Final report

From method to market – unlocking ecosystem service opportunities for livestock producers

Project code:P.PSH.1246

Prepared by: Joshua Peart, Steven Bray and Hayley McMillan
Department of Agriculture and Fisheries

Date published:29 February 2024

PUBLISHED BY
Meat & Livestock Australia Limited
PO Box 1961
NORTH SYDNEY NSW 2059

This is an MLA Donor Company funded project.

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

This publication is published by Meat & Livestock Australia Limited ABN 39 081 678 364 (MLA). Care is taken to ensure the accuracy of the information contained in this publication. However MLA cannot accept responsibility for the accuracy or completeness of the information or opinions contained in the publication. You should make your own enquiries before making decisions concerning your interests. Reproduction in whole or in part of this publication is prohibited without prior written consent of MLA.

Abstract

This project worked with ecosystem services market stakeholders and nine Queensland grazing businesses to identify and help overcome technical and economic barriers to ensure widespread market eligibility for Australian graziers, focusing on northeast Australia. At the inception of this project in 2020, more than $2.5 billion in government funds had been committed to payments for ecosystem services via carbon and natural capital markets. Concurrently, the Australian red meat industry had committed to carbon neutrality by 2030 – the most ambitious red meat climate target set worldwide to date. Occupying almost 50% of the Australian continent livestock production systems have enormous potential to partake in ecosystem service markets, including sustainable red meat product claims, however limited participation had then been achieved.

Opportunities for producers to engage in environmental markets were seen to be significant at the inception of this project. However the potential risks of focusing solely on carbon have since been identified as being potentially detrimental to business and the industry. Real-life case studies aided the identification of revisions and/or development of carbon market, natural capital and carbon insetting methods.

Specification of long-term objectives for individual businesses was identified as a key pathway to improve market engagement. It is recommended that further on-ground research specific to targeting implementation for, as well as the provision of impartial advice from government or other such bodies, will be critical in the progression of the industry’s environmental credentials.

Executive summary

Background

The Method to Market (M2M) project sought to identify and help overcome technical and economic barriers to grazier participation in ecosystem services markets. Results and findings of the project will aid decision making around carbon farming by individual landholders; assist Australia's red meat industry to mitigate carbon and natural capital risk; as well as the inevitable progression of brand claims. The project was a collaboration between the Queensland Department of Agriculture and Fisheries, Queensland Department of Environment, Science and Innovation, Cibo Labs, Integrity Ag, The University of Queensland, Agri Escondo, Bush Agribusiness, BooBook Ecological Consulting and Meat & Livestock Australia.

Objectives

- Review available literature on existing scientific methods for livestock producers to be remunerated for providing ecosystem services to the community whilst producing livestock.
- Consider enhancements to existing methods to improve producer adoption.
- Develop new scientific methods for livestock producers to be remunerated for providing ecosystem services to the community whilst producing livestock.

Methodology

An inter-disciplinary team of agricultural, social and environmental scientists; spatial, ag tech and method developers; and environmental credit and certification scheme operators worked with ecosystem services market stakeholders and nine extensive Queensland grazing businesses to identify and help overcome technical and economic barriers to grazier participation in ecosystem services markets. A range of activities were undertaken including:

- Review of opportunities available to landholders and barriers to participation.
- Review of soil carbon in northern grazing lands.
- Assessment of the carbon position of collaborating grazing businesses.
- Assessed opportunities and financial and productivity impact of becoming carbon neutral at the business scale.
- Contributed to tool and method development to enhance ease and accuracy of participation.

- Undertook field sampling to enhance biodiversity and vegetation model and tool development.
- Reviewed climatic impact of livestock business emissions.
- Undertook extension and education activities.

Results/key findings

- Project pre-conceptions were that poor landholder participation in ecosystem services markets could be solved by 'fixing and developing methods and aiding technical solutions that bring down the cost of participation', however, stakeholder survey results revealed ecosystem services markets revealed strong negative sentiment and concern around a broad range of complex issues relating to project design and implementation requiring broad systemic change if widespread uptake in grazing systems is to be achieved. It was proposed that the formulation of an advisory multi-stakeholder partnership or roundtable would incentivise a holistic and thorough approach to ensure benefits and integrity was maintained across environmental markets and the various stakeholders. This would be obtained by including representatives from each level of parties involved in carbon and environmental markets with expertise in the multifaceted areas impacted with the implementation of carbon projects.
- The identification of the key issues, being technical and financial, surrounding uptake of ecosystem market services in the land sector bear similar challenges to the development of brand claims from sustainability targets set out by the industry. It is critical that these barriers are considered and overcome before brand claims become more influential, so graziers have the opportunity to engage in meaningful programs that offer tangible rewards.
- Carbon emission reduction pathways that align most closely to production goals should be implemented for both economic and sustainability objectives.
- In the Queensland case studies, these pathways did not currently have the capacity to neutralise production emissions indefinitely but only for a period of time.
- The emission abatement options that are currently available are varied in their suitability for different production systems and can be antagonistic to production. They are also limited in their potential abatement on farm under current feasible methodologies. Given the difficulty of reducing emissions to zero and/or offsetting emissions on farm, a thorough analysis of productivity, business goals and sustainability goals is required.
- Often there are large proportions of vegetated areas on properties that are ineligible for carbon projects and ACCU generation, though they represent environmental stewardship by producers that should be recognised. Benchmarking environmental performance should consider the available opportunities for producers and the environmental qualities already present based on past activities.
- At the individual business scale the focus should be on identifying and implementing opportunities to reduce the climate impact of the business and ensure long term business sustainability.

Benefits to industry

- Real-life case studies from this project contributed to the identification, revision, improvement and/or development of current and proposed carbon market, natural capital and carbon insetting methods.

- Extensive environmental and productivity condition field data were collected that contributed to the development and validation of spatial methods to cost-effectively measure pasture biomass, tree biomass and native vegetation condition; both at state and national scales.
- Novel capacity for the Queensland Department of Agriculture and Fisheries to impartially contribute to industry engagement on the topics of carbon, biodiversity and natural capital opportunities in productive grazing systems.

Future research and recommendations

It is recommended that co-investment by industry, supply chains and government will further the uptake of environmental projects and advance the red meat industry's sustainability credentials. Key areas requiring investment to achieve this include:

- Globally recognised and locally relevant food and fibre carbon and 'nature positive' product labelling standards and formalisation of carbon insetting methods under industry agreed certification standards.
- Development of motivated, impartial regional champions with the skills, education and time to successfully help graziers navigate these markets through the development of business specific analyses and advice. This will largely be addressed through activities such as Carbon EDGE and the Carbon Farming Outreach Program.
- Collection and sharing of site-based data to support the national capacity to demonstrate zero deforestation claims, capacity for long-term soil carbon improvement, as well as fit-for-purpose spatial tools to scale up capacity for advisors to cost-effectively assess the cost/benefit of participation in ecosystem services markets and sustainable red meat product claims.
- Identification throughout grazing systems of northern Australia of the impact of retaining native woody vegetation in the form of shelter belts on pasture production, livestock production, carbon sequestration, water quality, property scale landscape attributes, biodiversity, and mitigating nature related risk. Tools to design placement of woody vegetation to maximise benefits and minimise negative impacts are required.
- Identification of a "workable" level of data accuracy and associated error for emission baselining to allow for meaningful and actionable engagement in low emission supply chains or business management.
- Further develop economic and environmental cost-benefit analyses of carbon projects to support optimisation of carbon, biodiversity and production focused management.
- Further investigation into the development and optimisation of technologies that support the demonstration of climatic sustainability and environmental stewardship for the purpose of increasing confidence in environmental crediting and reducing engagement costs.

Table of contents

1. Background

At the project's inception more than $2.5 billion in national and state government funds had been committed to payments for ecosystem services via carbon and natural capital markets (Clean Energy Regulator 2018; Department of the Environment and Energy 2019; Queensland Government 2019). Concurrently, the Australian red meat industry announced the carbon neutrality by 2030 (CN30) initiative – the most ambitious red meat climate target set worldwide to date. Occupying almost 50% of the Australian continent (ABS, 2016) livestock production systems have enormous potential to partake in ecosystem service markets, including sustainable red meat product claims, however limited participation had been achieved at the time.

Existing barriers to participation in these markets appeared to include the small, unmarketable size of individual farm carbon credit parcels; poor profitability of payments from the Emissions Reduction Fund (ERF) due to the low carbon price and comparatively high ERF transaction costs; policy–implementation gaps in emerging co-benefit schemes; and the perception that participation was 'too difficult and risky' for the financial return.

The project sought to identify and help overcome technical and economic barriers to grazier participation in ecosystem services markets, including sustainable red meat product claims, by engaging with market experts, stakeholders, and livestock producers to review, revise and/or develop new scientific methods for livestock producers to be remunerated for providing ecosystem services whilst producing livestock (i.e., generation of carbon credits, natural capital claims and/or co-benefit credits, water quality credits, etc.).

2. Objectives

1. Review available literature on existing scientific methods for livestock producers to be remunerated for providing ecosystem services to the community whilst producing livestock. *Technical reviews and social investigations are addressed in sections 4.1.1 and 4.1.2.*

2. Consider enhancements to existing methods to improve producer adoption. *Analyses of existing methodologies, contextualised by the scientific reviews, and the subsequent enhancements are described in section 4.5. Additional technologies developed which improve the scientific basis behind existing methods, as well as data collection/baseline methodologies, reduce barriers to uptake as raised by the revision of literature.*

3. Investigate and develop new scientific methods for livestock producers to be remunerated for providing ecosystem services to the community whilst producing livestock. *A variety of topics were addressed throughout section 4, including analyses surrounding the capacity of carbon emission reduction and sequestration on-farm.*

3. Methodology

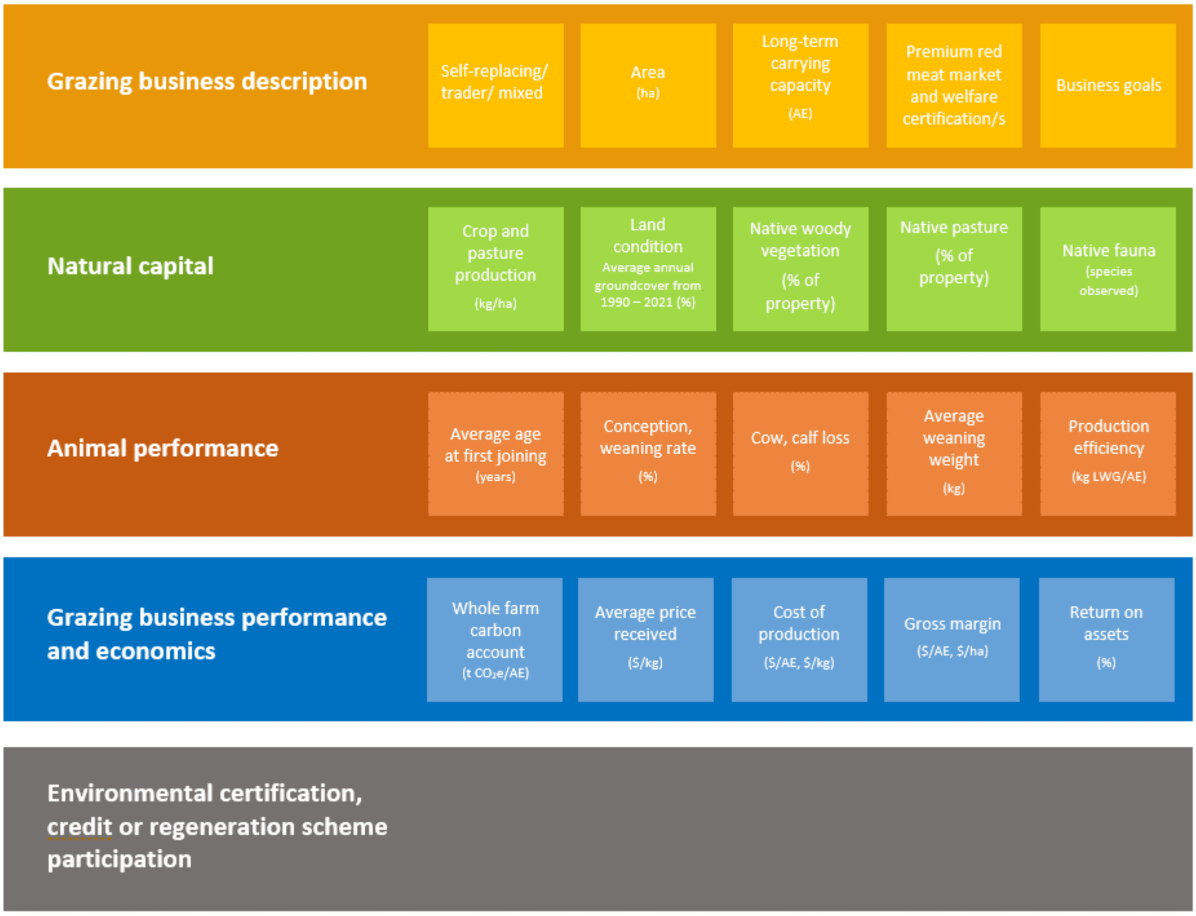
This project sought to overcome technical and economic barriers to producer participation in ecosystem services for premium red meat markets (grass fed, organic etc) whilst producing livestock. DAF engaged with livestock producers to review existing methods and develop new scientific methods for livestock producers to be remunerated for providing ecosystem services (generation of carbon credits, biodiversity credits, water quality credits) whilst producing livestock. Graziers were selected based on business size (typical family business with one to five properties) who had interest in exploring options in environmental and carbon markets.

A range of methods were examined for maximising the generation and gross margin of carbon credit and co-benefit parcels, such as: use of legumes in extensive grazing systems, animal supplementation for reduced enteric methane emissions, biodiversity enhancement, and a whole-of-farm method design.

Eight four-year, on-farm producer research and demonstration studies were conducted across intensive and extensive livestock systems in Queensland and evaluated using the framework described in Figure 1 at property and regional scales.

These on-farm studies aimed to address policy−implementation gaps in emerging ecosystem services schemes through three key focal areas: (1) developing and demonstrating affordable methods that clearly define baselines and changes in land condition and biodiversity at local and regional scales, (2) demonstrating the influence of land use practices on biodiversity at local and regional scales, and (3) providing clear, targeted information for the grazing industry regarding environmental market opportunities, eligibility, registration, requirements and feasibility.

Figure 1. Environmental and premium red meat market feasibility framework used to assess how improved pasture and animal management above 'business-as-usual' affect market access, whole-farm profitability and regional profitability.



Successfully addressing the three focal areas outlined above will enable widespread environmental market knowledge and access for livestock producers and provide producers with a means to communicate their environmental stewardship credentials including building on recently identified pathways to carbon-neutrality (CN30) and the Australian Beef Sustainability Framework.

4. Results

4.1 Carbon and Environmental Market Review

This aspect of the project aimed to identify and contextualise the main issues surrounding carbon and environmental markets with the purpose of directing the focus of the project and future study. This was conducted in two parts: an initial review of available literature on existing scientific methods for livestock producers to be remunerated for providing ecosystem services to the community whilst producing livestock was conducted; and a second study focusing on stakeholder perspectives and experiences to highlight social constraints to market engagement. Recommendations for alternative approaches were provided to address the issues identified.

The review and analysis of social constraints aimed to address project Objective 1 and were designed to provide a basis to address Objectives 2 and 3.

4.1.1 Review available literature on existing scientific methods for livestock producers to be remunerated for providing ecosystem services to the community whilst producing livestock.

Executive summary
A 'Review of Ecosystem Service Market Opportunities for Livestock Producers' (Appendix 9.1) authored by Beverley Henry, AgriEscindo, and the Queensland University of Technology (QUT) was undertaken at the beginning of the project (2020). Published literature on current ecosystem services market opportunities for livestock producers was reviewed, outlining their evolution, structure and function, and methods relevant to extensive grazing systems. The review highlighted key considerations, barriers to adoption, limitations and opportunities based on the available literature, resulting in seven recommendations on how to overcome barriers and enhance specific opportunities for livestock producers in current and emerging industry and policy settings. *The Method to Market project response to these recommendations is outlined in italics below*:

Recommendation 1: Identify gaps relevant to northern livestock producers and invest in research for new and improved methods for carbon and ecosystem services co-benefits, including:

- Investment in research to fill gaps in data and calculations of emissions abatement, certification information or quantifying co-benefits that will improve usability and accuracy of methods.
- More accurate, less conservative crediting ensuring greater confidence in the method and encouraging adoption.
- Collaborative arrangements across government, research and industry interest groups should be facilitated to reduce duplication and accelerate progress in method development. Similarly, collaboration should be sought in the less mature area of method development for ecosystem services, including for the Queensland Land Restoration Fund (LRF) and the Australian Farm Biodiversity Scheme.
- Consistency in the metrics used between schemes and markets, where appropriate to the objectives and priorities.

Investigations highlighted a variety of gaps associated with vegetation management, representing sources of genuine abatement that are currently ineligible for crediting under the ACCU Scheme (addressed in section 4.5). Other improvements in natural capital modelling were supported by the project for the purpose of increasing confidence which will reduce the tendency for conservative modelling and ACCU accreditation. Similarly, these developments can be applied to the less mature environmental market schemes.

Recommendation 2: Engage with certification and standard bodies and with scheme managers including Commonwealth and state governments to propose and explore development of new or varied crediting methods and certification protocols appropriate to northern beef enterprises.

Engagement with these bodies has occurred via DAF's engagement with advisory panels, feedback to method development and method application trialling for the purpose of revision and improvement to existing methods. This engagement has allowed for greater understanding of methodologies and method development for extension activities as well as improving the applicability of method for grazing systems.

Recommendation 3: The importance of communication and maintaining collaboration and capacity in industry and natural resource management networks should not be overlooked to encourage and support producers to participate in ecosystem services markets.

The design of this project was heavily focused on investigations from an interdisciplinary team to maximise communication between bodies working towards a common goal. This approach was responsible for ensuring a wholistic understanding of the various components within extensive grazing systems.

Recommendation 4: Ensure trainers/advisers are able to support market participation of northern livestock producers by supporting access to up-to-date understanding and skills needed to take advantage of carbon and ecosystem services market opportunities. Training of advisers in methods for crediting agricultural or vegetation projects and certification protocols for products as well as market and pricing mechanisms is an ongoing requirement to ensure producers have access to accurate information.

This has been highlighted as an area requiring additional support and is being serviced through training packages in development by government and industry. The project has participated in and provided feedback for this package and content. DAF is developing a 'carbon extension' team and have presented at workshops for extension officers and industry advisors.

Recommendation 5: Communicating the 'sustainability story' and maintaining confidence in verified carbon and co-benefit credits and certification labels.

Support and revision of co-benefit certification and schemes such as the trial of the Accounting for Nature method at 'Wirra'. Presented at workshops to increase knowledge and understanding around natural capital management and methods of improving ecosystem stability and biodiversity.

Recommendation 6: As stewards of large areas of grazing land, the red meat industry and northern Australian producers should seek to fully understand methods and opportunities for vegetation projects that align with farm business goals. Experience has shown that relatively low input cost projects that regenerate native forests or farm forestry plantations on part of extensive grazing properties have the potential to generate income in ecosystem services markets, e.g., for carbon offsets, biodiversity credits and reef credits, while providing multiple benefits on-farm, including climate resilience.

Beef cattle and sheep producers in Queensland manage large areas of land with potential for strategic forest activities under ACCU regeneration, environmental planting or farm forestry vegetation methods able to generate carbon credits with biodiversity or other co-benefits, while supporting livestock production. Analysis using the state's remote sensing capability could identify the most suitable areas to ensure positive impacts on productivity and to provide an indication of the potential volume of credits to inform decisions.

Vegetation feasibility assessments and co-benefit optimisation formed the basis of the majority of the carbon offset research performed by this project. Investigations into economic output optimisation and diversification included facilitation or support of Brodie Crouch's brigalow strip biodiversity study, Steak n Wood and CSIRO's FullCAM data collection.

Recommendation 7: Develop educational and training materials and ensure service providers and farm advisers are equipped to understand red meat industry and producer priorities and regional community and indigenous interests. Most producers will need to engage specialist services in methods and market mechanisms for ecosystem services crediting and pricing and for understanding certification schemes for premium pricing of products. Engaging with these providers will help to ensure producers receive practical, relevant advice.

Increasing the base understanding of producers from an impartial source for the purpose of facilitating producers to make educated decisions surrounding carbon and environmental market opportunities was a key objective of this project. Activities towards this end included workshop series in South-East and Central Queensland, webinars, industry days and information provided through the Carbon Neutral Grazier Network.

The review of literature was completed at a time when the generation of Australian Carbon Credit Units (ACCUs) was the main ecosystem service market opportunity available to graziers, with various international metrics identifying ACCUs as having amongst the highest integrity in the world. However private exchanges between the project team and landholders, experts, and stakeholders investigating and/or participating in the scheme revealed strong negative sentiment and concern around a broad range of issues relating to project design and implementation. These included but were not limited to:

- inadequate standards around project design, registration and monitoring.
- failure of auditors to recognise red flags due to inadequate expertise and experience in complex agroecological systems (e.g., acceptance of carbon projects with physiologically impossible abatement estimates in Australian farming systems).
- lack of investment in fit-for-purpose tools and technology that could quickly streamline and 'raise the bar' on project registration, design, monitoring and auditing.
- Landholders engaged with carbon projects registered by carbon service providers had no understanding of how much carbon they needed to sequester and/or the practical steps they would need to take to achieve carbon sequestration in their specific situation – the managing director of one prominent carbon service providers even stating to the project team, 'We don't tell farmers how to farm. We leave them to do what needs to be done'.

The literature review and extensive one-on-one consultation that followed to ensure the direction of the project reflected current market sentiment highlighted three key project focus areas:

1. Initiate an impartial investigation into the impact of policy, institutional and governance arrangements on landholder participation in current ecosystem services markets (see Section 4.1.2).
2. Specific recommendations for the revision and development of methods and method implementation (see Section 4.5) would likely focus on vegetation and soil methods since they represented both the greatest opportunity and the greatest risk to productive agroecological systems. Learning through real-life case studies was identified as the crucial next step (see Sections 4.3 and 4.4).
3. Help address the lack of impartial advice and expertise across the broad range of disciplines required to design and implement multi-benefit ecosystem service market projects in productive agroecological systems (see Section 4.1.2).

4.1.2 Carbon and ecosystem market assessment through communications with key experts, practitioners and stakeholders.

To examine the potential future direction for carbon and ecosystem services activities, a series of surveys and in-depth interviews were conducted as per a modified Delphi Approach. Bradd Witt and Rebecca Cotton from the University of Queensland (UQ) led this activity and conducted the analysis. The study obtained ethical approval 144 through The University of Queensland (2021/HE002294).

The study identified a multi-stakeholder round-table may be an avenue to address the complexities surrounding environmental market development, regulation and adoption (Appendix 9.2). The multifaceted panel would be equipped to address the varied aspects and interests of carbon projects and investors, respectively, while improving transparency between involved parties. This would ideally ensure that projects would be operated in a manner that delivers on carbon abatement and environmental co-benefits with minimal to positive impact on production.

Summary of the primary research activity:
Although ecosystem service payments are not a new concept, they have only recently become a reality in Australia. The last decade has seen the appearance of opportunities through markets for carbon sequestration (and avoiding land clearing), most of which have occurred in rangeland environments. There has been research in recent decades focusing on the barriers and opportunities for the uptake of ecosystem service payments at the landholder level. However, there has been limited research into how the policy, institutional and governance arrangements may be impacting the effective and efficient development of cohesive ecosystem service payment system that results in genuine and enduring environmental, social and community outcomes.

Using in-depth interviews with 34 diverse stakeholders, many interrelated themes were identified that provided insight into these markets. Complexity was found to be both the most prominent and overarching theme. Complexity as it related to the multifaceted nature of these markets; where carbon parallels the emerging biodiversity markets, and where cost, rigour and integrity must integrate fairly with the variation in natural capital across Australian landscapes. Complexity also exists in the types and numbers of actors in these systems, with convoluted lines of responsibility, jurisdictional appropriateness, regulation, financial investment, and oversight. There is currently a lack of transparency within these markets resulting in negative trust and engagement implications. We deduce that carbon and ecosystem services markets are in fact a 'complex policy problem' but have not been framed as such to date. We recommend a multi-stakeholder partnership or roundtable be used to tackle the symptoms of the negative sentiment associated with carbon and eco-system service markets, which may help in reducing some of the complexities, perverse outcomes and stakeholder trust issues described.

Summary of secondary research activity:
The second study (using a Modified Delphi method) received ethical approval through The University of Queensland (2023_HE001546).

Building on the first stage of the research (published in the Rangeland Journal's special issue titled "Carbon"), the secondary component sought feedback from relevant experts (using a modified Delphi method), on how the findings of the original project would work in reality.

The aims of the secondary research activity were defined as:

- *Evaluate the practical implications and approaches that could be used to develop a Multi-Stakeholder Partnership or Roundtable to address the key challenges that were identified in the earlier study.*
- *Determine alternative pathways to improve carbon and ecosystem services policy at national and state levels in Australia.*

The research participants for this study were a range of experts, practitioners and other key stakeholders engaged in the development, planning and implementation of a range of carbon and ecosystem service programs or Natural Resource Management (NRM) more broadly. These included researchers, state and national government agency staff (current and past) as well as non-government organisations such as conservation groups, agricultural organisations, NRM groups and the finance sector.

Results

Overall, there was a high level of curiosity and positivity towards how the suggested Multi Stakeholder Partnership may improve carbon and ecosystem services policy and coordination relating to grazing lands in Australia. None of the participants were negative towards the concept. However, there was much richness in the areas that would need careful consideration. The top areas of concern and suggestions related to the following themes, which will be discussed briefly:

- Getting engagement representation and stakeholders right
- Integrity
- Clarity of intent and specific aims or goals of any Multi Stakeholder Partnership
- Transparency
- Clarification and awareness of existing networks and processes

It was considered important that appropriate methods of identifying and grouping stakeholders be a top priority to ensure appropriate representation particularly of groups that in the past may have been more marginalised in decision making around carbon and ecosystem service markets. Examples were given such as landholders, Aboriginal and Torres Strait Islander groups, and NRM groups.

Procedural issues, related to stakeholder engagement, were also raised such as the importance of independence of any facilitators and advisors and different roles of expert versus stakeholder input. There was some caution raised around the complexity of involving large numbers of stakeholders and that values driven decisions may at times conflict with science-based decision making. The risks identified of values-based decisions was that it may lead too much compromise and too many trade-offs. The procedural issues included the importance of clarifying expectations and transparency about how decisions would be made. In summary most of the concerns related to stakeholder process is reflective of simple good governance and procedures related to managing stakeholder engagement in complex problems.

Another major theme identified by the work was the critical importance of having great clarity in the intent and aims of any Multi Stakeholder Partnership. Being clear about the boundaries and limitations of what the Multi Stakeholder Partnership can do or recommend in relation to ecosystem or carbon markets would be critical to avoid the situation of creating false expectations for the various stakeholders. Who drives the Multi Stakeholder Partnership and has ultimate oversight and jurisdiction over the Multi Stakeholder Partnership was also considered vital. A clear process to action recommendations will also be important.

The importance of having clear aims and goals complemented several key insights from participation that indicated that an Multi Stakeholder Partnership would need to be built on a clear understanding of existing networks, policies and other activities related to NRM and ecosystem service markets.

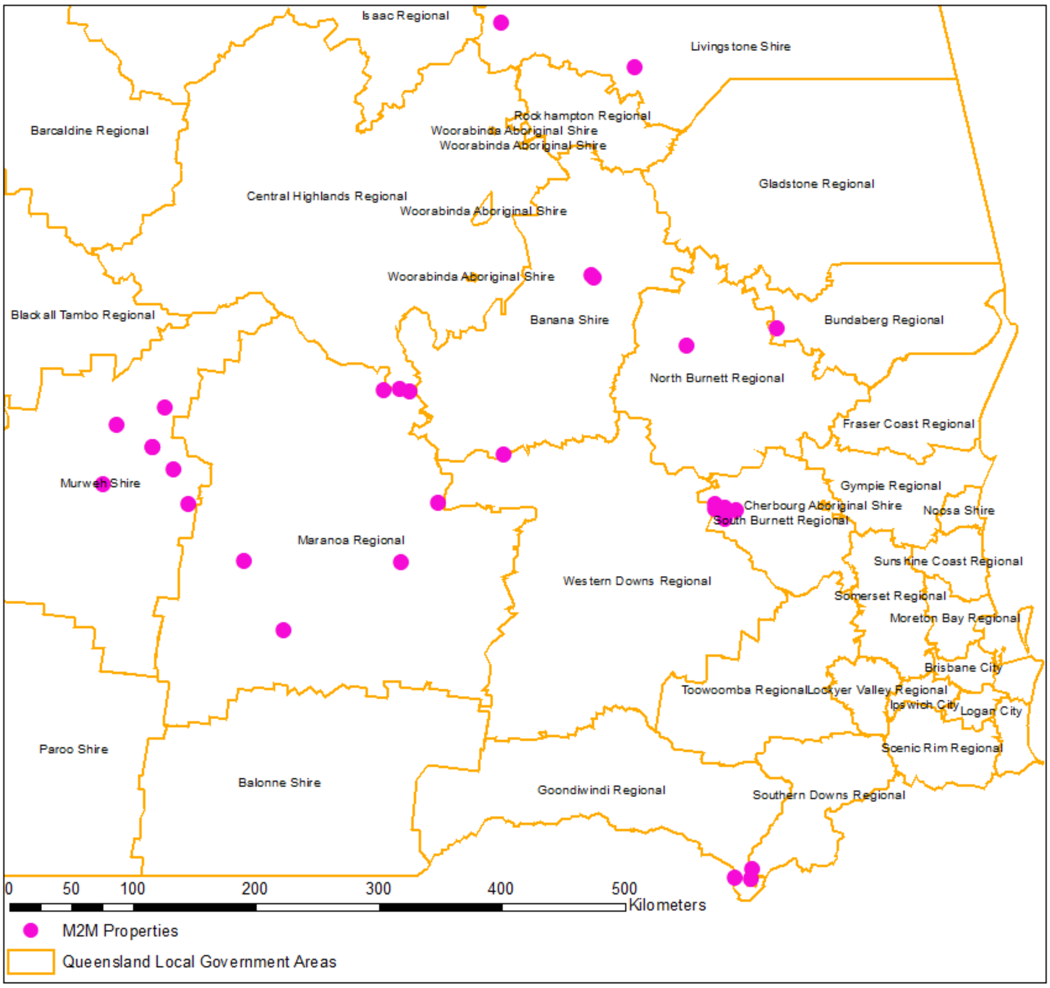
Other critical issues raised included the importance of science-based inputs to decision making and ensuring data stewardship and management. In addition, any process would need to have practical outcomes and be cost effective while avoiding any potential or perceived greenwashing. Finally, it should also be noted that some participants highlighted the need for flexibility in any system built on transparent piloting and formal evaluation to ensure learning and adaptation.

The synthesis of the findings from the second round of investigations is outlined in Appendix 9.3.

4.2 Case study sites

Nine businesses with 28 properties were selected for analysis. The businesses were primarily situated in central, southwest and southern Queensland, within the Brigalow Belt and Mulga Lands Bioregions (Figure 2; Table 1). Together, these bioregions represent highly influential areas for Queensland beef production, covering ~32% of Queensland, including high production areas such as the Fitzroy and Condamine regions (MLA, 2022). In respect to carbon market opportunities, the tendency for these bioregions to naturally regenerate woody vegetation from seed or rootstock lend favourably to ACCU carbon capture methodologies such as natural regrowth management and avoided clearing. These methods and their variations have been highly successful and collectively account for ~32% of projects registered through the Clean Energy Regulator and ~52% of ACCUs awarded as at the 10th of December 2023 (CER, 2023).

Figure 2. Approximate location of the nine grazing business partners.



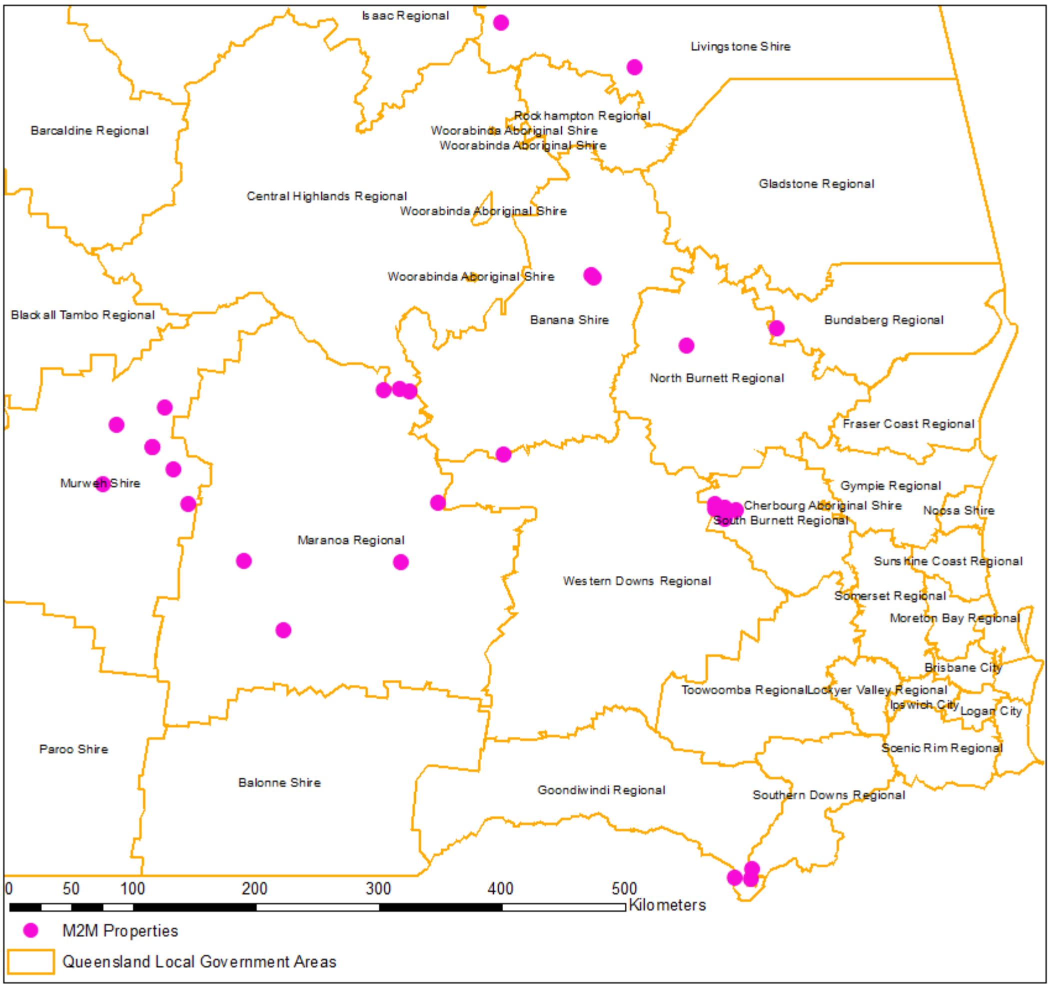

Isaac Regional
Livingstone Shire
Barcaldine Regional
Rockhampton Regional
Woorabinda Aboriginal Shire
Woorabinda Aboriginal Shire
Gladstone Regional
Central Highlands Regional
Woorabinda Aboriginal Shire
Woorabinda Aboriginal Shire
Blackall Tambo Regional
Banana Shire
Bundaberg Regional
North Burnett Regional
Fraser Coast Regional
Murweh Shire
Gympie Regional
Cherbourg Aboriginal Shire
Noosa Shire
South Burnett Regional
Maranoa Regional
Sunshine Coast Regional
Western Downs Regional
Somerset Regional
Moreton Bay Regional
Brisbane City
Toowoomba Regional
Lockyer Valley Regional
Ipswich City
Logan City
Paroo Shire
Scenic Rim Regional
Balonne Shire
Goondiwindi Regional
Southern Downs Regional
0 50 100 200 300 400 500
Kilometers
M2M Properties
Queensland Local Government Areas

Table 1. Identifier and approximate location of nine grazing business partners and their properties.

Region	Business ID	Property ID	Nearest town(s)
Central Queensland	1	1	Banana
		2	Monto
		3	Mt Perry
	2	4	Injune
		5	
		6	
		7	Rockhampton
	3	8	Durong
		9	
		10	
		11	
		12	
Southwest Queensland	4	13	Roma
		14	Roma
		15	Morven
	5	16	Morven
		17	Roma
		18	Mitchell
	6	19	Morven
		20	Augathella
		21	
		22	Mitchell
	7	23	Morven
Central Queensland	8	24	Banana
		25	Rockhampton
Southern Queensland	9	26	Texas
		27	
		28	

When considering environmental market opportunities, each aspect of the system on each property was considered – economics and value of production, biodiversity, carbon etc, as per Figure 2. To this end, the productive capacity of each business was analysed in coordination with business owners, Bush Agribusiness, CIBO Labs and Integrity Ag. The environmental and premium red meat market framework (Figure 1) served as an initial framework for identifying productive performance and land value under a beef herd production system. These were further refined to describe the relevant aspects of the businesses under four categories:

1. Grazing business description – general operation size and target market
2. Natural capital – description of the condition and productivity of the natural environment
3. Animal performance – description of the productive performance and fertility of the herd
4. Grazing business performance and economics – an economic analysis of the beef business and its emission profile.

These descriptions are displayed in section 4.2.1. Many of the indicators sought through this analysis are not well understood in many grazing business operations, with constraints presenting around data availability, consolidation/verification and analytical expertise. This was particularly relevant for natural capital accounting, the financial analysis and emission baselining. All of these were highlighted for further development to increase utilisation of these indicators for informing production management as well as carbon farming opportunity assessment. Collaboration with CIBO Labs, Bush Agribusiness and Integrity Ag was crucial for the progression of these knowledge or technology gaps and are discussed in subsequent sections. The additional data and insights from these developments and analyses are discussed in sections 4.2.2, 4.2.3 and 4.2.4.

4.2.1 Business descriptions

Table 2 to Table 9 provide a brief overview of the key performance indicators, business structure and other key points of information relevant to the analysis of extensive grazing systems from a carbon and ecological perspective as outlined in Figure 1. Eight of the nine businesses engaged with the project participated in completing this exercise.

Grazing business descriptions were predominantly compiled through communications held with business owners, Queensland Government FORAGE data and Bureau of Meteorology historical climate data (BOM, 2024, Zhang and Carter, 2018). Natural Capital indicators were sourced via spatial analytics provided by CIBO Labs, DESI Statewide Landcover and Trees Study (SLATS) data and on-ground surveys conducted throughout the project (see section 4.4.2) (DES, 2023b). A summary of spatial data and mobile applications used in the accumulation of this data is outlined in Appendix 9.4. Animal performance indicators were compiled through data collection from businesses and analysis conducted by the M2M team, which was also utilised in the assessment of business emission profiles. Grazing business performance and economics were compiled through the manipulation of regional top 25% business performances reported in the Australia Beef Report and business specific production data (McLean et al., 2023).

Table 2. Business 1 profile.

