly and in the rangelands to account for rainfall variability in production systems (Hacker and Smith 2007). In their rangelands natural capital assessment method, Climate Friendly reference the rainfall records for the past five years, and in the six months prior to field assessment (J. Hender pers comm). The Gascoyne Catchment Group's Rangelands Monitoring Tool also encourages users to include rainfall records (Gascoyne Catchment Group 2025).

3.6 Methods for assessing rangeland land condition

A rangeland in good condition is one where the fundamental ecological processes of water infiltration, nutrient cycling, energy capture, and species interactions are working effectively. Such landscapes retain ground cover, resist erosion, and respond well to rainfall by producing useful forage. They balance grasses, shrubs, and trees in a way that reflects natural seasonal and climatic patterns rather than degradation or dominance by unpalatable species. Well-functioning rangelands are both productive and resilient, able to support grazing systems while sustaining ecological health. Hence, rangeland condition may be correlated with the status of biodiversity. Waters et al (2018) described 'good' rangeland resource condition as the capacity to maintain both biophysical and socio-economic functions relative to a reference state. While biodiversity loss is often treated as an indicator of decline, the difficulty of identifying a valid benchmark means that industry assessments tend to focus on the resource base (soils and pastures) that underpin grazing. For many rangeland condition monitoring methods, a grazing impact is perceived through a change in species composition (i.e. the ratio of palatable to unpalatable species), increase in erosion or a change in plant density (Richardson 2003).

A central concept here is **landscape function**, or the way the land conserves and recycles water and nutrients for ecological processes (Ludwig et al 1996). Functional landscapes retain resources locally, while dysfunctional landscapes lose them through runoff or erosion. Land condition is therefore understood as both the capacity of the land to respond to rainfall and the measure of how well the grazing ecosystem is working, independent of seasonal fluctuations. In practice, land condition is assessed through **soil and pasture condition**. Soil condition reflects the ability of soils to absorb rainfall, cycle nutrients, resist erosion, and provide habitat for plant growth — strongly linked to organic ground cover from litter, plant bases, debris, and biocrusts. Pasture condition describes the plant community's capacity to capture solar energy and rainfall, produce forage, conserve soil health, and cycle nutrients, with both quantity and species composition playing a role.

These principles underpin the tools currently used by industry. The Land Condition Assessment Guide (McIvor 2012) provides structured protocols for field-based evaluation of soil stability and pasture composition. Landscape Function Analysis (LFA), developed by Tongway and Hindley (2004), uses indicators such as litter cover, canopy gaps, and surface stability to infer ecological function. These basic principles of rangeland ecosystem functioning provide the foundation for a number of rangeland land condition assessment tools, summarised in Table 3. Some of these approaches use qualitative descriptors (e.g. good, fair, poor, very poor), but the majority focus on trends in condition.

Limited data regarding the scale of uptake by producers of forage and/or land condition monitoring was able to be sourced for this literature review. Generally, feedback from those interviewed for this project indicated uptake was low (30–50%). This view is supported by data that was able to be obtained from Western Local Land Services (2024, unpublished), where only 43% of respondents had a specific ground cover target for their paddocks, and 74% had experienced problems with low groundcover. Anecdotally, photopoints at established monitoring sites have been more widely adopted by producers (C. Plummer; K. Bremer; M. Humphrey, pers comm). Carbon projects are increasing knowledge of and measurement by producers, and nature repair projects are likely to further enhance uptake (J. Maconochie, pers comm). One of the reasons producer adoption of some tools has been low may be due to accessibility issues (e.g. LCAT) (R. Hassett pers comm). While producer adoption has not been high, the tools have been used extensively by state government agencies and natural resource management agencies, generating a database of land condition assessment data. Being able to leverage simple assessments has benefits for both conservation and landscape management (Parsons et al 2017).

While production or land condition-focused methods do not measure biodiversity directly, they are valuable for monitoring trends in land condition, and detecting the effects of grazing management, both of which influence biodiversity. A 2001 review by Fisher found that while existing pastoral monitoring programs have potential for biodiversity monitoring due to their large spatial coverage, focus on perennial plants as an indicator and monitoring of overgrazing which is a driver of biodiversity change, their use is limited by sampling biases. Sampling is focused in the more productive, extensively used areas and underrepresents sensitive landscape features, which are significant for biodiversity.

Richardson (2003) conducted a review of the value of rangeland condition assessments in WA (WARMS) for assessing biodiversity and concluded that rangelands condition data does provide insights for biodiversity. However, some improvements were recommended to the existing WARMS methodology to properly incorporate biodiversity, consistent with the issues identified by Fisher (2001). These included:

- monitoring site selection – WARMS sites are biased towards areas of pastoral productivity
- modification of methods to capture data about key threatening processes.

A contemporary, long-term (10-year) study by Parsons et al (2017) undertook an in-depth exploration of the relationship between native vertebrate biodiversity and grazing land condition (using the ABCD framework) across woodland, shrubland and grassland in Queensland. The land condition scale partially explained richness and abundance patterns only for mammals (especially rodents), which tended to be higher in better-condition pasture (Parsons et al 2017). For other vertebrate groups, land condition rating was a very poor descriptor of richness and abundance (Parsons et al 2017). The land condition scale was not useful to assess wildlife diversity primarily because 'woody thickening' (increases in woody vegetation on grazed land, including shrubs and trees) lowers the 'grazing value' of land but promotes vertebrate diversity (Parsons et al 2017). Biodiversity decreased with increasing bare ground and erosion, although where trees and shrubs were also present, they mitigated the habitat degradation to some extent (Parsons et al 2017). In woodlands, trees and shrubs were particularly important for fauna, whereas in grasslands significant grass cover, low erosion and a range of heterogeneous features, including patches of bare ground, were important to maintain vertebrate diversity (Parsons et al 2017). Parsons et al (2017) concluded that some factors measured using the ABCD framework were useful for assessing habitat for wildlife. Changing the framework to include trees and shrubs as a positive rather than a negative effect (i.e. 'general thickening of woody plants' as an attribute of better land condition) would help align rangeland condition assessments with habitat for wildlife. The ABCD land condition framework is also poor as a guide to biodiversity where buffel grass is naturalised, as the ABCD assesses buffel grass positively from a productivity perspective, but from a biodiversity perspective it is negative (competitive with native species, creating a monoculture (section 3.7.4)).

Table 3: Summary of rangeland condition monitoring used by the pastoral industry

Tool	Relevant state/region	Brief description	Weblink
Land condition assessment tool (LCAT)	Queensland: subtropical, semi-arid and arid vegetation communities (grasslands, shrublands, woodlands and open forests)	QDAF Based on grazing land management (GLM) land condition framework, Stocktake, Landscape Function Analysis Presents scorecard for 15 indicators	arcgis.com/home/item.html?id=1155ea6c562d4ae9958b88794c5a0cda austrangesoc.com.au/wp-content/uploads/2025/01/15.-Land-condition-assessment-tool.pdf
Grazing land management (GLM) land condition framework	Qld	'ABCD' framework used to classify land condition. Indicators include bare ground, weeds, cover of perennial palatable plants, erosion.	mla.com.au/globalassets/mymla/documents/grazing-land-management.pdf hlw.org.au/resources/downloads/agriculture/56-agriculture-grazing-land-condition-factsheet/file
Western Australia Rangelands Monitoring System (WARMS)	WA	Pastoral rangelands monitoring conducted and reported every 5 years, by department staff. Indicators include vegetation cover, cover of perennial palatable plants, erosion.	library.dpird.wa.gov.au/cgi/viewcontent.cgi?article=1011&context=bulletins
Rangelands monitoring tool (RMT)	WA – Gascoyne, Pilbara	App developed by Gascoyne Catchment Group. Indicators include bare ground, weeds, cover of perennial palatable plants, erosion.	gascoynecatchments.com.au/rmt
SA Pastoral Land Management and Conservation Act 1989, monitoring	SA	Assessments conducted by Department for Environment and Water. Indicators focus on presence and diversity of palatable species and their utilisation, and soil erosion. Established sites are monitored every 14 years.	pir.sa.gov.au/aghistory/natural_resources/pastoral_land_management

3.6.1 Grazing land management (GLM) land condition framework

The GLM (or ABCD) condition framework can be used by land managers, and it is included as part of livestock industry extension programs (MLA 2023). Land types within a paddock are assessed individually and the condition of land is judged relative to its productive potential. Management of the land determines if the productive potential is realised or maintained.

3.6.2 Land condition assessment tool (LCAT)

The LCAT tool is a GIS based program, where data is entered and a score calculated. Indicators include:

- pasture composition, density and 'quality'
- groundcover and its components
- detailed erosion processes, soil surface features
- pest plant, understorey and overstorey composition density and management
- native animals
- total grazing pressure
- site impacts (e.g. fire, flood and drought).

Each indicator comprises an average of six values from which the user selects the value that is closest to describing what is observed. Indicator values are presented as pictograms.

A scorecard displays a suite of results related to GLM principles and 'hazards' associated with water quality, fire and ecological impacts. Generated results include grazing ABCD, Indicative biomass (kg/ha), erosion hazard, grazing alert (pasture deficit), water quality hazard, water contamination hazard, fire potential, invasive pest plant hazard, impact on natural state, site score (out of 100).

The Queensland government is currently funding a six-year program to map grazing land condition in key Great Barrier Reef catchments (Beutel et al 2025). This involves assessing thousands of grazing land sites using the Land Condition Assessment Tool (LCAT), modelling the ABCD land condition class at those sites and generating modelled land condition maps across the targeted regions (Beutel et al 2025). These sites, where they overlap with goat production regions, may have potential for leveraging for biodiversity assessments. The LCAT approach is applicable across western NSW and Queensland, in the northern territory and north of the wheatbelt in WA, and with calibration of relevant plant species could be adapted for SA (LCAT currently includes approximately 800 plant species) (R. Hassett pers comm). The LCAT tool is being developed as an easily accessible App, via the Survey123 platform – this aims to increase landholder adoption.

3.6.3 Rangelands Monitoring Tool (RMT)

The Rangelands Monitoring Tool (RMT) has been developed by Gascoyne Catchment Group (GCG) for pastoral businesses across the Gascoyne and Pilbara in Western Australia. The Rangelands Monitoring Tool© (RMT) enables pastoralists to conduct self-assessments of their rangelands and submit results to a central repository. The RMT supports rangeland assessment by providing:

- trends in perennial shrubs and grasses to track pasture composition
- indicators for monitoring rangeland condition
- measures of soil health, stability, infiltration, and nutrient cycling
- a method for recording and assessing erosion type and severity
- improved day-to-day management decisions for pastoral leases.