Theme	Metric	Score		
Grazing business description	**Self-replacing/ trader/mixed**	Mixed – Traditionally a self-replacing herd but increasingly starting to trade as well.		
	Area (ha)	15,116		
	Forage long-term carrying capacity in A land condition (AE)	4,673		
	Premium red meat market and welfare certification/s	Certified Humane Organic MSA LPA		
	Business goals prior to From Method to Market project	Improve infrastructure on property 1 and 2. Increase area under Leucaena. Align business to the Beef Sustainability Framework		
	Property Annual Rainfall	1	2	3
		622 mm	690 mm	815 mm
Natural capital	**Pasture production** Average cumulative growth in 2019 in all areas with <20% foliage projective cover (kg/ha)	1,500		
	Land condition			
	Average median season groundcover over 10 years (2012-2022) (%)	84		
	Number of times seasonal groundcover fell below 70% on >10% of property over 10 years (2012-2022).	22		
	Total native woody vegetation cover in 2019 (% of business)	6,548ha or 43% (83% voluntary)		
	Total native pasture in 2019 (% of business)	65		
	Native flora and fauna (species observed)	102 flora and 79 fauna species		
Animal performance	**Average age at first joining (years)**	2		
	Conception; weaning rate (%)	2016-2020 Weaning 71–86%		
	Cow, calf loss (%)	Difficult to ascertain in extensive systems		
	Average weaning weight (kg)	Black Box data not obtained.		
	Production efficiency (kg LWG/AE)	106.44kg/AE		
Grazing business performance and economics	**Whole farm carbon account (t CO_2e, t CO_2e/AE)**	6,722.00 t CO_2e 1.44 t CO_2e/AE		
	Average price received ($/kg)	$2.25/kg		
	Cost of production ($/kg, $/AE)	$1.59/kg $169.25/AE		
	Gross margin ($/Kg, $/AE, $/Ha)	$0.66/kg $70.59/AE $20.46/Ha		
	Return on assets (%)	1.73%		

Table 3. Business 2 profile.

<table>
<tr><th>Theme</th><th>Metric</th><th colspan="4">Score</th></tr>
<tr><td rowspan="7">Grazing business description</td><td>Self-replacing/ trader/mixed</td><td colspan="4">Self-replacing herd only</td></tr>
<tr><td>Area (ha)</td><td colspan="4">26,565</td></tr>
<tr><td>Forage long-term carrying capacity in A land condition (AE)</td><td colspan="4">8,628</td></tr>
<tr><td>Premium red meat market and welfare certification/s</td><td colspan="4">Organic
MSA
LPA</td></tr>
<tr><td>Business goals prior to From Method to Market project</td><td colspan="4">Maintain pasture yield/condition, improve grazing patterns, improve fertility in younger breeders, purchase another property and provide a safe environment for squatter pigeons. Provide opportunities for children to become involved in the industry.</td></tr>
<tr><td rowspan="2">Property Annual Rainfall</td><td>4</td><td>5</td><td>6</td><td>7</td></tr>
<tr><td>566 mm</td><td>566 mm</td><td>539 mm</td><td>988 mm</td></tr>
<tr><td rowspan="5">Natural capital</td><td>Pasture production
Average cumulative growth in 2019 in all areas with <20% foliage projective cover (kg/ha)</td><td colspan="4">1,500</td></tr>
<tr><td>Land condition
Average median season groundcover over 10 years (2012-2022) (%)
Number of times seasonal groundcover fell below 70% on >10% of property over 10 years (2012-2022).</td><td colspan="4">86
11</td></tr>
<tr><td>Total native woody vegetation cover in 2019 (% of business)</td><td colspan="4">12,728ha or 48%
(28% voluntary)</td></tr>
<tr><td>Total native pasture in 2019
(% of business)</td><td colspan="4">33</td></tr>
<tr><td>Native flora and fauna
(species observed)</td><td colspan="4">65 flora and 82 fauna species</td></tr>
<tr><td rowspan="5">Animal performance</td><td>Average age at first joining (years)</td><td colspan="4">Yearling</td></tr>
<tr><td>Conception; weaning rate (%)</td><td colspan="4">Yearlings 50% Second calvers 50% Breeders 80%
Weaning rate 50%</td></tr>
<tr><td>Cow, calf loss (%)</td><td colspan="4">Difficult to ascertain in extensive systems</td></tr>
<tr><td>Average weaning weight (kg)</td><td colspan="4">~200-250kg</td></tr>
<tr><td>Production efficiency (kg LWG/AE)</td><td colspan="4">81.52kg/AE</td></tr>
<tr><td rowspan="5">Grazing business performance and economics</td><td>Whole farm carbon account (t CO_2e, t CO_2e/AE)</td><td colspan="4">8,886.56 t CO_2e
1.03 t CO_2e/AE</td></tr>
<tr><td>Average price received ($/kg)</td><td colspan="4">$2.25/kg</td></tr>
<tr><td>Cost of production ($/kg, $/AE)</td><td colspan="4">$1.58/kg
$128.81/AE</td></tr>
<tr><td>Gross margin ($/Kg, $/AE, $/Ha)</td><td colspan="4">$0.68/kg
$55.23/AE
$17.90/Ha</td></tr>
<tr><td>Return on assets (%)</td><td colspan="4">1.37%</td></tr>
</table>

Table 4. Business 3 profile.

<table>
<tr><th>Theme</th><th>Metric</th><th colspan="5">Score</th></tr>
<tr><td rowspan="7">Grazing business description</td><td>Self-replacing/ trader/mixed</td><td colspan="5">Mixed</td></tr>
<tr><td>Area (ha)</td><td colspan="5">3,864</td></tr>
<tr><td>Forage long-term carrying capacity in A land condition (AE)</td><td colspan="5">1,677</td></tr>
<tr><td>Premium red meat market and welfare certification/s</td><td colspan="5">EU
MSA
LPA</td></tr>
<tr><td>Business goals prior to From Method to Market project</td><td colspan="5">Improving herd production, increase biodiversity through retaining Brigalow Regrowth and planting native species. Leave a profitable business for children and nephews to continue to be involved in the industry</td></tr>
<tr><td rowspan="2">Property Annual Rainfall</td><td>8</td><td>9</td><td>10</td><td>11</td><td>12</td></tr>
<tr><td>645 mm</td><td>645 mm</td><td>645 mm</td><td>645 mm</td><td>645 mm</td></tr>
<tr><td rowspan="5">Natural capital</td><td>Pasture production
Average cumulative growth in 2019 in all areas with <20% foliage projective cover (kg/ha)</td><td colspan="5">2,200</td></tr>
<tr><td>Land condition
Average median season groundcover over 10 years (2012-2022) (%)
Number of times seasonal groundcover fell below 70% on >10% of property over 10 years (2012-2022).</td><td colspan="5">85

12</td></tr>
<tr><td>Total native woody vegetation cover in 2019 (% of business)</td><td colspan="5">2,162ha or 56%
(73% voluntary)</td></tr>
<tr><td>Total native pasture in 2019
(% of business)</td><td colspan="5">20</td></tr>
<tr><td>Native flora and fauna
(species observed)</td><td colspan="5">106 flora and 86 fauna species</td></tr>
<tr><td rowspan="5">Animal performance</td><td>Average age at first joining (years)</td><td colspan="5">Yearling</td></tr>
<tr><td>Conception; weaning rate (%)</td><td colspan="5">Yearlings 65%
Second calvers 60%
Breeders 80%

Weaning rate 76%</td></tr>
<tr><td>Cow, calf loss (%)</td><td colspan="5">Difficult to ascertain in extensive systems</td></tr>
<tr><td>Average weaning weight (kg)</td><td colspan="5">~150-200kg</td></tr>
<tr><td>Production efficiency (kg LWG/AE)</td><td colspan="5">175.60kg/AE</td></tr>
<tr><td rowspan="5">Grazing business performance and economics</td><td>Whole farm carbon account (t CO_2e, t CO_2e/AE)</td><td colspan="5">3567.32 t CO_2e
2.13 t CO_2e/AE</td></tr>
<tr><td>Average price received ($/kg)</td><td colspan="5">$2.21/kg</td></tr>
<tr><td>Cost of production ($/kg, $/AE)</td><td colspan="5">$1.77/kg
$310.82/AE</td></tr>
<tr><td>Gross margin ($/Kg, $/AE, $/Ha)</td><td colspan="5">$0.44/kg
$77.27/AE
$4.46/Ha</td></tr>
<tr><td>Return on assets (%)</td><td colspan="5">1.64%</td></tr>
</table>

Table 5. Business 4 profile.

Theme	Metric	Score		
Grazing business description	**Self-replacing/ trader/mixed**	Growing out and trading		
	Area (ha)	17,932		
	Forage long-term carrying capacity in A land condition (AE)	4,925		
	Premium red meat market and welfare certification/s	LPA		
	Business goals prior to From Method to Market project	Provide for annual living costs, retirement, and opportunities for their children to become involved in the industry		
	Property Annual Rainfall	13	14	15
		602 mm	557 mm	516 mm
Natural capital	**Pasture production** Average cumulative growth in 2019 in all areas with <20% foliage projective cover (kg/ha)	1,000		
	Land condition Average median season groundcover over 10 years (2012-2022) (%) Number of times seasonal groundcover fell below 70% on >10% of property over 10 years (2012-2022).	79 23		
	Total native woody vegetation cover in 2019 (% of business)	3,025ha or 17% (55% voluntary)		
	Total native pasture in 2019 (% of business)	17		
	Native flora and fauna (species observed)	101 flora and 47 native bird species		
Animal performance	**Average age at first joining (years)**	Not applicable		
	Conception; weaning rate (%)	Not applicable		
	Cow, calf loss (%)	Difficult to ascertain in extensive systems		
	Average weaning weight (kg)	~150-200kg		
	Production efficiency (kg LWG/AE)	114.23kg/AE		
Grazing business performance and economics	**Whole farm carbon account (t CO_2e, t CO_2e/AE)**	3,1925.85 t CO_2e 6.48 t CO_2e/AE		
	Average price received ($/kg)	$2.24/kg		
	Cost of production ($/kg, $/AE)	$1.44/kg $164.49/AE		
	Gross margin ($/Kg, $/AE, $/Ha)	$0.80/kg $91.83/AE $25.22/Ha		
	Return on assets (%)	2.63%		

Table 6. Business 5 profile.

Theme	Metric	Score		
Grazing business description	**Self-replacing/ trader/mixed**	Mainly self-replacing herd Occasional trading		
	Area (ha)	29,264		
	Forage long-term carrying capacity in A land condition (AE)	3,529		
	Premium red meat market and welfare certification/s	LPA		
	Business goals prior to From Method to Market project	Provide for annual living costs, retirement, and opportunities for their children to become involved in the industry		
	Property Annual Rainfall	16	17	18
		471 mm	524 mm	552 mm
Natural capital	**Pasture production** Average cumulative growth in 2019 in all areas with <20% foliage projective cover (kg/ha)	600		
	Land condition Average median season groundcover over 10 years (2012-2022) (%) Number of times seasonal groundcover fell below 70% on >10% of property over 10 years (2012-2022).	78 19		
	Total native woody vegetation cover in 2019 (% of business)	16,101ha or 55% (36% voluntary)		
	Total native pasture in 2019 (% of business)	55		
	Native flora and fauna (species observed)	116 flora and 45 native bird species		
Animal performance	**Average age at first joining (years)**	1.5 to 2		
	Conception; weaning rate (%)	2013-2020 Weaning 82%		
	Cow, calf loss (%)	Difficult to ascertain in extensive systems		
	Average weaning weight (kg)	~150-200kg		
	Production efficiency (kg LWG/AE)	71.75kg/AE		
Grazing business performance and economics	**Whole farm carbon account (t CO_2e, t CO_2e/AE)**	12,225.16 t CO_2e 3.46 t CO_2e/AE		
	Average price received ($/kg)	$2.19/kg		
	Cost of production ($/kg, $/AE)	$1.41/kg $101.17/AE		
	Gross margin ($/Kg, $/AE, $/Ha)	$0.78/kg $56.10/AE $6.77/Ha		
	Return on assets (%)	1.67%		

Table 7. Business 6 profile.

Theme	Metric	Score			
Grazing business description	**Self-replacing/ trader/mixed**	Self-replacing herd only			
	Area (ha)	46,533			
	Forage long-term carrying capacity in A land condition (AE)	4,850			
	Premium red meat market and welfare certification/s	Organic GAP LPA			
	Business goals prior to From Method to Market project	Provide for annual living costs, retirement, and opportunities for their children to become involved in the industry.			
	Property Annual Rainfall	19	20	21	22
		386 mm	511 mm	576 mm	480 mm
Natural capital	**Pasture production** Average cumulative growth in 2019 in all areas with <20% foliage projective cover (kg/ha)	1,500			
	Land condition Average median season groundcover over 10 years (2012-2022) (%) Number of times seasonal groundcover fell below 70% on >10% of property over 10 years (2012-2022).	72 36			
	Total native woody vegetation cover in 2019 (% of business)	8,880ha or 19% (42% voluntary)			
	Total native pasture in 2019 (% of business)	34			
	Native flora and fauna (species observed)	141 flora and 78 native bird species			
Animal performance	**Average age at first joining (years)**	1.5 to 2			
	Conception; weaning rate (%)	2014-2020 Conception 91% Weaning 81%			
	Cow, calf loss (%)	2014-2020 Cow and heifer mortality = 3.3%			
	Average weaning weight (kg)	~150-200kg			
	Production efficiency (kg LWG/AE)	104.86kg/AE			
Grazing business performance and economics	**Whole farm carbon account (t CO_2e, t CO_2e/AE)**	8,254.36 t CO_2e 1.70 t CO_2e/AE			
	Average price received ($/kg)	$2.01/kg			
	Cost of production ($/kg, $/AE)	$1.31/kg $137.37/AE			
	Gross margin ($/Kg, $/AE, $/Ha)	$0.70/kg $73.87/AE $7.70/Ha			
	Return on assets (%)	2.61%			

Table 8. Business 7 profile.

Theme	Metric	Score
Grazing business description	**Self-replacing/ trader/mixed**	Self-replacing herd only
	Area (ha)	7,495
	Forage long-term carrying capacity in A land condition (AE)	712
	Premium red meat market and welfare certification/s	Organic GAP LPA
	Business goals prior to From Method to Market project	Provide for annual living costs, retirement, and opportunities for their children to become involved in the industry
	Property Annual Rainfall	23 528 mm
Natural capital	**Pasture production** Average cumulative growth in 2019 in all areas with <20% foliage projective cover (kg/ha)	600
	Land condition Average median season groundcover over 10 years (2012-2022) (%) Number of times seasonal groundcover fell below 70% on >10% of property over 10 years (2012-2022).	72 35
	Total native woody vegetation cover in 2019 (% of business)	3702ha or 49% (50% voluntary)
	Total native pasture in 2019 (% of business)	22
	Native flora and fauna (species observed)	84 flora and 69 native bird species
Animal performance	**Average age at first joining (years)**	1.5 to 2
	Conception; weaning rate (%)	2017-2020 Weaning 68%
	Cow, calf loss (%)	Difficult to ascertain in extensive systems
	Average weaning weight (kg)	~150-200kg
	Production efficiency (kg LWG/AE)	Undetermined
Grazing business performance and economics	**Whole farm carbon account (t CO_2e, t CO_2e/AE)**	4,090.72 t CO_2e 5.75 t CO_2e/AE
	Average price received ($/kg)	$2.98/kg
	Cost of production ($/kg, $/AE)	$1.29/kg $186.39/AE
	Gross margin ($/Kg, $/AE, $/Ha)	$0.69/kg $99.70/AE $9.47/Ha
	Return on assets (%)	3.63%

Table 9. Business 8 profile.

Theme	Metric	Score	
Grazing business description	**Self-replacing/ trader/mixed**	Self-replacing & trader (mixed)	
	Area (ha)	3,079	
	Forage long-term carrying capacity in A land condition (AE)	535	
	Premium red meat market and welfare certification/s	LPA only	
	Business goals prior to From Method to Market project	ROA >2% (productivity), reduce supplements & fodder by 50% (production), increase groundcover at property 25 by 25% (ecology).	
	Property Annual Rainfall	24	25
		622 mm	680 mm
Natural capital	**Pasture production** Average cumulative growth in 2019 in all areas with <20% foliage projective cover (kg/ha)	2026	
	Land condition Average median season groundcover over 10 years (2012-2022) (%) Number of times seasonal groundcover fell below 70% on >10% of property over 10 years (2012-2022).	Not assessed	
	Total native woody vegetation cover in 2019 (% of business)	1,412 Ha or 46%	
	Total native pasture in 2019 (% of business)	80%	
	Native flora and fauna (species observed)	Not assessed	
Animal performance	**Average age at first joining (years)**	2 years	
	Conception; weaning rate (%)	2017-2022 80%	
	Cow, calf loss (%)	3% 2023	
	Average weaning weight (kg)	213.5kg 2023	
	Production efficiency (kg LWG/AE)	Undetermined	
Grazing business performance and economics	**Whole farm carbon account (t CO_2e/AE)**	2,098.04 t CO2e 3.92 t CO2e/AE	
	Average price received ($/kg)	$2.23/kg	
	Cost of production ($/AE, $/kg)	$1.67/kg $459.80/AE	
	Gross margin ($/AE, $/AE, $/ha)	$0.56/kg $155.25/AE $26.98/Ha	
	Return on assets (%)	3.56%	

4.2.2 Emission baseline

Background

An emissions baseline is a starting point from which to track incremental improvement in sustainability or efficiency of production, as well as allowing a producer to report to the supply chain. Calculating the emission baseline of extensive primary systems such as grazing poses a number of challenges from a data availability perspective.

The typical profile of emission sources from a beef grazing operation is dominated by enteric herd emissions, followed by fuel and fertiliser usage and woody vegetation development. Data required to determine emissions from purchased inputs (fuel, fertiliser, electricity and purchased feed) are typically identified from financial records. Livestock emissions are assessed via the dry matter intake of the livestock, which is directly correlated to methane emissions. Dry matter intake can be determined by estimates of the duration, weight, weight gain, pregnancy status and number of animals that were carried in each age-class throughout the assessed period. This herd profile is generally constructed from a whole of herd count (e.g., at branding, weaning or pregnancy testing events), animal purchases and sales (e.g., financial records, kill sheets, transfer records), natural increases (e.g., branding, weaning or pregnancy testing records) and attrition rates. Weights and weight gains are typically opportunistically collected but are largely unavailable to the monthly or seasonal level of detail preferred for an emission baseline.

Stock records present the greatest source of error for the calculation of an emissions baseline, particularly in extensive systems. The accuracy of counts can be low, due to mis-musters or lack of time or resources to assess herds according to the age-classes required for emission calculations. Record keeping and data collation can be a significant barrier due to the lack of a formal record keeping system or stock transfers/updates not being uploaded. Often the historic need for these records has not been strong, and therefore the incentive for maintaining high integrity records, but lack of these records is an impediment for general business planning and analysis, but also future options in emissions abatement where accurate historic records are required. Data on weights and weight gains are influential factors in the determination of dry matter intake, and thus methane emissions. Often these data with reasonable accuracy are not readily available. This is particularly the case for animals which have no productive purpose in being weighed, such as breeders. The use of regional averages provides an alternative option to producers unable to source these statistics for their own herd but introduces another degree of error.

Businesses worked with the M2M team to consolidate three years of data into the required format. The relevant information was then assessed under the Sheep and Beef Greenhouse Accounting Framework (SB-GAF) developed by the University of Melbourne (Dunn et al., 2020) and multiple years were used to obtain an average of an operation's average total emissions. While an essential tool for extension purposes, the seasonal herd data entry format (monthly entry option now available) of the SB-GAF tool means that it can underestimate or overestimate emissions depending on when cattle are born, bought or sold. For example, if cattle are purchased or born early in a season, they won't be recorded as contributing to emissions calculations until the following season resulting in an underestimate.

An alternative method, the 'Beef Cattle Herd Management Calculator', operates on herd data with actual entry and exit dates which addresses this issue, however the additional detail required is significant. Herd records in extensive livestock systems typically harbour a significant number of discrepancies in an annual consolidation which render the advantage of the increased accuracy of the

'Beef Cattle Herd Management Calculator' over coarser analysis tools negligible. Additional discrepancies typically occur in the carry-over of stock due to seasonal variation, timing of sales year to year, property acquisition and property leasing, and lag times associated with these relatively common business factors. Generally, when applying the SB-GAF tool, seasonal influences are removed by averaging the historical herd fluctuations.

Integrity Ag conducted further analyses under a Life-Cycle Assessment (LCA) for individual years. The key distinction from the SB-GAF tool is that the LCA tool models a stable herd structure via an analysis of a breeding herd size and reproductive rates, as well as typical turn off rates and weights and deaths. A brief summary of the pros and cons of these approaches is presented in Table 10.

Table 10. Pros and cons of the SB-GAF tool, the LCA modelled stable herd and the beef herd management calculator for beef herd emissions.

	SB GAF Tool	**LCA Modelled stable herd**	**Beef herd management calculator**
Pros	Options to include regional averages if individual operation data is not available. Relatively easy to consolidate into a reasonable emission estimate. Multiple versions available. Reflective of incremental management change.	Insensitive to seasonal variation. Tolerant of inaccuracies in herd data. Least intensive.	Assumes herd data is captured accurately, this method is most accurate year to year. Will experience year to year variability. Should be sensitive to management change.
Cons	Reliant on multiple years of accurate herd data. Sensitivity of herd movement is limited to seasonal stock transfers. This creates stocking errors of up to 3 months. Highly sensitive to seasonal fluctuations.	Possible higher inaccuracy due to assumptions. Least sensitive to management practises. Need expertise to develop a stable herd model from often disparate data.	Requires a high degree of detailed data and reasonably complicated to complete. Records required are often quite different to how records are generally captured on typical grazing businesses.
Suggested Use	Ideal for producers who have sufficient herd data and want to track annual emission intensity performance over time. This would be sufficient to produce an emission baseline.	Suitable for producers who wish to have an idea of annual emission intensity but lack the herd data to perform a more in-depth analysis. This would be sufficient to produce a verified emission baseline.	Required for producers wishing to engage in the Beef Herd Management carbon methodology for the purpose of acquiring credits with the ACCU Scheme.

Each analyses listed above will provide two key figures:

- First, the **total business emission account** for all (Scope 1, 2 and 3) emissions that are produced on-farm or facilitate on-farm activities (including enteric emissions, manure management, fuels, electricity and fertiliser breakdown, as well as the emissions associated with the production of the fertiliser, licks, etc). This will provide the basis of emission reductions or offsets required to move the business towards being carbon neutral.

- The second figure is the **emissions intensity**, a metric that identifies the emissions produced in the production of the desired product, often reported in kilograms of carbon dioxide equivalents per kilogram of liveweight (kg CO_2e/kg liveweight). This is important as it is a performance indicator that can be used to compare businesses of similar structure (breeding, backgrounding, finishing, etc) in terms of their emissions efficiency irrespective of business size.

Results

Throughout the course of this study, the years of interest (2018-2021) were particularly variable, experiencing a significant drought followed by above average rainfall. Subsequently, the offloading of stock through the drought in 2018/19 reduced reported emissions intensity (due to high sales relative to herd numbers) while the following "rebuilding" of the herd yielded high emission intensity (reduced sales to re-build herd numbers – low sales relative to herd numbers). This created a greater error than would normally be associated with an average of three years. This highlighted the importance of a baseline period based on a number of years. Ideally, the effect of seasonal fluctuation would be removed by increasing the temporal range of interest, partially due to availability of records. For this reason, the LCA modelled herd analyses are reported with the results summarised here in Table 11 and Table 12.

Table 11. Emissions baseline and emission intensity of central and southwest Queensland grazing businesses for the financial year 2021.

Business ID	1	2	3	4	5	6	7	8
Total GHG emissions (t CO_2e)	6,722	8,887	3,567	31,926	12,225	8,254	4,091	2,098
Emission Intensity (kg CO_2e/kg liveweight)	12.2	12.6	12.6	12.9	12.3	12.9	23.9*	14.2

** Factors contributing to the outlier observed in the data are detailed in the below text.*

Table 12. Selected carbon footprint results analysed over three years

	Producer 1	Producer 2	Producer 3	Producer 5	Producer 6	Producer 7
	Carbon footprint (kg CO2-e kg LW^{-1})					
2021	12.2	12.6	12.6	12.3	12.9	23.9
2020	14.3	12.9	12.3	12.3	13.3	34.8
2019	12.3	11.4	11.7	11.9	14.2	28.9
Mean	12.9	12.3	12.2	12.2	13.5	29.2
2021 vs Mean	94%	102%	103%	101%	96%	82%

Total greenhouse gas emissions (GHGs) varied significantly between businesses, a function of the size and variation of each of the participant's herds. This is particularly prominent in low input beef production systems with herd emissions (enteric methane and manure) dominating with between 95.5-99.4% (average of 97.1%) of the total carbon dioxide equivalent (CO_2e) emissions. Conversely, fuel accounted for an average of less than 2% of total business emissions. Variation in total business emissions independent of business size can be attributed to production efficiency, which correlates closely with emission intensity.

The emission intensity calculated through the modelled average method provides a reasonable estimate of average business operations. The breeding operations included in the study were seen to be highly efficient in their breeder management with producers 1-6 performing better than the national average of 13.1 kg CO_2e/kg liveweight as reported by the Australian Beef Sustainability Framework (ABSF, 2023) in 2021. While this is indicative of good herd management, the fertility of the properties and the degree to which each property was 'developed' and maintained are both contributing factors to efficiency.

Additional analysis of financial year 2019 and 2020 allowed for insight into the accuracy of using a single year of production data to model herd emissions and emissions intensity. While the modelled year approach was sufficient to meet carbon neutral program eligibility requirements, the variation between years was reasonably significant, with an average of 5% variation of individual years from the 3-year average. Without close scrutiny, the drivers behind these fluctuations are unclear, however they are most likely attributable to seasonal impacts, to weaning rates, weight gains and sales. Further accuracy could be achieved with additional data however, for the majority of producers, this process achieves a workable figure for carbon-based assessments. Issues around this methodology would arise when producers are looking to track their own performance over time or demonstrate improved management from an emissions perspective. The removal of year specific data for ease of reporting as well as the removal of season-induced variation leads to a reduced sensitivity to incremental management change. Thus, it is likely that small improvements in production efficiency could be lost in the simplified modelling process.

A notable outlier was observed in producer 7 (Table 11), reporting an emission intensity approaching double that of the other producers. This can be attributed to an occurrence of a disease that affected the majority of the breeding herd in the years prior to the reported year, which severely affected weaning rates for the years within the scope of the analysis (2019-2021). This impact exacerbated the reduced production efficiency induced by poor seasonal conditions and highlights the potential impact of factors outside the control of the producer can have on emissions data.

4.2.3 Pasture and ground cover analysis

The spatial analytics provided by CIBO Labs to determine pasture and ground cover performance highlighted potential effects of management over time. These metrics are highly influenced by seasonality and rainfall. Following discussion between the M2M team and CIBO Labs, a report was created to compare property data to the benchmark performance of the area immediately surrounding the target property to provide insight into the influence of management on the response variables of interest. It should be noted that, while the removal of seasonal influences via this method is effective, factors such as land type, geomorphology and land use introduces a large suite of variables that can impact the figures. Therefore, additional understanding is required. For instance, properties surrounded by national park or areas that are largely undeveloped would not produce pasture based dry matter in volumes indicative of a reasonable baseline for the land type. Similarly, a property can be influenced positively or negatively under this analysis by the poor or superior management of a neighbour.

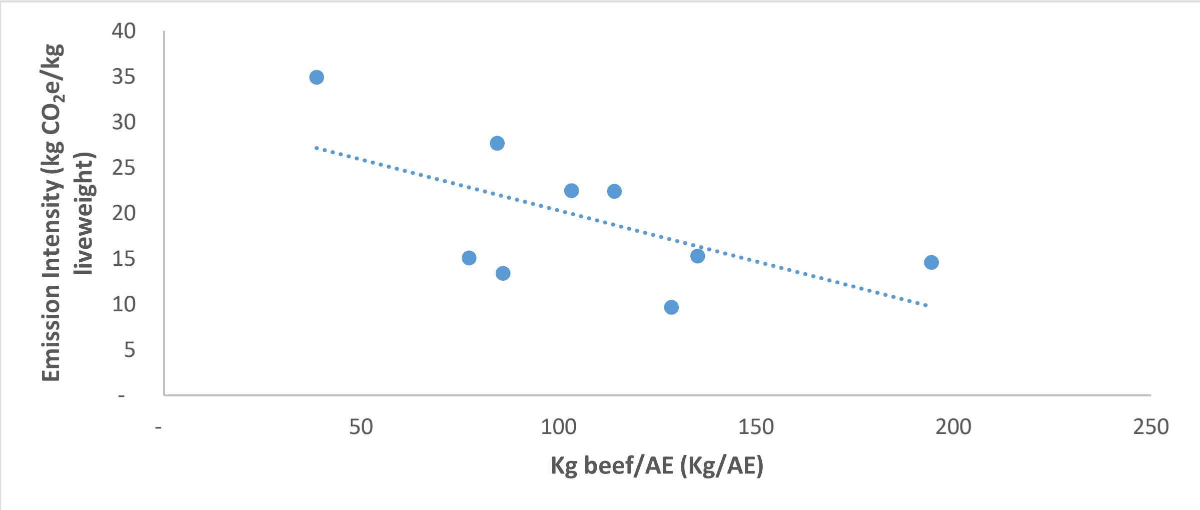
In general, ground cover was relatively consistent with the corresponding benchmark areas, with all properties scoring within 5% of the benchmark average over a 34-year period. Total standing dry matter (TDSM) was much more variable compared to the benchmark. Fourteen of the properties reported higher average pasture biomass from 2017-2023, averaging 17% higher with a maximum difference of a 55% increase. This could be attributed to a variety of factors however, from a carbon perspective, the opportunity to demonstrate the increased volume of a highly transient carbon pool becomes apparent. Of the 14 properties that performed higher than the benchmark area, the average increase in biomass was 260 kg/ha. This equates to a carbon dioxide equivalent of 476 kg CO_2e /ha or 0.476 of an ACCU. Across the property sizes analysed, conservative management of pasture could be relatively influential to a carbon account. Assessments of carbon in pasture biomass is currently excluded in official carbon accounts due to the highly transient nature of the carbon stock and its variability over time. The link between consistently higher pasture biomass and soil carbon is a research question that should be explored further.

4.2.4 Financial analysis

The average herd performance of five M2M businesses was analysed by Bush Agribusiness and compared to regional and whole industry data from the 2023 Australian Beef Report (Table 13). All businesses were located within the Brigalow region (Region 322) with the exception of Business 7, which was in the Mitchell Downs, Mulga and Desert region (Region 314). This analysis showed that the M2M businesses analysed had higher herd profits than the Top 25% from region 322 and the northern industry as a whole. This is typical of businesses that have their performance analysed, in that the better performing businesses are more likely to want to understand and analyse their performance. The average of the Bush AgriBusiness client database performance is approximately equivalent to the Top 25% of the wider industry. M2M businesses had a 16% higher herd productivity (kg beef/AE) than the Top 25% performers for both the region and wider industry. This was not necessarily supported by superior performance across the productivity drivers (reproductive rate, mortality rate and sale weight) but can rather be attributed to some of the M2M businesses being 'growing businesses', as opposed to mature breeding businesses which dominate the Australian Beef Report data and associated productivity drivers.

Having higher herd productivity means that these businesses will likely have lower emissions intensity of production than their industry peers. Table 13 shows the range in both the annual herd productivity figures and the emissions intensity. Whilst there is a negative correlation between herd productivity and emissions intensity, it is not as strong as would be expected (Figure 3). This is likely partly due to different herd information (classifications, timing etc.) being used for the two separate calculations, rather than the two factors not being correlated, as they are effectively measuring the same thing (i.e. emissions are a function of intake and animal equivalent (AE) is a proxy for intake, being defined as the dietary requirements of a 450kg steer at maintenance). Improvement in consistency of herd data classifications and calculations should improve the correlation.

Figure 3. Emissions intensity (kg CO_2e/kg liveweight) compared to production efficiency of kilograms liveweight produced per animal equivalent unit per year. The fitted line explains 37% of the variance (R^2 = 0.3739).



Further interpretation of the M2M business results show that these businesses benefit from more scale than their industry peers, have lower and better targeted herd expenditure, better labour efficiency and achieved a higher average price received. The overheads per animal unit were also lower than the average of the comparison data sets but not as low as the top performers.

Table 13. Average economic performance of five M2M contributor businesses as compared to the Australian Beef Report regional and northern industry averages.

All data are 2020-22 and presented in 2022 dollars	M2M Average	ABR 2023			
		322 - QLD Southern Inland		Northern Whole Industry	
	$/AE	AVG $/AE	Top 25% $/AE	AVG $/AE	Top 25% $/AE
Sales	758.34	507.35	544.06	430.09	438.42
Purchases	(505.67)	(92.61)	(92.67)	(75.98)	(74.23)
Inventory Change	178.18	(26.02)	(44.81)	10.53	24.20
GROSS PROFIT	**430.85**	**388.72**	**406.58**	**364.64**	**388.39**
ENTERPRISE EXPENSES					
Agistment	1.84	6.17	3.19	4.32	3.68
Animal Health	6.17	1.46	1.59	0.99	1.03
Contract & Mustering	4.90	6.23	8.80	7.82	7.91
Fodder & Supplementation	18.20	41.03	34.91	32.87	29.21
Insurance & Materials	0.14	8.12	8.91	6.42	5.59
Internal Enterprise Freight	2.35	13.37	13.80	13.78	13.52
Marketing & Promotion	0.07				
Selling Costs	14.29	8.85	8.34	8.25	8.09
	47.96	**85.22**	**79.55**	**74.46**	**69.05**
GROSS MARGIN	**382.89**	**303.50**	**327.03**	**290.18**	**319.35**
OVERHEAD EXPENSES					
Administration	10.20	12.01	10.07	10.62	9.09
Depreciation	28.87	34.68	23.29	28.83	19.41
Electricity & Gas	3.30	2.53	2.13	2.09	1.73
Fuel & Lubricants	13.20	15.33	12.36	13.66	11.63
Insurance	8.14	6.82	4.57	6.56	4.76
Landcare	3.43				
Materials	2.87	1.88	0.90	2.25	1.15
Motor Vehicle Expenses	11.95	4.36	2.38	4.02	2.83
Pasture	11.30				
Rates & Rents	8.18	11.63	7.52	10.49	7.63
R & M General	27.66	36.94	27.78	28.98	22.18
Wages	26.85	17.58	19.92	20.60	21.53
Wages (Owner)	23.86	72.72	43.64	57.13	31.90
	179.81	**216.47**	**154.55**	**185.23**	**133.84**
TOTAL OPERATING EXPENSES	**227.77**	**301.68**	**234.10**	**259.69**	**202.88**
EBIT (OPERATING PROFIT)	**203.08**	**87.03**	**172.48**	**104.95**	**185.51**
PRIMARY PERFORMANCE INDICATORS					
Average price received ($/kg LW sold)	$4.31	$3.88	$3.88	$3.71	$3.68
Cost of Production ($/kg LW produced)	$1.86	$2.96	$2.20	$2.65	$1.91
KG Beef/AE	123	102	106	98	106
Labour Efficiency (AE/FTE)	1,324	749	1,082	880	1,258
SECONDARY PERFORMANCE INDICATORS					
Reproductive Rate	60%	69%	72%	64%	65%
Mortality Rate	1.2%	1.4%	1.1%	2.5%	2.0%
Turnoff weight (kg/hd LW)	423 kg	442 kg	461 kg	406 kg	420 kg
Turnoff value ($/hd)	$1,824	$1,715	$1,787	$1,509	$1,544
Purchase weight (kg/hd LW)	256 kg				
Purchase value ($/hd)	$1,336				
Stocking Rate (AE/100 Ha)	30.1	19.6	22.5	7.7	9.3
Turnover (hd sold/ avg hd carried)	52%	39%	40%	35%	35%
Enterprise Size (Annual Avg AE)	3,275	1,778	3,010	2,043	3,920
Enterprise Size (Average breeders)	728	578	902	778	1458

4.3 Carbon in grazing

The carbon accounts of eight extensive grazing businesses were compiled and analysed. The analysis sought to identify the carbon opportunities and liabilities within extensive grazing businesses and highlight pathways to improve environmental credentials. This included annual greenhouse gas emission summaries, greenhouse gas abatement options, capacity to achieve carbon neutrality and the potential costs and benefits of participation in existing ecosystem service markets, whilst producing livestock.

Common sources of frustration for participating landholders around current environmental market opportunities were:

- the consistent focus on carbon in complex agroecological systems;
- market exclusion due to the additionality requirement of Australian Carbon Credit Units (ACCU), while historically poor stewardship and/or negative environmental outcomes were perceived to be perversely encouraged, and;
- the spotlight on emissions reduction in agriculture despite the continuation of long-lived greenhouse gas emissions from other industries.

The findings from this aspect of the project identified key challenges in achieving industry and national climate targets at the property scale. The lack of a defined "finish-line" was highlighted as a source of confusion and concern for producers wishing to engage in environmental schemes and the minimal opportunity to reward previous "good" management (from a carbon perspective). The progression of technology and accounting services to improve ease-of-use and confidence of carbon baselines, project performance and other opportunities will greatly increase producers' ability to accurately assess environmental and carbon-based options for their business.

4.3.1 Carbon farming

Carbon farming is the process of managing land for the purpose of sequestering carbon. This can be in the form of a project under a published methodology recognised by a carbon crediting scheme (e.g., Australia Carbon Credit Unit Scheme). Once credited, these credits can be traded as a commodity, typically through the Australian Carbon Credit Unit Scheme auctions or the spot market. The Australian carbon pricing initiative is one of 73 that has been implemented worldwide (The World Bank, 2024).

Generation of these credits support climate-based objectives of government and private industry. To date these objectives are mainly voluntary, however schemes such as the Safeguard Mechanism are aimed at enforcing emission reduction strategies on large emitters. Legislative action such as this and government commitments to carbon emission reduction has been highly influential in providing security and stability in the carbon market by securing market demand as seen in the Australian Carbon Credit Unit Scheme auctions. The free trading 'spot price' is consistently higher than Australian Carbon Credit Unit Scheme auction price, however the spot price is much more volatile (Figure 4 and Figure 5). The majority of land sector derived ACCUs are traded "over the counter" in direct transactions where there is poor price transparency, though markets indicate these prices are significantly higher than the spot market.

Figure 4. Spot Market Price

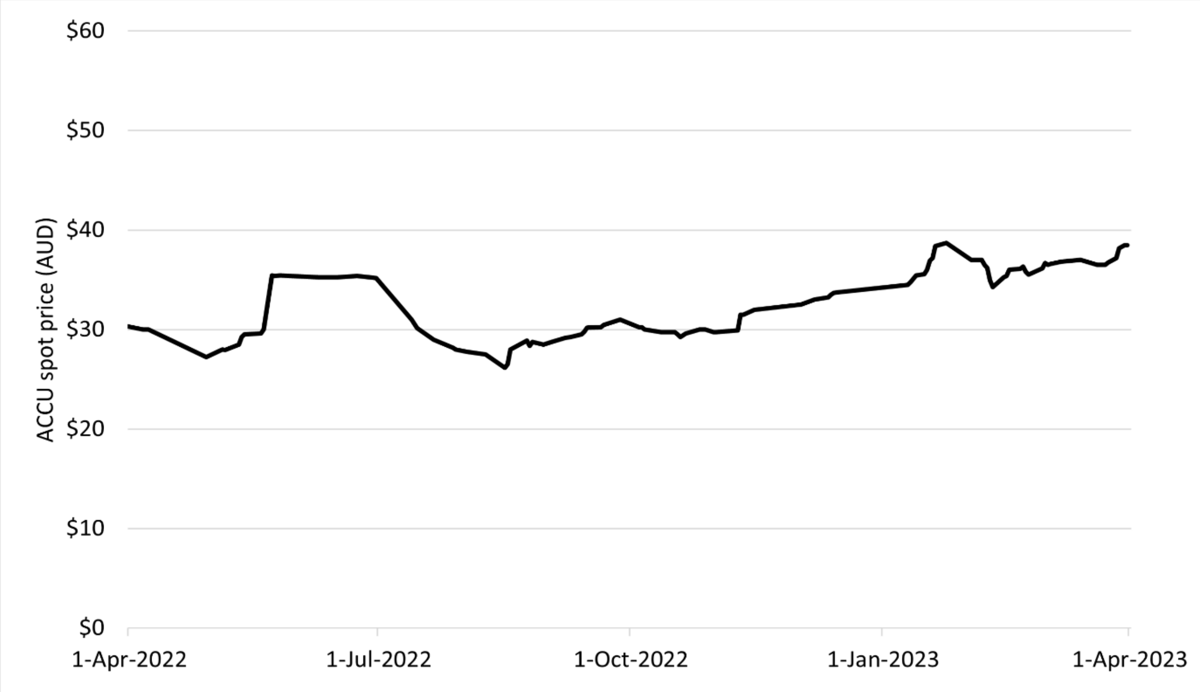
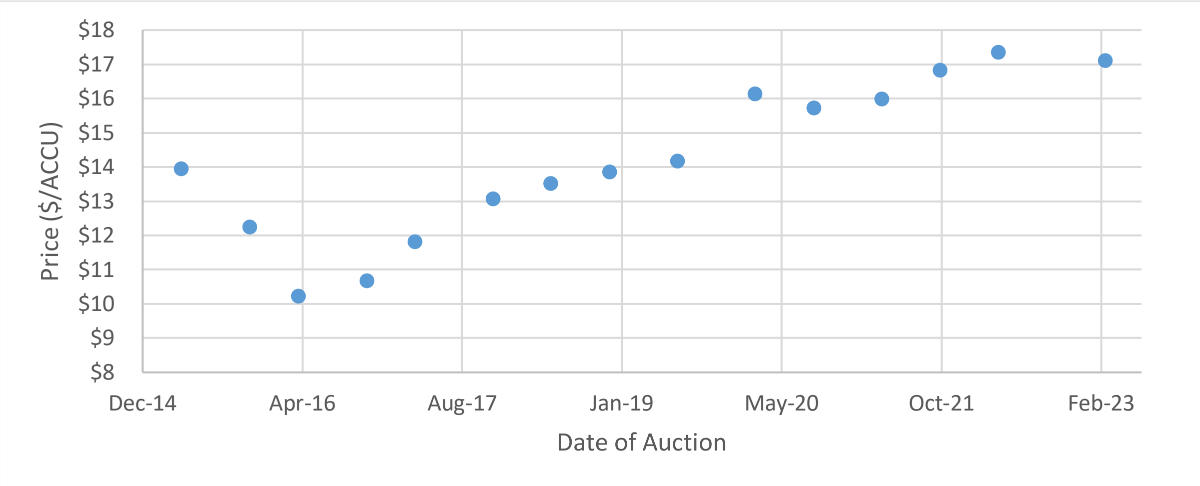


Figure 5. Australian Carbon Credit Unit Scheme Price from the first auction (April 2015) to auction 15 (March 2023).



Determination of the financial opportunity associated with carbon projects is a factor of sequestration potential (both rate and capacity), project management costs and the carbon price. This provides the basis of financial analysis of options for beef and other grazing businesses.

4.3.1.1 Methods available to the land sector

Australian methodologies (as of February 2024) applicable to beef production can be allocated to one of the three categories below.

1. **Savannah fire management methods** – predominantly aimed at the reduction of methane emissions associated with hot bush fires through fuel-reducing cool burns.
    a. Emission avoidance
    b. Sequestration and emission avoidance

2. **Agricultural methods** – aimed at reducing the volume of methane emissions produced per kilogram of beef produced (termed emission intensity – CO_2e/kg liveweight), through methane reducing supplements or enhancing the amount of carbon stored in soil.
    a. Beef cattle herd management
    b. Reducing greenhouse gas emissions by feeding nitrates to beef cattle
    c. Soil Carbon is classed in agricultural methods. These methods aim to capture carbon in agricultural soils through management change.
        i. Estimating soil organic carbon sequestration using measurement and models method
        ii. Estimating sequestration of carbon in soil using default values (model-based soil carbon)
3. **Vegetation methods** – these are methods that either promote the capture of carbon in growing forests or avoid emissions by deterring the clearing and subsequent release of carbon in existing forests.
    a. Avoided Clearing
    b. Native Forest from Managed Regrowth
    c. Plantation Forest
    d. New Farm Forestry Plantations
    e. Reforestation and afforestation
    f. Reforestation by environmental or mallee plantings (FullCAM)
    g. Verified carbon standard project
    h. Tidal restoration of blue carbon ecosystem
    i. Human Induced Regeneration – CLOSED

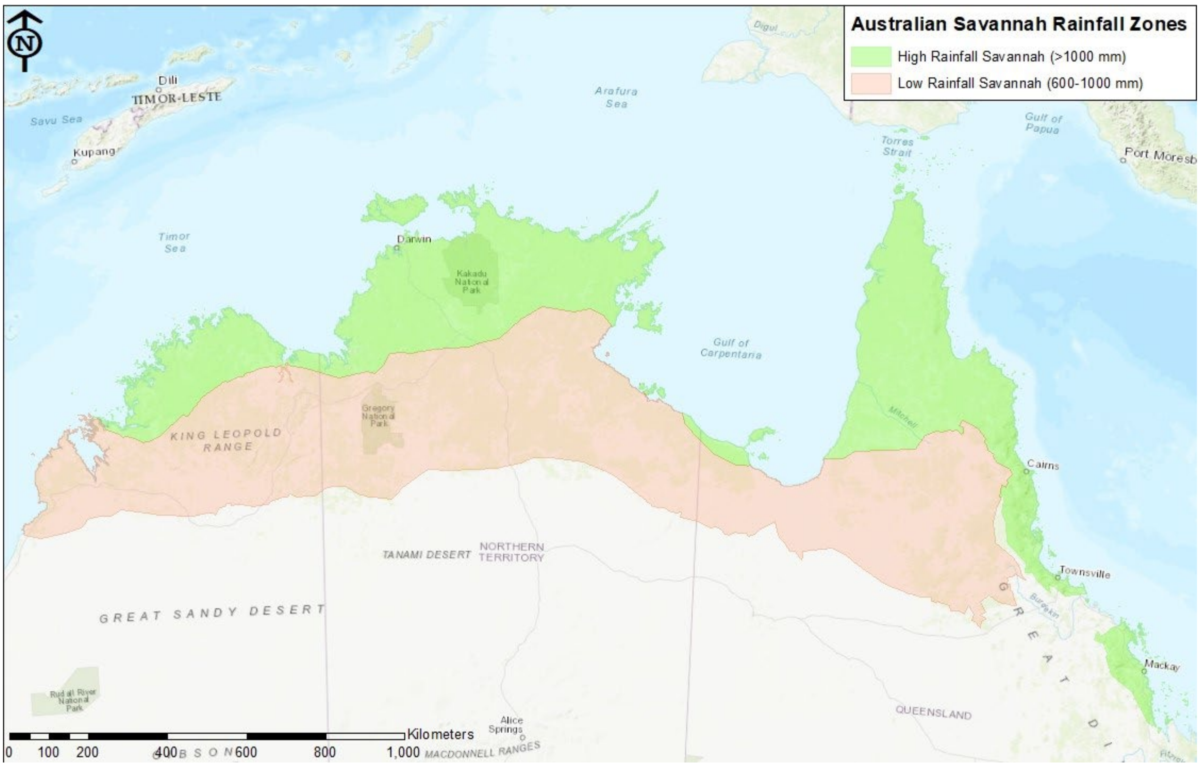
Agricultural methods typically align directly with production objectives due to the correlations between production efficiency and emissions intensity. As outlined in the Review of Ecosystem Service Market Opportunities for Livestock Producers' (Appendix 9.1), beef herd efficiency methods generally lack uptake due to the scale required to reach economic project viability, with costs arising from reporting and registration costs.

It is estimated that a minimum herd size of 50,000 head is required to feasibly engage in the beef herd efficiency method, however this varies with the current production efficiency of the herd, the capacity to improve the herd efficiency and the price of carbon. To date, there are 11 projects registered under the methodology with 974,000 credits issued. These are all undertaken by large, typically corporate, businesses. The opportunity for the development of producer groups to reach a feasible size is growing, however additional costs lie in the coordination and reporting of these groups. The development of methane inhibitors will also reduce the herd size required to achieve a viable return on investment from these methodologies.

Soil carbon has been a topic of considerable debate, particularly in the extensive livestock industry. The concept of carbon capture in soils via land management is an attractive one due to the productivity benefits associated with increased soil carbon fractions. Concerns have been raised as to the efficacy of such a concept due to the highly varied nature of soil carbon which arises from the sheer multitude of factors that influence it. In addition, the costs associated with measurement are often prohibitive as spatial variation can be dramatic, indicating the requirement for extensive baselining and fractional increase verification. Despite this, the methods remain popular, with 503 projects registered (~29% of all ACCU Scheme projects). Only seven of these have been awarded credits to date (February 2024) totalling less than 0.2% of the total ACCUs issues through the Scheme (CER, 2023). DAF and the M2M project commissioned a report on the 'Potential for soil carbon sequestration in northern Australian grazing lands: a review of the evidence' by Beverley Henry of AgriEscondo Pty Ltd.

Savannah burning methods are only applicable in northern Australian high and low rainfall savannah systems as defined by the Department of Climate Change, Energy, the Environment and Water (DCCEEW) (Figure 6) (DCCEEW, 2022b). The defined eligible zones cover large areas of national parks and protected zones while the remaining area has a very low carrying capacity for beef. While burning is a critical management technique to much of rangeland grazing, the woodland thickening that typically occurs without the presence of a hot fire, as addressed in the emission avoidance and sequestration method, can reduce this capacity further. For these reasons, only a small section of the Australian beef industry is eligible to participate in savannah burning methods. F

Figure 6. Australian savannah rainfalls zones as defined by DCCEEW for the Australian Carbon Credit Unit Scheme's savannah fire management methods (DCCEEW, 2022b).



Vegetation methods pose a number of unique challenges to beef production due to the fact that, while agricultural methods are directly in line with increasing production and performance, woody vegetation increase in northern Australia typically has a direct, negative correlation to pasture production (Zhang and Carter, 2018), although there are benefits for biodiversity and may be some benefit of additional shade and shelter for livestock wellbeing. The vegetation methods available to producers for ACCU generation listed above are based around three base concepts (CER, 2023). These are the increase of vegetative extent, avoided clearing of current vegetative extent and agroforestry. Currently, new regrowth retention methods are unavailable to producers with the human-induced regeneration (HIR) method being 'closed', however methods are currently in development to address this gap. Agroforestry opportunities are generally limited due to cost and difficulty establishing planted trees in grazing landscapes, however the method represents a genuine ongoing sequestration activity that can be attributed to an abatement of emissions from other activities of a business (e.g., methane emissions).

Avoided clearing has been a highly successful method, accounting for 4.4% of projects and 20% of awarded ACCUs as of the 10th of December 2023 (Emission Reduction Fund, 2023). The avoidance of emissions associated with the clearing of an existing forest requires participants to provide evidence of two or more previous clearing events as a proxy of the intention to clear the area again and thus the additionality of the carbon kept from the atmosphere. The method is particularly favourable in the Brigalow Belt and Mulga Lands bioregions due to the vegetation types' tendencies to naturally regenerate, which often leads to regular multiple clearing events. The previous evidence of clearing criterion has restricted engagement with the methodology, as many areas have either only been cleared once or evidence of a second clearing event cannot be obtained. The only way to engage these areas in a vegetation carbon project would be to clear the area and later register following the regeneration of the vegetation. This is a counter-intuitive and undesirable option that greatly impacts potential for biodiversity co-benefits and will release carbon to the atmosphere initially, with a project then promising to capture the carbon again. This issue is addressed further in section 4.4.

The increase of vegetative extent has been the most successful form of carbon capture developed under the Australian Carbon Credit Unit Scheme, with HIR and Native Forest from Managed Regrowth projects accounting for 28% of projects and being awarded 32% of the total ACCUs as at 10th of December 2023 (Emission Reduction Fund, 2023). This is due to the low costs of modelling and verifying carbon stocks associated with the vegetation, and a consequence of the relatively consistent nature of vegetation growth. Again, the vegetation types present in the Mulga Lands and Brigalow Belt bioregions are particularly suited to the accruement of carbon credits due to their readiness to regenerate, eliminating overhead costs and risk of establishment failure otherwise associated with plantings.F Costs arise in the form of lost production from reduced forage production and project compliance and legal fees. The HIR methodology has been removed as a vegetation crediting method, however an alternate methodology is being developed to cater to regrowth associated carbon sequestration.

Further detail on these methods and their viability can be found in the 'Review of Ecosystem Service Market Opportunities for Livestock Producers' (Appendix 9.1) and 'Potential for soil carbon sequestration in Northern Australian grazing lands: A review of the evidence report' (Appendix 9.17).

4.3.1.2 On-farm abatement models

Vegetation methods were the focus for feasibility studies on the businesses engaged in the project, due to the highly varied nature of soil carbon in grazing land systems, the scale requirement for herd methodologies and the location requirements for savannah burning. For this exercise two vegetation options were modelled "carbon and biodiversity" and "carbon only" which are described below. While avoided clearing is a highly successful method, two major requirements excluded the businesses from engaging in it for the purposes of this study. These were the requirement to prove two rounds of clearing events previously, and for it to be on category X areas as per the property maps of assessable vegetation (PMAVs) (further information on the vegetation management framework in Queensland can be found here:

https://www.qld.gov.au/environment/land/management/vegetation).

Areas highlighted for revegetation were assessed for their carbon potential via estimations from the Full Carbon Accounting Model (FullCAM) developed by CSIRO. While some of the various areas were already vegetated, all carbon pool estimations were assessed from an initial growth time of 0 (as if the area had been recently cleared and had no vegetation). This was conducted for ease of calculation and was justified as being insensitive of the time period of a project start date while capturing the majority of eligible carbon stocks. This method aligns with now closed HIR methodology, excluding areas that were already under forest cover (>20% tree cover and >2m high).

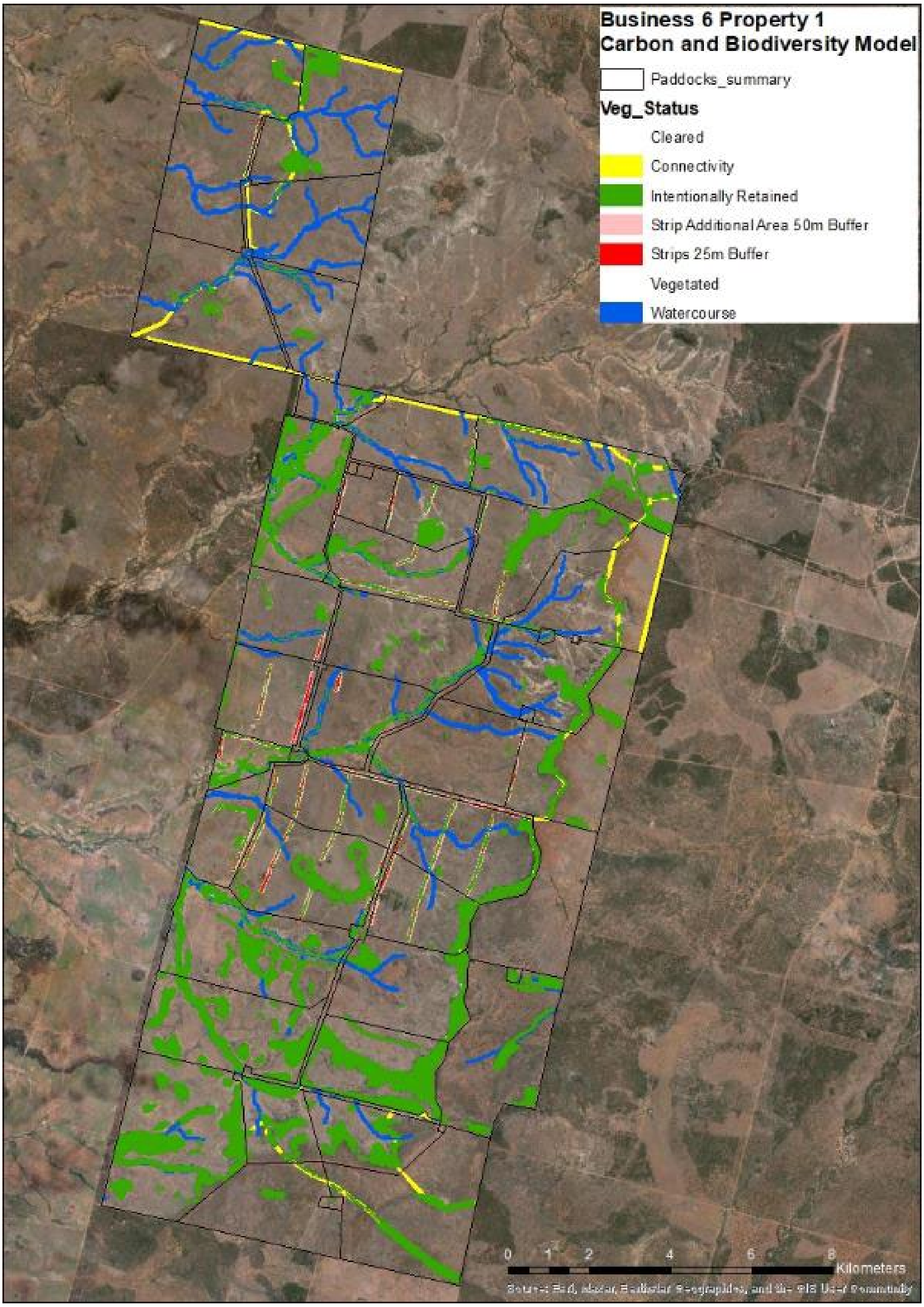
Typically, HIR projects have been conducted on a “paddock by paddock” basis for ease of management and reporting. While these are not invalid considerations, the project investigated the potential to maximise co-benefits of strategically distributed vegetation (Figure 7). Co-benefits were primarily focused on run-off reduction (reef) areas, increased connectivity between existing vegetation patches (biodiversity) and increasing animal shelter availability (production). This formed the basis of abatement options presented to producers and identified as a “carbon and biodiversity” scenario. Existing vegetation was identified via the SLATS Vegetative Extent model (DES, 2023b) and on-ground verification. This layer was visually broken into two categories:

1. Intentionally retained vegetation which specifies forest cover that is purposefully not cleared (e.g., remnant vegetation, shade clumps, regrowth strips) – labelled ‘intentionally retained’; and,
2. Regenerating regrowth which was likely to be re-cleared – labelled ‘vegetated’.

Biodiversity-related vegetative extent increase aimed to have a minimum width of 100m to reduce edge effects and allow for sufficient habitat to facilitate movement of species between patches of habitat. As part of the analysis, waterways, which are known to be of high strategic importance for biodiversity were buffered from existing watercourse layers available on QSpatial (DES, 2022). Vegetation connecting two or more patches of habitat that facilitate species movement between the patches was labelled a connectivity corridor. Connective corridor benefits were difficult to define as spatial distribution and connectivity of vegetation has not historically been targeted in biodiversity metrics, with most attention being focused on distance to edge and other area-based analysis. Investigations undertaken and assisted by the M2M project address this data gap further, however data availability is a key constraint. Products such as the Spatial Biocondition model (Section 4.4.2.3) will eventually be key in addressing these constraints by allowing for predictions to be made on optimising local and landscape scale vegetation plans.

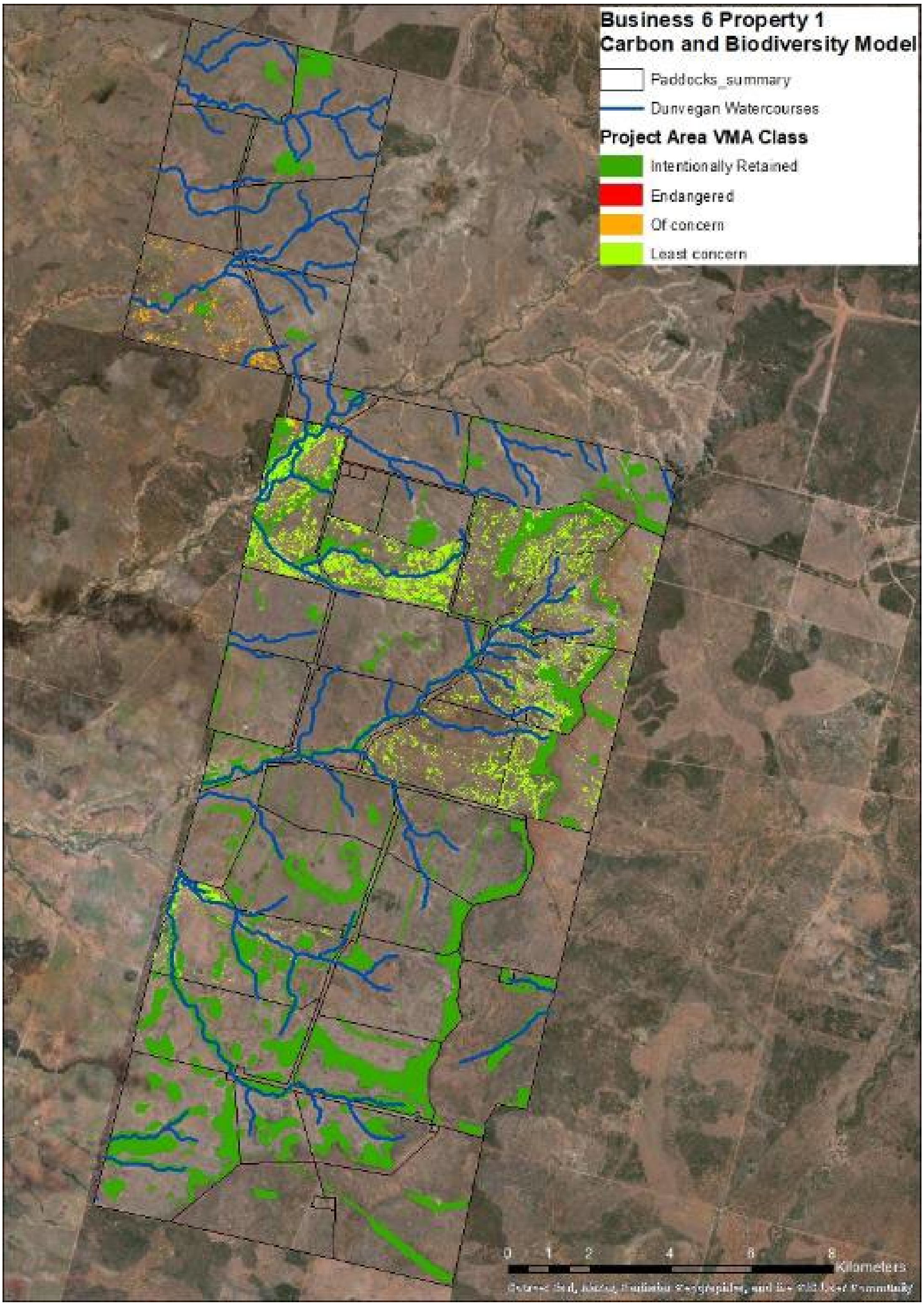
Shelter belts and shade clumps are widely adopted by producers however their design and distribution are highly varied. Assessing their impacts on production are highly complex (with both positive, negative and intangible impacts) and the economic benefits are not well understood and difficult to assess at the paddock or property scale (Donaghy et al., 2010, McKeon et al., 2008, Sangha et al., 2005, Scanlan, 2002). The abatement options activity therefore were not focussed on new shelter belts and instead focused on enhancing existing vegetation to 50m or 100m minimum widths. A paddock cover analysis was also undertaken to indicate to producers where additional belts may be beneficial, however this was purely an informative exercise.

Figure 7. ***The "carbon and biodiversity" abatement option model for a SW Queensland property. Modelled are existing vegetation patches as identified by the SLATS Queensland Vegetative Extent, watercourses, shelter belts and connectivity lines identified for revegetation.***



An alternative model was constructed to identify the impact of "paddock by paddock" carbon projects on carbon neutrality, productivity and land value (Figure 8). This was named as a 'carbon only' scenario. This scenario was conducted for 10 of the contributing properties. All paddocks were assessed for their capacity to revegetate (i.e. regrowth was present) and paddocks were typically excluded if the area eligible for a carbon project was less than 20% of the paddock or less than 20 hectares. Exceptions were made for dense eligible areas even if the whole paddock didn't reach 20% eligibility and areas of close proximity to other vegetation was also included.

Figure 8. ***The "carbon only" abatement option model for a SW Queensland property. Modelled are existing vegetation patches as identified by the SLATS Queensland Vegetative Extent and areas eligible for registration to a carbon project.***



4.3.1.3 Economic analysis

A bioeconomic analysis assessed the accruement of ACCUs and the associated reduction in the carrying capacity for all abatement options modelled (Table 14, Table 15). Project fixed costs were assessed assuming carbon service provider commission rates of 30%. Carrying capacity was determined through correlations between tree basal area and pasture production by grazing land types using data from StockTake 2014, associated with FORAGE (Zhang and Carter, 2018). It should be noted that, while the effect of trees on pasture production has been the focus of many studies, the complex nature of vegetation's distribution, species, and density effects on micro-climatic conditions, and thus pasture production, makes such a generalised analysis prone to uncertainty. While the data was the best available to the project for the relevant systems, it should be viewed as indicative only. Caveats to the StockTake data are outlined in appendix 9.18. The value of ACCUs were set at $17.35 (reflective of the ACCU Scheme price – Figure) and cattle production figures were based on the Australian Beef Report 2023 (McLean et al., 2023) and production statistics provided by the collaborating businesses.

All carbon projects were seen to outperform cattle production under a business-as-usual scenario. It should be noted that the reduction in carrying capacity was significant in all scenarios however vegetation methodologies require permanence for a minimum period of 25 years. In theory, these areas could be cleared after this period and lost production due to increased vegetation coverage would be regained, however this would be highly undesirable from a carbon and biodiversity perspective. Variation in carrying capacity reduction comes as a result of varying land types on the different paddocks and properties.

Table 14. The financial return of selling carbon credits accrued on carbon and biodiversity style project scenarios. Return increase indicates the increase in financial return relative to grazing only for the project area. All financials are net present value (NPV) of net profits from identified areas over 25 years. AE reduction is the reduction in carrying capacity on the project area after 25 years.

Property	Area (Ha)	Grazing Only	Carbon + Grazing	% Return Increase	AE Reduction (%)
1	356	$1,024,660	$1,151,918	12%	42%
2	208	$369,088	$463,775	26%	56%
4	29	$123,923	$132,944	7%	26%
5	145	$587,249	$628,515	7%	27%
6	205	$604,594	$645,962	7%	26%
7	58	$190,789	$209,238	10%	28%
8-12	107	$209,187	$277,121	32%	58%
13	380	$804,168	$893,774	11%	25%
14	4	$9,858	$10,580	7%	10%
15	192	$431,364	$471,145	9%	21%
16	321	$490,380	$636,411	30%	41%
17	142	$599,735	$644,572	7%	30%
18	247	$232,673	$356,806	53%	44%
19	1274	$456,542	$1,060,396	132%	73%
20	517	$796,665	$928,663	17%	21%
21	109	$144,180	$216,864	50%	66%
22	215	$153,647	$189,966	24%	38%
23	273	$391,192	$500,796	28%	52%

Table 15. The financial return of selling carbon credits accrued on carbon only style project scenarios. Return increase indicates the increase in financial return from a grazing only return for the project area. All financials are the net present value (NPV) of net profits from the identified areas over 25 years. AE reduction refers to reduction in carrying capacity on the project area after 25 years.

Property	Area (Ha)	Grazing Only	Carbon + Grazing	% Return Increase	AE Reduction (%)
1	2610	$8,637,214	$9,207,164	7%	37%
2	1317	$2,415,185	$2,760,053	14%	49%
4	554	$2,356,533	$2,458,054	4%	22%
8-10	541	$1,091,163	$1,381,696	27%	58%
13	578	$1,388,468	$1,481,678	7%	21%
15	1283	$2,432,751	$2,578,368	6%	23%
18	2525	$2,602,838	$3,594,478	38%	46%
19	914	$296,107	$746,838	152%	65%
22	554	$411,838	$549,458	33%	64%
23	1888	$1,866,372	$2,445,325	31%	48%

Additional costs to the implementation of a carbon project exist in the change and possible reduction of future land value, which occurs with reduction in carrying capacity as detailed above. As this cost occurs over time with the increase in canopy cover, the final cost to asset value was assessed 25 years following the implementation of the project, in line with the standard duration of a vegetation project. Ten properties were assessed for business-as-usual and both “Carbon and Biodiversity” and “Carbon Only” scenarios (three valuations per property).

While the analysis can only be viewed as indicative due to the complexity of the system, the impact of all “carbon only” projects on asset value was deemed to be significant, while only 2 “carbon and biodiversity” projects returning a significant impact. The estimated effect of both avenues for carbon projects on land value was ~$17.20/ACCU for central Queensland properties and ~$4.30/ACCU for properties in the south-west. Variation in these values are reflective of land value, partially a product of productivity of land types, and the volume of ACCUs the land type produces. The lower production land types within the south-west were expected to have a much lower cost per ACCU produced, an effect that is reflected in the behaviour of the market with uptake of carbon projects being higher in these relatively low productivity, high carbon gross margin potential areas. This variation needs to be carefully considered by producers when evaluating carbon project options.

4.3.2 Carbon sequestration – vegetation

Development of the methodologies and opportunities to integrate carbon projects into agricultural practice is imperative. In this project, carbon methodology progression was predominantly focused on recognition of carbon sinks and pools that lie in gaps between existing or closed methods. Specifically, sparse vegetation, either due to the natural tendencies of the ecosystem or through management, that would prevent woody vegetation achieving forest status (>20% canopy cover and >2m in height), but represents a large carbon sink on farm that has not been recognised previously. Similarly, carbon pools associated with woody agricultural species, e.g., the shrubby legume Leucaena, are not currently eligible for a carbon project. These topics are addressed in Section 4.5.

An additional three areas of opportunity for further development were explored by the M2M project. These were:

- Integrating native species, such as manuka, into silvo-pastoralism vegetation-based methodologies.
- Providing data to enhance the FullCAM model.
- Regrowth management variation and eligibility for inclusion in methods.

4.3.2.1 Mānuka field trial

In investigating integrating vegetation-based carbon and production outcomes, native species with productive output were highlighted as an opportunity for producers. Macadamia and other such horticultural crops are excluded due to the primary purpose of their plantings being for a harvestable product, however Mānuka plantings for the purpose of carbon also exhibit additional benefit for apiaries. The production of Mānuka honey associated with an environmental planting would alleviate the burden of sale of carbon credits to cover the financial viability of a project.

The M2M project's southernmost collaborating grazing business had experienced a failed attempt to establish a large-scale leptospermum plantation on historically cleared grazing land for Mānuka honey production and carbon sequestration. The plantation establishment failure was assessed as largely due to the severe drought at the time, planting agronomy and possibly species/variety selection. The M2M project team assisted in establishing a smaller-scale varietal trial (5 types) with two within-row spacings and improved agronomy to better understand shrub survival, growth rate, mature canopy size, mature shrub height and carbon sequestration potential in this region. The improved establishment agronomy included provision of individual irrigation drippers, mulching around seedlings at planting and application of herbicide, including pre-emergent herbicide prior to planting seedlings.

Results to date

Seedlings of the best varieties are generally healthy but relatively slow growing. Plant survival was good for *Leptospermum polygalifolium* spp polygalifolium (Poly), with 85% survival after two years Figure 9). Three other Mānuka types *L. polygalifolium* spp tropicum – Cardwell (Card), *L. brachyandrum* (Brachy) and *L. whitei* (whit) had an average plant survival of 54% declining from 76% the previous year. The worst survival was for *L. petersonii* (Peter) with only 12% survival. The tallest Mānuka types were *L. polygalifolium* spp polygalifolium (Poly) (av. 71 cm) and *L. polygalifolium* spp tropicum – Cardwell (Card) (av. 79 cm) after 2 years, although there was quite a lot of variation within types. In the last 12 months height has not increased substantially with frost and seasonal impacts reducing height through the year. *L. petersonii* (Peter) was the shortest type at an average of 18 cm tall.
A draft height to above-ground carbon biomass relationship has been derived from harvesting 15 individuals from the 'spares' in the trial and from the original planting (Figure 11).

Although the seedlings are still relatively small, some plants have flowered (Figure 12). Flowers from 5 plants were sampled for DHA, the active ingredient in Mānuka honey and sugar content. Two samples (*L. polygalifolium* spp polygalifolium (Poly)) were classed as high and 2 samples as medium *L. polygalifolium* spp tropicum – Cardwell (Card), indicating potential for Mānuka honey production if the plantation could be adequately established.

Overall seedlings looked healthy even if they were relatively slow growing. There are weeds throughout the Mānuka paddock, but it is hard to say if the weeds are impacting plant survival and plant height. The weeds may be providing some beneficial 'protection', particularly during the relatively wet season (where competition for moisture would be less extreme) and from frosts.

If Mānuka plantings were to be pursued, additional agronomic trials to consider include post-planting weed control for grass and broadleaf weeds and evaluating application of fertiliser with the aim of improving growth rates.

Figure 9. Leptospermum plant survival over time.

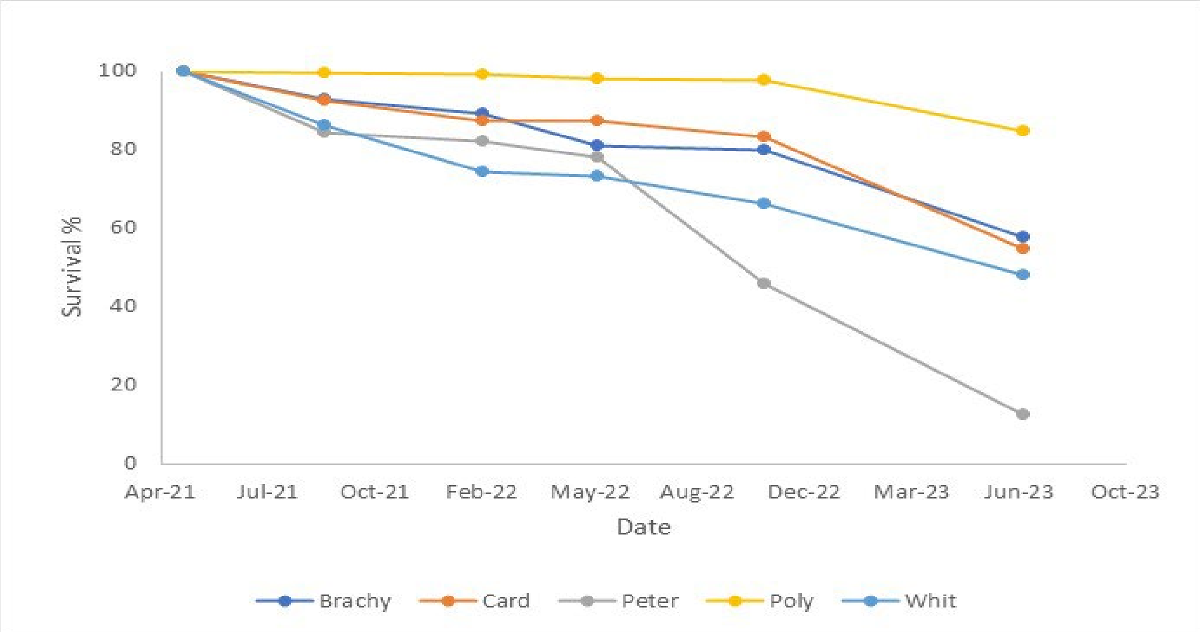


Figure 10. Leptospermum plant height over time.

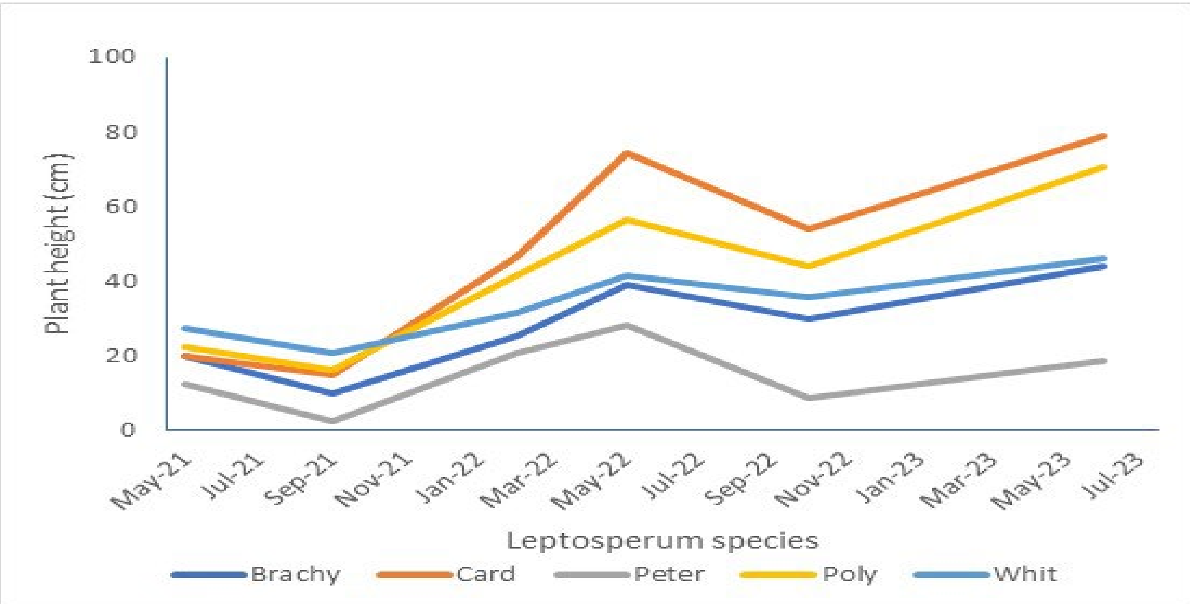


Figure 11. Leptospermum biomass to plant height relationship.