Evidence collected through the RMT can be used to communicate with regulators, industry, and conservation agencies. It also provides a credible basis for informing the public about the condition and management of rangeland resources. Most importantly, it equips pastoral managers with timely insights to adjust management practices in response to land and vegetation indicators.

The GCG explored a range of alternative monitoring methods, including David Tongway's Landscape Function Analysis, Queensland's Department of Primary Industries' Stocktake® program, Grazing Land Management, and the Western Australian Rangeland Monitoring Systems. Building on the principles of these systems and applying the Pasture Monitoring Sites approach to assessing and monitoring perennial species trends, GCG developed the Rangelands Monitoring Tool (RMT) using a value-based approach.

Table 4: Summary of the ABCD land condition classes

A condition	B condition	C condition	D condition
■ good coverage of perennial grasses or palatable shrubs dominated by 3P species ■ bare ground less than 40% most years ■ few weeds and no significant infestations ■ good soil condition, no erosion, good surface condition ■ 100% long-term carrying capacity	Similar to A, with: ■ some decline of 3P grasses or shrubs; increase in other species (annuals, less-favoured grasses, weeds, woody weeds) ■ bare ground less than 50% in most years ■ some decline in soil condition; some signs of previous erosion and current signs of erosion risk ■ 75% long-term carrying capacity	Similar to B, with: ■ general decline of 3P grasses or shrubs; large amounts of annuals, less-favoured species ■ bare ground greater than 50% in most years ■ obvious signs of past erosion and/or susceptibility currently high ■ 45% long-term carrying capacity	■ general lack of any perennial grasses, palatable shrubs or forbs ■ severe erosion or scalding, resulting in hostile environment for plant growth ■ dominance by herbaceous weeds or woody weeds ■ less than 25% of long-term carrying capacity. Often no long-term ability to carry stock

This method reduces subjectivity in interpreting rangeland trends and provides a consistent framework that landholders can apply. Permanent monitoring sites are established on a property, which are representative of the lease and sensitive to changes in management.

The system evaluates three key components of rangeland health:

1. Plants – Each plant species is assigned a value between 1 and 10, based on its environmental and commercial significance.

2. Soils – Five soil attributes (annual cover, cryptogams, litter, soil roughness, vegetation cover) are assigned values between 1 and 10, reflecting their contribution to stability, nutrient cycling, and infiltration.

3. Erosion – The three main types of rangeland erosion (pedestalling, rills and gullies, scalding and sheeting) are given negative values between 0 and -10, according to their adverse impacts on stability and infiltration

The RMT provides photo examples of attributes such as soil roughness, vegetation cover to assist with the scoring. The combined values generate a Site Stability Index (SSI), which serves as a benchmark for tracking changes at the site, land system, property, or catchment scale. Rainfall and seasonal comments can be added for each site, in addition to photos.

3.6.4 Western Australia Rangelands Monitoring System (WARMS)

The Department of Primary Industries and Regional Development (DPIRD) monitors and reports on the vegetation condition of pastoral rangelands in Western Australia, and has done since the early 1970s. The Western Australia Rangelands Monitoring System (WARMS) was formalised and adopted as the preferred method in the early 1990s (Richardson 2003). Currently, every five years a full report details the state, trend and risk of decrease of vegetation condition in the WA pastoral rangelands using information derived from remotely sensed vegetation cover data, rainfall data, livestock data and station-level rangeland condition assessment data (DPIRD 2025).

Data sources include remotely sensed vegetation cover (from TERN (Terrestrial Ecosystem Research Network)); reported stocking rates (Pastoral Lands Board); total vegetation cover, which includes living and dead annual and perennial vegetation and litter cover, and are median seasonal values derived from Landsat and Sentinel satellites (DPIRD 2025). Vegetation condition is via on-ground assessment of species composition, density and vigour of perennial vegetation, which also assesses erosion (DPIRD 2025). On-ground assessment target the more productive pasture associations because they generally experience the greatest grazing pressure, and are considered leading indicators of cover change (and are most responsive to grazing management) (DPIRD 2025). There are 1600 WARMS sites across the WA rangelands, which have been stratified based on vegetation type, and located at least 1.5km from water. Median annual rainfall is also collated and included in reports.

Richardson (2003) noted there is considerable overlap between biodiversity monitoring and the WARMS program, as grazing is a higher order threatening process, able to be manipulated through management.

3.6.5 South Australian Pastoral Land Management and Conservation Act 1989, monitoring

Under the South Australian Pastoral Land Management and Conservation Act 1989, monitoring of established sites is required every 14 years. Monitoring is conducted by Department of Environment and Water pastoral officers. Assessments began as pastoral inspections in the 1940s, and evolved into a more formalised method in the 1980s (similar to WARMS). The focus is on trends in condition at different sites, therefore there is reluctance to change the assessment methodology given the depth of historical data.

The assessment method is loosely based on SA's rangeland assessments method (RAM), with 1ha sites located at least 1.5km from water. The composition of the vegetation is assessed as well as utilisation, focusing on palatable species. Erosion is also assessed, but ground cover is not (crown separation ratio is used instead, to assess the clumpiness of the site).

The addition of remote sensing to the measurement toolbox has been reviewed, however it can't differentiate palatable species from others, so has limited use. Calibration is also required, as geological differences in sites impact the results. A focus of both South Australian and Western Australian monitoring is to measure decline in condition, so issues can be addressed before they become severe (J Maconochie pers comms). Remote sensing at this stage is most reliable for picking up areas when they are already degraded and therefore of limited value (J Maconochie pers comms).

3.6.6 Forage assessments (amount and utilisation)

In addition to the land condition assessments undertaken by pastoralists, estimating forage available for livestock production, is also relevant to biodiversity assessment. In the rangelands, grasses, herbs, shrubs and trees all form part of the diet of livestock. Knowledge of plant species, and their palatability, perenniality, and ability to respond to rainfall and grazing is a key skill of pastoralists (MLA 2023). Pastoralists also assess utilisation of the available forage, by monitoring the level of defoliation of key plant species, which provides a practical indicator of grazing pressure (MLA 2023).

Palatable perennial species are considered robust rangeland indicators as they are preferentially grazed, especially during dry periods when grazing stresses are most intense (Richardson 2003). Perennial plant persistence and growth is also a good indicator of ecological processes (Richardson 2003).

3.7 Approaches to biodiversity measurement in livestock systems

3.7.1 Metrics and measures for biodiversity

There are three aspects to measuring biodiversity in livestock production systems:

1. metrics
2. methods for capturing data
3. data interpretation.

There are many, scientifically-valid ways of measuring biodiversity. The approach used to establish a biodiversity baseline for the Australian goat industry, and to enable reporting of trends over time, must fulfill the following criteria:

- scientifically rigorous
- alignment with established industry approaches
- alignment with supply chain needs
- scalable (farm to region)
- sensitive to management
- cost-effective (i.e. the value of the data/information must match the cost of obtaining it).

In the recently completed Rangelands Living Skin project (McDonald et al 2024), a group of technical experts, producers and other stakeholders identified key environmental indicators (including some relevant to biodiversity) as being most important to report on:

- vegetation (including ground cover, vegetation condition, perenniality, floristic diversity, weeds)
- soil (including soil condition, soil carbon, soil erosion)
- fauna (key indicator fauna species such as birds, habitat for threatened species, pest animals and unmanaged TGP)
- ecosystem (connectedness, habitat type and extent, landscape function)
- livestock productivity (including stocking rates and stock type, TGP, feedbase quantity and quality).

Each of the listed indicators were assessed with regards to i) method and ease of measurement, ii) sensitivity to management, and iii) use in management decisions (McDonald et al 2024). Only ground cover and plant biomass were identified as meeting all three assessment criteria. However, this review appeared to underestimate the capability of remote sensing for connectedness, and for assessing structural diversity in the vegetation. The nature positive farming project (AWI) has found that the capability for automating remote sensing is readily available, the missing piece is market signals for what is needed. However, calibration and ground -truthing of remote sensing to increase reliability of the data was a continual theme through all interviews conducted during this literature review.

Reflecting the dynamic rainfall, and slow change nature of rangeland environments, the majority of indicators were considered slow in their response to management, or dependent on external factors (McDonald et al 2024). However, exceptions included ground cover, perenniality, soil condition and erosion, carrying capacity, stock type, biomass and pasture composition (McDonald et al 2024). Important habitat-type can be identified remotely, but condition requires on-ground assessment, and it was considered slow to change (and not strongly influenced by management) (McDonald et al 2024).

Given the heterogeneity of the rangelands and the preference for management approaches tailored to the business goals and environment (Campbell and Hacker 2000), practice-based biodiversity measures risk being too complex and/or not meaningful. However, carefully selected practice measures have potential to be used in conjunction with outcome-based measures to even out the noise associated with seasonal variation, and account for the slow response times of the environment to changed management.

3.7.1.1 Metrics for biodiversity

Vegetation composition and structure remain among the most widely used and cost-effective indicators of biodiversity in livestock systems (Dorrough et al, 2012; Table 4). The majority of approaches for measuring biodiversity do not directly measure fauna populations, but use presence of suitable habitat as a proxy.

In rangelands systems, metrics such as species richness, vegetation cover, and structural complexity provide insights into ecological condition. Vegetation cover, particularly that of perennial grasses and shrubs, is a strong predictor of biodiversity and land condition (Bastin et al 2012).

Functional group metrics are commonly used as a cost-effective alternative to full species inventories. Functional groups are collections of plant species that, regardless of their taxonomic identity, have similar morphological, physiological, or phenological characteristics, and respond in similar ways to ecological processes such as grazing, fire, or rainfall. They are used as surrogates for monitoring ecosystem function in rangelands. Groupings such as palatable versus unpalatable species, annuals versus perennials, and woody versus herbaceous species offer meaningful ecological information while reducing identification effort and data processing requirements (Phelps et al 2022). For example, changes in the abundance of palatable shrubs or the replacement of perennials with short-lived annuals can indicate persistent browsing pressure (Eldridge et al 2016). This approach is the basis of South Australian pastoral rangeland monitoring (SA RAM method).

3.7.1.2 Methods for measuring biodiversity

Measuring biodiversity in agricultural production systems uses a range of ecological field survey techniques to measure vegetation condition and habitat structure. These methods are being increasingly complemented by remote sensing tools aimed at improving the scalability, repeatability, and cost-effectiveness of biodiversity assessments (Dorrough et al 2012; Watson et al 2011).