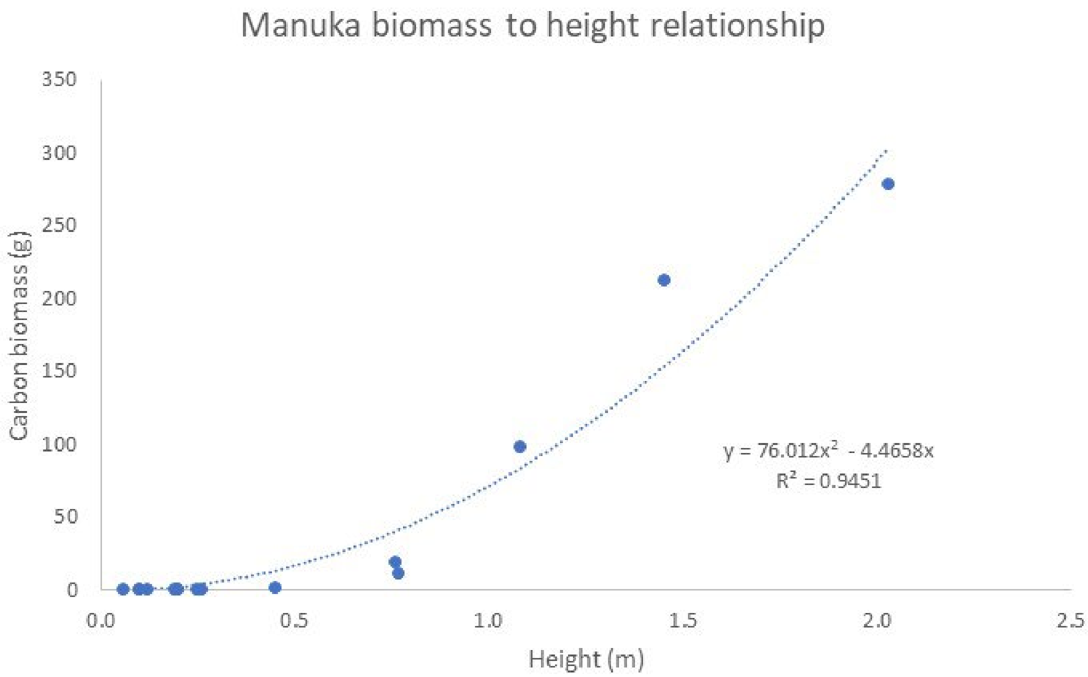


Figure 12. Leptospermum flowers and sampling nectar. Note the bee.

4.3.2.2 FullCAM modelling field data

The development of CSIRO's FullCAM model underpins vegetation sequestration methods such as HIR and Avoided Clearing. Improving the accuracy of the model has highly significant outcomes for carbon market engagement in increasing integrity of ACCUs as well as identifying differences in carbon stocks with management change. The M2M project in collaboration with the Steak n Wood project and CSIRO has contributed to improving the modelling through conducting vegetation and debris surveys across established DAF sites at Boatman, Monamby, Charleville Reserve, Wambiana and Oaklands. These site assessments were performed in collaboration with CSIRO and saw a total of 47 plots surveyed. Treatments surveyed included mulga thinning at three densities at Boatman, Monamby and Charleville Reserve, four grazing management treatments at Wambiana , pasture spelling and clearing trial at Oaklands and livestock exclusion at Wambiana, Boatman and Monamby. All sites had historical data with the Boatman and Monamby sites dating back to the 1960s when individual trees were tagged.

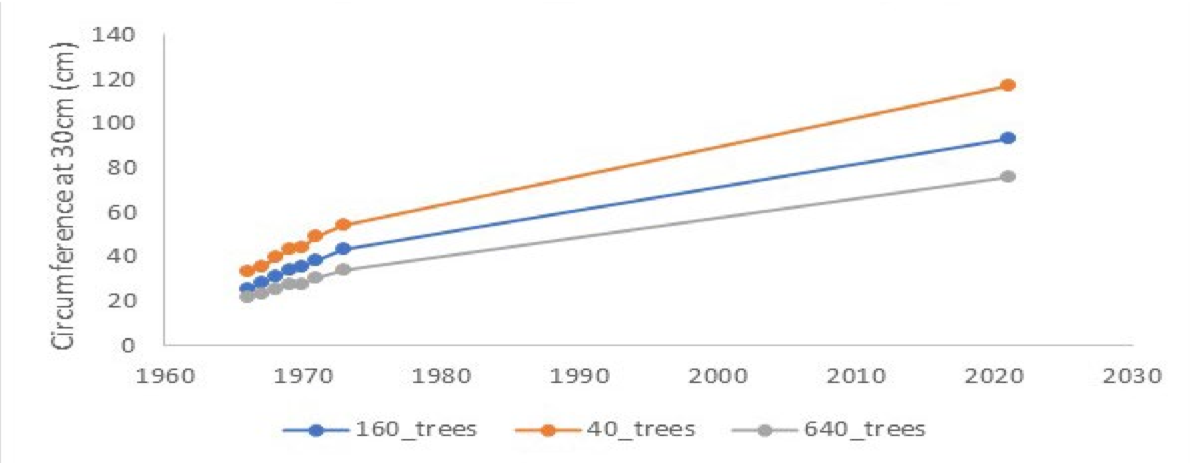
For Boatman 336 trees were tagged in 1966. In late 2022, 163 tagged trees were relocated and remeasured, 44% of original tagged trees (Table 16). Of the remeasured trees 110 (67%) were still live and 53 (33%) were dead, either standing or fallen. Many live trees had poor canopy and trunk health in 2022. Tree growth differences were maintained over the 56 year old trial (Figure 13).

Data analysis is ongoing however data from Boatman and the other trial sites will be used to improve the FullCAM tree model to replicate a range of grazing land management options.

Table 16. Boatman summary stats on tagged trees (336 initial tagged trees)

	Still live 2022 (no.)	Dead/fallen 2022 (no.)	Total remeasured 2022 (no.)	Percent dead of remeasured trees	Percent of original tagged trees remeasured
40 trees	19	8	27	30%	24%
160 trees	34	15	49	31%	44%
640 trees	57	30	87	34%	78%
Total	110	53	163	33%	48.5%

Figure 13. Circumference of tagged live mulga trees at Boatman from 1966 to 2022



4.3.2.3 Existing vegetation considerations

Typical on-farm vegetation throughout the Brigalow Belt includes a proportion of original or ‘virgin’ scrub that was left in the original development of a property, old regrowth that has been allowed to reclaim areas, and young regrowth that is usually under some sort of management plan (re-clearing). Much of the virgin vegetation and old regrowth was brought under state control for ongoing protection with the introduction of the *Vegetation Management Act 1999* (VMA). As carbon crediting methodologies require carbon sinks to be 'additional' – specifying that the carbon would either not have been sequestered or would have been emitted prior to the registration of a project – areas under VMA protection do not qualify for a ACCU scheme project.

While the majority of properties were extensively developed prior to the introduction of state legislated vegetation protection, some properties have extensive coverage of vegetation (beyond 50%) that is ineligible for carbon markets. This lack of recognition for previous management on property is a common issue in the carbon space and has been the cause of much of the dissatisfaction among producers who have been proactive in their environmental stewardship.

While the justification of the additionality approach is critical for incentivising change, the implications are that producers who already have extensive vegetation coverage across their property are in a similar position in respect to their business emissions profile as those who have very little vegetation coverage, with the key point of difference being that their opportunity to revegetate and offset business emissions is highly diminished due to lack of eligible area. Development of metrics that recognise previous stewardship would be beneficial to addressing this lack of recognition, however it is unlikely that these assets will be considered for ACCU generation. The existence of these properties raises the question of, at what point is a property considered to have an ecologically or climatically sustainable coverage of vegetation, and have done 'their part' for carbon and biodiversity goals? While ecological or climatic sustainability is difficult to quantify or considered at a property scale, the development of achievable benchmarks on a regional scale would be highly advantageous in this space.

4.3.3 Carbon Sequestration – Soil

M2M project contributed to two significant soil carbon activities.

1. Report commissioned titled "Potential for soil carbon sequestration in Northern Australian grazing lands: A review of the evidence" and subsequent scientific paper.
2. Supported QUT and DES to undertake soil sampling at the Wambiana grazing trial.

4.3.3.1 Literature review

DAF through ASQ – Animal Science and the M2M project commissioned AgriEscondo (Dr Beverley Henry) to examine the available evidence for increasing soil carbon sequestration in northern Australian grasslands and woodlands using practical grazing and pasture management strategies.

Increasing soil carbon has long been recognised as beneficial for soil health and plant growth, in addition, long-term storage of soil organic carbon has increasingly become of interest to offset emissions of greenhouse gases from sources such as fossil fuel combustion and agricultural emissions (methane and nitrous oxide) to limit global warming. However, how much mitigation can be achieved through soil carbon sequestration in grazing land has been the subject of debate.

The review of evidence found few long-term soil carbon field studies have been conducted in northern grazing lands and that there is limited reliable data on the response to regionally relevant grazing management strategies. The following key findings from available evidence on the potential to increase soil carbon sequestration and generate carbon offsets have moderate to high uncertainty:

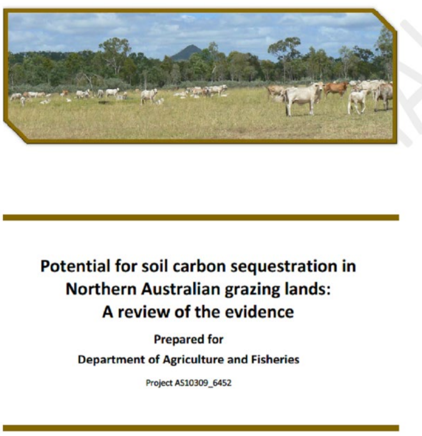
- Pasture improvement by sowing more productive grasses or nitrogen-fixing forage legumes generally increases sequestration but the rate may decline after periods as short as a decade.
- Field studies report inconsistent results for the response of soil carbon to livestock grazing management strategies:

  - High grazing pressure is associated with lower soil carbon than conservative stocking.
  - Destocking may give a small increase in soil carbon sequestration, especially in degraded grasslands but can be economically undesirable. Destocking of land used for grazing is not eligible to earn carbon credits under the ERF 2021 soil carbon method.
  - Rotational grazing studies overall showed no significant impact on sequestration in soil.
- Reducing the frequency and intensity of burning may result in small increases in soil carbon, but gains would be modest, and likely result in a trade-off with pasture production.
- Land conversion from cultivated cropping to permanent pasture increased soil carbon sequestration but opportunities for this strategy are limited in northern Australia.
- Land conversion from tree cover to grassland indicated no significant change in soil carbon.
- Conversion from well-managed grassland to forest cover showed no significant soil carbon stock change while conversion of degraded grassland to forest cover gave a small increase.

In summary, cost-effective opportunities for soil carbon sequestration in Australia's northern grazing lands appear modest. Inconsistent trial results on the potential to achieve and maintain increased soil carbon stocks in these landscapes contribute to uncertainty. Investing in long-term field studies and improved measurement and modelling data for understanding baselines and soil carbon dynamics in these extensive landscapes, and developing clear, evidence-based information resources will reduce uncertainty and support management decisions and policies for economic and environmental benefits.

The findings of the report "Potential for soil carbon sequestration in northern Australian grazing lands: A review of the evidence" (Figure 14) has been widely promoted through two webinars, presentations at the Australian Rangeland Conference and Beef 2024 and published in The Rangeland Journal (section 4.6.1).

Figure 14. Potential for soil carbon sequestration in Northern Australian grazing lands: A review of the evidence report. Available at https://futurebeef.com.au/wp-content/uploads/2023/02/Soil-Carbon-Sequestration-in-Northern-Grazing-Lands.pdf


Potential for soil carbon sequestration in
Northern Australian grazing lands:
A review of the evidence

Prepared for
Department of Agriculture and Fisheries

Project AS10309_6452

4.3.3.2 Wambiana grazing trial soil sampling

The Wambiana grazing trial south of Charters Towers is one of the few long term grazing trials with historic soil carbon data dating back to 2008, which has been previously published. The M2M team facilitated communication between the Wambiana trial team and QUT to prioritize treatments and sampling locations for resampling. Forty-four soil cores were sampled in August 2023 and are currently being processed by QUT.

4.3.4 On-farm carbon assessments

The Australian Red Meat Industry's carbon neutral by 2030 (CN30) target is an industry target and does not require all Australian red meat businesses to achieve carbon neutrality. However, the initiative has generated interest from producers and stakeholders including Government in exploring the feasibility of carbon neutrality at the farm or business-level.

Scope 1 emission sources on-farm are typically on-going, including the use of fossil fuels, breakdown of fertiliser and, most significantly, ruminant enteric emissions. While emission reduction is being investigated for all the emission sources listed above, there is no current method of eliminating enteric emissions entirely nor is it the aim (Arndt et al., 2022, Beauchemin et al., 2022).

Sequestration, through vegetation management in particular, has been identified as the most viable mode of offsetting emissions in the foreseeable future. However, there are biophysical constraints that limit the amount of sequestration achievable within a sustainable extensive grazing business.

Given the current limited nature of direct emissions abatement options on farm, carbon neutrality on farm could achieved for a short duration, but would be unsustainable in the long term (> 25 years), due to ongoing emissions but only finite sequestration potential. The development of new cost-effective abatement options could substantially reduce emissions, but not eliminate the reliance on continued sequestration. As a result, it is imperative that business plans with a target of achieving carbon neutrality are aware of the on-going and dynamic nature of maintaining a low or carbon neutral position and that adopted methods of emission abatement do not jeopardise the future viability of the business (e.g., by reducing livestock carrying capacity).

The project analysed the seven South West and Central Queensland businesses for their potential to achieve a carbon neutral target (recognising that individual business are not currently required to be carbon neutral as part of the industry-wide CN30 target) and the productive/economic costs of implementing the management strategies identified. The analysis consisted of completing an emission baseline before assessing emission reduction and abatement strategies. The vegetative carbon sequestration scenarios as outlined in Section 4.3.1 were used for this analysis.

4.3.4.1 Emission reduction considerations

While carbon farming methodologies have a variety of requirements that are often prohibitive to uptake (including size, economic feasibility and ineligibility), reducing emissions via practice change for the purpose of improving the businesses climatic-impact credentials requires no framework. Registration and verification may be required if the business deems it necessary to be formally recognised for the purpose of marketing/market access, however pre-existing management strategies that improve emissions efficiency do not exclude participation in emissions reduction recognition. That is, additionality is not required for improving the measurable emissions intensity associated with a product.

Scope 1 emissions

Producers have the most capacity to influence Scope 1 emissions which are produced on property through the activities of their business. Scope 1 includes the three major sources of primary production emissions; being on-farm fuel usage, fertiliser decomposition, and herd associated emissions (enteric fermentation and manure decomposition). For the businesses analysed, fuel usage average less than 2% of emissions but is required for on-farm transport, machinery for vegetation management and, to a lesser degree, stock handling. Adopting solar and newer technology vehicles and machinery may reduce on-farm fuel consumption further.

Fertiliser use efficiency – particularly nitrogen-based fertilisers – can reduce nitrous oxide emissions and is strongly correlated with improved economic benefits. Fertiliser-use efficiency is improved by following agronomic best management practices - such as the 4 Rs – right source, right rate, right time and right place. The eight businesses did not have significant fertiliser usage and thus have very little capacity to influence emissions from this source.

Herd emissions are the greatest source of emissions as outlined above, accounting for an average of 97.1% of the eight businesses emissions. Management strategies that influence the rate of emission revolve around the production efficiency and health of the herd. Specifically, this includes the weaning rate, weight gain, turn-off rate and mortality rate. All of these components essentially boil down to maximising the conversion of pasture into a saleable liveweight which is the primary driver behind economic success. Methods to improve these key performance indicators form the basis for most best management practices but briefly, they include:

- breeder body condition management;
- disease, parasite and pest management;
- genetic selection;
- bull selection and testing;
- removal of low fertility cows;
- effective weaning regime;
- controlled joining;
- diet quality management;
- appropriate stocking rate;
- legume introduction;
- nutrient deficiency supplementation.

The producers contributing to this project were highly varied in the management styles employed, with each focusing on the optimisation of slightly different aspects of their production system.

Pasture management was a key focus of development for all producers. This included woody-vegetation-based development for maintenance (e.g., regrowth management) and optimising pasture diversity and yield. Key to this, legume establishment has generally been conducted across viable areas. Emission abatement associated with increased legume coverage is three-pronged; due to increases in soil carbon; increases in animal performance improving emissions intensity and; direct emissions reduction through methanogenesis inhibition (Badgery et al., 2023, Henry, 2023).

Legumes such as Leucaena and Desmanthus have a direct anti-methanogenic impact when consumed, however this is not currently captured in accounting standards or rewarded through an ACCU scheme at time of writing (Black et al., 2021, Badgery et al., 2023, Stifkens et al., 2022, Suybeng et al., 2019, Suybeng et al., 2020).

Scope 2 emissions

Scope 2 emissions are derived primarily from grid sourced electricity usage. Strategies to reduce consumption are mainly based around energy efficiency of machinery particularly pumps and cold rooms, or the introduction of renewable energy sources on property (e.g., solar panels). Scope 2 emissions typically make up less than 1% of the grazing businesses emissions assessed.

Scope 3 emissions

Scope 3 emissions, also referred to as imbedded emissions are the emissions involved in the creation of a product or service that occur off the property. As a result, a producer has very little capacity to directly influence the emissions reported here but should be aware of activities that may increase the proportion of Scope 3 emissions to their baseline in a given year (e.g., purchased livestock, energy used to produce and transport fertiliser).

Emerging technologies

The novel technologies with the greatest potential impact for the red meat industry are rumen micro-biome manipulation, influencing the methanogenic pathways in the rumen to reduce methane emissions rates. Products that are currently available are 3-NOP (Bovaer®) and red asparagopsis, although the amount of emissions reduction can vary significantly depending on dosing and feeding regime (Fouts et al., 2022, Króliczewska et al., 2023, Prathap et al., 2021). While these products are currently un-economical in extensive grazing due to cost of production and difficulties in dietary delivery, research is underway to address these barriers to uptake. A variety of other feed additives including probiotics, prebiotics, saponins, tannins, lipids and essential oils continue to be investigated for methane inhibition potential but have largely been deemed as unviable due to a variety of economic and scientific barriers (Fouts et al., 2022, Króliczewska et al., 2023, Prathap et al., 2021).

Other developments that are potentially easier to implement across the national herd over an extended timeframe include the manipulation of genetics to select for reduced methane emission. There are three main approaches to achieving these objectives: direct genomic selection (potential to reduce up to 25% of emissions); indirect genomic selection, and; genome wide association and selection (Króliczewska et al., 2023, Prathap et al., 2021). These would be implemented through existing pathways such as estimated breeding values (EBVs). Advantages to these approaches are that progress can be made incrementally, are persistent and cumulative. This is as opposed to the on-going management required by feed additives or vaccines.

Vaccines against methanogenic populations in the rumen have also been researched. Various approaches have been investigated, targeting various methanogenic components of the rumen microbiome, many have been rejected for reducing animal production efficiency or the capacity to digest roughage (Króliczewska et al., 2023, Lassen and Difford, 2020, Prathap et al., 2021). This comes as a result of the integral processes some methanogenic microbes perform in the rumination process (e.g., protozoa) (Króliczewska et al., 2023, Prathap et al., 2021). The remaining vaccines have highly varied results ranging between 7-70% reductions in-vitro, but have little lasting effect (Fouts et al., 2022, Króliczewska et al., 2023, Lassen and Difford, 2020, Prathap et al., 2021).

Additional forms of methane management in development include physical interception and oxidation via masks as well as nanotechnology which directly interact with methanogens in the rumen. These technologies have been shown to reduce emissions by 60% and 15% respectively (Mundra and Lockley, 2024, Altermann et al., 2022).

None of the methodologies identified to date have shown the capacity to eliminate enteric fermentation emissions.,

While management improvements can be made to reduce total business emissions as highlighted above, the intricacies of each individual business largely dictate what is feasible on-farm. The emissions intensity of the businesses as reported in Section 4.2.2 are predominantly below the national average, indicating that the producers are already operating efficiently. Efficient producers may be approaching a maximum viable threshold of emissions intensity and efficiency for their operation, until direct interventions, like methane suppressing supplements become commercially attractive.

4.3.4.2 Emission abatement potential

Significant portions of all properties did not meet the eligibility criteria for an ACCU carbon project due to vegetation already exceeding or having no potential to achieve forest cover. Carbon and biodiversity scenarios had an average excluded area of approximately 24% of the original area outlined in Section 4.3.1, varying between 0-64% in individual properties. As this area focused on water-way revegetation, much of this area were disturbance zones. The carbon only project areas excluded an average of 64% of the area, varying between 26-86% of the paddocks identified as suitable.

Most scenarios exhibited the potential to offset at least one year of the business's emissions over a 25-year project. Table 17 displays abatement potential against the relevant business's emissions. Offsets refer to the duration the ACCUs acquired would offset the business emissions. ACCUs reported are reflective of the carbon sequestered over a 25 year project lifetime less ERF discounts and risk of reversal buffers (25%).

Table 17. Total emissions and abatement potential of the modelled areas for carbon and biodiversity and carbon only projects.

Business ID		1	2	3	4	5	6	7
Total emissions (t CO2-e)		6,722	8,887	3,567	31,926	12,225	8,254	4,091
Carbon + Biodiversity	ACCUs	75,454	34,335	20,202	28,273	76,695	175,364	30,745
	Business Area (%)	3.7	1.6	2.8	3.2	2.4	4.5	3.6
	Offsets (Years)	11.2	3.9	5.7	0.9	6.3	21.3	7.5
Carbon Only	ACCUs	438,960	43,066	101,830	73,410	274,113	126,975	172,138
	Properties assessed	2 of 3	1 of 4	1 of 1	2 of 3	1 of 3	2 of 4	1 of 1
	Business Area (%)	26	2.1	14	10.4	8.6	3.2	25.2
	Offsets (Years)	65.3	4.9	28.6	2.3	22.4	15.4	42.1

The modelled scenarios showed across the seven businesses, participating in the modelled carbon and biodiversity projects delivered enough ACCUs that - if retired as offsets - could neutralise total farm emissions for 0.9 to 21 years, and 2.3 to 65 years with the modelled carbon only projects.

As the projects modelled in this scenario mature, ACCU yields from the forests and soils under scheme projects will decline as the rate of sequestration in these sinks, declines. Mature forests will sequester carbon at a greatly reduced rate as compared to sequestration in the first 25 years. Developing further modes to reduce direct emissions would be required to maintain a low carbon or carbon neutral position.

Implications of limited on-farm abatement potential via soil and carbon sequestration methods paired with the current inability to eliminate enteric emissions are that, while carbon neutrality can be achieved, it cannot be sustained on-farm in perpetuity. Off-farm abatement may be required, which may be impacted by future availability and price.

4.3.4.3 Economic analysis of carbon neutral options

While emission reduction through increasing production efficiency generally aligns with economic return, and some of the feed additives have been theorised to improve feed conversion efficiency, other means of obtaining carbon neutrality (e.g., vegetative offsets) will incur a monetary or production cost. Soil carbon is a potential offset that could improve production, however opportunity is deemed to be limited in extensive grazing land due to the constraints associated with the method outlined in Section 4.3.3.

The costs associated with lost production to achieve on-farm carbon neutrality should reflect the productive value of the areas reported in the cost-benefit analysis of carbon farming against grazing production (Section 4.3.1.3), as there would be no sale of credits (with achieving carbon neutral) to offset the lost return. Implications for future land value would also be of consequence here (not included in Section 4.3.1.3). These considerations returned a cost of production figure of ~$17.2/ACCU for the central Queensland properties and ~$4.3/ACCU for the south-west to implement offsetting projects on-property. This produces the basis for an annualised cost estimate for achieving carbon neutrality via vegetation-based sequestration. This cost could be recovered in a market premium as the market develops.

Currently (early 2024) there is little opportunity or advantage in the current market for carbon neutral beef, premiums or market access, to recoup additional costs. This is an area of the market that is being investigated by retail businesses such as Coles who have launched carbon neutral beef brands based on producers with high emission efficiency and supplemented with off-farm offsets. The market premiums created by Coles as at January 2024 are as reported in Table 18.

Producers selected for supplying to this market demonstrate an emission intensity of less than 12 kg CO_2e / kg liveweight. Assuming dressed percentage of 52% and a saleable meat yield of 73%, the total emission profile per kilogram of saleable beef is 31.6 kg CO_2e/retail kg. At a SPOT carbon price of $34/ACCU, the marketed beef would have an additional production cost of $1.07/kg. Currently there is no premium being sought by the retailer (Coles) as additional costs are absorbed by other product qualities however it does indicate that consumers are willing to pay for the premium product. To date this premium is not available to the average producer but demonstrates the potential for additional costs of production to be met by the market.

Table 18. Coles carbon neutral beef premiums currently on the market (January 2024).

	Regular ($/kg)	Carbon Neutral ($/kg)	Premium ($/kg)	Additional price premium paid by consumer (%)
Mince	$13.00	$21.00	$8.00	53%
Eye Fillet	$52.22	$69.70	$17.48	31%
Porterhouse	$40.00	$51.35	$11.35	26%

As on-farm sequestration, under the current understanding, is limited in its capacity, any producer that opts for reduced production from increasing vegetative extent would have to revert to sourcing credits off-farm to maintain a carbon neutral status into the future. In this sense, unless productive capacity can be enhanced, offsetting on-farm emissions via vegetation would serve to reduce business scale. Although other benefits such as biodiversity, aesthetics, cultural value or livestock welfare should be considered.

4.3.5 Australia's livestock emissions in the national accounting framework

Understanding the carbon and methane cycles for industry and livestock businesses and the relevance of widely publicised discussions/commentary on the emissions metrics particularly for methane were common issues where producers and advisor were seeking accurate, scientifically-based information from a trusted source. In response, the M2M project researched and developed content for use in presentations and assessed the impact for case studies to enable comparison and improved knowledge. The below description outlines the basis for the information provided during the M2M project to improve understanding, reduce uncertainty and barriers to uptake of strategies for grazing businesses.

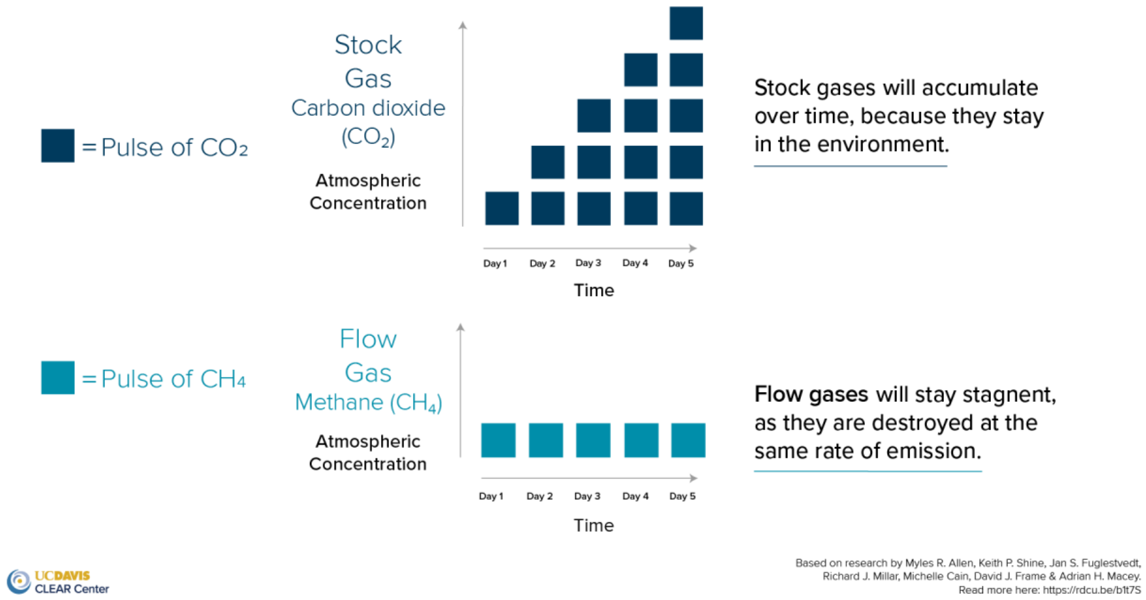
Methane emissions account for the majority (80-90%) of extensive livestock emission profiles using the internationally applied, Global Warming Potential over 100 years (GWP100) metric, which uses the carbon dioxide equivalent unit. The GWP100 metric was chosen internationally as a compromise to enable comparisons across greenhouse gases, industries and countries. However, as for any compromise, a single metric may not be the best fit for specific individual circumstances. Debate around the accounting metrics has been present in the scientific literature since the 1990s, however it has garnered accumulating scrutiny, including in the rural media for the impact on livestock industries, over the last few years.

Greenhouse Gas Emission Accounting Metrics

Government and industry targets currently aim for carbon neutrality as a mode of achieving climate stability. The internationally accepted metric for equating emissions to a carbon dioxide equivalent (CO_2e) is the GWP100 (Global Warming Potential over 100 years) metric (Lee et al., 2023). Using a metric to equate the different gases is required to guide investment and policy decisions in an efficient manner. The GWP100 metric was initially developed in 1990 and adopted by the International Panel for Climate Change (IPCC) to consolidate the differences in radiative forcing potential and atmospheric lifetime of various gasses (United Nations, 1998). This was achieved by modelling the radiative forcing potential of a pulse emission of various gasses over a period of time as they decay (Intergovernmental Panel on Climate Change, 2023). As the relevant gasses decay at different rates, a timeframe had to be selected. While there were a number of timeframes proposed, the "global warming potential" over a 100-year period was selected as it had the most relevance to global industry and the economy.

However, as with any compromise, the GWP100 metric does not accurately reflect climatic effects of emissions in all circumstances. Of relevance to the ruminant livestock industries, the GWP100 metric begins to misrepresent the climatic effects when assessing continual emission sources of short-lived greenhouse gases (e.g., methane). This is due to the fact that, while carbon dioxide is persistent in the atmosphere, some greenhouse gasses (GHGs) break down in the atmosphere via natural processes. A consequence of this phenomenon is that constant emissions of short-lived GHGs will eventually reach an equilibrium between the emission rate and rate of decay, leading to the atmospheric concentration stabilising despite emissions continuing. These are referred to as a short-lived climate forcer or a flow rgas (Figure 15). By comparison, ongoing emissions of carbon dioxide (particularly from fossil sources) are additional to the atmosphere and will continue to add to atmospheric concentration while a non-renewable emission source exists. This is referred to as a stock gas. As flow gasses are being equated to a climatic impact over a period of time, they are misrepresented as having additional atmospheric impact with every emission, similar to a stock gas.

Figure 15. Stock vs flow gasses (Clear Center, 2020).



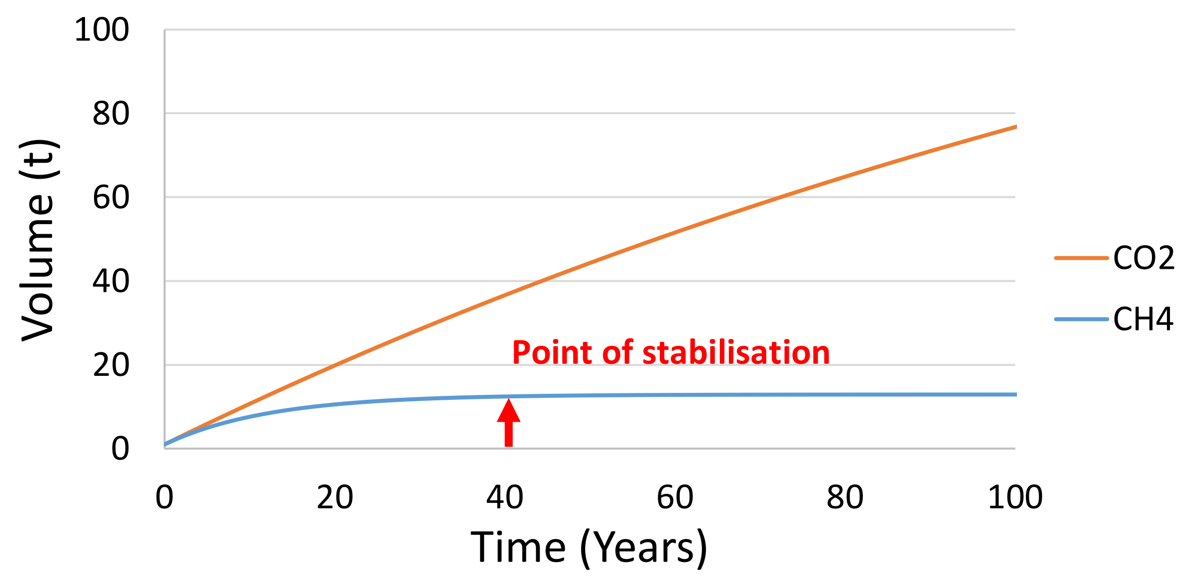
The continual emission of a flow gas will achieve a static atmospheric radiative forcing, therefore the associated thermal impact and temperature rise will reach an equilibrium. The temperature equilibrium, will occur over thousands of years due to the thermal buffering of the biosphere and is particularly influenced by the ocean, however the majority of the increase in temperature will occur in the short term, as is typical of thermodynamic stabilisation.

Methane

Methane is a short-lived climate forcer with a relatively high radiative forcing potential (~170 times that of CO_2). It has an atmospheric half-life of approximately 8.6 years and an effective lifespan of ~12 years. With continuous emissions, an atmospheric concentration and radiative forcing equilibrium (>95% of the asymptote) will be reached after 40 years following the first year of emissions from a constant source (Figure 16). Ongoing emissions (of the same amount) following this period will only maintain atmospheric concentration and radiative forcing, as described above. Reductions in the rate of emission would, inversely, reduce the total concentration of methane in the atmosphere provided that the emission source has already reached its atmospheric equilibrium.

By comparison, application of the GWP100 metric assumes that with continual methane emissions, the volume in the atmosphere would continue to grow ad-infinitum, similar to the long-lived gas CO_2 in Figure 16.

Figure 16. The atmospheric accumulation of methane and carbon dioxide in the atmosphere given a constant emission and decay rate.



Australian Livestock Emissions

Ten percent of Australia's national emissions are derived from livestock methane (DCCEEW, 2023b). Australian livestock numbers fluctuate with seasonal conditions, however the cattle herd has been relatively stable since 1972, while Australia's sheep flock declined dramatically since 1990 but has since stabilised and increased marginally (Figure 17) (ABS, 2013). The total methane emissions associated with Australia's primary livestock has declined by approximately 25% from the emissions reported in 1990 (ABS, 2013, ABS, 2023, Carter et al., 2010).

While the red meat industry has certainly contributed to atmospheric methane concentration increases since the industrial revolution (early 1900s) as livestock numbers increased, the livestock methane from Australia's grazing industries is likely to have reached its atmospheric concentration peaking and even declined with the reduction of the national flock since the 1990s (Figure 18). In addition, the warming associated with the growth of the industry and its subsequent emission plateau is likely to have already generated a significant portion of the total warming that the livestock methane emission source will generate. As climate stabilisation is the key aim of international agreements surrounding the climate crisis, nullifying the Australian livestock contribution to further warming is justifiable under the above rationale. Specifically, this could involve a reduction in enteric emissions through improving production efficiency or supplements, or the offset of those emissions through existing strategies, to the point at which the current temperature increase associated with herd/flock emissions is maintained. Any reduction below that could possibly be rewarded.

It should be explicitly noted that any increase in herd size above the current relatively stable level, without improvement in emissions intensity, will increase atmospheric temperatures associated with the livestock industry, which obviously has implications for future industry growth.

Figure 17. Australian reported cattle herd and sheep flock numbers from 1860 to 2021 (ABS, 2013, ABS, 2023).

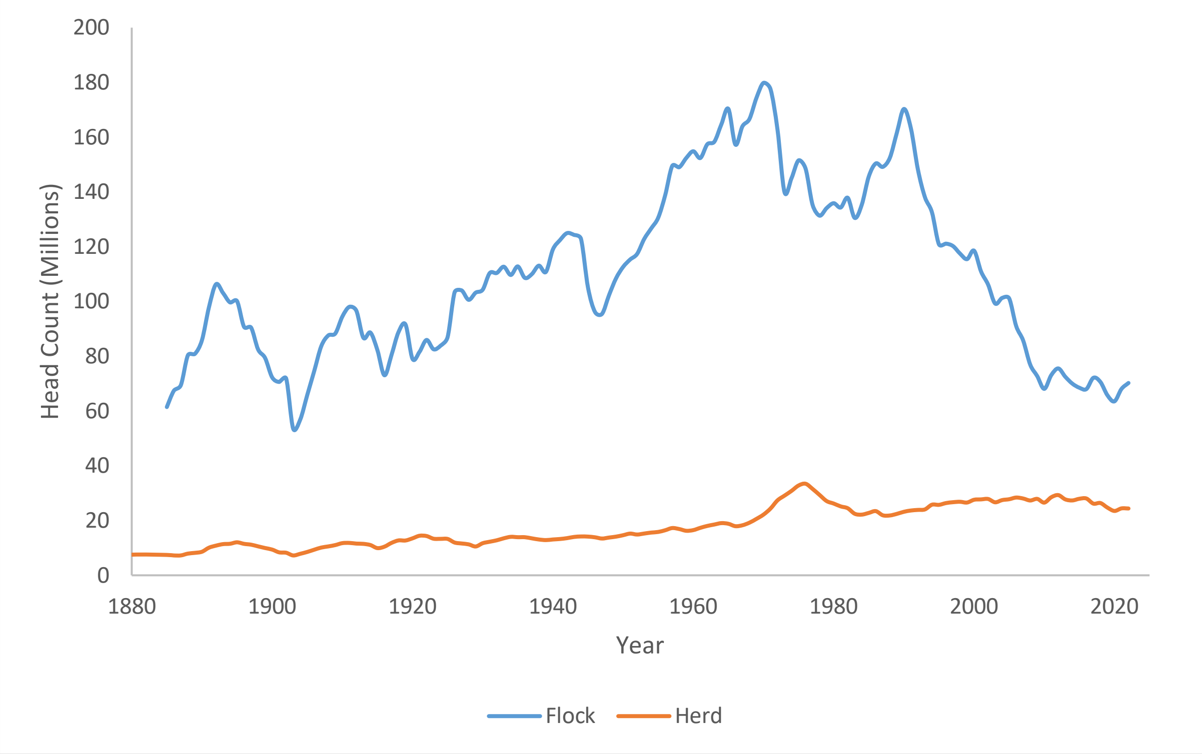
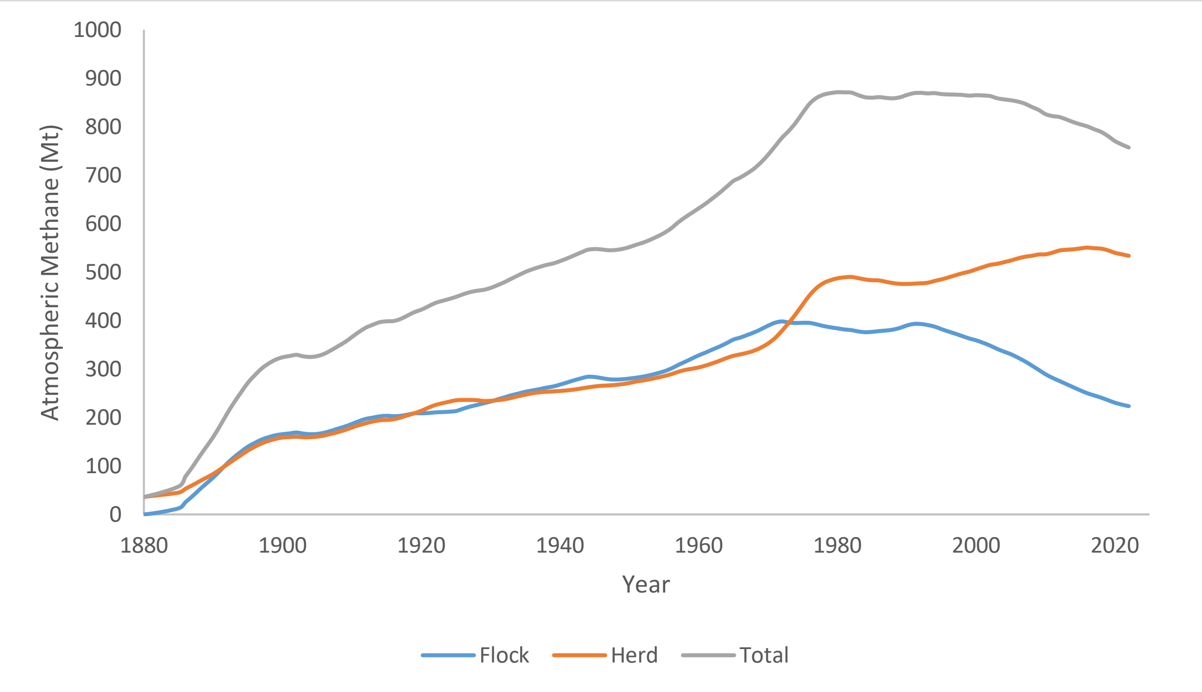


Figure 18. Atmospheric methane addition from Australian livestock as modelled from ABS reported national herd and flock counts, national emissions inventory and IPCC reported atmospheric methane breakdown rates (ABS, 2013, ABS, 2023, Carter et al., 2010, DCCEEW, 2023b, Intergovernmental Panel on Climate Change, 2023).