In rangelands, field-based metrics such as the foliar or basal cover of perennial grasses, presence of palatable shrubs, and evidence of shrub recruitment are widely recognised as effective proxies for biodiversity and grazing land condition (Table 4). These metrics are sensitive to grazing pressure, reflect ecological function, and are logistically feasible for repeated monitoring at a landscape scale. In the rangelands, there can be challenges with reliance on foliar cover, as it can be

subject to significant seasonal fluctuation, as well as the influence of recent grazing, which make it unattractive as a parameter for monitoring long term changes due to management (R. Hacker pers comm). Basal cover is better in principal but is very low (only about 2% even in good condition grassland) and therefore difficult to measure precisely (R. Hacker pers comm). As part of WARMS in WA grasslands, frequency was used as a measure of perennial grass abundance, recorded as presence of species in quadrats) (R. Hacker pers comm).

Habitat metrics and associated condition scoring have been widely used to estimate faunal habitat quality. This involves evaluating structural attributes of vegetation layers, availability of features such as hollow-bearing trees and fallen woody debris, and the degree of habitat connectivity at both paddock and landscape scales (Watson et al 2011). For example, woodland bird assemblages, particularly small insectivorous and hollow-nesting species, have been shown to respond strongly to habitat condition metrics such as tree density, midstorey complexity, and connectivity of remnant patches (Radford et al., 2005). Direct fauna surveys are often limited by time, cost and detectability constraints, making habitat condition scoring a practical surrogate for fauna.

Remote sensing uses satellite imagery, which is captured on a regular basis to measure vegetation and soil/land attributes. The technology can also be used to capture electromagnetic energy reflected or emitted by the ground and vegetation to create maps. It is currently in use for natural capital measurement in livestock production systems (e.g. tree cover, ground cover, biomass). This development has been facilitated by improvements in spatial and temporal resolution of satellite imagery, and advances in data processing platforms. In the rangelands where on-ground ecological monitoring can be constrained by remoteness, labour availability, and spatial scale, remote sensing has potential to be employed. The range of vegetation indices derived from remote sensing data used to monitor ecological condition include:

- normalised difference vegetation index (NDVI)
- enhanced vegetation index (EVI)
- fractional cover
- foliage projective cover (FPC).

The Australian Feedbase Monitor, hosted by CiboLabs and delivered as a service for MLA members via their myMLA log-in, to measure biomass and groundcover, is an example of this technology being adopted by industry (cibolabs.com.au/australianfeedbasemonitor). However, there are some limitations to remote sensing, particularly around calibration of data (the accuracy of remote sensed ground cover data has been questioned by producers in SA, NSW and WA (J. Maconochie, S. McDonald, K. Bremer pers comms)). Jayasinghe and Thomas (2025), provide an overview of remote sensing tools available for monitoring rangeland ecosystem services, and concluded that challenges around data quality and model uncertainty mean reliable field data is critical for model calibration.

Habitat connectivity (structural and functional), underpins the capacity of flora and fauna populations to persist. Structurally connected habitats facilitate seed dispersal, shrub recruitment, and the movement of pollinators and predators, all of which are critical to maintaining ecological processes and biodiversity. Functionally, the ability of wildlife to move across the landscape enables population resilience to localised disturbances such as overgrazing, drought, or fire. Fragmentation, whether due to vegetation clearance, overgrazing-induced bare ground, or physical infrastructure, can isolate vegetation patches. This increases vulnerability to erosion, invasion by non-native species, and further biodiversity loss. Connectivity metrics derived from remote sensing data, such as patch size and connectivity, shape and inter-patch distance, provide valuable insights into the extent to which grazing systems support, or hinder, landscape-scale ecological function.

Remote sensing technologies offer scalable and cost-effective approaches for monitoring vegetation and biodiversity indicators across broad landscapes. A challenge with field work in the rangelands is the cost and low sample size of field surveys – targeting field sample locations using remote sensing capability can assist (Climate Friendly, pers comm). Satellite data products, such as fractional ground cover, woody vegetation extent, and vegetation indices (e.g. NDVI, EVI), enable repeatable assessments of ecosystem condition, and can be used alongside total grazing pressure data and rainfall to determine the relative influence of grazing versus climatic variability (Bastin et al., 2012). This information is increasingly becoming more readily and freely available. For example, VegMachine.net is a free platform available for analysing vegetation trends across Australian landscapes (Trevithick et al 2025).

Drones are increasingly being used by both producers and ecologists to capture high-resolution aerial imagery, which can complement field work by providing more accurate, repeatable and spatially extensive data on vegetation condition and landscape features (Perotto et al 2025). Research into evaluating the relationship between different drone-based sensors and traditional rangeland metrics is being conducted in the US (Perotto et al 2025), and the utility and uptake of this technology globally is likely to grow. The Accounting for Nature (AfN) method NV-10 is an example of a vegetation condition assessment methodology designed to build and leverage remote sensing capability (including the use of drones) (section 3.7.2.2).

Lidar imagery is also becoming more widely used. It is used for measuring carbon sequestration in human induced regeneration carbon projects (section 3.7.2.9 provides more detail), and may be able to be value-added for biodiversity. However, at present it is costly and unlikely to be widely adopted by industry, except where required for carbon or nature repair/biodiversity projects.

The use of Artificial Intelligence (AI) to increase the accessibility of land condition assessments is also being tested. CiboLabs currently have a prototype platform that assesses land condition, based on the BioCondition method (Eyre et al 2015) using a photo of the site uploaded to the platform (grass density, 3P species, soil erosion bare ground and soil surface condition, tree density, presence of weeds) (P. Tickle pers comm).

3.7.2 Current industry standard approaches to measuring biodiversity

There are currently no industry-standard, outcome-based (or practice-based) methods for measuring biodiversity (or natural capital) in livestock systems (section 1.1 outlines livestock industry sustainability frameworks). However, there are a number of current approaches, relevant to measuring biodiversity in rangelands environments. McDonald et al (2024) conducted a review of assessing natural capital in rangelands systems as part of the Rangelands Living Skin project. They identified three schemes as relevant to measurement of natural capital in the rangelands (Accounting for Nature, Ecological Outcome Verification, Science-based targets initiative), and Farming for the Future and the natural capital measurement catalogue were noted as other tools. However, there are other methods in use, identified during this literature review, which may be more applicable. The approaches relevant to biodiversity at a property scale in the rangelands, and reviewed here, are:

1. Farming for the Future (FftF) and Nature Positive Farming (AWI)
2. Accounting for Nature (AfN) (methods NV-03, NV-07 and NV-10)
3. Clean Energy Regulator (CER) nature repair market – replanting native forest and woodland ecosystems (rangelands ineligible for this method)
4. Climate Friendly (CF) rangelands nature repair method (under development)
5. Native Vegetation Council (SA) rangelands assessment manual (SA RAM)
6. Ecological Outcome Verification (EOV)
7. Green Collar / Farming for the Future rangeland natural capital assessment (under development)
8. Australian Collaborative Rangeland Information System (ACRIS)
9. Clean Energy Regulator Human Induced Regeneration (HIR) carbon project method
10. Biodiversity assessment method (BAM), NSW
11. BioCondition, Queensland.

3.7.2.1 Farming for the Future and Nature Positive Farming

Farming for the Future (FftF) is a public good research project aimed at quantifying relationships between on-farm natural capital and the productivity, profitability and resilience of Australian producers. FfTF assess the relationships between on farm natural capital and farm business performance. The indices they developed represent the capacity of on farm natural capital to generate ecosystem services linked to agricultural production.

The Farming for the Future project (Ogilvy et al 2023), measured natural capital (including biodiversity) on 130 livestock farms across southern Australia (Tasmania, Victoria and NSW). These metrics have been adopted by the wool industry for reporting on the natural capital and environmental performance of wool production, and tested in southern environments (Australian Wool Innovation 2024). The relevant metrics to biodiversity are:

- aquatic condition
- ecological condition
- fertiliser use intensity
- pesticide, herbicide, fungicide use
- shade and shelter
- tree cover
- ground cover.

Except for herbicides, the input metrics are unlikely to be relevant in a rangelands context as these are typically low (nil) input systems. McDonald et al (2024) considered that the indices used in the FftF research could be readily applied to the rangelands context (and this is now underway via a partnership between FftF and Green Collar (section 3.7.2.7). FftF is farmer-focused and make their outputs useful for on-farm decision making. The state and transition model (STM) approach has been developed for shrub-grass-mulga community in WA rangelands (Luxton et al 2025). Details about the FftF metrics and approach are summarised in **Table 5** (FftF).

3.7.2.2 Accounting for Nature

AfN is designed to measure environmental condition through time, enabling the reporting of improving or degrading natural capital, and can be scaled from paddock to national. The Accounting for Nature (AfN) framework provides a standardised approach to measuring environmental condition through the use of Environmental Condition Accounts (ECAs) covering assets such as vegetation, soils, freshwater, and fauna. AfN benchmarks indicators against reference conditions, representing ecological integrity in a relatively undisturbed state. Currently eight rangelands/pastoral projects registered in the rangelands use **AfN method NV 03**, and one uses **method NV 10**. The **NV-07** method has been used by corporate pastoral companies to baseline their native vegetation (P. Capell pers comms), and NV-10 has been used at over 1000 sites on commercial cattle properties across the NSW and Queensland rangelands (I. McConnel pers comm).

AfN NV 03, the GreenCollar Native Vegetation Condition Monitoring Method (Shoo and Sinclair, 2023), has been developed to generate Environmental Accounts for use in environmental markets including co-benefit verification for carbon projects. Selection of indicators, and benchmarks has primarily been informed by existing state vegetation assessment frameworks. This method does not include some of the basic measures for assessing rangeland condition outlined in section 3.5 (e.g. ground cover and grasses and herbs). Details about the metrics and approach are summarised in **Table 5** (AfN – NV-03).

AfN NV 07, the Bush Heritage Australia – Vegetation Assessment Methodology (Appleby et al 2021) has been developed to assess the condition of conservation targets of native vegetation at the property/landscape scale. It is suitable for assessing vegetation condition in a wide variety of landscapes from arid rangelands to heathlands and grassy woodlands. Details about the metrics and approach are summarised in **Table 5** (AfN – NV-07).