Carbon neutrality vs industry climate impact

Recommendations

To better understand the issues and challenges it is recommended to:

- Undertake additional modelling at **the business** and regional scale, to determine the total methane stocks contributed to the atmosphere via livestock business associated emissions, taking into account annual fluctuation in livestock numbers related to climate and markets, to define the total radiative forcing and predicted temperature impact contributed by livestock business or region.
- Investigate emission reduction and offset options on-farm and regionally to limit the temperature impact.
- Undertake a cost-benefit analysis to compare the impact at business and regional scales of the climate neutral versus the carbon neutral pathway using GWP100 metric.

4.4 Natural capital assessments

Summary

Natural capital markets are a relatively new concept in Australia and provide an alternative to 'carbon' focussed markets.

The Australian government's *Enhancing Remnant Vegetation Pilot* was of interest to the participating grazing businesses. Of the eight grazing businesses, two had properties located within the eligible pilot regions and both initiated successful project applications. These businesses will receive biodiversity enhancement payments over the 10-year project period. These payments have two elements:

- A rental component that represents a 'rental' payment for using the land for conservation purposes. For the avoidance of doubt, the Australian Government did not lease or take any other legal proprietary interest in the project area.
- A management activity component that was designed to cover the costs of the management activities necessary to enhance the condition of the remnant vegetation, including any revegetation.

After two popular application rounds this pilot ceased, with the Australian Government indicating it would instead focus on its Nature Repair Market.

In addition, the M2M project explored the opportunity and challenge of undertaking natural capital certification via environmental accounting. This included contributing to:

- Development of remote sensing technologies to reduce the cost of measuring natural capital condition at scale.
- A trial of Australia's first certifiable environmental accounting method designed to simultaneously assess the environmental and productivity condition of Australia's grazed systems under the Accounting for Nature® framework.
- Development of a revised environmental accounting method to simultaneously assess the environmental and productivity condition of Australia's grazed systems under the Accounting for Nature® framework.

- Cost-benefit analyses of carbon + co-benefit projects in grazing systems of southwest and central Queensland.
- An investigation of native shelter belts as a means of integrating conservation with agricultural production.

4.4.1 Nature-related risk

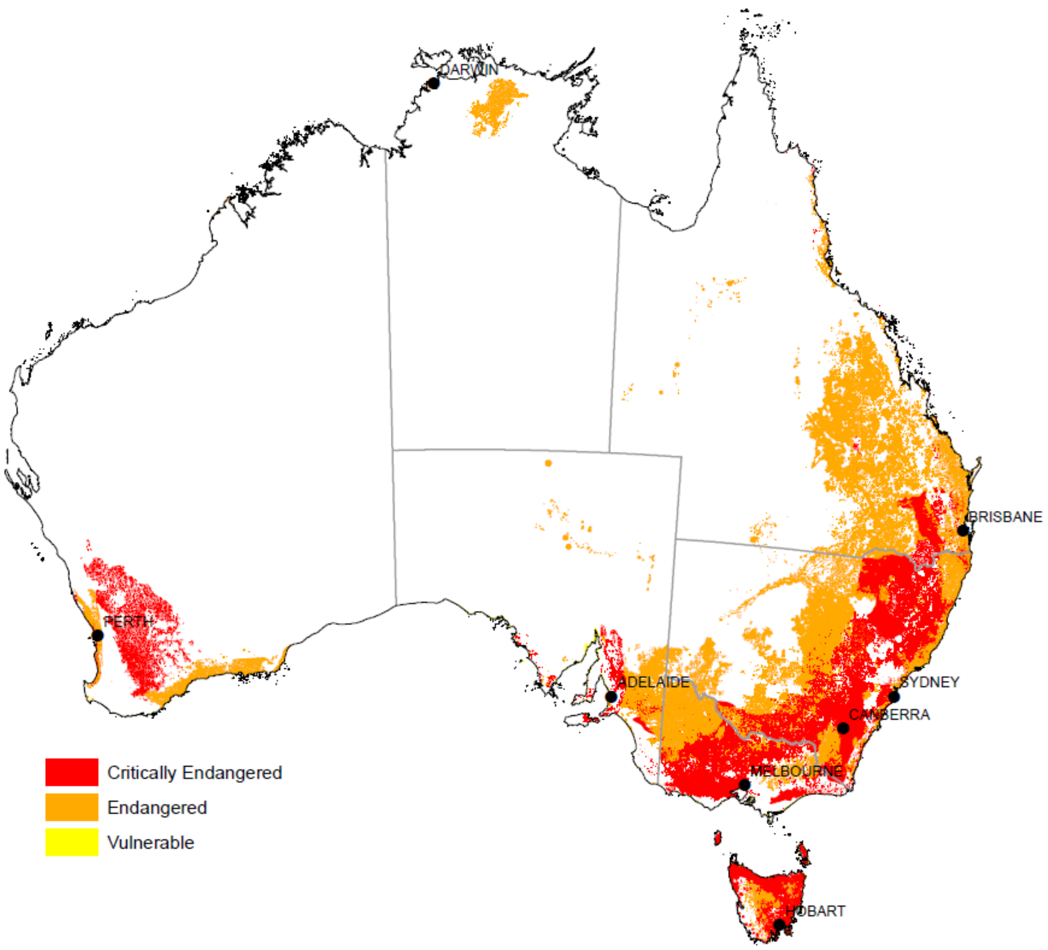
Improving habitat condition to reduce environmental degradation and improve landscape connectivity – 'the degree to which the landscape facilitates or impedes movement among resource patches' (Taylor et al., 1993) – has long been a major goal of global conservation plans (Fischer and Lindenmayer, 2007, Prober et al., 2019, Watson et al., 2017, Worboys et al., 2010). More recently, mainstream recognition of 'nature-related risk', including biodiversity loss and environmental degradation, has been listed as existential threats to humanity – alongside weapons of mass destruction, adverse effects of technology and collapse of states or multilateral institutions. These existential threats have solidified the notion that failure to act now will inevitably lead to 'catastrophic physical impacts and severe economic harm that would require costly policy responses' (McLennan, 2021). The rise in environmental, social and governance (ESG) credentials and targets by multi-national companies, natural capital certification schemes, carbon + co-benefit credit schemes, and the formation of the 'Kunming-Montreal global biodiversity framework' and 'Taskforce on Nature-Related Financial Disclosures' are further acknowledgment of the ever-increasing expectation for industries, business and government to understand, communicate and act on nature-related risk.

Nature-related risk within Australia's red meat industry – a historical context

Australia is renowned for its biodiversity, owing to its unique and highly varied ecological communities. An ecological community is a naturally occurring group of native plants, animals and other organisms that are interacting in a unique habitat (DCCEEW, 2022a). Their structure, composition and distribution are determined by environmental factors such as soil type, position in the landscape, altitude, climate, and water availability. These factors also result in differences in their agricultural productivity potential. Not surprisingly, historical clearing of native woody vegetation has focused on ecological communities with moderate to high agricultural productivity potential significantly impacting biodiversity and connectivity in those regions. The rise of technology has increased the understanding of the ecological communities present in agricultural systems to the point where it is now apparent that ecological communities and associated vegetation types are at risk of collapse (Figure 19). Australia accounts for approximately 11% of the world's described threatened plant and animal (chordate) species (Chapman, 2009).

Australia's most modified landscapes occur on private and leasehold land, with higher impacts from historical land clearing and modification for agriculture and urban development (ABS, 2023). These tenures represent 58% of Australia's landmass and account for 67% of Australia's remaining native forest extent (ABS, 2023). Grazing native vegetation (~325.4 million hectares) and modified pastures (~46.7 million hectares) is the major land use (ABS, 2023). In the face of climate change, a distinct but interdependent issue, the Australian red meat industry is therefore particularly exposed to nature-related risk.

Figure 19. Generalised distribution of where threatened (vulnerable, endangered or critically endangered) Ecological Communities listed under the *Environment Protection and Biodiversity Conservation (EPBC) Act 1999* are likely to occur (DCCEEW, 2023a).



Opportunity or risk from understanding nature-related risk

Given the grazing industry's vast range; proximity to Australia's remaining native forest (the majority of which is continuous, not fragmented); and as custodians of much of the remaining extent of many threatened or endangered ecological communities, Australia's red meat industry is uniquely poised to demonstrate a pivotal role in reducing nature-related risk throughout Australia. At the grass roots level, this would involve environmental accounting under a suitable natural capital certification framework (described below) to understand and communicate whether management actions are maintaining, improving, or degrading the condition of natural capital assets (e.g., agricultural soils, modified pastures, native vegetation, water, fauna). Collaborative effort (between industry, government, and not-for-profit organisations) to compile and maintain environmental accounts would mean decision makers within business and government alike would benefit from the data they contain, and the rich underlying spatial datasets assembled to produce them. For example, accounts could be used to underpin regional scale environmental condition modelling to simultaneously enable nature positive sustainability claims and informed reporting by government (against national and international natural capital targets) at scale. Unlike other pathways to environmental market participation, the opportunity is greatest for grazing businesses with a historical commitment to maintaining and improving the condition and resilience of their agroecological system.

Requirements for facilitating the development of nature-related incentives

The success of the nature-related risk pathway assumes the availability of independently substantiated, internationally recognised frameworks for natural capital accreditation, environmental accounting, supply chain reporting and globally recognised 'nature positive' product labelling standards.

External co-contributions in the form of technical and on-ground support; as well as financial support where grazing businesses incur significant upfront (e.g., tree planting) or ongoing costs (e.g., opportunity loss) would be essential. Technical support must include access to spatial models capable of efficiently predicting the environmental benefits of proposed projects at the property and regional scales to enable informed decision making by landholders and investors; while financial support for projects with significant upfront costs should be front-loaded.

What to look for in a natural capital certification scheme
Progress towards the above-mentioned foundations has been an iterative process over more than 20 years. Until recently, the technical 'push' to develop environmental accounts proceeded largely independently of the 'pull' from the intended or likely end-users of accounts (i.e., decision makers within industry and government) (Vardon et al., 2016).

This has ensured the evolution of internationally agreed upon frameworks with a high level of impartiality (e.g., United Nation's Standard for Environmental Economic Accounting (SEEA)) that, when adopted by natural capital accreditation schemes, can be confidently used to underpin sustainability claims alongside well-defined and recognised product labelling standards. These schemes should also be compatible with other red meat industry standards and certification systems.

The chosen scheme must also seek to balance scientific rigour and practical limits on the tools and datasets that can be assembled with reasonable resourcing. In striking this balance, scheme design must first consider the needs of the intended users of the information, including decision-makers and potential investors, and the information that is currently available. This means the scheme must provide adequate flexibility in method design to suit a range of environmental account accuracies and scales.

4.4.2 On-farm flora and fauna surveys to support the development of remote sensing products

Emerging natural capital certification and credit schemes offer a significant opportunity to the red meat industry if vegetation and productivity condition can be accurately and cost-effectively measured and communicated at scale. No-where in Australia is this statement more prevalent than in Queensland; where extensive grazing occupies 83% of the state (Figure 20), supporting 44% of the national cattle herd (MLA, 2022); and where 16 broad vegetation groups (Figure 21) and >1400 described regional ecosystems support a staggering 72%, >50%, 85% and 57% of Australia's native bird, reptile, mammal and plant species, respectively (Chapman, 2009, DES, 2023b).

The primary objectives of this work were to:

1. use established methods to build on existing field datasets for native vegetation and pasture condition for Queensland to help train and verify models for current and future remote sensing tools and products.
2. establish datasets that demonstrate the change in native vegetation condition across condition states typically present in extensive grazing systems of Queensland (e.g., remnant vegetation, mature native regrowth, young native regrowth and pasture).

3. Build capacity within the Queensland Department of Agriculture and Fisheries (DAF) to identify, measure and communicate opportunities for demonstrating natural capital stewardship and improvement in productive grazing systems.

4.4.2.1 Methods for flora and fauna surveys

Monitoring site stratification and selection

Broad vegetation groups (BVG) 9 and 10 were identified as important to livestock production and common to the seven participating grazing businesses located across central and Southwest Queensland (Figure 21). Within these BVGs, areas containing regional ecosystems (RE) dominated by Brigalow (*Acacia harpophylla*) and mulga (*Acacia aneura*) in a range of condition states were identified (Table 19). Wherever possible, a minimum of five monitoring sites per condition state were systematically selected. These were located at least 1 km apart to ensure independence of fauna data (Eyre et. al., 2022); and 50 m from any major disturbance (e.g., from a road, dam, water point etc.).

Figure 20. Extensive grazing systems occupy 1.4 million km^2 (or 83%) of Queensland's total area (DES, 2023a).

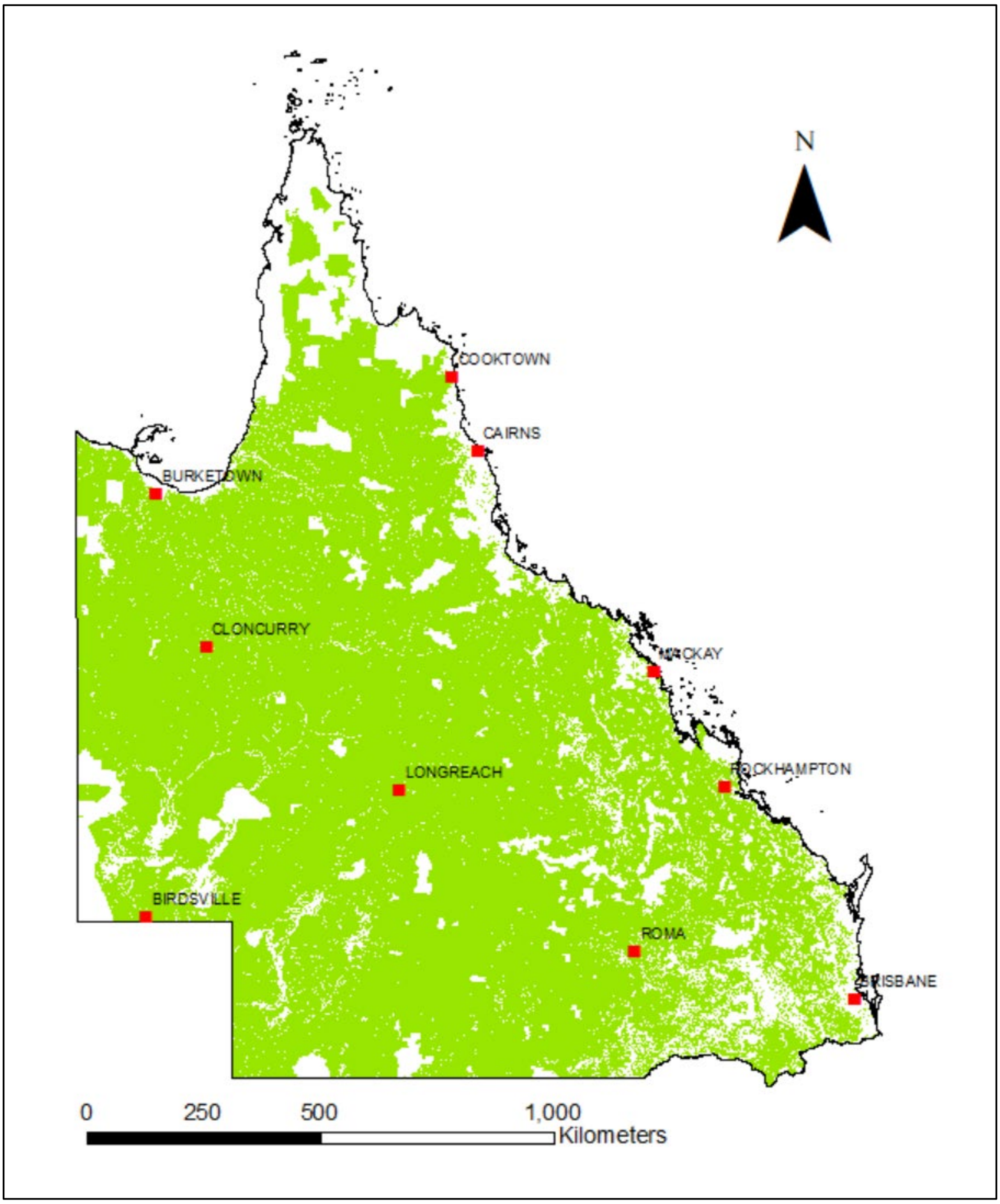


Figure 21. Pre-clearing Broad Vegetation Groups of Queensland (Neldner et al., 2023a).

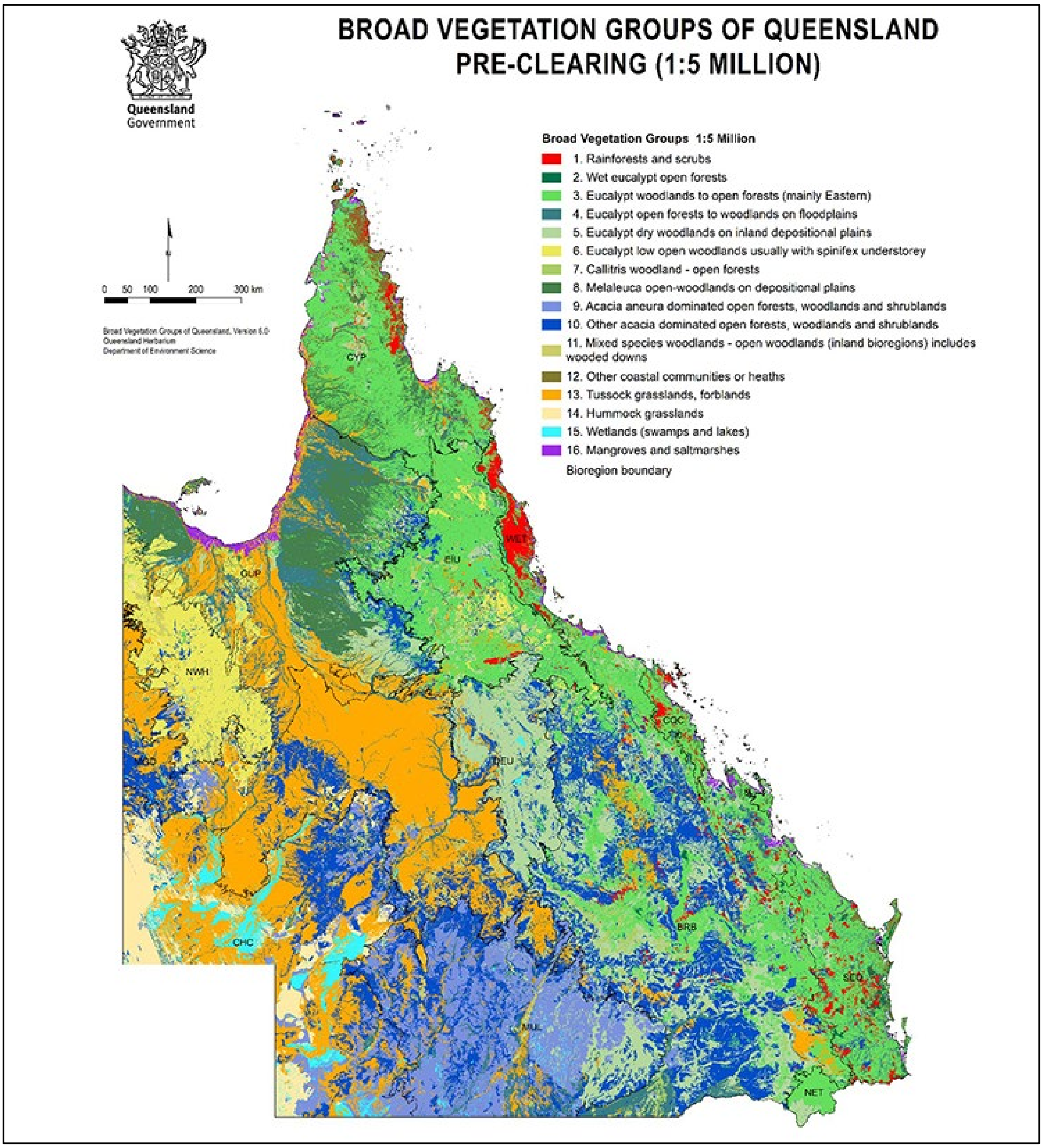


Table 19. Number of monitoring sites established per vegetation condition state across Central and Southwest Queensland grazing businesses.

Region	Condition state	Number of monitoring sites
Central Queensland	Brigalow remnant	8
	Brigalow old regrowth (> 15 years)	8
	Brigalow young regrowth (< 15 years)	6
	Brigalow cleared pastures AB grazing land condition	9
	Brigalow cleared pastures CD grazing land condition	0
	Brigalow Leucaena-grass pastures	5
	Subtotal	*36*
Southwest Queensland	Brigalow remnant	9
	Brigalow old regrowth (> 15 years)	0
	Brigalow young regrowth (< 15 years)	7
	Brigalow cleared pastures AB grazing land condition	4
	Brigalow cleared pastures CD grazing land condition	3
	Subtotal	*23*
	Soft Mulga remnant	8
	Soft Mulga selective fodder harvesting	6
	Soft Mulga regrowth (<15 years)	6
	Soft Mulga cleared pasture AB grazing land condition	4
	Soft Mulga cleared pasture CD grazing land condition	4
	Subtotal	*28*
Grand total		**87**

BioCondition assessments

Vegetation condition was assessed at each of the selected sites using the BioCondition assessment framework (Eyre et al. 2015). BioCondition defines vegetation condition as "...the relative capacity of a regional ecosystem to support the suite of species expected to occur in its reference state". The reference state refers to the natural variability in attributes of a regional ecosystem (RE) in a stable state that is mature and relatively long undisturbed in the contemporary landscape, also termed the 'Best-on-Offer' (BOO) condition.

The BioCondition framework sets out the procedures and standards by which condition for biodiversity can be assessed for a regional ecosystem in Queensland. It is a site-based, quantitative and repeatable assessment tool that provides a numeric score based on the assessment of 10 key site-level habitat and floristic attributes, and three landscape-level attributes known to be important to biodiversity (

Table **20**) relative to benchmark values specific to the regional ecosystem being assessed. The score can be summarised as a condition rating of one (good or functional condition) through to four (poor or dysfunctional condition) (Table 21). The methods used to assess each of the site-level condition attributes are detailed in Eyre et al. (2015) and summarised in Table 20 and Table 21. At each primary monitoring site, a 100 x 50 m BioCondition plot was marked out (Figure 22), the centre of which coincided with the centre of all biodiversity and grazing land assessments.

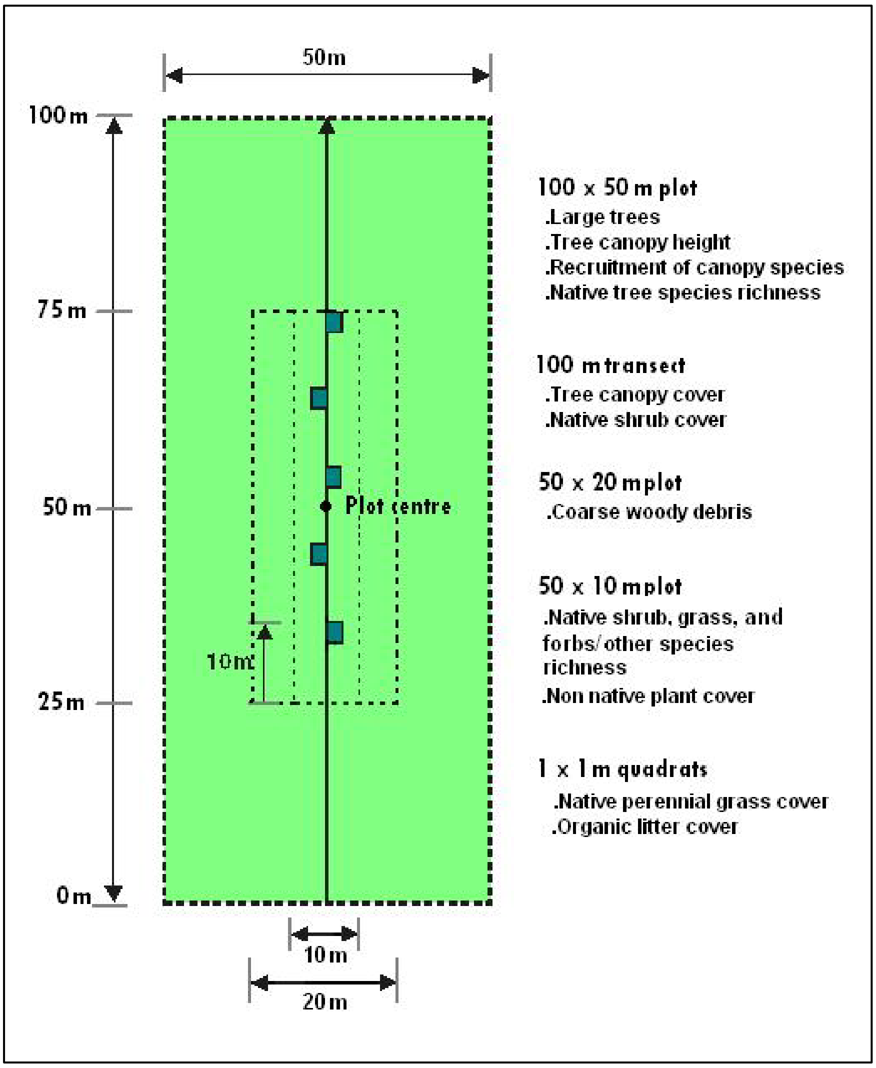
Table 20. The assessable attributes and weightings for deriving the final BioCondition score. Assessable attributes and weightings change in ecosystems where attributes are naturally absent (e.g., native grasslands).

	Attribute	**Weighting (%)**
Site based condition attributes	Large Trees	15
	Tree Canopy Height (m)	5
	Recruitment of canopy species	5
	Tree canopy cover (%)	5
	Shrub layer cover (%)	5
	Coarse woody debris	5
	Native plant species richness for four lifeforms (Trees, Shrubs, Grasses, Forbs & Others)	20
	Non-native plant cover (%)	10
	Native perennial grass cover (%)	5
	Litter cover (%)	5
Landscape attributes	Size of patch	10
	Context	5
	Connectivity	5
TOTAL		100

Table 21. BioCondition scores range from 0 to a maximum of 1 and can be further categorised as a rating of 1 (for 'functional' biodiversity condition) to 4 (for 'dysfunctional' biodiversity condition).

BioCondition rating	BioCondition score
1	>0.8
2	>0.6-0.8
3	0.4-0.59
4	<0.4

Figure 22. BioCondition plot layout



Floristic surveys

Flora life forms that were targeted for survey included trees, shrubs (woody plant that is multi-stemmed from the base or if single stemmed, usually less than 2 m tall), mistletoes, vines (woody), forbs (herbaceous species including rushes, creepers, trailers and non-woody climbers), grasses (Poaceae), sedges (Cyperaceae) and ferns (Table 22).

Ground floristics and attributes of ground cover were assessed within five 1 x 1 m subplots located along the centre transect. The cover (%) of each flora species identified within each subplot was recorded. The presence of all ground layer species were recorded within the 50 x 10 m subplot area. Shrub species within the 50 x 10 m subplot were identified and number of stems counted. All tree species were counted and recorded in the larger 100 x 50 m plot.

Table 22. Summary of the methods used to assess site-based BioCondition attributes

Attribute	Assessment method
Large trees	The number of large trees was assessed by counting the number of trees within the 100 x 50 m plot area over a certain diameter at breast height (dbh) size threshold, as recorded on the benchmark document for the RE being assessed.
Tree canopy height	Tree canopy height (measured to the top of the highest leaves) refers to the median canopy height in metres, estimated for the trees in the ecologically dominant layer (EDL) or canopy layer within the 100 x 50 m assessment area.
Recruitment of dominant canopy species	The recruitment attribute assesses the presence of regeneration of the dominant canopy species in the 100 x 50 m assessment area.
Tree canopy cover	Involves the estimation of the vertical projection of the tree canopy over the 100 m transect. If the community includes the presence of a distinct emergent or subcanopy layer, these layers are also assessed. In BioCondition, trees are defined as; Woody plants more than 2 m tall with a single stem or branches above the base.
Shrub layer cover	Involves the estimation of the vertical projection of the shrub canopy over the 100 m transect. In BioCondition, shrubs are defined as; Woody plant that is multi-stemmed from the base (or within 200 mm from ground level) or if single stemmed, less than 2 m tall.
Coarse woody debris	Coarse woody debris refers to logs or dead timber on the ground that is >10 cm diameter and >0.5 m in length (and more than 80% in contact with the ground). Assessment is conducted by measuring the length of all coarse woody debris to the boundary of the 50 x 20 m plot (i.e. 0.1 ha). The total measured value is multiplied by 10 for comparison with the benchmark which is a metre per ha value.
Native plant species richness by lifeform	Assessment is based on the number of native shrub, grass and forb/other species observed in the 50 x 10 m plot for each benchmarked life-form group. Native tree species richness is assessed over the 100 x 50 m plot. See Eyre et al. 2015a for a description of the life form groups.
Non-native plant cover	Non-native plant cover is the percentage cover of the total vegetation cover that is comprised of exotic and non-indigenous species, assessed within the 50 x 10 m sub-plot. Where there are non-native plants present in more than one layer, such as a grass in the ground layer and shrub in the shrub layer, then the cover in each layer is added together.
Native perennial grass cover	Perennial grass cover refers to the average percentage cover of native perennial grasses, assessed within each of the five 1 x 1 m quadrats and averaged to give a value for the site.
Litter cover	Litter is defined as including both fine and coarse organic material such as fallen leaves, twigs and branches <10 cm diameter. Organic litter cover refers to the average percentage cover assessed within each of the five 1 x 1 m quadrats.

Bird surveys

At each site, diurnal bird surveys were conducted within a 100 m x 100 m quadrat, using the method outlined in Eyre et al. (2022). Birds were sampled over a four- to six-day survey period, where birds were sampled in six, 5-min counts per quadrat; twice during the 'early morning' (<2 h after sunrise), twice during the 'late morning' (between 2- and 4-h after sunrise) and twice during 'other' times of the day (between 4-h after sunrise and 2-h before sunset). Surveys were conducted on different days by one observer on fine, calm days. Only birds seen or heard within the quadrat were counted. Birds flying over the quadrat were excluded, unless they are observed to be actively hawking or foraging within the quadrat.

Camera trapping

On central Queensland properties, five camera traps were deployed at each site for a duration of 14 nights over a single survey period. The five cameras took three photographs per trigger, with no interval (reset period) between the triggers, and camera sensitivity set to normal. Each of the five cameras was set to target different mammal groups, as follows:

1. One wide-angle camera to target medium to large mammals, including feral predators was set up per site. The camera was placed approximately 30 – 50 cm high on a tree, facing the bait with a slight downward angle. The bait, peanut butter and oats in a canister and a chicken wing, was set up approximately 5 m in front of the camera as per Eyre et al. (2022). FeralMone®, an attractant to aid with detection of foxes, cats and wild dogs, was also sprayed near the bait. This camera was set to take photographs 24 hours per day.

2. Two white-flash close-up LED cameras to target small to medium-sized mammals. These cameras have a custom focal distance of 75cm and were placed approximately 30 cm high on a tree with a standard bait mixture of peanut butter and oats in a plastic canister secured in front. This setup provided colour night-time images that aided the identification of small mammals. These cameras were set to record images from dusk until dawn, in order to target the activity period of small mammals.

3. Two infrared-flash close-up cameras to target small to medium mammals. These cameras also had a custom focal distance of 75cm and were setup as per the close-up white flash cameras to record images from dusk until dawn.

Images of fauna captured by the cameras were identified by experienced personnel to species level, when possible, and to species groups (e.g., small mammal species) when definite identification could not be made due to poor image quality or definitive features not being visible in photograph/s.

4.4.2.2 Results for flora and fauna sampling

Central Queensland
More than 10,000 flora observations were recorded in brigalow dominated RE, representing 76 native forb species and other lifeforms, 32 native grass species, 33 native shrub species and 39 native tree species. Of the 180 native flora species observed, 179 native species were listed as 'least concern' under the Queensland's *Nature Conservation Act 1992* (NC Act). Species richness ranged from 65 to 106 native flora species per grazing business (Appendix 9.20). As anticipated, average BioCondition score declined in the order of old regrowth, young regrowth and pasture; relative to remnant vegetation (Figure 23). Under the BioCondition Framework, grazing businesses were actively maintaining remnant vegetation in moderate (BioCondition score 0.4-0.59) to very good condition (BioCondition score >0.8). Due to fragmentation of the habitat, landscape scale attributes (i.e., patch size, context and/or connectivity) moderated the BioCondition scores by reducing the site scale score by between 8–16% at six of the seven remnant brigalow dominated sites measured.

More than 7,500 fauna observations were recorded in brigalow dominated RE; representing 113 native bird species and 14 native mammal species. Of the 127 native species observed, 125 were listed as 'least concern' under the NC Act. Eighty-six percent (n=14) of flora and fauna species listed under the NC Act occurred in remnant and old regrowth condition states. Native birds dominated fauna species richness; which ranged from 78 to 82 native fauna species per grazing business (Appendix 9.21). Native bird species richness was highest in remnant vegetation and followed a similar pattern to the decline observed in BioCondition score and native flora species richness, across the various condition states measured (Figure 23, Figure 24 and Figure 25). As anticipated, reduced native mammal species richness was observed in pasture compared with remnant vegetation (Figure 25). The number of unidentified canines and feral mammal species (i.e., mice, hares, cats, foxes and pigs) observed did not differ between habitats (Figure 25).

Figure 23. Average BioCondition score (±StDEV), and average BioCondition score excluding landscape attributes, across different condition states measured in Brigalow dominated regional ecosystems on several central Queensland grazing properties.

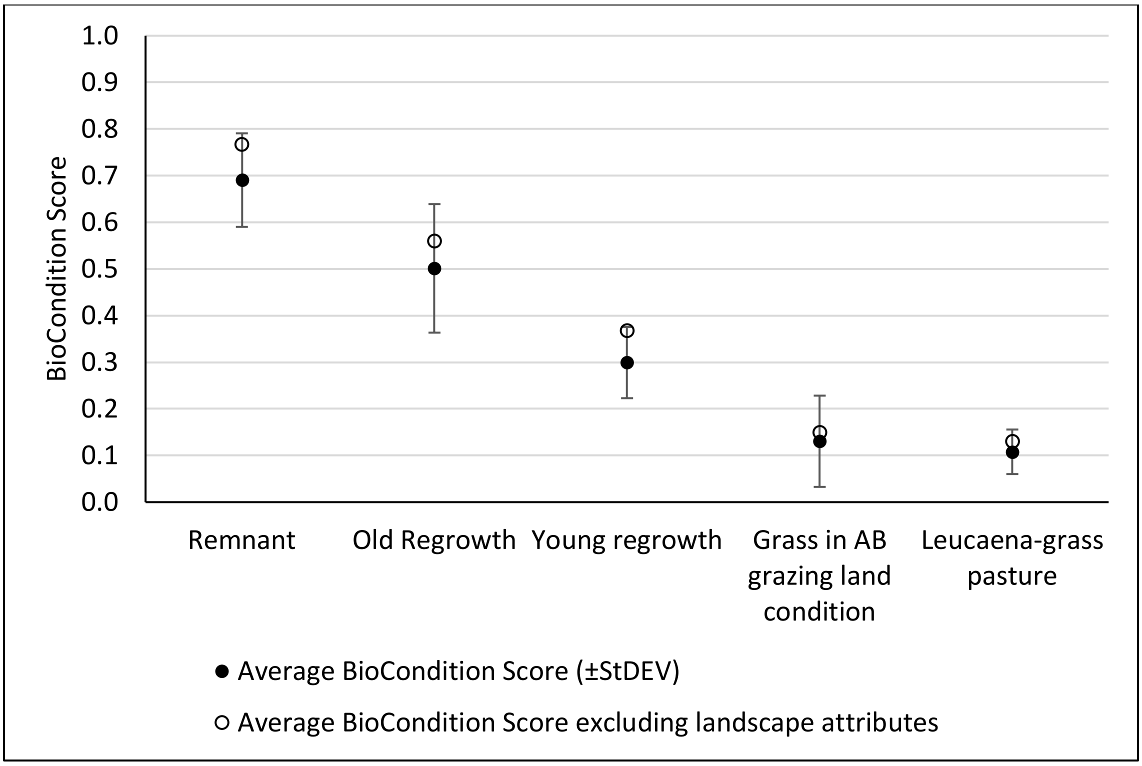


Figure 24. Average flora species richness (±StDEV) across different condition states measured in Brigalow dominated regional ecosystems on several central Queensland grazing properties. Note that species richness does not infer abundance.