AfN NV 10, the Integrated Vegetation Condition Method (Bush Heritage Australia and Climate Friendly 2024), is applicable to rangelands, Australia-wide. This method integrates remotely sensed data and on-ground observations to assess the condition of vegetation communities and monitor long-term change in condition of native vegetation, to inform and assess outcomes of land management over time. It is suitable for properties between 2,000 and 2,000,000 hectares, with open canopy vegetation communities such as grasslands, heathlands, and woodlands. It is applicable to a range of Ecosystem Functional Groups including tropical-subtropical forests, temperate-boreal forests and woodlands, shrublands and shrubby woodlands, savannas and grasslands, deserts and semi-deserts. It is not suitable in systems comprising dense canopy cover (i.e., areas where high-resolution remote sensing is unable to accurately survey shrub and ground layer indicators). Details about the metrics and approach are summarised in **Table 5** (AfN – NV10).

3.7.2.3 Clean Energy Regulator – Nature Repair Market

The Australian Government's Nature Repair Market has launched, with one approved method for biodiversity credits (August 2025), replanting native forest and woodland ecosystems. This method is not applicable to rangelands environments, however the general approach and indicators are consistent with many of the other biodiversity methods reviewed here, and are likely to be adapted to rangelands methods. The nature repair method uses a reference ecosystem approach for measuring the biodiversity outcomes of projects (Clean Energy Regulator, 2025). The reference ecosystem is the highest level of ecological integrity, stability and resilience the land could attain, providing a benchmark value to measure projects against. Given it is not relevant in a rangelands context further details are not provided here, but are accessible at cer.gov.au/document_page/replanting-native-forest-and-woodland-ecosystems-method-information-pack.

3.7.2.4 Climate Friendly rangelands nature repair method

Climate Friendly, in collaboration with Bush Heritage and Australian Land Conservation Alliance, are developing a rangelands method for the Nature Repair Market. They are also working on a remote-sensed natural capital assessment, which is being tested on goat properties (J Hender pers comms). This is assessing properties with low level accuracy using regional assessment. A challenge for remote sensing identified by Climate Friendly is the lack of reliable, publicly available vegetation layers for the rangelands (this issue has also been identified for areas outside the rangelands by Farming for the Future). Climate Friendly believe that a single score for assessing biodiversity in rangelands will mask important information, and that sub-elements are important. They noted that the ground layer is key, which is supported by the focus on this in rangelands land condition assessments. Climate Friendly's approach uses reference condition benchmarks, which is consistent across methods including FftF, AfN and CER (Climate Friendly 2024a and 2024b). The Climate Friendly method identifies important ecosystems (or biodiversity hotspots), which is consistent with some other methods. Climate Friendly is farmer-focused and make their outputs useful for on-farm decision making (Climate Friendly 2024a and 2024b). Details about the metrics and approach are summarised in **Table 5** (CF).

3.7.2.5 Native Vegetation Council (SA) rangelands assessment method (RAM)

The Native Vegetation Council (NVC) rangelands assessment method (RAM) was developed for assessing native vegetation systems in the arid zone of South Australia (Native Vegetation Council 2024). It is intended for use in native vegetation clearance application areas, proposed significant environmental benefit offset areas and heritage agreements. Each area to be assessed is termed a 'block', which is divided into stratified 'sites'. Each site relates to a vegetation association found within the block. Vegetation associations are based on landform types, paddocks and the grazing gradient. Three components of the biodiversity value of the site are measured and scored:

- vegetation condition (including a measure of land condition)
- conservation value
- landscape context.

The three component scores are combined to provide a 'unit biodiversity score' (per hectare) and then multiplied by the size (hectares) of the site to provide a 'total biodiversity score' for each site. The scores are added for the overall block. The method aligns the assessment of vegetation (and land) condition with the 'Rangelands Assessment Method' developed by the (then) Natural Resources South Australian Arid Lands for the rapid assessment of pastoral properties in sheep and cattle country. Details about the metrics and approach are summarised in **Table 5** (SA RAM).

3.7.2.6 Ecological Outcome Verification (EoV)

Ecological Outcome Verification (EOV) is designed to measure the trend in the health of the land and ecosystems, including soil health, biodiversity and ecosystem function. McDonald et al (2024) observed that EOV comprises short term and long-term indicators, which could be used or adapted to those identified by producers, technical experts and stakeholders during their consultation. EOV is currently used in Australia, including in the rangelands. EoV is farmer-focused and make their outputs useful for on-farm decision making. Details about the metrics and approach are summarised in **Table 5** (EOV).

3.7.2.7 Green Collar/Farming for the Future rangelands natural capital assessment method

The Farming for the Future metrics outlined in section 3.7.2.1 are currently being refined by Green Collar, to provide metrics suitable for measuring natural capital in the rangelands. The work done by McDonald et al (2014) in the Rangelands Living Skin project is also being used to refine these metrics (C Waters, *per comms*). The purpose of this work is to link with market mechanisms

to drive change, and generate a value for the natural capital of a property and link to profitability. Green Collar currently have 4.6 million hectares (300 properties) with projects (C Waters, *per comms*), and it is intended to use some of these to benchmark natural capital and test the metrics (meaning Lidar technology will be available for measurement). The metrics will be finalised and publicly available by the end of 2025. They will then be tested in the field during 2026. Some of the metrics being considered include:

- connectedness of vegetation patches (Lidar)
- ground cover (Lidar) (also being used as an indicator of grazing)
- soil surface condition
- pasture biomass (Lidar)
- pasture composition (field-based)
- woody biomass (Lidar)
- woody diversity (field-based)
- recruitment (size class distribution of woody vegetation)
- landscape function (clumpiness and distance between clumps, Lidar)
- water remote areas
- wet refugia.

Green Collar note the importance of being able to distinguish what proportion of change is driven by management versus climate; and also understanding that every property is unique, particularly in the context of historical landuse, current enterprises and capability of land managers (C. Waters, pers comm).

3.7.2.8 Australian Collaborative Rangeland Information System (ACRIS)

The data sets used by the Australian Collaborative Rangeland Information System (ACRIS) to report change in Australia's rangelands from 1992 to 2005 were comprehensive, covering themes including landscape function, sustainable management, total grazing pressure, fire and dust, biodiversity, and socio-economic indicators (Bastin 2008). The information used to detect change in biodiversity (summarised in **Table 7**, Appendix 8.2) drew on a broad suite of sources: the expansion of protected areas (CAPAD), the listing of threatened species and communities (EPBC database), and monitoring of habitat loss through tree-clearing programs such as SLATS. Additional datasets included large-scale bird population surveys (Birds Australia Atlas), waterpoint mapping, and the extent of flora and fauna surveys across rangeland bioregions. Indicators of ecological pressure were also incorporated, such as the distribution of transformer weeds, the number and condition of wetlands, and remotely-sensed measures of ground cover (e.g. the Bare Ground Index). Most of these datasets were collected at regional or bioregional scales, which limits their direct application at farm-scale, and several have since been superseded by new remote-sensing technologies. The ACRIS work highlights the importance of ground cover, water point distribution and tree cover for measuring biodiversity, as well as field surveys data. Ensuring there is some consistency with some of the ACRIS measures may enable comparisons or interpretation of trends.

3.7.2.9 Clean Energy Regulator Human Induced Regeneration carbon project method

The Human-Induced Regeneration (HIR) method requires evidence that land management has promoted natural regrowth of native vegetation. As part of the project lifecycle, Lidar surveys are increasingly flown to establish baseline vegetation structure and monitor subsequent changes in canopy height, cover and density. These Lidar datasets, while primarily collected for carbon accounting, also provide valuable insights for biodiversity monitoring. For example, Lidar can capture fine-scale structural habitat features such as tree height profiles, gaps, and understory density, which are strongly linked to faunal diversity. This creates opportunities to align carbon-focused monitoring with ecological indicators, reducing duplication of effort. In addition, HIR projects often overlap with datasets from other monitoring programs, including remote sensing of ground cover, protected area expansion, and threatened species distributions. Integrating these datasets with Lidar outputs may enhance the capacity to track biodiversity outcomes alongside carbon benefits. The overlap highlights the potential for consistent measures of vegetation structure and change to support both compliance under the HIR method and broader biodiversity measures.

3.7.2.10 Biodiversity Assessment Method

The NSW Biodiversity Assessment Method (BAM) (Department of Planning, Industry and Environment, 2020) is part of the Biodiversity Offsets Scheme (BOS), and is also used by the NSW Biodiversity Conservation Trust (BCT) to assess vegetation. The BAM is used to identify biodiversity values and assess potential impacts and uses GIS (spatial) datasets and field-based assessments. The approach includes:

- Identification of waterways and wetlands, and mapping of ecological communities.
- Mapping habitat connectivity, geological features and areas of outstanding biodiversity value (including threatened ecological communities).
- Native vegetation cover.
- Plant species list, growth form, cover and abundance.
- Tree regeneration, stem size, fallen logs, litter.

Data is compared to benchmark for the relevant vegetation community to generate a score. The BAM also assesses habitat suitability for threatened species. Details about the metrics and approach are summarised in **Table 5** (BAM).

3.7.2.11 BioCondition Assessment Framework

The BioCondition Assessment Framework (Eyre et al 2015) for Queensland provides a measure of how well a terrestrial ecosystem is functioning for biodiversity. It is a site-based, quantitative assessment able to be used in any vegetation. Condition refers to the degree to which the attributes of a patch of vegetation differ from the attributes of the same vegetation type in its reference state.

As with many of the other methods, the BioCondition method is designed for use by assessors who have a reasonable working knowledge of regional ecosystem mapping and vegetation assessment.

The primary components of BioCondition include:

- the assessment unit (mapping of regional ecological communities)
- a suite of vegetation condition attributes that act as surrogates or indicators of biodiversity values
- benchmarks for each of the attributes for each regional ecosystem
- an assessment method
- a scoring system that provides a final 'condition' score.

The attributes assessed using the BioCondition method include:

- mapping patch size, habitat context and connectivity
- native vegetation cover (tree, shrub, grass)
- large trees and tree canopy height
- native plant species richness
- tree regeneration, coarse woody debris, litter
- weed cover
- distance to permanent water.

Data is compared to benchmark for the relevant regional ecosystem to generate a score. Details about the metrics and approach are summarised in **Table 5** (BioC).

3.7.3 Location of monitoring points

Bastin (2008) noted that site based monitoring cannot account for all the spatial heterogeneity and biophysical processes occurring in complex rangeland landscapes. Pastoral monitoring systems can only report on the soils and vegetation found within the area of the monitoring site, and their limitations for regional reporting of landscape health have been demonstrated (Bastin 2008). Spatial variability in habitat quality can range from metres to kilometres – influenced by distribution of water and nutrients as well as grazing (Eyre et al 2011). The noise associated with this variability not only requires appropriate allocation of monitoring sites, but also commitment to long-term monitoring, to detect change.