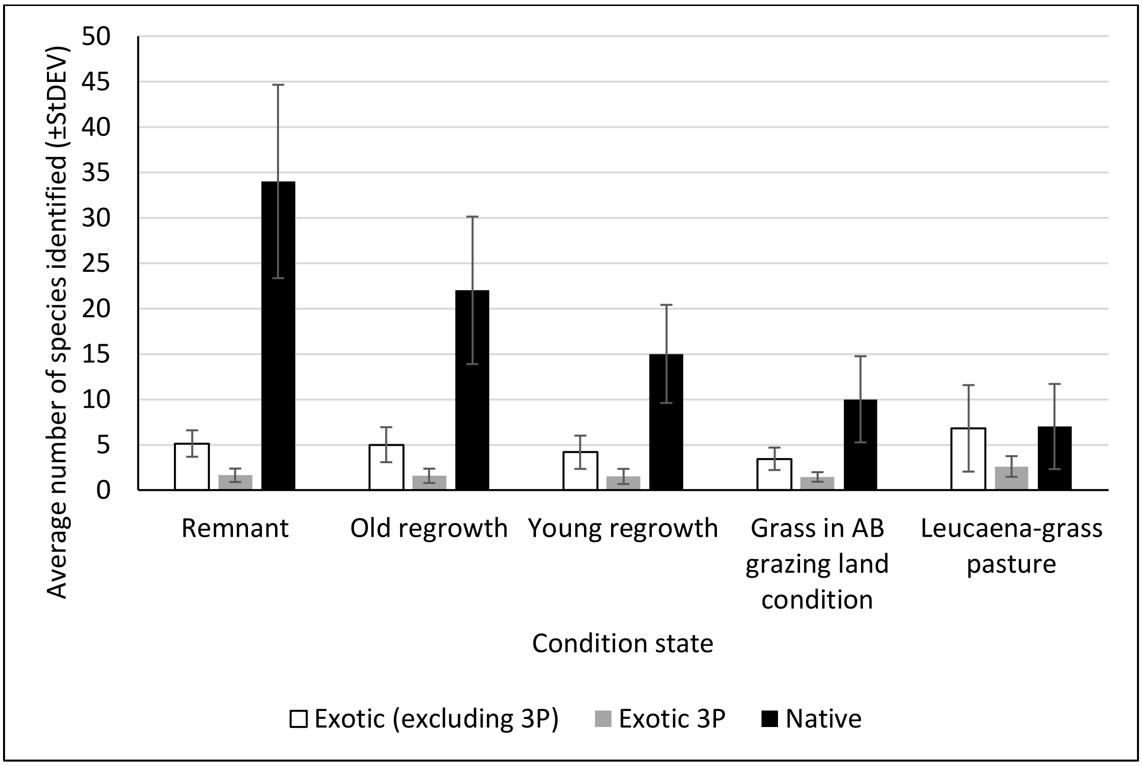
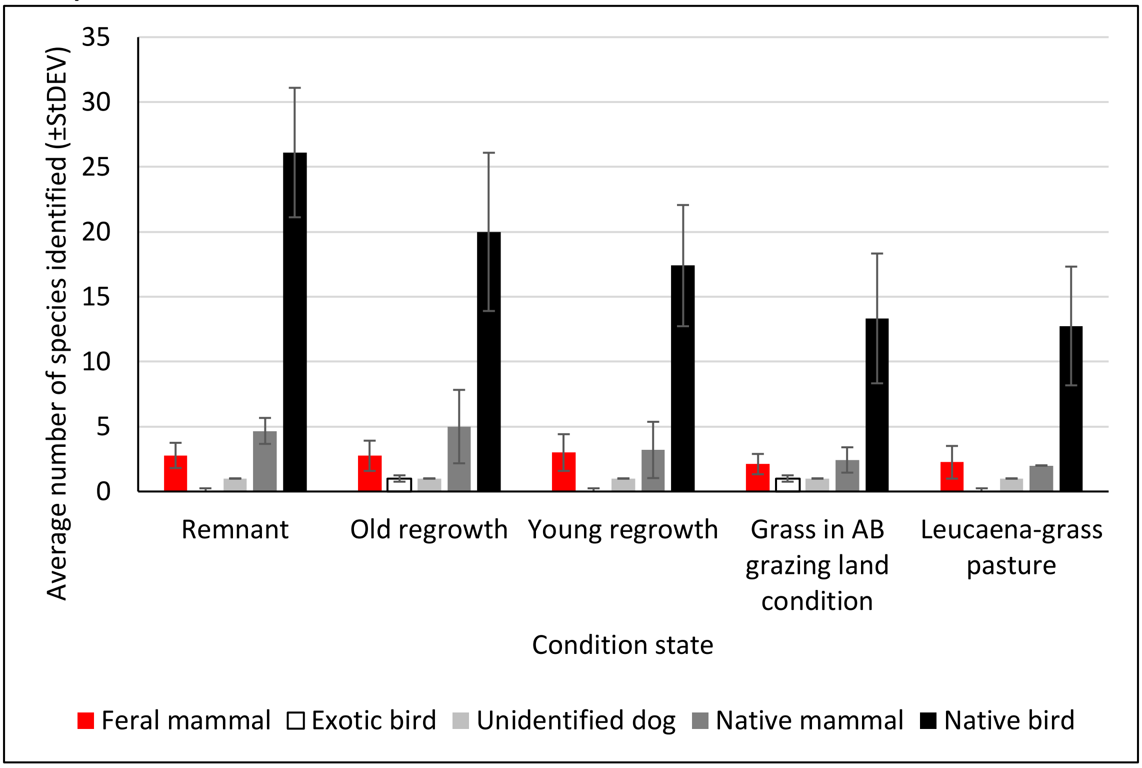


Figure 25. Average fauna species richness (±StDEV) across different condition states measured in Brigalow dominated regional ecosystems on several central Queensland grazing properties. Note that species richness does not infer abundance.



Southwest Queensland

More than 10,000 flora observations were recorded in Brigalow and mulga dominated REs, representing 95 native forb species and other lifeforms, 54 native grass species, 33 native shrub species and 32 native tree species. Of the 214 native flora species observed, 213 species were listed as 'least concern' under the *Nature Conservation Act 1992*. Species richness ranged from 84 to 141 native flora species per grazing business (Appendix 9.23). As anticipated, average BioCondition score declined in the order of selective fodder harvesting (for mulga REs), young regrowth and grass pasture; relative to remnant vegetation (Figure 26 and Figure 30). Under the BioCondition Framework, grazing businesses were actively maintaining remnant vegetation in good (BioCondition score >0.6-0.8) to excellent condition (BioCondition score >0.8). Landscape scale attributes reduced site BioCondition scores by between 7–13% at eight of the 17 remnant sites measured.

More than 2,000 bird observations were recorded in Brigalow and mulga dominated RE; representing 96 native bird species. Of these, 95 native bird species were listed as 'least concern' under the *Nature Conservation Act 1992*. Observations of flora and fauna with an elevated conservation status (n=2) occurred in remnant vegetation. Bird species richness ranged from 45 to 78 native bird species per grazing business (Appendix 9.24). There did not appear to be a difference in bird species richness or abundance across the different condition states measured in brigalow dominated REs. In mulga dominated REs, bird species richness and abundance was lower at pasture sites relative to remnant vegetation (Figure 28, Figure 29, Figure 32 and Figure 33).

Figure 26. Average BioCondition score (±StDEV), and average BioCondition score excluding landscape attributes, across different condition states measured in Brigalow dominated regional ecosystems on several Southwest Queensland grazing properties.

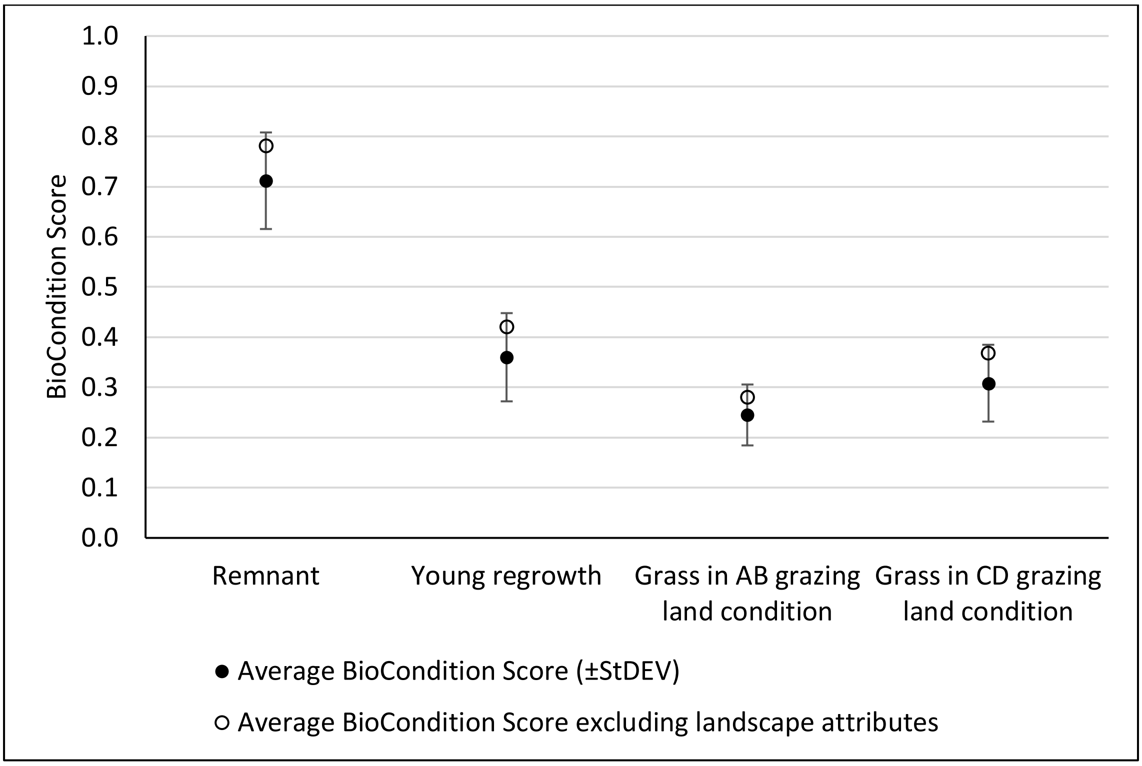


Figure 27. Average flora species richness (±StDEV) across different condition states measured in Brigalow dominated regional ecosystems on several Southwest Queensland grazing properties. Note that species richness does not infer abundance.

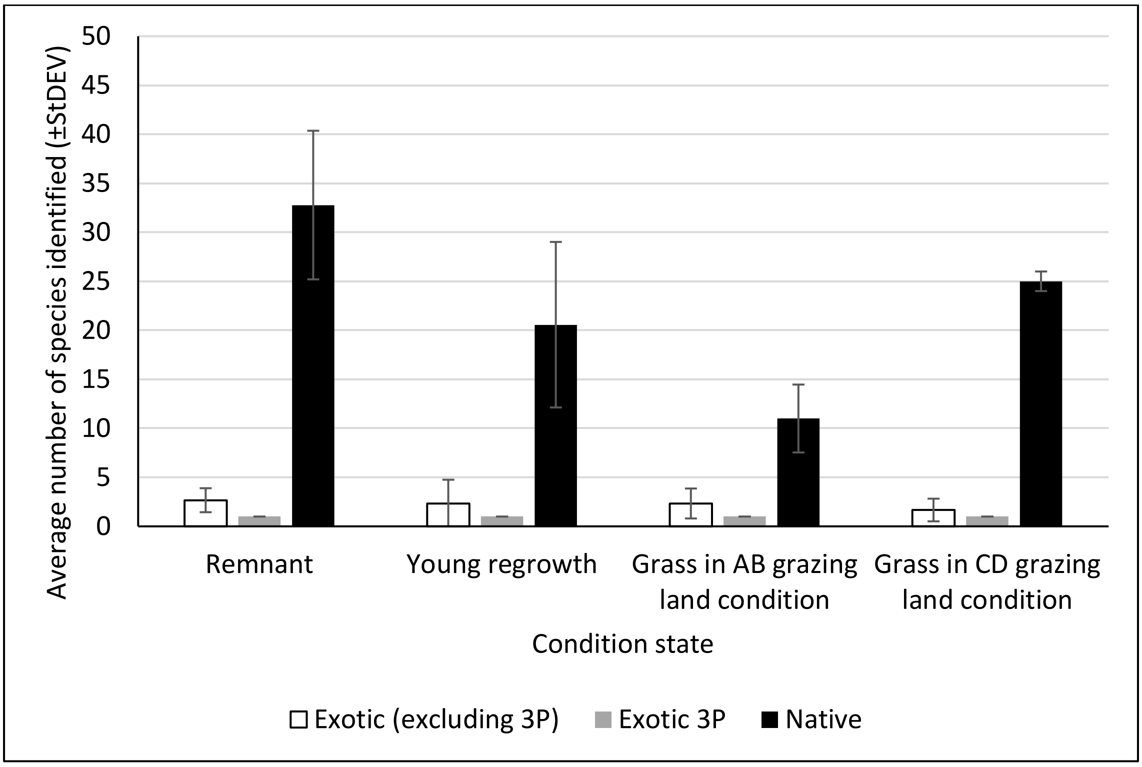


Figure 28. Average bird species richness (±StDEV) across different condition states measured in Brigalow dominated regional ecosystems on several Southwest Queensland grazing properties. Note that species richness does not infer abundance.

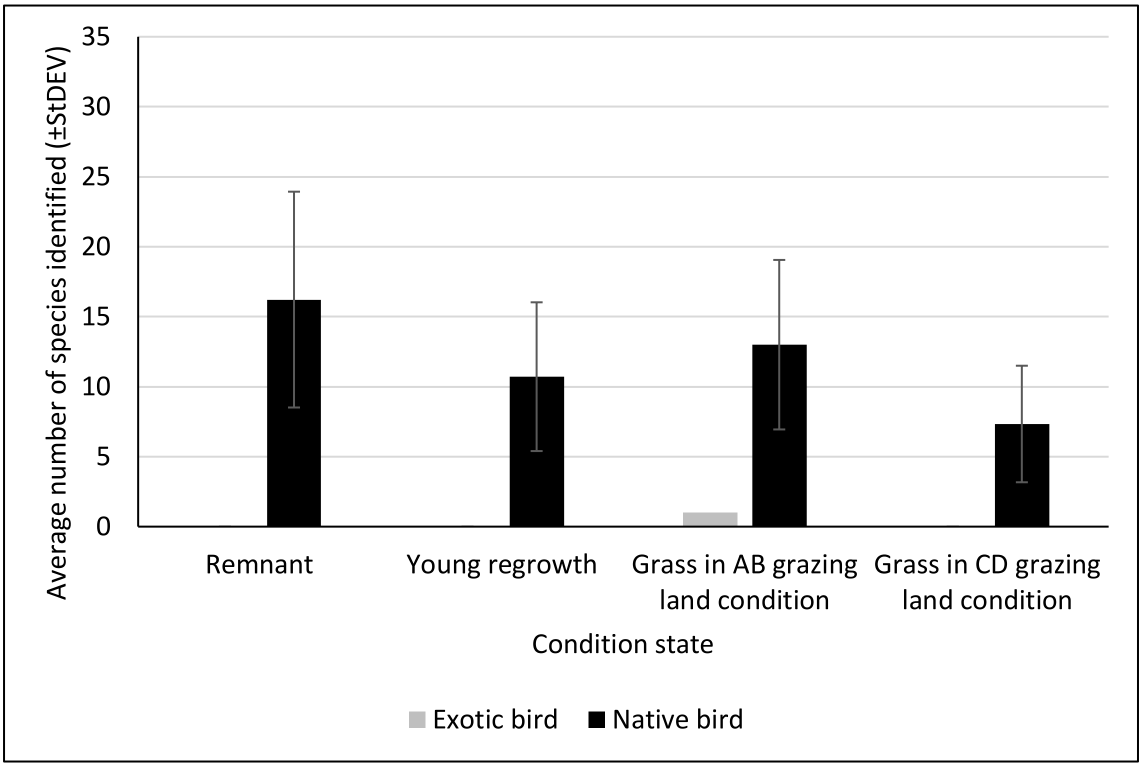


Figure 29. Average bird abundance (±StDEV) in Brigalow dominated regional ecosystems on several Southwest Queensland grazing properties.

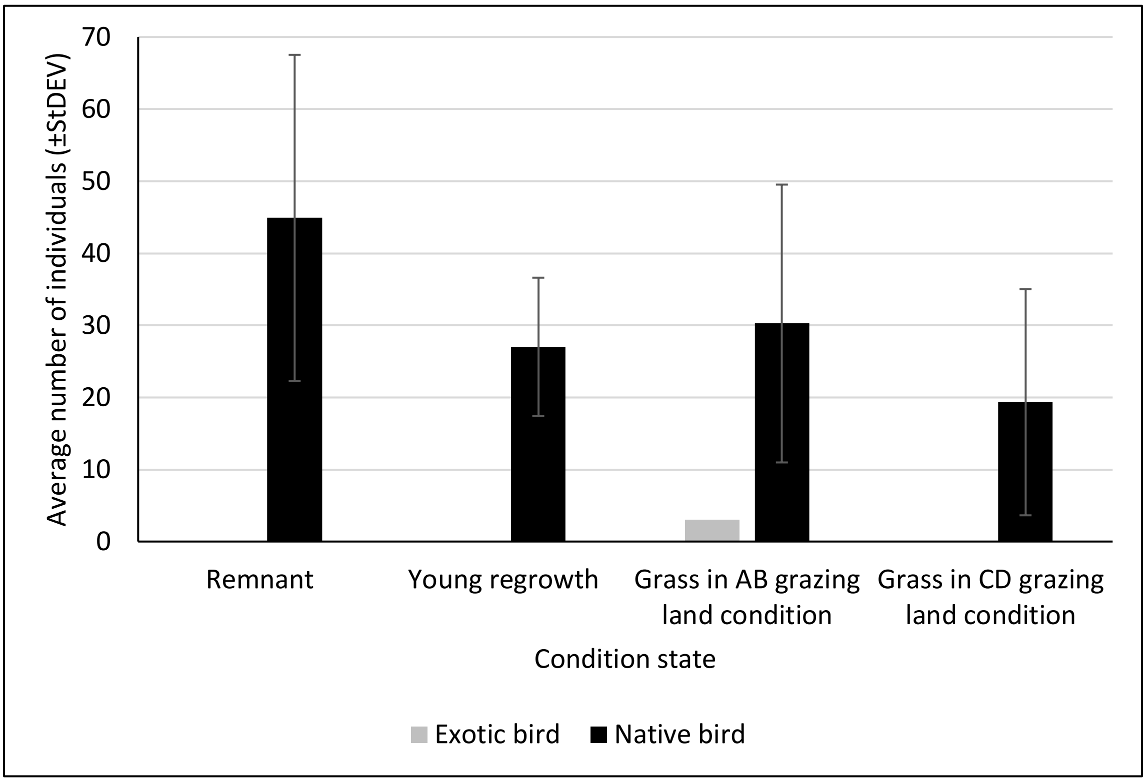


Figure 30. Average BioCondition score (±StDEV), and average BioCondition score excluding landscape attributes, across different condition states measured in mulga dominated regional ecosystems on several Southwest Queensland grazing properties.

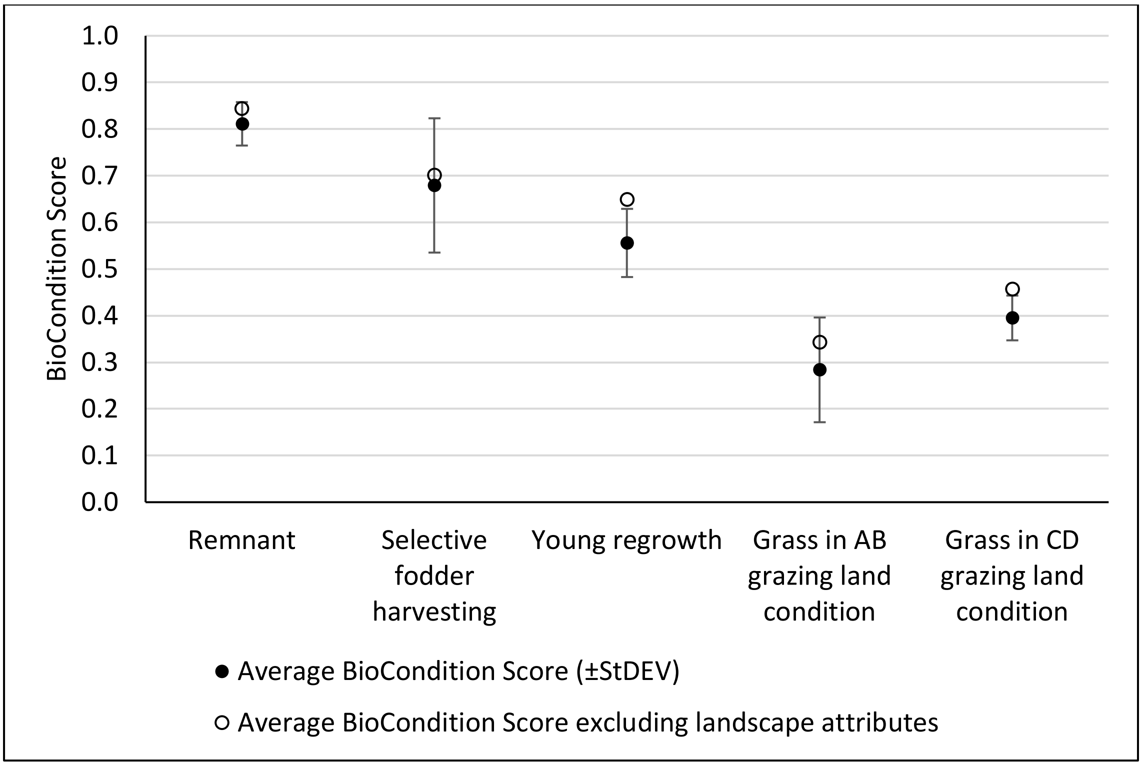


Figure 31. Average flora species richness (±StDEV) across different condition states measured in mulga dominated regional ecosystems on several Southwest Queensland grazing properties.

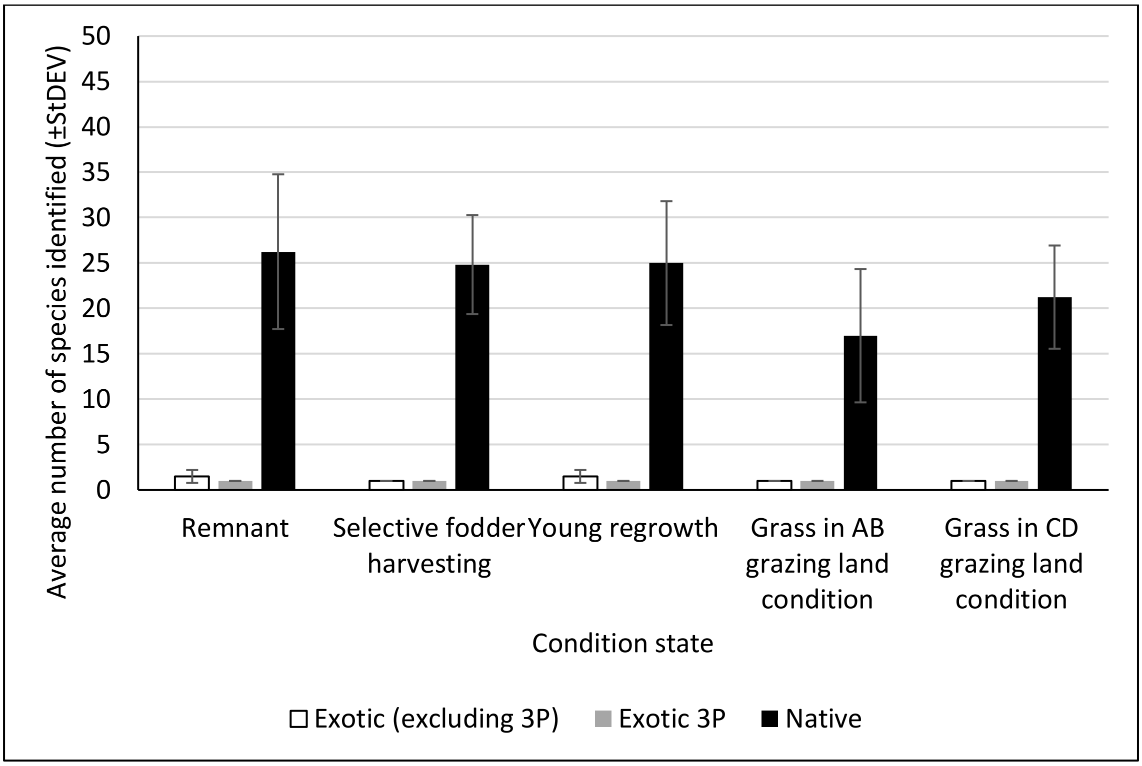


Figure 32. Average bird species richness (±StDEV) across different condition states measured in mulga dominated regional ecosystems on several Southwest Queensland grazing properties.

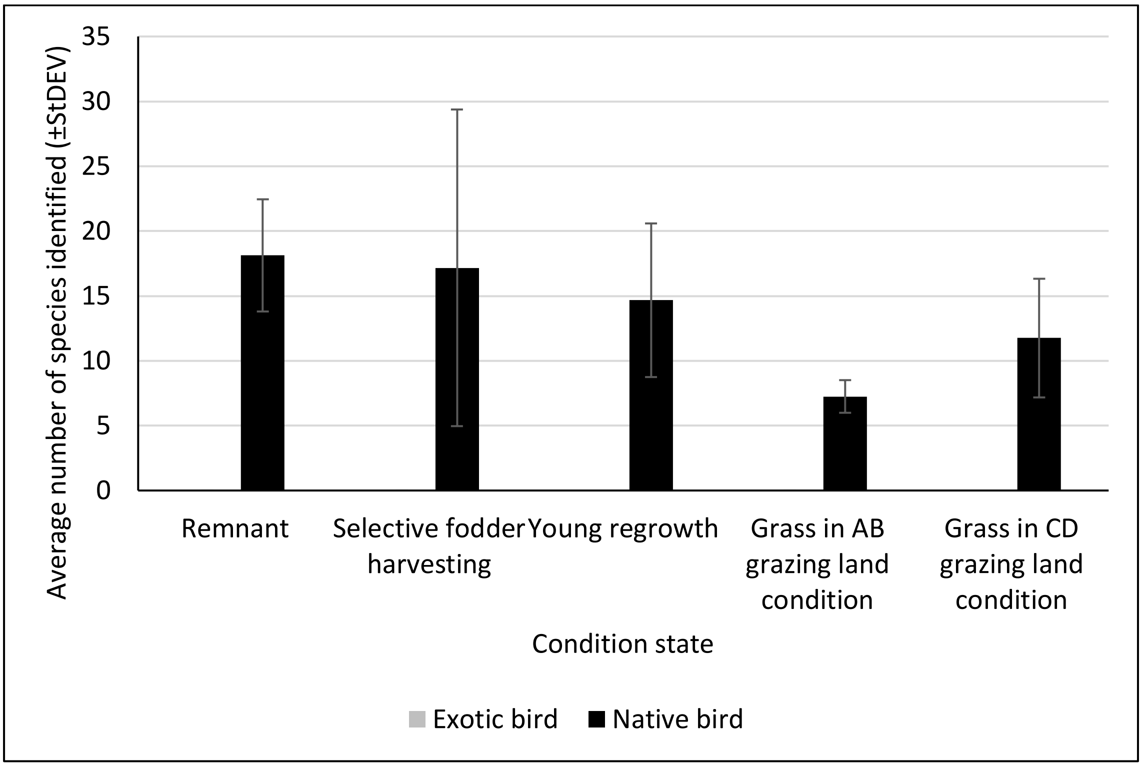
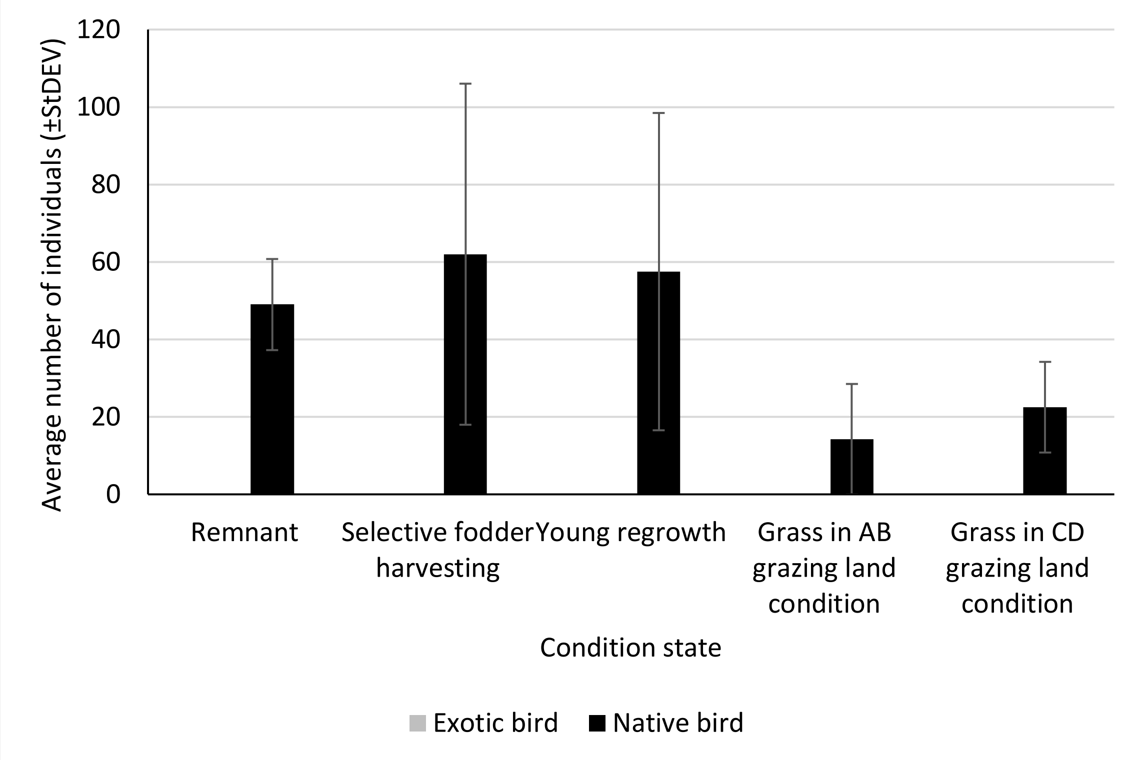


Figure 33. Average bird abundance (±StDEV) in mulga dominated regional ecosystems on several Southwest Queensland grazing properties.



4.4.2.3 Spatial BioCondition pilot project

The Department of Environment, Science and Innovation (DESI) is working to create a map of vegetation condition for Queensland, known as Spatial BioCondition (SBC), for all tenures and all terrestrial vegetation types. SBC is a collaboration between the Queensland Herbarium and Biodiversity Sciences and Remote Sensing Sciences business units of the Queensland Department of Environment, Science and Innovation and the Joint Remote Sensing Research Program. Spatial BioCondition is a modelling framework that relies on three types of data: the state-wide pre-clear regional ecosystem mapping; state-wide, high resolution remote sensing datasets; and data from many field sites which have been scored between 0 (poor condition for biodiversity) and 100 (highly functional condition for biodiversity) using the BioCondition assessment framework. Model outputs are designed to provide maps comprising a 30m grid of vegetation condition score which can be interpreted at a range of scales. The inherent limitations of predictive models using remote sensing means that SBC predictions are indicative of broad patterns of vegetation condition and care must be taken interpreting the results at a property or finer scale.

Project progress

Field site data collected, collated and stored by the Queensland Herbarium and Biodiversity Sciences, as well as contributions from external organisations yielded 45,877 field sites which were assessed for accuracy. The quantity and quality of training data was found to significantly influence the accuracy and value of the SBC model output; with data from only 24,072 field sites deemed suitable to train and verify the SBC model. As of July 2023, central Queensland field data collected as part of the M2M project had been incorporated into the SBC model, with data from 37 of the 38 sites deemed suitable. Southwest Queensland field data had been entered into the Queensland Herbarium and Biodiversity Sciences database and will be assessed and incorporated in the next SBC model output.

The SBC model has since been found to be systematic and repeatable: comparison of BioCondition scores for 235 independent field sites (in the Brigalow Belt and Southeast Queensland bioregions) with model predictions yielded an R^2 value of 0.68 and a mean absolute error of 12.91, indicating that the model explains about 70% of the variation in BioCondition. The current version of SBC – Spatial BioCondition of Queensland 2019- Demonstration version 1.0 – provides condition predictions for the year 2019 for the Southeast Queensland and Brigalow Belt bioregions only. These were published to Qspatial on the 7th of September 2023 (Figure 34).

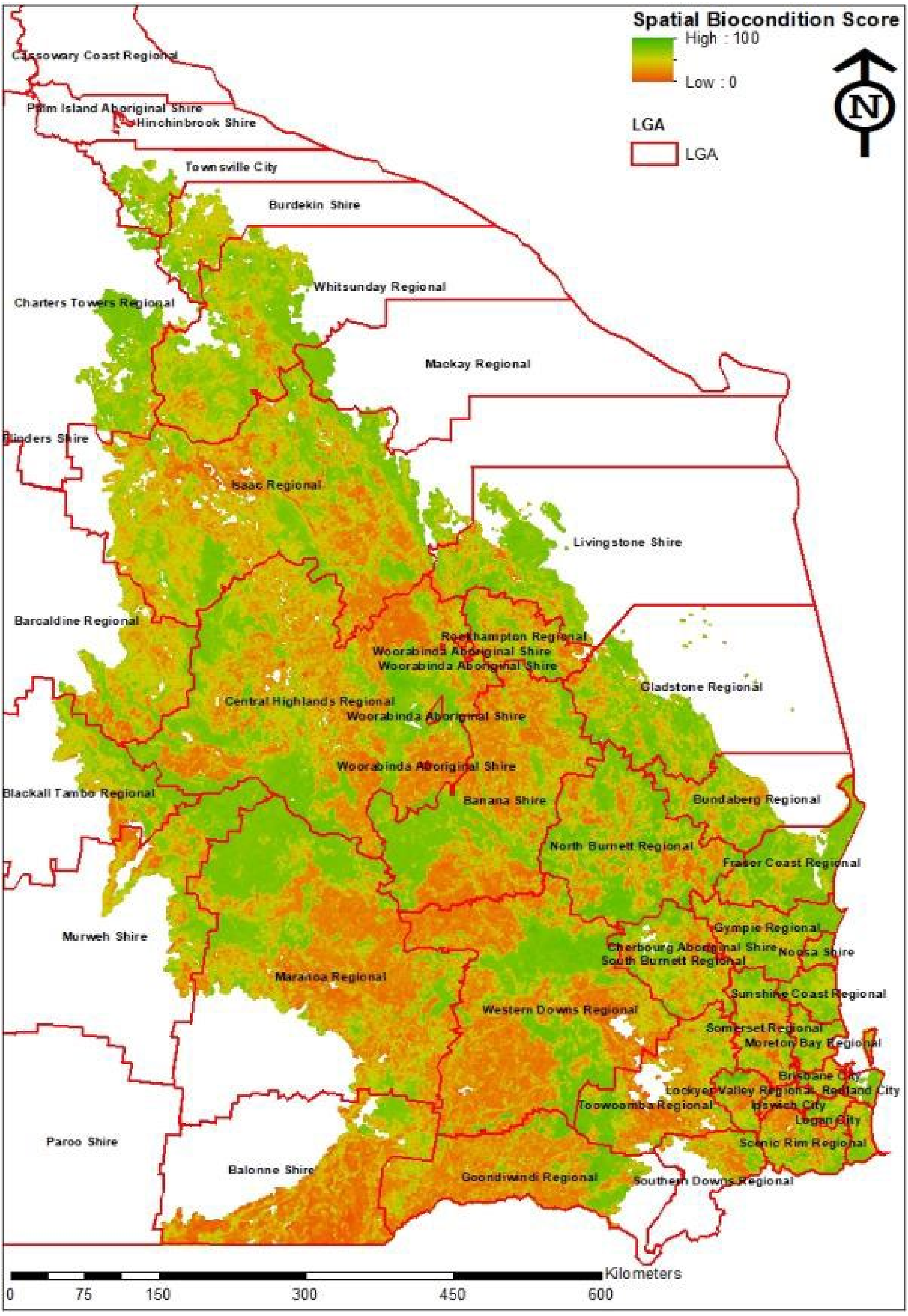
Limitations of Spatial BioCondition

Spatial BioCondition is intended to be used for regional applications. It may be used at a more localised scale but is likely to have some limitations at some locations as it shares the limitations of its remote sensing input datasets. These include: resolution, detectability and currency for remote sensing inputs; scale and heterogeneity for regional ecosystem mapping; volume, quality and currency for site training data. Some important BioCondition attributes (such as weed cover, species diversity, large trees or fallen woody debris) are either currently not measurable or are difficult to detect using remote sensing at the scale required. Currently, no predictions or mapping are provided for:

- regional ecosystems with insufficient training data to apply the framework;
- marine, intertidal, native grassland and predominantly unvegetated ecosystems; and
- urban, suburban, commercial, and industrial areas.

The Spatial BioCondition project team are currently working on expanding Spatial BioCondition to include other bioregions and investigating ways to incorporate habitat context and connectivity into the framework. This will likely be important for valuing regrowth retention to improve carbon and biodiversity as discussed in section 4.3.2 above. The collaboration between M2M and the DESI Spatial BioCondition team has influenced the priority for progression of this task.

Figure 34. Spatial BioCondition scores for the Brigalow Belt and South-East Regions. Higher values represent better ecological health and biodiversity value.



4.4.2.4 The Australian Farm Biodiversity Certification Scheme

The Australian Farm Biodiversity Certification Scheme (AFBCS) was initiated by the Australian Government in 2021 as part of the Agriculture Biodiversity Stewardship Package. The original vision for the AFBCS was that it would be a voluntary scheme that would provide farms and farm business with the opportunity to be certified as ‘biodiversity friendly’. This was intended to generate environmental benefits through improved biodiversity stewardship, while providing benefits to participating landholders through securing access to markets, improving access to capital and potentially allowing producers to obtain price premiums for products from certified farms.

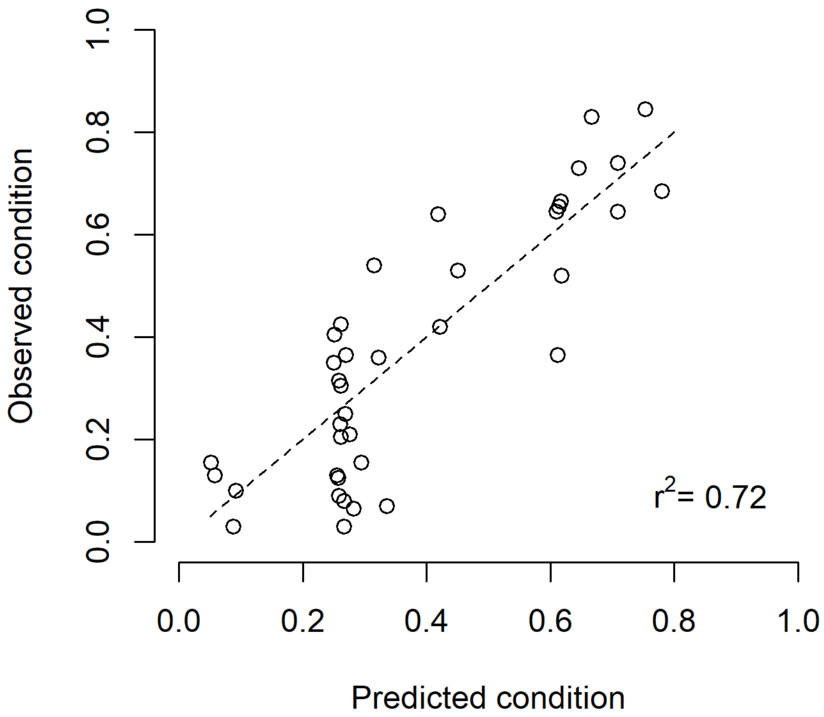
The draft Standard authored by Australian National University (ANU) relies on the use of a Biodiversity Condition Scoring method to undertake a rapid initial gateway assessment. This assessment compares the condition of vegetation for biodiversity on the applicant property to the average condition for biodiversity on similar properties in the surrounding natural resource management (NRM) region. Farms that pass the initial gateway assessment proceed to a second phase that involves a site assessment by an accredited assessor, the development and agreement on a management plan, and a commitment to maintain or improve on-ground biodiversity condition over time to retain certification.