Patchiness in forage utilisation around water points have been highlighted as complicating broad-scale biodiversity assessments. It has been proposed that landholders should monitor areas where animal activity is concentrated, such as near to water points, as these will be the first to exhibit signs of excessive grazing pressure, and can be used as an indicator of broader scale, long-term impacts (Fisher et al 2004). In contrast, a biodiversity monitoring framework proposed by Eyre et al (2011) highlighted the importance of accounting for sensitive and refugial ecosystems within more extensive resilient landscapes.

Fisher et al (2004) highlighted the need for information such as knowledge of species distribution, accurate listings of threatened or priority species and ecosystems, as well as an ability to delineate management 'hotspots' in monitoring biodiversity (e.g. wetlands, riparian areas, breakaways, threatened vegetation communities). Eyre et al (2011) proposed that to detect change in biodiversity, surveillance sites must be stratified by broad land-type, dominant management regime, and condition state, and include both broadly representative ecosystems and restricted ecosystems of high biodiversity value.

Fortunately, national and state data bases, and remote sensing capability, have improved to a large degree, making it now possible to spatially identify features such as threatened ecological communities, wetlands and waterways, threatened species, land forms and vegetation communities or ecosystem types. **Table 5** highlights that all of the contemporary biodiversity monitoring approaches explored for this review use pre-existing spatial datasets to conduct a preliminary assessment of the property, and target on-ground sampling locations.

3.7.4 Interpreting change

Bastin (2008) noted robust monitoring must be accompanied by interpretation that is sensitive to land management, since metrics dominated by broad-scale drivers such as climate may mask the impacts of grazing systems. The WARMS and SA rangeland monitoring use measures designed to capture grazing impacts. This principle, also highlighted in the natural capital review (McDonald et al. 2024), is particularly relevant to the Australian goat industry. Establishing a credible biodiversity baseline will depend on selecting metrics that reflect the influence of grazing practices on land condition, rather than wider climatic or ecological shifts.

The majority of the methods, whether assessing land condition or biodiversity/natural capital, use reference states to compare to – is the ecosystem being assessed in the best condition it could be? Degradation from that state generates a score or a rating. State and transition models (STM) also describe and measure the condition compared to reference state, but they also assess the likelihood of it being improved by a transition event (Angela Hawdon, pers comms). State and transition models describe the integrity of different states in an ecosystem (including a historic and/or best-available reference state and current modified states) and the drivers of transitions between states (Bestelmeyer et al. 2017, Luxton et al 2025). The application of STMs to ecological restoration requires ecosystem specific models that focus on restoration pathways. Although the concept was developed in Australian rangelands, STMs have only been patchily implemented in Australia (Bestelmeyer et al. 2017), but are likely to be the preferred approach in nature repair market methods (Angela Hawdon, pers comms). Bestelmeyer et al (2025) noted the need for systematic development of STMs to improve their utility and credibility.

A key challenge with using both STM and reference benchmarks is having sufficient information about a relevant reference condition for the ecosystem type / vegetation community in the location being assessed. Accounting for Nature method NV—10 addresses this by enabling the use of any of the following to establish reference sites:

- local reference sites
- published benchmarks
- modelled benchmark
- expert elicited benchmark.

The majority of biodiversity approaches outlined in **Table 4** generate a score for each sampling site, and amalgamate these to generate an overall score. For some a score is generated for subcomponents assessed (Climate Friendly, Farming for the Future), while others generate an overall biodiversity condition score (Accounting for Nature, RAM). The rangeland condition indicators outlined in section 3.5 use qualitative descriptors (e.g. good, fair, poor, very poor), and also focus on trends in condition.

Both rangeland condition and biodiversity assessments focus on the value of assessment in generating a baseline or starting condition. This can be used to identify what is needed (if anything) to improve condition, and highlights the value of having subcomponent scores in being able to interpret and act on results.

Once a baseline is established, quantitative measures of change can be generated by using the same methods for future assessments. For simplicity in reporting, trends or directions of change may be used (e.g. stable, improving, deteriorating). The direction of change is the focus for reporting for the Australian Beef Sustainability Framework and the Sheep Sustainability Framework, and will be key for the goat industry.

Consensus must be reached on how to interpret changes for reporting biodiversity in the Australian goat industry. Bastin (2008) proposed three components to interpreting change:

1. The amount of change required to differentiate a trend from background noise. He highlighted the value of benchmark or reference areas to help indicate change compared to an undisturbed or natural state.
2. Judging whether the change is positive or negative may depend on the perspective of the end user. The example of buffel grass was provided to highlight that this is positive from a production view point, but negative for biodiversity. Woody weeds, or invasive native scrub may also be positive or negative depending on the perspective.
3. Determining the cause of the change (e.g. management or natural).

Of the three components highlighted by Bastin (2008), the most challenging in measuring biodiversity in the Australian goat industry is likely to be the second point – judgement on whether a change is negative or positive, particularly in the examples highlighted. This will need to be explored during the pilot phase of the project.

Determining the cause of any changes, and distinguishing trends from background noise, may also be challenging, but selection of appropriate measures and measurement methodology should mitigate these challenges, but only over longer time scales.

3.7.4.1 Buffel grass

Buffel grass was used to rehabilitate badly degraded and eroded areas, and is now considered ‘naturalised’ in most Australian rangelands, except South Australia where it remains a ‘declared’ weed (Hacker and McDonald 2021). Buffel grass is an ecological transformer, and places native ecosystems at risk through competition and elevated fire frequency and intensity. It is currently nominated for listing as a Weed of National Significance (WONS) (abc.net.au/news/2025-04-20/graziers-and-environmentalists-clash-over-buffel-grass/105145268), which has divided the community. A situational approach to assessing the presence of buffel grass may be the most appropriate (R Hacker pers comms), and this approach has been adopted by Climate Friendly in their assessments. This would mean that where buffel grass is well-established in pastoral situations it is assessed as being positive for ground cover, compared to bare ground. However, it is not sown beyond current areas, particularly where its transformer capability is likely to impact biodiversity values and alter ecological communities it is assessed as a negative.

3.7.4.2 Invasive native scrub (INS)

Invasive native scrub (INS) may also require situational interpretation, as at a landscape scale both scrub or wooded areas and open areas are required to optimise biodiversity (Parsons et al 2017). In the eastern areas of the southern rangelands (e.g. mulgalands of south western Queensland and north western NSW) it is a feature (Hacker and McDonald 2021). In the higher-rainfall environments in the east of the rangelands INS was reported as early as the 1870s and continues to be of concern to landholders.

While shrub encroachment is generally viewed as negative by pastoralists, some ecosystem services are not affected, or may be enhanced, by encroachment so that no single state (including grassland without shrubs) will maximise all services (Eldridge and Soliveres 2014). The effects of shrubs on ecosystems are strongly scale-, species- and environment-dependent. From a pastoral perspective, encroachment can be both a symptom of land degradation (when it is due to the reduction of perennial grass competition), and a cause (when encroachment of shrubs into healthy grassland occurs) (Hacker and McDonald 2021). In situations where land condition overall is poor, INS have biodiversity value. However, where biodiversity is higher and land condition reasonable, the impact of INS is negative and should be assessed as a threat. Recent research by Waters (2025) has highlighted the complexities associated with heterogeneous rangeland landscapes and management histories. This results in complex local site characteristics influencing regeneration of woody species (Waters 2025).

3.7.5 Economic considerations

Evaluating the economic outcomes from biodiversity management, and the biodiversity outcomes associated with sustainable pastoral management, in goat production systems is central to supporting sustainable rangeland grazing. Increasingly it has been demonstrated that investments in biodiversity can align with, and improve, productivity and profitability, when appropriately managed. For instance, Radford et al. (2023) demonstrated that higher levels of natural capital, such as native vegetation cover, soil condition, and bird diversity, are associated with better long-term farm performance, including greater pasture productivity and reduced inputs. Farming for the Future (Macdoch Foundation and La Trobe University, 2022), has further shown that farms with well-managed natural capital assets are profitable. Data collected from over 130 livestock farms across Australia indicate that environmental and economic outcomes are not mutually exclusive; rather, they can be synergistic under appropriate grazing management (Ogilvy et al, 2023, unpublished project report). While this research has not been conducted within rangeland systems, it highlights the potential for goat enterprises, to benefit from practices that improve functional biodiversity (e.g. perennial groundcover, diverse shrubs) and ecosystem services. Hacker and McDonald (2021) outlined studies that indicated conservative stocking (moderate stocking rates and early response to drought conditions) gave the best economic and ecological outcomes, with higher production per head, improved reproduction rates, reduced production costs, and opportunities to improve both the genetic potential of the herd/flock and land condition. Waters (2025) observed that management of herbivore type and grazing intensity will create opportunities for multi-use, integrated landscapes.

3.7.5.1 Market incentives

There is growing interest from banks, supply chains and government (via market-based incentives) in linking biodiversity metrics to financial incentives (Lindenmayer et al. 2022). These include carbon and biodiversity credit schemes, sustainability-linked loans, and product differentiation based on environmental stewardship. Opportunities for ecological restoration are increasing driven by global and national drivers such as the nature repair initiative, Kunming Montreal agreement and Australia's nature repair market (Luxton et al 2025).

Hacker and McDonald (2021) highlighted the emerging opportunities for landholders to be paid for generating ecosystem services. There are currently 182 carbon projects in the rangelands registered with the Clean Energy Regulator (human induced regeneration (HIR method) (Macintosh et al 2024). These projects are likely to lend themselves to stacking with nature repair projects, once a method is available, and wider uptake is likely with increased economic returns of dual projects.

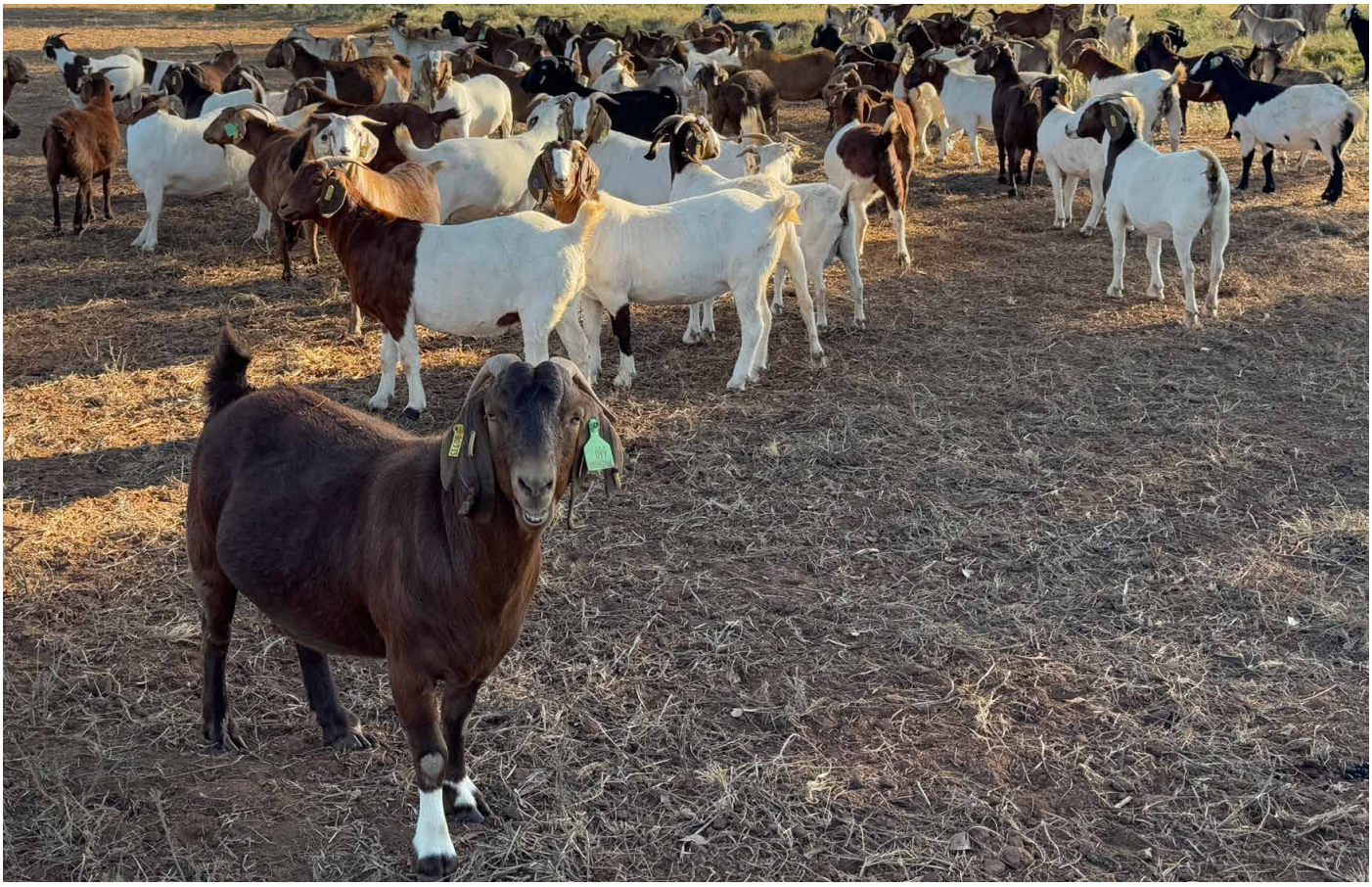


Table 5: Summary of the measures used in existing biodiversity assessment methods. Methods use a mix of field-based and remote-sensed measures. Orange shading indicates remote-sensed, green field-based and grey a combination of remote-sensed and field-based. ✓ = explicitly included/required, ✗ = not included, ~ = optional/partially included

	FftF	EoV	AfN NV03	AfN NV07	AfN NV10	CF#	SA RAM	BAM	BioC
Ground cover (bare soil %)	✓	✓	✗	✗	✗	✓	✗	✗	✗
Tree/shrub canopy (cover/height)	✓	✗	✓	✓	✓	✓	✓	✓	✓
Recruitment (trees/shrubs)	✓	✗	✓	✗	✓	✓	✓	✓	✓
Large trees/basal area	✗	✗	✓	✓	~	✓	✓	✓	✓
Native spp richness (woody)	✗	~	✓	✓	✓	✓	✓	✓	✓
Non-native woody cover^	✗	~	✓	✓	✓	✓	~	✓	✓
Ground layer cover (native/non-native)	✓	✓	✓	✓	✓	✓	✓	✓	✓
Litter/cryptograms	✓	✓	✗	✓	✓	~	~	✓	✓
Coarse woody debris	✓	✗	✗	✓	✓	✗	✗	✓	✓
Forage condition	✓	~	✗	✗	✗	✓	✓	✗	✗
Weeds identified	~	✓	~	✓	~	~	~	✓	✗
Riparian condition	✓	✗	✗	✗	✗	✓	~	✗	✗
Landscape context/connectivity	✓	✗	✓	✓	✓	✓	✓	✓	✓
Vegetation mapping and stratification	✓	~	✓	✓	✓	✓	✓	~	✓
Randomised sampling points	✗	✓	✓	✓	✓	~	✓	~	✓
Minimum sample intensity rules	✓	✗	✓	✓	✓	✗	✓	✓	✓
Use of ecosystem benchmarks/reference condition	✓	✓	✓	✓	✓	✓	✗	✓	✓
Identify biodiversity ‘hot spots’	✗	✗	✗	✗	✗	~	✓	✓	✗
Seasonal/rainfall adjustment	✓	~	✗	✗	✗	✓	✗	✗	✗
Qualified ecologist required	✓	✓	✓	✓	✓	✓	✓	✓	✓

rangelands nature repair method under development, this assessment is based on the nature capital assessment report for the rangelands ^ Non-native woody may be a plantation or farm forestry cover, which is not considered weedy by the producer Farming for the Future (FftF), Ecological Outcome Verification (EOV), Accounting for Nature (AfN), Clean Energy Regulator Nature Repair Market replanting native forest and woodland ecosystems (CER), Climate Friendly (CF), South Australian rangeland assessment method (SA RAM), NSW Biodiversity Assessment Method (BAM), Queensland BioCondition (BioC)

4 Discussion

While there are some practical tools for producers to use in monitoring rangeland condition (e.g. ground cover, forage, etc), uptake of these tools has not been widespread. However, there are synergies between many of the measures being promoted to producers as key to sustainably managing their resource base, and the measures suitable for monitoring biodiversity. It may be possible for a rangeland biodiversity monitoring program to make use of existing pastoral monitoring programs because of their large spatial coverage and focus on measuring impacts of overgrazing, and all pastoral monitoring programs collect information about perennial plants (Richardson 2003).

Being able to promote the multiple uses of data collected and encourage producer participation in monitoring, will support producer buy-in to biodiversity monitoring. One of the biggest fears producers have regarding biodiversity monitoring is that data will be used against them (or industry), particularly when taken out of context (J Falkenhagen pers comms). This is a theme also found in the beef industry – particularly around remote sensed data, where there are justifiable concerns about accuracy, and producers wanting opportunity to validate data for their properties (J Mitchell pers comms).

Hacker and McDonald (2021), in their review of sustainable use of the rangelands, noted differences between producers' experience and scientific evidence regarding impacts of grazing system on rangeland condition. There were valid reasons to explain why producers' observations were not able to be replicated using experimental designs, and the producers' experiences were important to record. Using producers' knowledge of the country they manage, and building that knowledge, is an opportunity that should be embraced in establishing a method for biodiversity monitoring in the Australian rangelands.

The approach to establishing a biodiversity baseline for the Australian goat industry (rangelands), recommends using existing industry rangeland condition measures as a starting point. This will be less daunting for industry, and more likely to engage producers already familiar with these approaches. It also leverages the existing expertise in support and advisory networks (e.g. QDAF, Local Land Services).

The shortlisted biodiversity measures must be meaningful now, but should also include measures under development, with appropriate safeguards. An example is the use of remote sensing for ground cover assessments. It is currently not accurate or reliable in all environments across the rangelands, but the only way this will improve is calibrating remote sensed data with ground-truthed data. Anecdotally, remote sensed data is currently capable of differentiating between good sites (A condition) and very poor ones (D condition), but not B or C condition. This could be useful information in stratifying and identifying sites for field assessments. **Table 6** outlines in detail the metrics being proposed for the pilot, and the proposed method/s of measurement. The justification for shortlisting these measures is outlined here.

Outcome-based measures currently used for monitoring rangeland condition, and recommended for inclusion in a pilot to measure biodiversity in the rangelands are:

- forage condition (e.g presence and diversity of palatable, perennial grass and shrub species)
- soil condition (e.g. cryptogam, litter, cover, soil roughness), erosion.

Soil condition and erosion indicate whether landscapes are functioning well and able to retain and respond to rainfall. Healthy, functioning landscapes are critical for biodiversity. Forage condition can be used to assess the level of grazing pressure. The presence of diverse, perennial species in the ground and shrub layer is also key to landscape function and biodiversity.

Total grazing pressure (TGP) and rainfall are key to being able to interpret data, and information on both should be captured. TGP will be challenging, but is more straightforward and meaningful than attempting to assign the grazing pressure to particular species. This will be explored during the pilot with a range of measures for TGP proposed. The presence of exclusion fencing on properties may influence the unmanaged component of TGP.

The presence of biodiversity hot spots (including threatened vegetation communities and species, and habitats such as wetlands, riparians areas, breakaways, etc) should be highlighted. The condition of these sensitive and important areas for biodiversity is also important, however assessing these directly may be challenging due to remoteness and cost. How these areas are managed may be a suitable proxy for condition assessments. FftF and Climate Friendly both use the presence of woody tree cover in riparian areas (assessed via remote sensing) as an indicator of waterway condition. This is a simple, low-cost measure, with existing methods ready for application.

Having areas remote from water is important for biodiversity. The SA RAM uses grazing gradients to identify areas for field survey. This technique could be trialled in a similar way to how shade and shelter are measured by Climate Friendly and FftF.

Tree cover and ground cover can both be measured using remote sensing, however, some field assessments are critical for data validation. Connectivity of vegetation is assessed by the majority of the methods summarised in **Table 5**. It is also straightforward, using remote sensing, and is ready for use.

Field-based measures to assess the quality of habitat such as recruitment of trees and shrubs, tree and shrub cover, species diversity and presence of weeds are recommended. While field-based measures are expensive, requiring an ecologist to visit the property, alternative measures such as relying on remote sensing alone do not have the necessary rigour. ACRIS, in reporting on trends in rangeland condition, used field data (e.g. bird surveys, wetland condition, presence of weeds), highlighting the importance of on-ground observations and data. These appeared to be opportunistic surveys, rather than surveys delivered specifically for the purpose of collecting data for ACRIS.