The draft Standard envisages that three levels of certification will be offered:

1. Gold level certification for properties with a biodiversity condition score equal or above the regional benchmark, and a commitment by owners to improving biodiversity condition.
2. Green level certification for properties with a biodiversity condition score equal or above the regional benchmark by owners who commit to maintaining biodiversity condition.
3. Provisional certification for properties who do not quite meet their regional benchmark, but whose owners commit to undertaking specific activities to improve biodiversity condition within a specified timeframe.

As of July 2023, central Queensland BioCondition field data collected as part of the M2M project had been compared with the AFBCS biodiversity condition model, yielding promising results (Figure 35). Development of the AFBCS was paused following the change of government in May 2022. Since the announcement of the new Nature Repair Market, further consideration is being given to progressing the AFBCS.

Figure 35. Regression of BioCondition field data collected across different condition states in Brigalow dominated regional ecosystems of central Queensland grazing properties and biodiversity condition predicted by the Australian Farm Biodiversity Certification Scheme model.



4.4.3 On-farm pasture surveys to support the development of remote sensing products

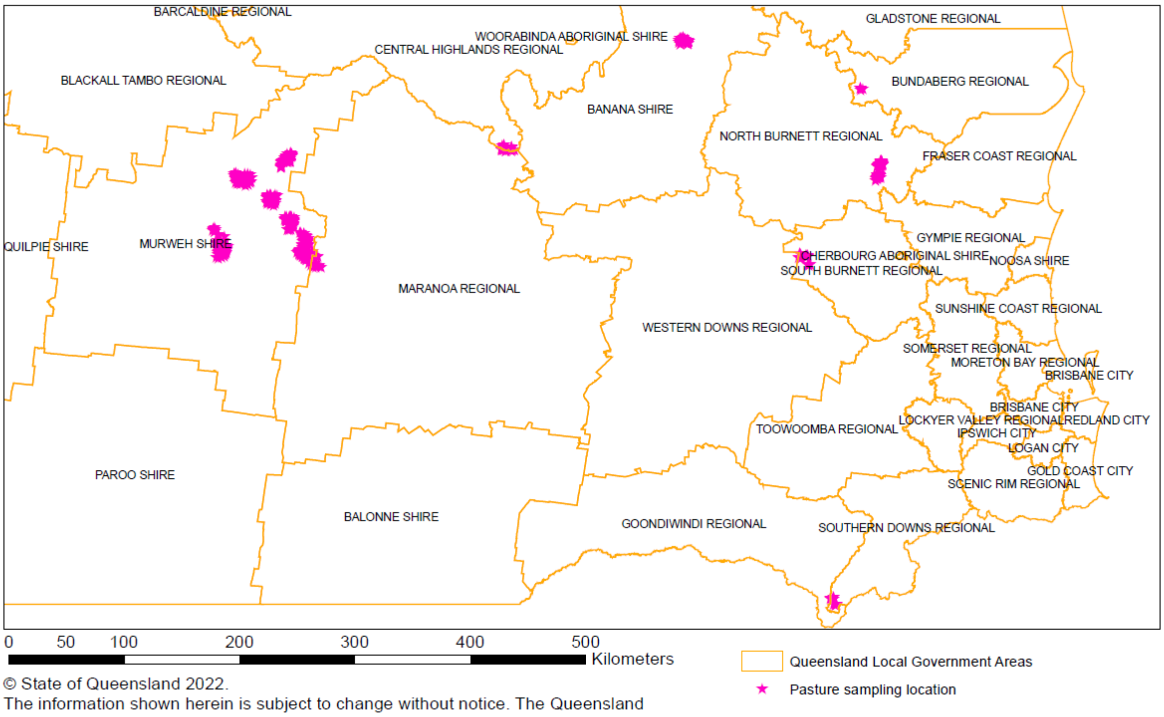
Pasture biomass represents a base performance indicator to beef production and can be used as an indicator of land condition and grazing management. It also represents a significant volume of carbon that is otherwise excluded from the national carbon balance of grazing systems due to its variability and high rate of turnover. The development of accurate pasture biomass models presents the opportunity to demonstrate conservative management styles for ecological, carbon and production benefits. CIBO Labs has been improving the accuracy of the Sentinel-2 derived model to deliver a highly accurate, 5-day pasture estimation across Australia enabling the quantification of long-term pasture management down to a 10 m resolution.

4.4.3.1 Methods and results for pasture biomass

To improve remote predictions of pasture biomass in cleared, uncleared and regrowth situations alike, 675 pasture transects were assessed by DAF staff across 22 grazing properties and two neighbouring national parks (Figure 36 and Table 23). The team used the Cibo Labs 'Pasture Biomass Collector' application, a relatively simple and reliable tool for collecting and submitting estimates of pasture biomass and composition which can be used by the public, including livestock producers. Data collected within the application included a GPS location and photograph for each transect and quadrat; estimates of total standing dry matter for each quadrat; and the dominant, co-dominant and sub dominant pasture species, % unpalatable species, % unpalatable 3P species, % average dry matter and % average green fraction across the length of each transect. All records were stored in, and could be easily downloaded from, the Cibo Labs online database as line features (transect data) and point data (quadrat data). The method Cibo Labs use to calculate average total standing dry matter for each transect is described in Figure 37.

While crowd sourced data is generally sampled in open pasture, the team used a stratified approach that encompassed a range of broad vegetation groups, woody cover (Figure 38) and pasture yields (Figure 39). Data were collected over the life of the project, encompassing years where participating properties experienced above and below average rainfall, helping to tease out seasonal differences in pasture production across different broad vegetation groups and condition states.

Figure 36. Location of pasture biomass assessments across Central, Southwest and Southern Queensland.



© State of Queensland 2022.
The information shown herein is subject to change without notice. The Queensland Government shall not be liable for technical or other errors or omissions contained herein. The reader/user accepts all risks and responsibility for losses, damages, costs and other consequences resulting directly or indirectly from using this information.
Property boundaries are shown as a locational aid only and do not represent legal cadastral boundaries. Datum GCS_GDA_1994.

Figure 37. Outline of a pasture monitoring site showing the method used by Cibo Labs for estimating total standing dry matter. Sites needed to be uniform and free from disturbance for at least 20m in any direction.

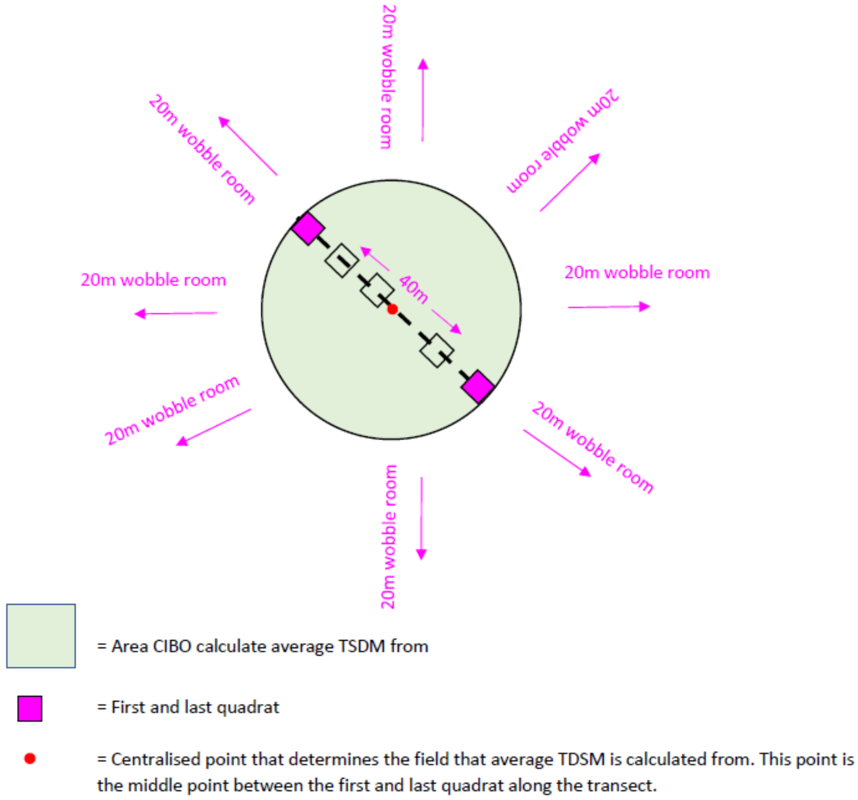


Figure 38. Foliage projective cover by pre-clearing broad vegetation groups of pasture transects.

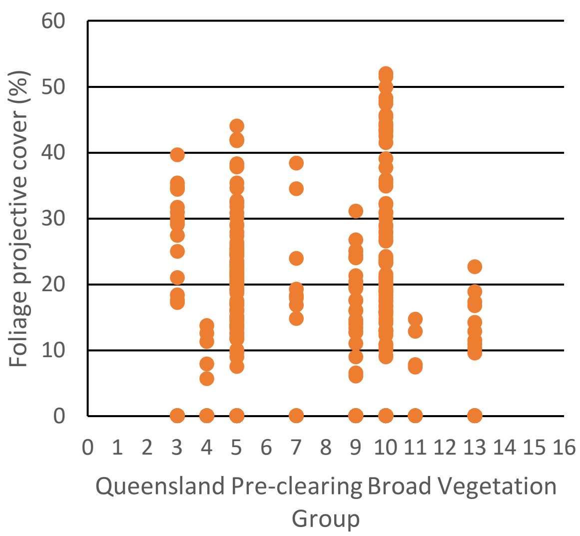


Figure 39. Average total standing dry matter of pasture transects.

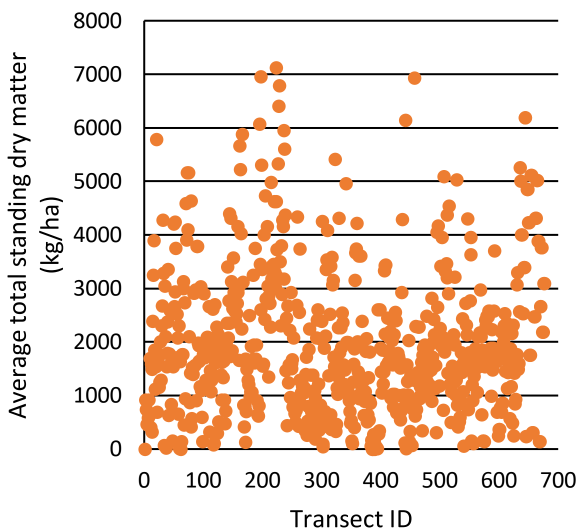


Table 23. Number of pasture biomass transects, quadrats and pre-clearing broad vegetation groups assessed on 22 de-identified properties, and two national parks across Central, Southwest and Southern Queensland.

			Pre-clearing Broad vegetation group[1]							
Region and property ID	Number of transects assessed	Number of quadrats assessed	3	4	5	7	9	10	11	13
Central Queensland	**203**	**1868**	**32**	**1**	**94**			**68**		**8**
1	1	10	1							
2	20	181	2		2			16		
3	26	261	22	1	3					
4	4	37	2					2		
5	49	478			49					
6	6	54						6		
7	5	50	5							
8	14	127			2			12		
9	12	110						12		
National Park 1	4	36						4		
10	6	54						6		
11	10	92						10		
12	46	378			38					8
Southwest Queensland	**17**	**169**	**5**	**16**	**95**	**17**	**79**	**186**	**11**	**46**
13	9	89			7			46		
14	8	80			3		25	27		11
National Park 2	455	3623			15	4	2	2		
15	53	491		1				3	1	6
16	66	475	1		4	5	1	4		
17	23	190		11			14	43		
18	11	110		4				16	10	22
19	15	150	1		51		21	13		7
20	68	544	3		15	8	16	32		
Southern Queensland	**52**	**408**			**17**					
21	93	708			9					
22	74	547			8					
Grand Total	**675**	**5660**	**37**	**17**	**206**	**17**	**79**	**254**	**11**	**54**

[1] See figure 21 for definitions of Queensland's pre-clearing broad vegetation groups.

The improved accuracy for pasture biomass which incorporated the M2M assessments is outlined in Table 24. As could be expected, errors are most significant at the extremities of the total standing dry matter (TDSM) categories, indicated by the Mean Absolute Percentage Error (MAPE). For practical stocking rate management, this is unlikely to be significant (due to area size and the management strategies for those areas), however it may present as a constraint to carbon stock estimations in some regions.

Table 24. The cross-validation metrics for selected TDSM ranges of the pasture biomass model. Metrics selected for accuracy are mean error, standard deviation (StDev), root mean square error (RMSE), mean absolute error (MAE) and mean absolute percentage error (MAPE).

TSDM range	Mean Error (kg/ha)	StDev Error (kg/ha)	RMSE (kg/ha)	MAE (kg/ha)	MAPE (%)
0 - 1000	287	543	618	184	90.5
1000 - 2000	35	563	564	235	25.7
2000 - 3000	268	735	783	453	24.0
3000 - 4000	618	892	1085	637	24.3
4000 - 6000	1218	1193	1705	1073	27.9
6000 - 10000	2404	1915	3074	2263	35.1

Limitations in improving the accuracy arise from a variety of sources, but predominantly in the fundamentals of the model. Various types of pasture data are collected (pasture cuts, plate meter samples and visual estimates) with varying accuracy to increase training and validation dataset size. The model cannot exceed the accuracy of the training data which poses a significant constraint as improving on-ground data collection accuracy is time intensive and expensive. Improvements in training data distribution is on-going as "blind-spots" with relatively few training data points are being filled with client-collected data. This is likely to be highly targeted as client uptake increases and feedback often occurs where estimations are the least accurate.

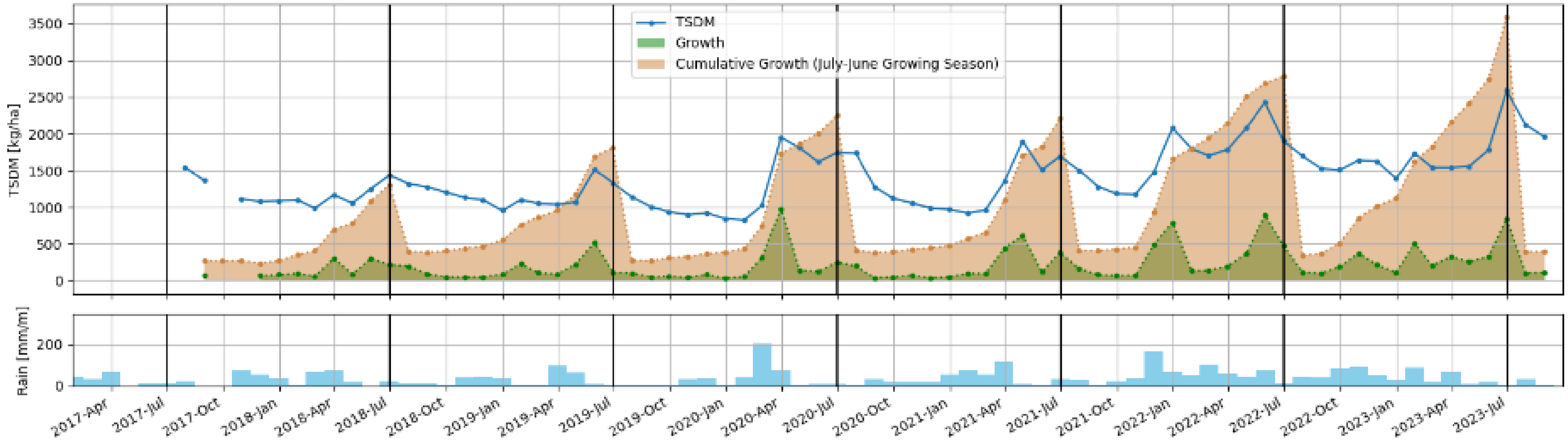
4.4.3.2 CIBO Labs product improvement through collaboration

The following CIBO Labs product developments were supported through contribution of funds by CIBO Labs and DAF through the M2M project.

Pasture Biomass Production Model:
The biomass production model has also been developed as an indicator of land condition and productivity. Figure 40 displays biomass production over a six-year period from 2017-2023 on a project contributing property. Advantages in the availability of this model lie in the provision of additional data for pasture management decisions such as pasture recovery and availability, and typical "green" dates indicating the start of the growth season. Applications for the development of feed-use efficiency metrics may also be beneficial to producers looking to fine-tune their grazing management which would improve emissions intensity. From a carbon perspective, the addition of biomass production allows for the identification of minimum carbon stocks in pastures at any one time as well as the "cycling" carbon present in the fluctuation of standing dry matter.

Although this data has typically been employed for improving data driven management decisions for stocking rate, its application to achieve the co-benefits stated here were investigated through the ground truthing (or qualitative 'pub-testing') during this project and will be further developed in future projects and initiatives.

Figure 40. Modelled pasture growth, annual cumulative pasture growth and total standing dry matter (TDSM) over time and against rainfall. Cumulative growth follows a financial year to better suit seasonal drivers.



Landscape Response Units:
Queensland's land types have been a critical resource for the identification of production, carbon and ecological capacity of land managed in Queensland grazing systems. The process of identification and describing areas of similar soil and vegetation types and amalgamating them into an accessible map has been identified as an opportunity to improve data accessibility for landholders and developers to assess environmental market opportunities. Landscape response units (LRUs) are a variation and extension on Queensland Land Type mapping, capturing vegetative and geological variation. The model has been developed for all Australian systems and model approximately one order of magnitude of detail greater than the land type layers. Advantages of the development of this model include the potential for providing a basis for an Australia-wide land type map which could underpin collaborations on ecological based studies across regions and states. It will also provide the opportunity for the amalgamation of various pre-existing datasets that investigate the same or similar LRUs, depending on the focus of the studies.

Further development of the model will include reducing pixel size to improve detail and accuracy, however this will incur significant computing costs which are prohibitive at present. Other logistical improvements will include refining Land Types that are highly similar but differ by region. Inclusion of existing land type definitions from other states that are not covered by Queensland Land Types will also improve the integration of the model across Australia.

Currently the model is integral to CIBO's land condition, Northern Land Types layers and other models. As described above, the development of highly accurate and consistent spatial modelling is crucial to the removal of overhead expenses in environmental and carbon baselining and modelling, removing barriers to producers across Australia. It will provide greater certainty of the potential a business has to improve their environmental credentials as well as improve the accuracy of the estimation of the value of improvements based on location, ecosystem type and proximity to surrounding features.

4.4.3.3 'Innovative science to support climate smart grazing land management' project

A collaborative Department of Environment, Science and Innovation and Department of Agriculture and Fisheries 'Innovative science to support climate smart grazing land management' project funded through Drought Climate and Adaptation Program and Queensland Reef Water Quality Program aims to develop and deliver new and improved products and information to assist stakeholders to manage the risks associated with Queensland's variable and drought-prone climate. The 'Climate Smart' project will undertake new research in pasture modelling, remote sensing and climate forecasts to provide seasonal forage budget information with up to six-month outlooks for managers to use. The new seasonal forage budget information will be available for all property owners in Queensland via the FORAGE decision support system and new interactive mapping tool MyFORAGE both found at the LongPaddock website (https://www.longpaddock.qld.gov.au).

High quality pasture data collected during the Methods to Market project was provided to Climate Smart project team to assist in the validation of a machine-learned modelling approach to estimate pasture biomass. The development of a scientifically robust, machine-learned model will be used in combination with climate forecasts to provide the seasonal forage budget information to property managers to assist in critical management decisions and achieve better outcomes for grazing industry, the land and reef water quality.

4.4.4 Supported activity: Wirra Natural Capital Project

Background

(Adapted from Carbon Storage Partnership Natural Capital Explainer developed by Anthony O'Grady, CSIRO with input from Hayley McMillan, DAF.)

Improved management and accounting of natural capital will help agricultural enterprises better understand the environmental drivers of their profitability and improve the resilience of their enterprise. It will also help farmers to better prepare for engaging with more environmentally aware/demanding customers and consumers; to engage in emerging environmental stewardship programs; or to be more attractive to the growing market for sustainability-linked or impact-linked finance initiatives.

Natural capital describes the stocks of environmental and ecosystem assets that contribute to agricultural enterprises. The basic process for business scale accounting can be summarised as:

1. Develop a natural capital asset register for the farm
2. Define the extent and condition of these natural capital assets
3. Quantify the 'environmental services' that these assets generate
4. Determine the value of these 'environmental services' to the enterprise (or to society)
5. Integrate with farm financials to communicate the enterprise's environmental transactions, for example via natural capital income statements and balance sheets or thematic carbon, water or biodiversity statements.

To put these steps into context, measuring natural capital involves steps 1–2, while natural capital accounting involves steps 1–5. Well known methods like BioCondition and those under certification schemes like Accounting for Nature (AfN) only involve steps 1-2 for a pre-defined subset of total natural capital. Accounting for Nature is the leading natural capital certification scheme in Australia. The M2M team supported the Barfield Road Producer Group to trial AfNs '*Method to assess the Econd and Pcond of permanent and perennial pastures*' on central Queensland property, 'Wirra'. Econd and Pcond refer to the ecological and productive condition of an area respectively compared to a regional ecosystem "optimal" figure.

Results

The Wirra Natural Capital Project has been successfully registered (Account ID: AfN-ACCOUNT-45) and indicators assessed on 43 sites (six more than the 37-site minimum required by the project) (Figure 41). The project has scored the property based on ecological and production metrics (Figure 42) and includes a breakdown of the regional ecosystems measured (Figure 43). The process has allowed the M2M team to understand the AfN project registration process, indicators measured, skills and time required, scalability, and benefits to landholders. For the owners of Wirra, the learnings to-date and provision of robust evidence of species richness on their fattening block have been "well worth it in itself". Notably, from our first project meeting to post-site assessment, the M2M team observed a dramatic shift in attitude toward the suggestion of a wildlife corridor to simultaneously improve carbon and biodiversity outcomes on-farm. As a result, expert advice on the potential for restoration of the target regional ecosystem has been sought and provided to the landholders.

Figure 41. Wirra Natural Capital Project registration map under Accounting for Nature's '*Method to assess the Econd and Pcond of permanent and perennial pastures*'.

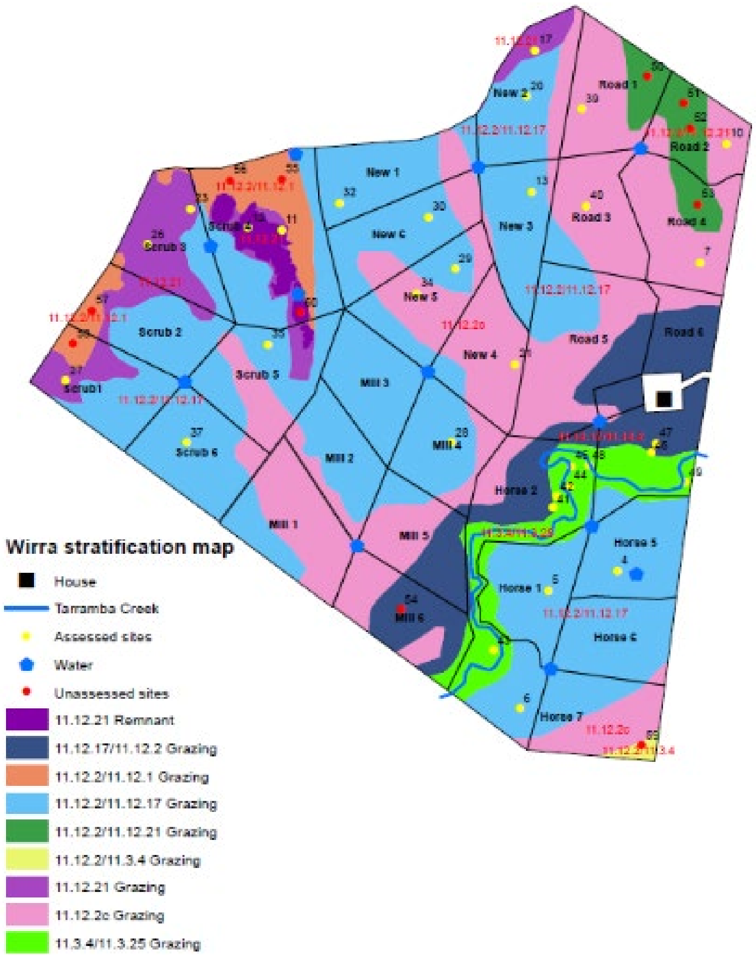
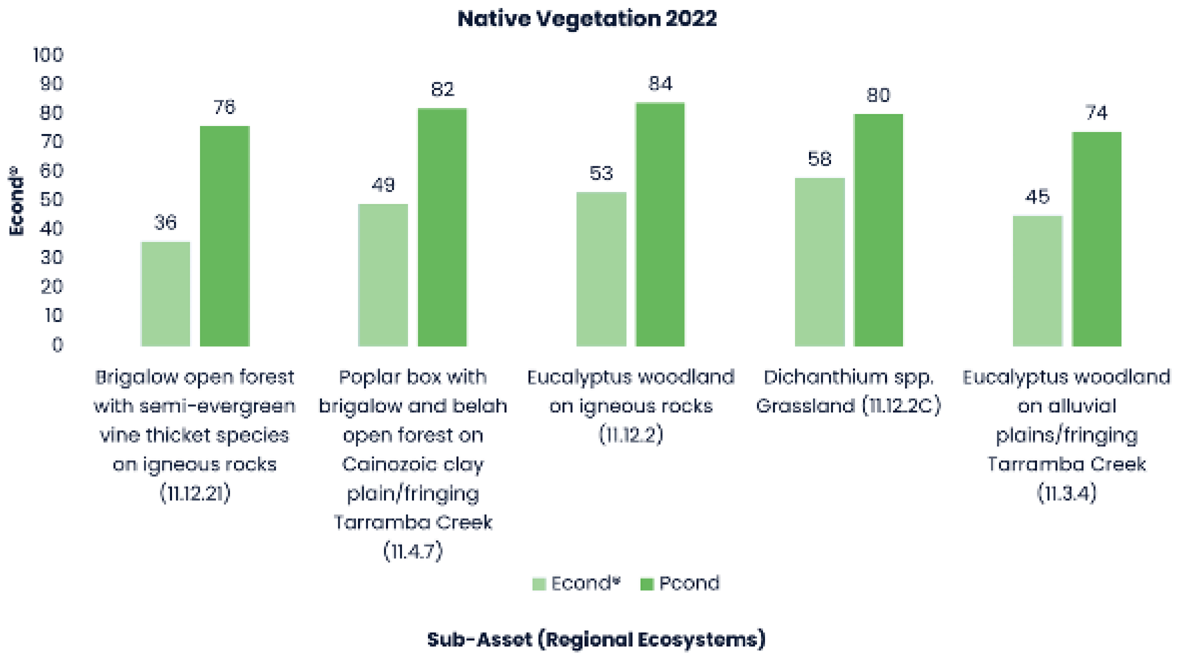


Figure 42. Wirra natural capital account ECond/PCond summary and target.

Figure 43. Wirra natural capital account summary by regional ecosystem performance.



AfN Method scalability

Twenty-six much larger properties that make up eight grazing businesses in central, southwest and southern Queensland have since been stratified to determine the minimum number of sites that would be required under the AfN method (Appendix 9.28). On average, fewer sites (26±12) were required per property. This is because on properties larger than 100ha, site requirements are largely dictated by the number of categories present rather than by property area. Under an 'aggregated project', a business scale assessment averaged 48±13 sites. The cost of an ecologist undertaking 50 site assessments under this method would be approximately $23,000, providing properties were located close together (Appendix 9.29). This cost will be prohibitive for most landholders without adequate incentive; either through increased market/finance access, in-kind contributions, and/or direct renumeration. However, the AfN process is well-designed and highly rewarding; particularly for well-managed businesses which have been largely excluded from environmental market opportunities to date (i.e., as carbon credit markets continue to reward 'historic' poor performance). For these reasons, a lower-cost method under AfN that combines self-assessable on-ground evidence with remotely sensed vegetation condition and pasture cover is worthy of industry consideration. Such a method would require support from Australia's red meat industry peak bodies, as well as automated site stratification and mapping to ensure producer uptake. Other methods such as AgForce's AgCarE program are available but were not investigated through the course of this project.

Extension

Communications of these findings as well as the on-ground experiences of the landholders were presented at a field day on the Wirra property on the 26th of May 2023. Attending were graziers, advisory and sustainability groups such as RCS, FBA and Landcare Farming, and key market influencers such as McDonalds. While the economic incentives are still in development, familiarising producers with natural capital accounting opportunities and potential market drivers is crucial in preparing the industry for upcoming change.

4.4.5 Supported activity: Integrating conservation with agricultural production: linear strips of native vegetation support declining woodland birds and provide benefits to pasture

University of Queensland honours student, Brodie Crouch, aimed to identify the impact of tree strips on pasture productivity on four grazing properties in the southwestern extent of the Brigalow Belt. His research builds on previous research that identified compensatory pasture production in paddocks adjacent to tree strips. Results from this project will help inform practical recommendations and considerations for graziers wanting to maximise the benefits of regrowth retention on-farm. His thesis was supervised by Professor Martine Maron, Dr Bradd Witt and Dr Hayley McMillan, and his project was a 2022 collaboration between UQ and the Queensland Department of Agriculture and Fisheries. With permission, Brodie's honours thesis is provided in appendix 9.30 and his abstract is provided below.

Abstract

Linear strips of native vegetation are common features of agricultural landscapes. They may be retained on farms for the benefits they can provide to the production system. These strips can also provide important habitat resources for a variety of taxa. Substantial scope remains to increase the number and extent of these strips, yet their uptake as an on-farm conservation measure is restricted by uncertainty surrounding both their impacts on production, and also their habitat value to taxa of conservation concern. Here we ask whether a declining woodland bird community uses strips of native vegetation retained in otherwise-cleared grazing landscapes, and explore the characteristics of strips that influence woodland bird species richness and abundance within the strips. We quantify the impact that strips have on adjacent pasture production in the highly-modified brigalow Acacia harpophylla *landscapes of southern Queensland, Australia. We surveyed the bird communities of 47 sites within retained strips ranging from 30 – 388 m in width, and sampled pasture basal area along transects perpendicular to the strip edge. We found that brigalow-dominated strips were used by declining woodland birds. Using generalised linear mixed models, we found that the abundance of woodland birds was greater at sites in wider strips, although species richness was not affected by strip width. However, the species richness of woodland birds was negatively correlated with abundance of native but aggressive honeyeaters of the genus Manorina. Five of eight pasture survey transects showed strong evidence of a positive effect of strips on pasture basal area. These results suggest that the retention of both remnant and regrowth brigalow-dominated vegetation in the form of strips could be an effective vegetation management strategy that delivers improved outcomes for woodland birds whilst minimising pasture productivity losses.*

Communication of findings

Following the conclusion of the research, Brodie has been active in the communication of the findings. To date, the results have been presented at the Western Queensland Beef Research Council meeting (Quilpie – November 2022), and as a poster at the Ecological Society of Australia conference (Wollongong – November/December 2022) and the Australian Rangelands Conference (Broome – September 2023). A scientific paper based on the thesis is being prepared for publication in the journal *Agriculture, Ecosystems and Environment (AAE)*.

4.5 Method enhancement and development

4.5.1 Woody vegetation sequestration method developments

Methods to improve adoption of carbon farming projects have been investigated by the project, predominantly through collaboration with Integrity Ag and Environment. It was determined that broadening the options of eligible vegetation-based activities while maintaining integrity would have the greatest impacts for producers engaging in this space. CSIRO has been engaged to determine if FullCAM has the capacity to become integrated with these methods. This assessment investigated the potential to quantify, forecast, or account for forest carbon taking into account canopy cover percentages as well as discussions around limitations of the model. Preliminary investigations into the forest growth model called 3-PG have begun as a result of these interactions. Preliminary scoping into policy concerns and issues surrounding these methods has been undertaken through communications held with the Department of Climate Change, Energy, the Environment and Water (DCCEEW).

The proposed methods are outlined below, however further detail on both as well as further analysis of the ACCU Scheme and recommendations for further development are presented in appendix 9.31.

Method 1: Restoring Degraded Forest Framework

The objective is that degraded forests are restored to their ecological benchmarks, and the difference in carbon stock is quantified and awarded to the proponent. This framework aims to incentivise restoration of degraded forests by quantifying new and additional carbon sequestration from active forest restoration. The framework recognises the gap in potential sequestration between a forest in a degraded state, and that of the forest's ecological benchmark. As the forest is restored, the additional carbon sequestration is modelled and measured: carbon sequestration is quantified as the composition and structure of the forest improves towards its ecological benchmark, resulting in carbon sequestration associated with additional growth and healthier vegetation communities. Forest restoration techniques may include active forest management and the removal or management of forest cover suppressors, such as unrestrained grazing, ongoing clearing activity or excessive woody stem density. Identification of improvement would be linked to the canopy cover density and height of the vegetation.

For example: Paddock A contains forest with a canopy cover averaging 30%. Paddock A was heavily grazed, and the only trees on this paddock were mature trees that were well established when grazing was introduced. Unrestrained grazing had resulted in soil erosion and no juvenile trees; all saplings were either snapped or eaten. The vegetation community of Paddock A had a known ecological benchmark that suggested a canopy cover of 60% was achievable. Once the framework was implemented, the unrestrained grazing over Paddock A was managed to allow for the succession of saplings to develop beyond their vulnerable juvenile stage, and the forest was restored from 30% canopy cover to 60% canopy cover. The associated change in carbon biomass (t CO2-e/ha) from this increase was modelled. After verification processes were carried out and necessary discounts were applied to the t CO2-e figure, the carbon sequestration amount was awarded to the proponent in the form of an offset or inset, thereby incentivising the restoration.

In this sense, the method would be similar to that of the retired HIR methodology, however the removal of the requirement for no existing forest cover (>20% canopy cover above 2m high) would greatly increase the area eligible for participation. Quantification of the sequestered carbon poses a technical barrier as the FullCAM calculator models uninterrupted growth based on soil type, vegetative communities and time. Carbon sequestration estimations here would require quantification of carbon stocks when the vegetation canopy density is lower than the ecological normal as well as the reduced carbon stock associated with lack of vegetative complexities such as understorey vegetation. Furthermore, the increase in total carbon stocks associated with the increased canopy cover and vegetative complexity needs to be modelled via economically viable methods such as satellite imagery. It is suggested that the Physiological Processes Predicting Growth (3-PG) Model, a forest growth model, be assessed for its applicability here. Additionally, LiDAR or other such assessments may be better suited once fully developed. Assessment of the ecological benefits associated with this style of abatement should also be a key priority as the method incentivises significant ecological restoration that currently aligns with co-benefit criteria (particularly biodiversity).

Legislative issues that may arise from the development of this method include the demonstration of additionality, a key requirement for all emission abatement methodologies. The mode of suppression that inhibits the forest from reaching its ecological potential needs to have a clear impact that, if managed, is responsible for the increased vegetative development. In addition, the forest would have to be shown to have reached a stable equilibrium below that of its ecological potential, demonstrating that no further carbon sequestration would occur without anthropogenic intervention. It is suggested that a baseline period of 15 years be implemented to demonstrate the carbon estimation area's (CEA) equilibrium stability. Satellite imagery derived products may be suitable to document the baseline.

Method 2: Regenerating Sparse Woody Framework

Carbon sequestration is quantified for regeneration, or partial regeneration, of land without the requirement of the forest exceeding 20% canopy cover thresholds. This framework aims to incentivise the partial regeneration of land that quantifies new and additional carbon sequestration of the regeneration whilst allowing for canopy cover density to be capped, either by natural factors or active management (e.g., thinning). This framework recognises that many proponents cannot justify the loss of primary grazing productivity that may be associated with regenerating land beyond 20% canopy cover. In many instances, it may be possible for the proponent to maintain a sufficient level of primary productivity while simultaneously partially regenerating land (i.e., increase forest canopy cover, but not beyond 20%, and maintaining it at this predetermined density). Additionally, this would incentivise the regeneration of naturally open regional ecosystems, those ecosystems that do not support a canopy density above 20%, a scenario that was excluded by vegetation methods to date which required forest cover (>20% canopy cover above 2m) or the potential to achieve >20% canopy cover.

The carbon sequestered via the growth of the forest is modelled, and the framework allows for the proponent to maintain the forest at the predetermined density. This option may increase the accessibility of the carbon market, opening it up to a large area of land - particularly cleared grazing land where the increase of forest cover would not greatly adversely impact grazing, providing canopy cover is limited to a density below 20%. The removal of the 20% canopy cover threshold may prove to be a removal to a significant barrier to entry for many landholders. For example: Paddock B was historically cleared and used for grazing. Only a few large trees existed on the otherwise treeless slopes – the canopy cover averaged 5%. Once the framework was implemented, grazing was strategically managed through additional fences to allow for the regeneration of native saplings. The land that previously had an average canopy cover of 5% was regenerated to a canopy cover of 15%, and was maintained at this level. The proponent conducted ecological thinning on patches that were becoming too dense and hampering productivity, so long as the canopy cover did not fall below 15%. The associated change in t CO2-e from this increase in carbon stocks was modelled. After verification processes were carried out and necessary discounts were applied to the t CO2-e figure, that carbon sequestration amount was awarded to the proponent in the form of an offset or inset, thereby incentivising the regeneration.

This methodology would again be similar to that of the retired HIR methodology with the key departures including the removal of the requirement for areas to achieve forest cover. Quantification of sequestration potential could be achieved via existing methodologies such as FullCAM, however use of this would require some minor alterations. Specifically, FullCAM is used to determine the sequestration associated with forests that are allowed to regenerate naturally from a cleared area. Employing this for areas under ecosystems that do not exceed 20% canopy cover naturally is justifiable, however its use for quantification of anthropogenically maintained canopy density would not accurately reflect the scenario. While additional carbon sequestration associated with age can be accounted for under the model as it stands, the variation in growth patterns (correlation between canopy cover and total biomass) arising from the managed reduced density would not be accurately addressed by FullCAM. This would have to be supported by on ground data.

Similar to the ‘Restoring Degraded Forests Framework’, legislative issues may arise around the demonstration of additionality. That is, proving the system was at equilibrium or actively managed by a producer such that the additional vegetation produced through the course of a project as described above would not have been present had the project not proceeded. In demonstrating this, it is suggested that the baseline period also be extended from 10 to 15 years so an accurate equilibrium can be calculated.

Additional recommendations

Following the discontinuation of the HIR methodology, the most successful carbon farming method to date, development of a new method that encapsulates this form of carbon capture has culminated in the forthcoming Integrated Farm and Land Management (IFLM) method which is still under development as at February 2024. While in its draft stage, the method aims to amalgamate a variety of carbon capture methods into a single project, allowing for ‘method stacking’ on single carbon estimation areas and the removal of multiple project registration fees on a single property. In this manner, smaller carbon projects that would otherwise be economically unviable due to project fees could be combined to reach a sufficient return to justify project registration. Currently, an aspect of the method would include the eligibility of projects similar to those outlined in the HIR method. The inclusion of the above methodologies would further the applicability of IFLM to a greater area and thus remove further barriers for uptake while maintaining method integrity.