While outcome-based measures are preferable, as they provide unequivocal quantitative evidence of positive biodiversity management, many measures of biodiversity can be slow to respond (R. Hacker, S. McDonald, J. Hender pers comm; McDonald et al 2024). However, management practices can be changed quickly, and, depending on the chosen practices, can be relatively easily assessed. In the short-term, as remote sensing technology continues to improve, a combination of practice and outcome-focused biodiversity measures, at an industry level, may be the most pragmatic way to proceed. Settling on appropriate practices, applicable across the rangelands, regardless of location, and without being prescriptive may be challenging. However, Hacker and McDonald (2021) suggested principles and guidelines for sustainable pastoral management, which provide a valuable starting point (**Table 8**, Appendix 7.3).

Based on reviewing the literature and discussions with industry stakeholders, suggestions for practice-based measures include:

- regular monitoring of ground cover and forage condition, and adjusting stocking rate in response
- resting paddocks for periods of time from continuous grazing pressure from domestic livestock (and minimising grazing pressure in these areas from non-domestic livestock)
- maintaining areas remote from water
- biodiversity hotspots identified and proactively managed to protect biodiversity values (appropriate actions may vary depending on the asset)
- proactive control of feral animals (pigs, foxes, cats)
- where the operation undertakes wild harvesting of goats, their contribution to TGP is accounted for to inform management of animals not fit for commercial sale. Where TGP is unsustainable unsaleable animals are culled and not released
- artificial water sources are turned off when livestock aren't in a paddock
- goats are mustered and harvested more than once per year.

Selecting a suite of outcome- and practice-based measures is important, particularly for the pilot, so they can be ground-truthed, and results cross tabulated and compared. Following the pilot, some metrics or methods may be assessed as not being fit for purpose, while others may be able to be refined to improve their usefulness. Designing the monitoring program with future technological advances in mind is critical – this will enable data consistency through time, with robust information around trends. Presenting the scores (and trends) for individual measures is also important. This provides richer information, and enables producers and industry to identify where there are areas for improvement and the appropriate remedial actions to take.



5 Conclusions and recommendations

This work has thoroughly reviewed the methods currently used for assessing rangeland land condition and natural capital (biodiversity), and explored the relationship between grazing management (goat production) and biodiversity. The purpose of data collection is of primary importance in selecting suitable measures – they must be capable of delivering what's required. They must also be:

- scientifically rigorous
- aligned with established industry approaches
- aligned with supply chain needs
- scalable (farm to region)
- sensitive to management
- cost-effective (i.e. the value of the data/information must match the cost of obtaining it; and the more end uses for data, the more valuable it is).

The shortlisted measures being proposed for establishing a biodiversity baseline for the Australian goat industry (**Table 6**), are consistent with current industry methods. They will also be suitable for all rangelands livestock enterprises (cattle, sheep and goats), as they are specific (and unique) to the rangelands environment. However, many may also be relevant for livestock production areas outside the rangelands (e.g. ground cover, tree/shrub recruitment, etc), further increasing their relevance.

Ensuring consistency between goat industry biodiversity measures and those used in other rangeland monitoring programs will enable value-adding rather than duplication; noting that the end use of data determines the level of rigour, independence and accuracy required.

By accounting for rainfall, the proposed approach separates climate from grazing impacts, enabling informed interpretation and decision-making. Collecting data on TGP is key to understanding grazing impacts. What is being proposed is consistent with other approaches that don't directly measure fauna, but assume a relationship between fauna populations and healthy habitat. Remote sensing is key to minimising costs of measurement, and only with further use will these tools become better calibrated and more useful. However, it is currently not considered reliable enough to be the sole measure. Field-based monitoring is included to improve the rigour of biodiversity assessments. Some of these leverage existing industry activities, while others specifically target biodiversity. All outcome-based measures should be compared to reference condition, as a means of assessing the results for biodiversity performance. The responsiveness of the measures to management, and the speed of change are also important considerations in enabling trends in condition over time to be determined.

Using producers' knowledge of the country they manage, and building that knowledge, is a significant opportunity in measuring biodiversity for the goat industry, in the Australian rangelands. Additionally, the proposed approach recommends including existing industry rangeland condition measures, to leverage existing expertise and data.

5.1 Challenges

There are likely to be a number of challenges in implementing on-farm pilots to test biodiversity measures, in the context of establishing a biodiversity baseline for the Australian goat industry. These include:

- selecting sample sites so they are representative vs selecting sites in poorer condition where change can be more easily measured vs targeting biodiversity hotspots
- sample size of the pilot is too low for robust analysis and comparisons
- establishing an appropriate reference (benchmark) condition for sample sites
- interpreting trends (particularly in the context of seasonal variation, TGP and goat grazing pressure)
- moving from farm to industry scale reporting
- increasing adoption of rangeland condition assessments by producers
- reliability of base spatial data sets such as native vegetation mapping layers
- reliability of remote sensed data.

Awareness of these challenges and risks will enable the pilot to be designed to manage them. However, the pilot will also provide an opportunity to test risks, and limitations, to the proposed approaches for measuring biodiversity (noting that establishing the baseline is only the first step – ongoing monitoring to establish trends over time will be a critical component to reporting goat industry sustainability).

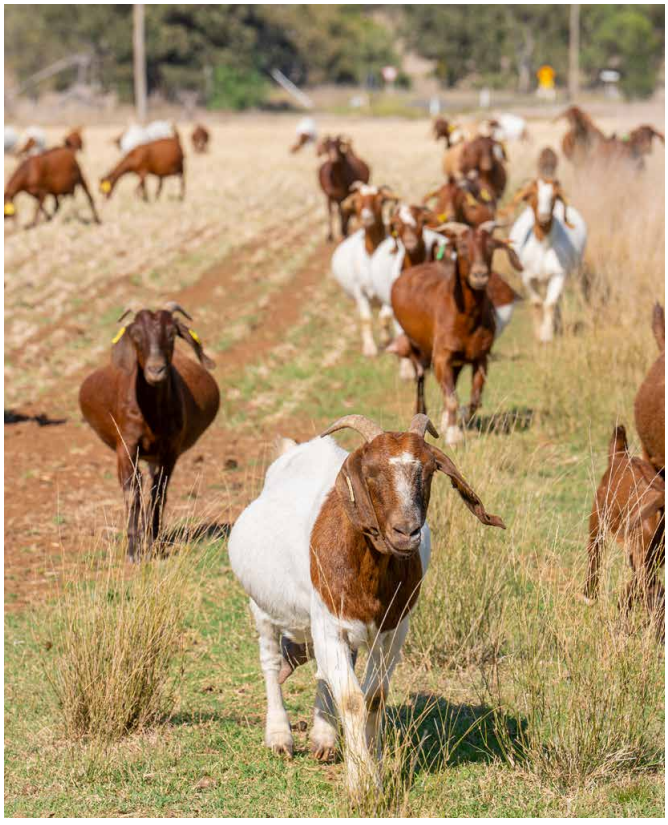


Table 6: Proposed measures for measuring biodiversity of rangelands goat businesses, with the purpose of establishing an industry baseline. Orange shading indicates remote-sensed (including desktop/farm data), green field-based and grey a combination of remote-sensed/farm data and field-based. (McDonald et al 2024, Table 2 utilised as a reference in preparing this table)

Measure	Details	Proposed data collection method	Benefits	Challenges	Sensitivity to management	Rigour
Seasonal rainfall	Recent rainfall compared to long-term records (expressed as a decile).	Desktop (BoM records). Station records.	Separates seasonal conditions from management. Low cost, readily available.	Changes to long-term rainfall averages.	NA	High.
Total grazing pressure (TGP)	Estimate of TGP (domestic and non-domestic).	Desktop (e.g. review regional aerial survey data). Business livestock records. Presence of exclusion fencing (boundary/internal). Utilisation and recruitment of palatable shrub and grass species used as an indicator of TGP. Step-point dung transect. Kangaroo predictive management tool (if available).	TGP critical driver of rangeland condition. Important data for business management. Moderate cost.	Accurate measures of both domestic and non-domestic herbivores can be challenging in the rangelands. TGP data is regional not property-focused.	Moderate. Limitations to controlling kangaroo numbers; goat harvesting dependent on limited processor space.	Moderate. Relevant records often lacking.
Remoteness from water	Heterogeneity of grazing, and areas remote from water are important for biodiversity. Information can be used to locate monitoring sites, and provide a measure of proportion of property that is remote from water (>3 and >5km).	Map permanent watering points using aerial imagery and confirm locations with landholder. Create 0.5km, 3km and 5km radius circles around each watering point. Monitoring plots located randomly >0.5km from water points (in the same paddock).	Areas remote from water are important biodiversity refuges. Important to inform monitoring site location. Once remote sensing codes are set up, will be a simple low cost measure.	In areas where high density of water points remoteness from water may not differentiate areas. Conflict between best biodiversity outcomes and best production outcomes.	High. Artificial watering points (bores and troughs) can be managed to influence landscape use by browsers.	Moderate. Natural water sources, particularly after rainfall, will be difficult to map (however many of these are highly ephemeral).
Conservation significance (biodiversity hot spots)	Landscape features important for biodiversity, and locations of threatened species or communities are identified and managed to protect biodiversity values.	Desk top and remote sensing to identify, with confirmation by landholder. Management practices used and field observations for condition.	Can focus limited time and resources on areas known to be important for biodiversity. 'Storytelling' value for industry. Low cost to identify; condition assessments more expensive.	Focusing only on hot spots risks missing biodiversity across majority of landscape. Validating management practices with positive outcome. Quality and availability of data is variable.	Low. Context and historical land management may influence both condition and management.	Moderate. Depends on available databases and quality of aerial imagery. Lends itself to drone imagery, for difficult-to-access locations.

Measure	Details	Proposed data collection method	Benefits	Challenges	Sensitivity to management	Rigour
Riparian tree cover	Healthy waterways are important for biodiversity. Tree cover can be used as a proxy for waterway health. % waterways with tree cover.	Remote sensing – water course and tree cover layers. Ground truth – assess riparian condition.	Low cost. Healthy waterways are critical for biodiversity.	Tree cover may not always be correlated with good condition Riparian weeds aren't differentiated, upper reaches of catchments may naturally be tree-less.	High. Riparian tree cover can be improved with appropriate management. Slow to change.	Moderate. Rigour will increase with ground-truthing to confirm if native cover or weeds.
Organic ground cover	% ground with vegetation. To minimise impacts of seasonal variability, either average over 5-years' preceding or compare to the regional average.	Remote sensing. Validate with field observations (soil condition).	Remote sensing is low cost. Ground cover field measures can be easily done by pastoralists. Significant amounts of pre-existing data from existing rangelands monitoring tools.	Remote sensing is not calibrated for many areas (e.g. WA) or landscape types (e.g. gibber). Reference state for ground cover will vary depending on the ecosystem type.	High. Seasonal conditions a stronger driver than management, so this must be factored into interpretation.	High. Remote sensing alone is not reliable at this time, but with increasing use (and calibration) this will improve.
Soil surface condition	Cover (basal and foliar), cryptogams, litter, soil roughness, erosion.	Field observations.	Standard rangeland condition measure. Correlated with productivity and sustainability. Many producers may already be monitoring. Significant amounts of pre-existing data from existing rangelands monitoring tools.	Producers may do observations, but likely to be a lack of on-farm records. Encouraging wider industry uptake. Cost of field assessments by ecologist.	High. Slow to change.	High.
Biomass	Diversity of perennial, palatable plants, and utilisation (RAM and LCAT methods), is a cross-check for TGP, as well as a measure of biodiversity. Average over preceding 12 months and/or compare to regional average.	Field observations (vegetation condition) and remote sensing (NDVI).	Standard rangeland condition measure – opportunities to leverage existing industry activities. Correlated with productivity and sustainability. Pre-existing data from existing rangelands monitoring tools.	Producers may observe, but likely to be a lack of on-farm records. Encouraging wider industry uptake. Cost of field assessments by ecologist	High.	High. Well-developed field methods, data reliability may depend on data collector (e.g. producer, ecologist, extension officer). Remote sensing measures are under development and improving

Measure	Details	Proposed data collection method	Benefits	Challenges	Sensitivity to management	Rigour
Vegetation condition	Vegetation condition compared to benchmark condition for that vegetation community is an established proxy for biodiversity: • Cover of weeds (tree/shrub/ground). • Native shrub/tree recruitment. • Native cover (tree/shrub/ground cover). • Utilisation (RAM and LCAT methods). • Coarse woody debris.	Field observations and remote sensing.	Habitat condition used as a proxy for fauna. High level of rigour with existing methods.	Limit to coverage (ie number of sites) due to property scale. Cost of field assessments by ecologist. Depends on vegetation mapping accuracy (variable, but improving), to identify sites and establish reference benchmarks.	High. Slow to change.	High. Dependent on field assessments by qualified person, quality of regional vegetation mapping, and availability of benchmarks.
Management practices	i. Assessing ground cover and forage condition and adjusting stocking rate in response. ii. Resting paddocks. iii. In harvested rangeland situations, contribution to TGP is accounted for before unsaleable animals are released. Where TGP is unsustainable unsaleable animals are culled. iv. Targeted management of biodiversity hotspots. v. Proactive control of feral animals (pigs, foxes, cats). vi. Turn off artificial water when livestock aren't in a paddock. vii. Muster and harvest goats regularly to effectively manage TGP.	Producer supplied data (responses to survey questions).	Simple, low cost to collect. Change in practices is quicker to measure than on-ground change resulting from those practices. 'Storytelling' value for industry. May enable some interpretation of outcomes measures.	Connecting management practices with outcomes. Requires large enough sample size to be meaningful at industry level. Complex array of management suited to different situations.	NA	Low. While there is evidence for positive outcomes from these practices, how they are applied in the field can vary, with differing outcomes. Can be a time lag between practice change and measurable impacts in the positive direction.

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7 Appendix

7.1 Glossary

Biodiversity	The variety of different plants, animals and micro-organisms, and the ecosystems they are part of, found in a specified place. It encompasses species richness, genetic variation within species and ecosystem diversity (AASF). Ensuring the conservation and enhancement of plant and animal species, genetic diversity, and natural ecosystems (ABSF).
Composition	The mix of species contained in vegetation, or in the diet of grazing animals.
Continuous grazing	Grazing method in which pasture is grazed continuously and only the stocking rate is varied.
Dry sheep equivalent (DSE)	Standard unit for comparing the feed requirements of various livestock, where 1 DSE equals the monthly feed requirement of a 50kg, non-pregnant ewe.
Ecosystem(s)	Communities of organisms (microbes, plants and animals), their environment (soils and climate) and the way in which they interact.
Ecosystem resilience	Capacity of an ecosystem to withstand disturbances, such as fires, floods, or pollution, and retain its fundamental structure and function over time.
Farmed goats	See managed goats.
Forage budgeting	The process of determining short-term carrying capacity by balancing forage demand with forage supply
Forbs	Broad-leaved herbs other than grasses or sedges; dicotyledons exhibiting a variety of leaf shapes; have a tap root.
Functional diversity	The variation in the ecological roles and traits 10of organisms within a community or ecosystem, influencing processes like productivity, nutrient cycling, and stability.
Genetic variation	The differences in DNA among individuals of the same species, resulting in a variety of traits.
Ground cover	The proportion of the ground surface that is not bare. Litter, biocrusts, organic debris, and plant bases are the main components of ground cover.
Harvested rangeland goats	Goats captured from a wild state and not part of a managed breeding program or subjected to animal husbandry (also known as wild harvested).
Herbs	Non-woody plants including grasses, forbs and sedges
Land condition	The capacity of grazing land to respond to rain and produce useful forage. It is also a measure of how well the grazing land ecosystem is functioning. It is determined by both soil condition and pasture condition.
Landscape function	The way in which the landscape operates to conserve resources, especially water and nutrients, and make them available for ecological processes. How well a landscape is functioning is closely related to land condition
Land system	Land area or group of areas throughout which there is a recurring pattern of topography, soils and vegetation
Land type	A broad association of similar soils and vegetation types that are easily recognised by livestock producers and landholders in a region; an area of grazing land with a characteristic pattern of soil and vegetation.
Managed goats	Goats that are part of a managed breeding program and/or subjected to animal husbandry.
Rotational grazing	A grazing method that involves sequential grazing of subsections of the management area at stocking densities that are higher (sometimes markedly so) than the overall stocking rate to allow grazed plants to recover before further defoliation, and/or reduce species- or patch-selective grazing. Rotational grazing includes a wide range of practices that differ in the number of subdivisions, the number of flocks or herds, the duration of graze and rest periods and the criteria for moving animals.

Refugia	Refugia are habitats or geographical areas that plants and animals retreat to or persist in, where environmental conditions are buffered over time. Refugia have been suggested as priority sites for conservation because they facilitate survival of biota under adverse conditions.
Soil condition	The capacity of the soil to absorb and store rainfall, store and cycle nutrients, provide habitat for seed germination and plant growth, and to resist erosion.
Stacking	Stacking refers to two or more projects being undertaken on the same, or partially overlapping, areas of land to generate carbon and biodiversity credits
Total grazing pressure (TGP)	Combined grazing pressure exerted by all managed and unmanaged herbivores on the vegetation, soil and water resources of rangeland landscapes. A central tenet of TGP is the balance between supply and demand for feed.
Wild harvested goats	See harvested rangeland goats.
Woody weeds	Native woody species that increase in abundance under pastoral management (e.g. due to the reduction of competing perennial grasses and/or the absence/suppression of fire). Also known as Invasive Native Scrub.

7.2 ACRIS biodiversity datasets

Table 7: Datasets used by ACRIS to report change in biodiversity in Australia's rangelands (from 1992–2005) (from Bastin, 2008)

Information type	Dataset	Description
Protected areas (progress to CAR)	Collaborative Australian Protected Areas Database (CAPAD)	Biennial reports from relevant state and territory agencies to CAPAD on the size of protected areas within each IBRA bioregion
Threatened species and biotic communities	EPBC database on number and status of threatened species and communities	
Habitat loss: extent and fragmentation due to tree clearing	Clearing mapped from Landsat TM imagery	Selected results for Queensland based on the State wide Landcover and Trees Study (SLATS) program. Similar results for parts of the northern NT and the eastern rangelands in NSW where clearing occurs
Bird population composition	Birds Australia Atlas	Abundance and distribution of bird species across the rangelands, as surveyed and reported by members of Birds Australia
Waterpoint distribution and distance	Mapped waterpoints	Habitat remoteness indicator based on jurisdictional mapping of waterpoints for pastoral leases in SA, WA and the southern NT
Terrestrial fauna surveys	Number of surveys and records for fauna	The number of fauna surveys, and records for species collected across rangeland IBRA bioregions and subregions. Changes can be reported where sites have been resurveyed.
Terrestrial flora surveys	Number of surveys and records for flora	Across rangeland bioregions and, where available for sub IBRAs, the number of flora/ vegetation surveys and records on plant species. Changes can be reported where sites have been resurveyed.
Transformer weeds	Maps of weed distributions	The distribution and abundance of invasive exotic plants that transform habitats for native biota. Changes can be mapped where weed distributions have been resurveyed
Wetlands	Numbers of Ramsar and other critical wetlands	Distribution and condition of wetlands critical as habitat for biota such as waterbirds and frogs across rangeland IBRA bioregions.
Habitat condition	SLATS derived Multiple Regression Bare Ground Index	As an indicator of habitat condition for biota, the extent, amount and type of groundcover measured remotely across the rangelands.

7.3 Principles and guidelines for sustainable pastoral management

Table 8 summarise the principles and guidelines for sustainable rangeland management practices, outlined by Hacker and McDonald (2021). These have formed the basis of proposed practice-based measures for biodiversity measurement.

Table 8: Principles and guidelines for sustainable pastoral management in the southern rangelands Hacker and McDonald (2021)

Principle	Guideline
1. Manage grazing within a risk management framework based on the concept of tactical grazing	1. TGP DSE/ha 2. Carrying capacity estimate (DSE days/ha/100 mm rainfall (annual average) 3. Estimate short-term grazing capacity 4. Land management objectives and grazing strategies for paddocks 5. Monitoring 6. Trigger points to assist decision making 7. Proactive management of non-domestic grazing pressure
2. Develop infrastructure to allow best management of both domestic and non-domestic grazing pressure	1. Fencing for cost-effective control of non-domestic grazing pressure 2. Fence to land type when replacing fences 3. Water points for efficient mustering and to control access
3. Incorporate management of invasive native scrub (where appropriate) into overall property management on an ongoing basis	1. Monitor for woody seedlings in good seasons (where germination likely) 2. Keep open areas open 3. Cost benefit of control and follow up 4. Consider potential for carbon sequestration project (and nature repair)
4. Seek to enhance biodiversity conservation at landscape scale	1. Don't undertake new water development in areas remote from water 2. Special care for sensitive areas 3. Control foxes and cats 4. Consider biodiversity objectives and impacts with grazing management 5. Consider opportunities for stewardship payments

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