In the development of this method, it is imperative that accounting and reporting requirements remain as cost-effective as possible while maintaining the desired integrity of carbon credits acquired. Most influential in this will be the method of measurement employed to demonstrate carbon sequestration. While techniques exist that provide greater accuracy for reflecting total carbon stocks, the use of remote sensing technology remains the most effective method for providing accurate results while reducing project operational costs. Data collection and model refinements are therefore crucial to improving method uptake, and particularly so for the above methods which require model development.

Method 3: Emission Reduction Framework for Leucaena

Leucaena has been considered to have high potential for grazing systems engaging in carbon and environmental markets. This is due to the fact that the plant, being a woody fodder source, represents a stable sink of carbon; it promotes greater soil carbon stocks; and it reduces enteric methane production through improved production efficiency and inhibiting methanogenic pathways within the rumen. To date, Leucaena plantings have not been eligible for carbon abatement methodologies under the ACCU Scheme. Key barriers to the development of this method surround technical difficulties in determining the emission reduction as a result of the consumption of Leucaena. Economically, the obtainment of ACCUs via such a method would be similar to those of the Beef Herd Management Method which, as discussed in 4.3.1.1, require a scale often prohibitive to the average producer. A key difference between these methods is that the herd management method is based on incremental production efficiency improvements which has limited potential for emission avoidance in economically productive herds where-as the additional emission avoidance as a result of methanogenesis inhibition increases the potential for the Leucaena method. This would have the effect of reducing the herd size required. Additionally, as Leucaena is often economically viable via production benefits, the requirement for the carbon project to pay for the practise change and project management is lessened or removed. Soil and vegetative based carbon abatement could be included as additional to this, however herd associated emissions make up the focus of the below proposal.

Key technical implementation requirements for this style of carbon abatement methodology would be similar to those of the Beef Herd Management method. Aside from the herd size required for economic viability, a key barrier to uptake of this method to date has been availability of herd data and the verification of that data. Similarly, obtaining accurate numbers, duration of grazing, weights and weight gains of stock grazing the Leucaena/grass paddock poses a significant barrier to most producers, however this is greatly reduced as compared to a whole of herd assessment. Additional data requirements surround this methodology as a result of its dependency on demonstrating Leucaena intake. Quantification of areas under Leucaena as well as its relative biomass can be calculated from existing satellite imagery techniques and services such as CIBO labs. Verification of dietary intake can also be obtained via dung samples. This data would provide the premise of the discount rate of methane emission applied to the herd.

Key considerations behind the applicability of this method predominantly revolve around project size and additionality. As Leucaena planting is highly capital intensive, land use change often occurs in small increments. This, in turn, reduces herd size applicable for the project and thus limits the volume of emissions avoided, and the number of ACCUs awarded. As project registration and data verification fees stand to remain significant, it is unlikely that the method would be economically viable. In addition, as Leucaena is a highly productive improved fodder crop, the awarding of ACCUs could only occur if no additional cattle were carried as a result of the implemented Leucaena. That is, emission reduction associated with the consumption of Leucaena cannot be awarded if the Leucaena increases the carrying capacity of the paddock and that additional carrying capacity is realised due to the increased number of stock and associated increased methane emission rate. As the additional carrying capacity is typically taken advantage of by commercial producers, this would nullify the avoided emissions abatement.

Options such as insetting remain for producers who wish to avoid the cost and risk of a project to generate ACCUs, however the emission reduction associated with Leucaena would be integrated into an emission baseline methodology. Paddock associated herd performance would become redundant and verification of the methanogenic inhibition would be the only necessary addition to the herd emission calculations. This insetting method could also be applied to all Leucaena in an operating system rather than new and additional Leucaena. Additional cattle carried associated with the increase of Leucaena's extent would also be tolerated by this approach as, despite the total business emissions increasing with the additional cattle, the emissions intensity would reflect the improved management.

Further detail of the method framework, justification, limitations and potential are outlined in appendix 9.32.

4.5.2 Herd record collection and storage

Bush Agribusiness undertook analyses to investigate the barriers and opportunities surrounding accurate herd data collection. This includes assessing the application of herd data collected for business analysis in the production of an emission baseline as well as an economic analysis of emission reduction through herd management.

Accurate herd data underpins reliable business and emissions calculations.

The biggest challenge the industry has with regard to understanding business performance and emissions intensity is a poor understanding of herd numbers, both in total and by class. This is a challenge that Bush AgriBusiness faces in acquiring data from beef businesses in order to perform accurate business and herd analysis. It is also a challenge in getting accurate data for herd emissions calculations. The challenge is exacerbated by the data sought for both processes being requested in different formats and with different terminology, despite being essentially the same data.

A larger effect of this problem is that poor herd performance is often undiagnosed by producers, meaning that there is reduced incentive to improve herd performance, for the benefit of herd productivity or emissions intensity. There is a need to address this issue by developing standardised herd classifications protocol. Standardised protocols will make it easier for producers to record information at property level for their day-to-day management, and also for improved analysis of the herd performance or emission intensity by service providers. Bush AgriBusiness is working to develop this system with the intention of setting the standard for industry.

Information required for understanding herd performance is the same as required for herd emissions

Further to the above point, the data required to generate accurate information on herd performance is effectively the same as that required for calculating emissions. Bush AgriBusiness has been receiving feedback from clients that they are providing the same herd data for herd analysis as they were for providing data for emissions calculations, albeit in slightly different format with different terminology (which the above point addresses).

Building on the issue detailed above, Bush AgriBusiness has changed the herd information it collects in order to:

- Improve accuracy of herd information collected
- Calculate herd emissions using same calculations as national inventory and SB-GAF tool (analysis limited to herd)
- Provide herd information needed to other users/providers to calculate emissions to reduce double up of effort to provide data. The majority of additional information relates to the specific age of cattle.

Decreasing herd emissions intensity is good for business performance

Collaboration between DAF and Bush Agribusiness (and other contractors) has enabled enhanced 'industry' learnings. Although not the direct finding of this project, collaboration, discussion and past data collation has led to work which has highlighted how herd emissions intensity (t CO_2e/kg beef) is an inverse of herd productivity (Kg Beef/AE). This is because the number and productivity of an AE is effectively a measure of intake and herd emissions are a function of intake. Bush Agribusiness work has consistently shown over time that Kg Beef/AE is one of the most important profit drivers for a beef business. Improvements in herd productivity (ceteris paribus – all other things being equal) will increase the income and profit of a beef business. From analysis over time, changes in the three key productivity drivers (reproductive rate, mortality rate, sale weight) explain around 75% of the differences in herd productivity (Kg Beef/AE). From this, Bush Agribusiness have developed a multivariate model to predict changes in herd productivity resulting from changes in the key herd productivity drivers; see McLean et al. (2018).

To demonstrate effect of small changes in herd productivity drivers on emissions intensity, a multivariate formula was applied to the 12-year average performance of the northern beef industry. In these calculations AE is used as a proxy for intake, with one AE representing 2,920kg DM intake per year (McLennan et al., 2020). This is a different method to typical calculations based on the inventory calculations, however the analysis is based on incremental changes, not absolute, so this assumption does not limit the analysis and relative difference in the results. The results of changing each variable (reproductive rate, mortality rate and sale weight) independently are shown in Figure 44, along with the base assumption for each.

Figure 44. Reductions in emission intensity resulting from changes in herd productivity drivers. Note "Emission Reduction" below refers to the reduction in emission intensity.

Reproductive Rate Base - 62.2%		Emission Reduction
Increase in reproduction rate	1%	**0.8%**
	2%	**1.6%**
	3%	**2.3%**
	4%	**3.1%**
	5%	**3.8%**

Mortality Rate Base - 2.6%		Emission Reduction
Decrease in mortality rate	0.25%	**1.5%**
	0.50%	**2.1%**
	0.75%	**2.8%**
	1.00%	**3.5%**
	1.25%	**4.1%**

Sale Weight Base - 402 kg		Emission Reduction
Increase in sale weight	5	**1.8%**
	10	**2.8%**
	15	**3.8%**
	20	**4.7%**
	25	**5.7%**

4.6 Industry engagement

A variety of industry engagements have occurred promoting the findings of the project and providing science-based information to advisors and producers. Environmental markets can feature conflicting advice which stems from the misapplication of information and miscommunication via word of mouth. The M2M project had a unique opportunity to deliver specific information from a neutral, non-commercially motivated standpoint, contrasting to producers being supplied with information only by providers with direct financial interests. That being said, there are carbon service providers that do provide 'good' advice. To date, communication of the M2M material has occurred via presentations at industry events such as producer workshops, conferences and forums. A range of publications have also been developed.

4.6.1 Publications

Potential for soil carbon sequestration in Northern Australian grazing lands: A review of the evidence.

DAF through ASQ – Animal Science and the M2M project commissioned AgriEscondo (Dr Beverley Henry) to examine the available evidence for increasing soil carbon sequestration in northern Australian grazing lands using practical grazing and pasture management strategies. The report is available at https://futurebeef.com.au/wp-content/uploads/2023/02/Soil-Carbon-Sequestration-in-Northern-Grazing-Lands.pdf.

Carbon and ecosystem service markets in rangelands and grazing systems are a wicked problem: Multi-stakeholder partnership or roundtable as a vehicle forward?

This research, a collaboration between UQ and the project and detailed in section 4.1.2 investigates the opportunities and constraints to environmental markets as perceived by landholders and business managers in the Australian Rangelands.

Greenhouse Emissions Accounting: the on-farm implications of the choice of business, industry and Government targets

Due to significant amounts of media and producer interest, the project conducted a review to investigate the climatic impact of the activities of grazing businesses which were then compared to their impact when analysed using the IPCC endorsed GWP100 metric. The impact of business emissions and required offsets to achieve business, industry and Government targets were assessed. Preliminary work was presented at the Australian Rangeland Conference in Broome and a series of draft fact sheets have been developed.

Brigalow, Buffel, Birds and Bovines

This research was conducted through collaboration between DAF and UQ as detailed in section 4.4.5. The project investigated linear vegetation (shade lines) retention on farm and its impacts on: pasture growth of areas immediately adjacent to the strip and; their value to threatened and endangered woodland birds in developed landscapes. The project thesis is available in appendix 9.30.

4.6.2 Fact sheets and case studies

A series of draft fact sheets have been developed including:

- Carbon and methane cycles in a grazing business and how methane behaves in the atmosphere and impacts the climate.
- Herd data collection for use in developing a carbon baseline and tracking changes in emissions.
- Correlation between business economic and productivity indicators and emissions intensity.
- The Wirra natural capital assessment under the AfN framework.
- Economic impact of implementing vegetation-based carbon project scenarios.

4.6.3 Workshops

Throughout the course of the project there was a perceived lack of impartial advice for landholders in the carbon and environmental market sector. To address this, a carbon workshop series was developed in conjunction with the Natural Resource Management association for south-east Queensland, Healthy Land and Water and a private consultant Christophe Bur, which was aimed to provide a starting point for producers wishing to learn about the carbon and environmental market sector. This involved a brief overview of:

1. the scientific basis of climate change;
2. international and industry specific targets;
3. market drivers;
4. sources and sinks on farm;

5. emission baselining;
6. emission reduction management;
7. carbon farming opportunities and risks;
8. project set up and engagement; and,
9. biodiversity crediting schemes.

This information was delivered over the course of a day and was provided to four groups in Toogoolawah, Gatton, Crows Nest and Boonah in south-east Queensland in June and July of 2023. The information was well received with participants reporting an average increase in understanding from 3.9/10 to 6.9/10.

A second series of refined workshops were delivered across the Burnett-Mary and Fitzroy regions in central Queensland in December of 2023. These were funded by the Methods to Market, Queensland Pasture Resilience, Grazing Extension Support and Grazing Futures Livestock Business Resilience projects. The workshops covered the same information, however further emphasis was placed on improving production efficiency to reduce herd associated emissions. Presentations were conducted in Gayndah, Moura and Emerald and were attended by 51 producers and industry advisors. Feedback indicated 6.3/7 satisfaction rating and on average attendees' knowledge and understanding of carbon on farm improved from 2.7 before the workshop to 5 after the workshop. 100% of attendees learnt something new and 74% of people intend to make an on-farm change with the most common planned changes being to begin a carbon baseline (38%) and implement legume and pasture development (35%). At least two producers have started ERF projects following these workshops.

4.6.4 Industry Events

Targeted information regarding carbon and environmental markets and other learnings from the project were presented to industry bodies and producers through a variety of industry events. Predominantly this consisted of MLA BeefUp forums, Northern Cattlemen's Association, Bush Agribusiness producer groups, Natural Resource Management group workshops, MLA Breakfast, Farm Financial Counsellor workshop, among others. A field day was additionally held at 'Wirra', conveying learnings from engagement with Accounting for Nature (AfN).

These extension and adoption activities were supplemented by the creation and management of the Carbon Neutral Grazier Network, established in 2021, which has supplied targeted information on carbon and environmental market engagement, research, development and on-ground experiences to an audience of >570 members across Australia.

4.6.5 Online resources

Many of the developed resources mentioned in this report are available at https://futurebeef.com.au/resources/from-method-to-market/

5. Conclusion

The M2M project, through collaborations with industry consultants, graziers and technology developers, has investigated environmental and carbon market opportunities on-farm. The research has targeted a key knowledge gap in the market as to the impacts of industry targets and carbon farming opportunities on primary production.

Activities throughout the project have predominantly focused on six aspects surrounding this topic:

1. analysis of the existing carbon market legislation efficacy and impacts to livestock systems;
2. scientific methods of carbon abatement on-farm;
3. scientific assessments of potential to measure and enhance existing natural capital;
4. economic and productivity assessments of integrating carbon and livestock agriculture;
5. technology development to support accounting and demonstration of management impacts on carbon and natural capital; and,
6. communication of technical advice regarding carbon and environmental markets.

The multifaceted nature of the project has been critical in demonstrating the need for a holistic approach incentivising practice change. The project has also highlighted the opportunities for the integration of different industries (e.g., timber) to achieve a variety of productive and environmental objectives. As extensive livestock occupies the majority of the Australian land mass, this integration is crucial to increasing biodiverse habitats and stabilising/increasing floral and faunal populations.

5.1 Key findings

Key findings of the project are as follows:

- Project pre-conceptions were that poor landholder participation in ecosystem services markets could be solved by 'fixing and developing methods and aiding technical solutions that bring down the cost of participation', however results revealed ecosystem services markets to be a 'wicked problem', requiring deep and broad systemic change if widespread uptake in grazing systems is to be achieved.
- At present there is little indication of direct premiums from the supply chain for low carbon or carbon neutral meat. Supply chain interest in emissions on farm may increase in future. The reward for producers who maintain data to estimate emissions or implement strategies to reduce total emissions, may be advantageous for market access and/or reduced regulation risk.
- Carbon emission reduction strategies that align closely to production goals should be implemented for both economic and sustainability objectives.
- Strategies to reduce direct emissions in extensive grazing are currently limited to production efficiency. Novel interventions may have the capacity to further reduce total emissions substantially but are unlikely to reduce emissions completely. Emission abatement options are therefore required but are varied in their suitability and can be antagonistic to production.
- Carbon sequestration opportunities on-farm can offset total emissions, but the amount of annual sequestration will decline over time. Thorough analysis of sustainability goals for each business is required to ensure they do not jeopardise business resilience and longevity.
- Soil carbon opportunities in northern grazing land are likely to be modest and have reversal risk particularly during dry periods.
- On-farm vegetated areas represent broader environmental stewardship by producers which should be recognised. Benchmarking environmental performance should consider the available opportunities for producers and the environmental qualities already present.
- Emissions reduction is a dynamic and on-going process. A focus on short-term targets presents a risk to industry, in the absence of immediate pathways to participation.
- Increasing the availability of impartial advisors is crucial to the positive progression of the industry in carbon and environmental markets.

5.2 Benefits to industry

As monetarily incentivising carbon abatement and environmental stewardship is a relatively new concept, the development of the industry has been rapid and led to considerable variation in enthusiasm, confusion and mistrust across the industry. The project has delivered a number of outcomes that are of specific benefit to the industry:

1. Real-life case studies from this project have aided the identification, revision and/or development of carbon market, natural capital and carbon insetting methods.
2. Analysis of options for carbon and biodiversity markets, to help the red meat industry identify opportunities and avoid costly mistakes.
3. Extensive environmental and productivity condition field data that contributed to the development and validation of spatial methods to cost-effectively measure pasture biomass and native vegetation condition; both at state and national scales.
4. Novel capacity for the Queensland Department of Agriculture and Fisheries to contribute to impartial industry engagement on the topics of carbon, biodiversity and natural capital opportunities in productive grazing systems. This has been conducted through workshops, presentations and the development of the Carbon Neutral Grazier Network.

6. Future research and recommendations

The following areas have been highlighted for further research and development:

1. Improving herd record collection to increase emission baseline accuracy and business performance analyses. Clear definitions of stock class and uptake of animal age-class recording will be critical to this.
2. Determine acceptable accuracy of data collection and acceptable error for accounting for participation in zero or low emission supply chains.
3. Investigate the bioeconomic viability of carbon markets to incentivise woody vegetation retention at lower vegetation density that can be managed in combination with maintaining grazing productivity. Outcomes would direct carbon methodology development under the ACCU Scheme.
4. Further develop economic and environmental cost-benefit analyses to support optimisation of carbon, biodiversity and agricultural production focused management.
5. Further investigate the suitability and implementation of multi-stakeholder partnerships as a mode of addressing the complexities surrounding environmental market development, regulation and adoption.
6. Identification of the impact and property planning for retaining native woody vegetation in the form of shelter belts on pasture production, livestock production, carbon sequestration, water quality, property scale landscape attributes, biodiversity, and mitigating nature related risk throughout grazing systems of northern Australia.
7. Support grazing businesses to determine strategies to negate the climate impact of the business in perpetuity.
8. Further investigate methanogenic inhibition capabilities of plants existing in Australian grazing systems and assess their potential for increased distribution and density. This would

also inform on regional variation in enteric methane production and improve the accuracy of Australian livestock's emissions profile.

9. Evaluate the thermal impact of grazing system emissions on the climate to determine an appropriate level of offsets to become climate neutral and achieve industry and government targets.

While there are many aspects that have been and continue to be developed to reduce capital input barriers and increase method confidence for the purpose of increasing economic potential of market participation, several fundamental components need to be addressed to ensure the longevity of the markets and the extensive livestock industry.

These components predominantly concern the long term aspirations and objectives for climate, carbon and biodiversity and their interactions with extensive grazing. As grazing businesses manage a defined property area that, in turn, has a limited capacity to produce food, sequester carbon and support ecosystems/biodiversity, the optimisation of all three aspects needs to be a priority to ensure the land mass is being used effectively. Currently, there is little in the way of long-term objective planning for these considerations which may lead to ineffective land use. For this reason, the following recommendations are crucial to improving clarity for producers on the purpose of incentivised management change as well as ensuring all aspects of the managed systems are valued and considered as the industry progresses in the environmental space:

1. Further investigation into the development and optimisation of technologies that enhance climatic sustainability and environmental stewardship.
2. Investigate and quantify the effects of woody vegetation connectivity corridors on biodiversity for the purpose of identifying opportunities to increase effective habitat area while mitigating the impact on productivity.
3. Further develop economic and environmental cost-benefit analyses to support optimisation of carbon, biodiversity and production focused management.

In the broader context of industry progression, the following areas of investigation/development are recommended:

1. Globally recognised food and fibre carbon and 'nature positive' product labelling standards.
2. Formalisation of carbon insetting methods under an industry agreed certification framework, acknowledging the work underway by Climate Active.
3. Collection and sharing of site-based and remote sensed data to support national capacity to demonstrate zero deforestation claim, capacity for long-term soil carbon improvement, as well as low-cost spatial tools for advisors to assess the cost/benefit of participation in ecosystem services markets.
4. Development of impartial regional champions with the skills, education and time to successfully help graziers navigate the environmental markets.

7. References

ABS 2013. Historical Selected Agricultural Commodities, by State (1861 to Present), 2011. *In:* STATISTICS, A. B. O. (ed.). Australian Bureau of Statistics.

ABS 2016. National Land Account, Experimental Estimates. ABS Website.

ABS 2023. Agricultural Commodities, Australia. *Annual.* Australian Bureau of Statistics.

ABSF 2023. Australian Beef Sustainability Framework - Annual Update 2023. RMAC.

ALTERMANN, E., REILLY, K., YOUNG, W., RONIMUS, R. S. & MUETZEL, S. 2022. Tailored Nanoparticles With the Potential to Reduce Ruminant Methane Emissions. *Frontiers in Microbiology,* 13.

ARNDT, C., HRISTOV, A. N., PRICE, W. J., MCCLELLAND, S. C., PELAEZ, A. M., CUEVA, S. F., OH, J., DIJKSTRA, J., BANNINK, A., BAYAT, A. R., CROMPTON, L. A., EUGÈNE, M. A., ENAHORO, D., KEBREAB, E., KREUZER, M., MCGEE, M., MARTIN, C., NEWBOLD, C. J., REYNOLDS, C. K., SCHWARM, A., SHINGFIELD, K. J., VENEMAN, J. B., YÁÑEZ-RUIZ, D. R. & YU, Z. 2022. Full adoption of the most effective strategies to mitigate methane emissions by ruminants can help meet the 1.5 °C target by 2030 but not 2050. *Proceedings of the National Academy of Sciences,* 119**,** e2111294119.

BADGERY, W., LI, G., SIMMONS, A., WOOD, J., SMITH, R., PECK, D., INGRAM, L., DURMIC, Z., COWIE, A., HUMPHRIES, A., HUTTON, P., WINSLOW, E., VERCOE, P. & ECKARD, R. 2023. Reducing enteric methane of ruminants in Australian grazing systems – a review of the role for temperate legumes and herbs. *Crop and Pasture Science,* 74**,** 661-679.

BEAUCHEMIN, K. A., UNGERFELD, E. M., ABDALLA, A. L., ALVAREZ, C., ARNDT, C., BECQUET, P., BENCHAAR, C., BERNDT, A., MAURICIO, R. M., MCALLISTER, T. A., OYHANTÇABAL, W., SALAMI, S. A., SHALLOO, L., SUN, Y., TRICARICO, J., UWIZEYE, A., DE CAMILLIS, C., BERNOUX, M., ROBINSON, T. & KEBREAB, E. 2022. Invited review: Current enteric methane mitigation options. *Journal of Dairy Science,* 105**,** 9297-9326.

BLACK, J. L., DAVISON, T. M. & BOX, I. 2021. Methane Emissions from Ruminants in Australia: Mitigation Potential and Applicability of Mitigation Strategies. *Animals (Basel),* 11.

BOM 2024. Weather Station Directory. *In:* METEOROLOGY, B. O. (ed.).

BRAITHWAITE, L. 1996. Conservation of arboreal herbivores: the Australian scene. *Australian Journal of Ecology,* 21**,** 21-30.

CARTER, J., BRUGET, D., HENRY, B., HASSETT, R., STONE, G., DAY, K., FLOOD, N. & MCKEON, G. 2010. Modeling Vegetation, Carbon and Nutrient Dynamics in the Savanna Woodlands of Australia with the AussieGRASS Model. *Ecosystem Function in Savannas: Measuring and Modelling at Landscape to Global Scales*.

CER. 2023. *Emission Reduction Fund* [Online]. Available: https://www.cleanenergyregulator.gov.au/ERF [Accessed 13 December 2023].

CHAPMAN, A. D. 2009. Numbers of living species in Australia and the world. *Report for the Australian Biological Resources Study.* Canberra: Department of the Environment, Water, Heritage and the Arts.

CLEAR CENTER. 2020. *Greenhouse gas emissions: What is the difference between stock and flow gases?* [Online]. UC Davis. Available: https://clear.ucdavis.edu/news/greenhouse-gas-emissions-what-difference-between-stock-and-flow-gases#:~:text=Unlike%20stock%20gases%2C%20flow%20gases,lifespan%20of%20about%2012%20years. [Accessed 2024].

DCCEEW. 2022a. *About threatened ecological communities* [Online]. Available: https://www.dcceew.gov.au/environment/biodiversity/threatened/communities/about [Accessed 31 January 2024].

DCCEEW. 2022b. *Savannah Fire Management - Emissions Avoidance Method* [Online]. Department of Climate Change, Energy, the Environment and Water. Available: https://www.dcceew.gov.au/climate-change/emissions-reduction/emissions-reduction-fund/methods/savanna-fire-management-emissions-avoidance [Accessed 07/02/2024].

DCCEEW 2023a. Australia - Species and Communities of National Environmental Significance - Downloadable Grids - Number occurring across Australia. *In:* DEPARTMENT OF CLIMATE CHANGE, E., THE ENVIRONMENT AND WATER (ed.).

DCCEEW 2023b. National Inventory by Economic Sector (NIbES). *In:* DEPARTMENT OF CLIMATE CHANGE, E., THE ENVIRONMENT AND WATER (ed.) *Australia's National Greenhouse Accounts 2021.* DCCEEW.

DES 2022. Watercourse Lines. *In:* SCIENCE, D. O. E. A. (ed.). QSpatial.

DES 2023a. Land Use Mapping - 1999 to 2017 - Queensland. *In:* SCIENCE, D. O. E. A. (ed.). QSpatial.

DES 2023b. Statewide Landcover And Trees Study (SLATS) Sentinel-2 - 2021 woody vegetation extent - Queensland - Whole of state. *In:* SCIENCE, D. O. E. A. (ed.). QSpatial.

DONAGHY, P., BRAY, S., GOWEN, R., ROLFE, J., STEPHENS, M., HOFFMANN, M. & STUNZER, A. 2010. The Bioeconomic Potential for Agroforestry in Australia's Northern Grazing Systems. *Small-scale Forestry,* 9**,** 463-484.

DUNN, J., WIEDEMANN, S. & ECKARD, R. 2020. A Greenhouse Accounting Framework for Beef and Sheep properties based on the Australian National Greenhouse Gas Inventory methodology. *In:* MELBOURNE, U. O. (ed.).

EMISSION REDUCTION FUND 2023. Emission Reduction Fund Register. Clean Energy Regulator.

EYRE, T., KELLY, A., NELDNER, V., WILSON, B., FERGUSON, D., LAIDLAW, M. & FRANKS, A. 2015. *BioCondition A Condition Assessment Framework for Terrestrial Biodiversity in Queensland Assessment Manual Queensland Herbarium, Science Delivery Version 2.2 February, 2015*.

EYRE, T. J., FERGUSON, D. J., HOURIGAN, C. L., SMITH, G. C., MATHIESON, M. T., KELLY, A. L., VENZ, M., HOGAN, L., ROWLAND, J. & HERBARIUM, Q. 2022. *Terrestrial vertebrate fauna survey guidelines for Queensland*, Department of Environment and Science.

FISCHER, J. & LINDENMAYER, D. B. 2007. Landscape modification and habitat fragmentation: a synthesis. *Global ecology and biogeography,* 16**,** 265-280.

FOUTS, J. Q., HONAN, M. C., ROQUE, B. M., TRICARICO, J. M. & KEBREAB, E. 2022. Enteric methane mitigation interventions. *Translational Animal Science,* 6**,** txac041.

HENRY, B. 2023. Potential for soil carbon sequestration in Northern Australian grazing lands: A review of the evidence.

INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE 2023. *Climate Change 2021 – The Physical Science Basis: Working Group I Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change,* Cambridge, Cambridge University Press.

KRÓLICZEWSKA, B., PECKA-KIEŁB, E. & BUJOK, J. 2023. Strategies Used to Reduce Methane Emissions from Ruminants: Controversies and Issues. *Agriculture,* 13**,** 602.

LASSEN, J. & DIFFORD, G. F. 2020. Review: Genetic and genomic selection as a methane mitigation strategy in dairy cattle. *Animal,* 14**,** s473-s483.

LEE, H., CALVIN, K., DASGUPTA, D., KRINNER, G., MUKHERJI, A., THORNE, P., TRISOS, C., ROMERO, J., ALDUNCE, P. & BARRETT, K. 2023. Climate change 2023: synthesis report. Contribution of working groups I, II and III to the sixth assessment report of the intergovernmental panel on climate change.

MCKEON, G., CHILCOTT, C., MCGRATH, W., PATON, C., FRASER, G., STONE, G. & RYAN, J. 2008. Assessing the value of trees in sustainable grazing systems.

MCLEAN, I., WELLINGTON, M., HOLMES, P., BERTRAM, J. & MCGOWAN, M. 2023. Australian Beef Report. Toowoomba QLD: Bush AgriBusiness.

MCLEAN, I. A., HOLMES, P. R., WELLINGTON, M., HERLEY, J. & MEDWAY, M. 2018. Pastoral Company Benchmarking Project 2012-2017. Meat and Livestock Australia.

MCLENNAN, M. The Global Risks Report 2021 16th Edition. 2021. World Economic Forum Cologny, Switzerland.

MCLENNAN, S. R., MCLEAN, I. & PATON, C. 2020. Re-defining the animal unit equivalence (AE) for grazing ruminants and its application for determining forage intake, with particular relevance to the northern Australian grazing industries.

MLA 2022. Cattle numbers – as at June 2021

Natural Resource Management Region. *In:* V02, M. C. D. M. J. (ed.) 2 ed.: Meat and Livestock Australia.

MUNDRA, I. & LOCKLEY, A. 2024. Emergent methane mitigation and removal approaches: A review. *Atmospheric Environment: X,* 21, 100223.

NELDNER, V., NIEHUS, R., WILSON, B., MCDONALD, W., FORD, A. & ACCAD, A. 2023a. The vegetation of Queensland. Descriptions of broad vegetation groups. Version 6.0. Queensland Herbarium, Department of Environment and Science. *Information Technology and Innovation*.

NELDNER, V. J., NIEHUS, R. E., WILSON, B. A., MCDONALD, W. J. F., FORD, A. J. & ACCAD, A. 2023b. The Vegetation of Queensland. Descriptions of Broad Vegetation Groups. *In:* SCIENCE, Q. H. A. B. (ed.) 6 ed. PO Box 5078, Brisbane QLD 4001: Department of Environment and Science.

PRATHAP, P., CHAUHAN, S. S., LEURY, B. J., COTTRELL, J. J. & DUNSHEA, F. R. 2021. Towards sustainable livestock production: Estimation of methane emissions and dietary interventions for mitigation. *Sustainability,* 13, 6081.

PROBER, S. M., DOERR, V. A., BROADHURST, L. M., WILLIAMS, K. J. & DICKSON, F. 2019. Shifting the conservation paradigm: a synthesis of options for renovating nature under climate change. *Ecological Monographs,* 89, e01333.

SANGHA, K. K., MIDMORE, D. J., ROLFE, J. & JALOTA, R. K. 2005. Tradeoffs between pasture production and plant diversity and soil health attributes of pasture systems of central Queensland, Australia. *Agriculture, Ecosystems & Environment,* 111, 93-103.

SCANLAN, J. C. 2002. Some aspects of tree-grass dynamics in Queensland's grazing lands. *The Rangeland Journal,* 24, 56-82.

STIFKENS, A., MATTHEWS, E. M., MCSWEENEY, C. S. & CHARMLEY, E. 2022. Increasing the proportion of <i>Leucaena leucocephala</i> in hay-fed beef steers reduces methane yield. *Animal Production Science,* 62, 622-632.

SUYBENG, B., CHARMLEY, E., GARDINER, C. P., MALAU-ADULI, B. S. & MALAU-ADULI, A. E. O. 2019. Methane Emissions and the Use of Desmanthus in Beef Cattle Production in Northern Australia. *Animals (Basel),* 9.

SUYBENG, B., CHARMLEY, E., GARDINER, C. P., MALAU-ADULI, B. S. & MALAU-ADULI, A. E. O. 2020. Supplementing Northern Australian Beef Cattle with Desmanthus Tropical Legume Reduces In-Vivo Methane Emissions. *Animals (Basel),* 10.

TAYLOR, P. D., FAHRIG, L., HENEIN, K. & MERRIAM, G. 1993. Connectivity is a vital element of landscape structure. *Oikos*, 571-573.

THE WORLD BANK. 2024. *Carbon Pricing Dashboard* [Online]. The World Bank. Available: https://carbonpricingdashboard.worldbank.org/ [Accessed 07/02/2024].

UNITED NATIONS 1998. Kyoto protocol to the united nations framework convention on climate change.

VARDON, M., BURNETT, P. & DOVERS, S. 2016. The accounting push and the policy pull: balancing environment and economic decisions. *Ecological Economics,* 124, 145-152.

WATSON, D. M., DOERR, V. A., BANKS, S. C., DRISCOLL, D. A., VAN DER REE, R., DOERR, E. D. & SUNNUCKS, P. 2017. Monitoring ecological consequences of efforts to restore landscape-scale connectivity. *Biological Conservation,* 206, 201-209.

WORBOYS, G., FRANCIS, W. L. & LOCKWOOD, M. 2010. *Connectivity conservation management: a global guide (with particular reference to mountain connectivity conservation)*, Earthscan.

ZHANG, B. & CARTER, J. 2018. FORAGE – An online system for generating and delivering property-scale decision support information for grazing land and environmental management. *Computers and Electronics in Agriculture,* 150, 302-311.

8. Acknowledgements

In the completion of this report, it is important to recognise the many contributions by the various parties and individuals involved. In the conception of the project, the importance of and opportunities from collaborating with a wide array of skills and expertise were highlighted as a key point of the methodology to ensure a multifaceted and holistic assessment of carbon and environmental markets. Key to this outcome were the following:

Grazing Business owners: your support and willingness to engage with the project was critical to its progression. The ability for the findings of this project to be tied back to on-ground examples ensured that the research conducted was focused on improving understanding and opportunities for the people within the grazing industry.

Queensland Department of Agriculture and Fisheries: Kerry Goodwin and Lester Pahl for their producer engagement and data collection, particularly in the early parts of the project and the extension officers who supported enhanced producer engagement across Queensland. We wish Hayley McMillan well for her maternity leave towards the end of the project.

Queensland Department of Environment, Science and Innovation: who provided a great introduction to ecological understanding and directed the trajectory of environmental valuation.

Cibo Labs: your remote sensing data, technical advice, technologies development and listening to project ideas and issues greatly assisted in the accumulation of information required to accurately assess businesses and it was highly interesting delving into the remote sensing world with great guidance.

The University of Queensland: led social-based investigations into the barriers to uptake for producers. Additionally, the investigations by UQ honours student Brodie Crouch on the benefits of tree strips for pasture and birds added a highly valuable aspect to the project.

Agri Escondo: who provided critical advice and direction from the conception of the project, allowing for immediate progression into the research and subsequently undertaking a thorough review of the potential for soil carbon sequestration in northern grazing land.

Bush Agribusiness: who lent their expertise to economic evaluation of businesses involved in the project and supplied livestock data for the purpose of creating emission baselines.

Integrity Ag: for the provision of expertise on a broad array of topics including emission baselining and carbon project feasibility assessments.

BooBook Ecological Consulting: who were critical in the ecological assessments completed in south-west and central Queensland. Your depth of knowledge and passion throughout the process was a highlight of the project.

Meat & Livestock Australia: who provided the funding for the development of the project as well as providing opportunities for industry engagement and networking.

In addition to the expertise and value each of the above added, it was a pleasure to work with those involved. Thank you for making this project as rewarding as it was.

9. Appendix

9.1 Review of Ecosystem Service Market Opportunities for Livestock Producers

Provided separately.

9.2 Carbon and ecosystem service markets in rangelands and grazing systems are a wicked problem: Multi-stakeholder partnership or roundtable as a vehicle forward?

https://www.publish.csiro.au/RJ/RJ23029

9.3 Is a Multi-Stakeholder Partnership or Roundtable a better way forward? Synthesis report.

Provided separately.

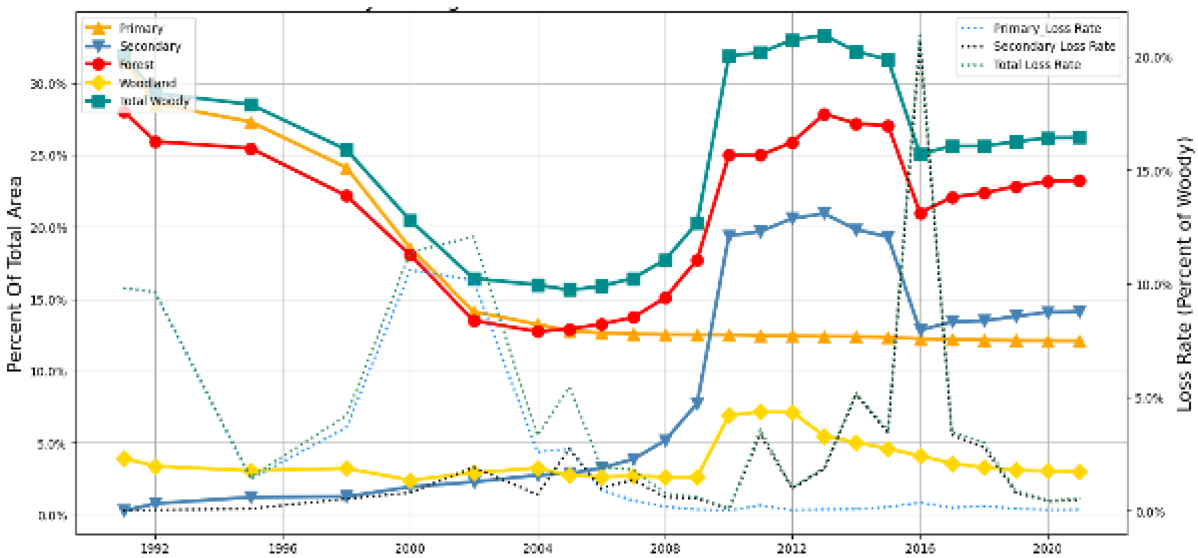
9.4 Mobile applications and spatial data used during the planning, data collection and analysis phases of assessing carbon and biodiversity on-farm

Name	Source	Use
Avenza Maps 4.1	Avenza Systems Inc (2023) https://store.avenza.com/?campaignid=10221828697&adgroupid=102940455500&adid=453083166133&gclid=Cj0KCQjw7uSkBhDGARIsAMCZNJsQ-IJKpxjUXdiY7kl6gt73B3lXNUE9C7btfrNKE7kPlEWkJn5s6rMaAga6EALw_wcB	Georeferenced field data and photographs, property navigation, and access track mapping
ArcGIS Survey123 Version 3.15.159	Esri Inc. (2022) https://survey123.arcgis.com/	Georeferenced field data and photographs
Queensland Imagery Latest State Program Public Basemap Service	Queensland Department of Resources (2019) https://qldspatial.information.qld.gov.au/catalogue/custom/detail.page?fid={8FACBDAA-31D0-49C7-AEFB-43602F73D6FE}	Identify areas of interest
Statewide Landcover And Trees Study (SLATS) Sentinel-2 - 2020 woody vegetation extent - Queensland - Whole of state	Queensland Department of Environment and Science (2022) https://qldspatial.information.qld.gov.au/catalogue/custom/detail.page?fid={6334BD69-51E4-4CCF-AB44-E5B2309BD9F5}	Identify areas of interest
Broad vegetation groups - pre-clearing and 2021 remnant - Queensland series	Queensland Department of Environment and Science (2023) https://qldspatial.information.qld.gov.au/catalogue/custom/detail.page?fid={68F91B63-55D3-4954-A36C-1D6E0054CF1E}	Identify areas of interest
Vegetation management pre-clear regional ecosystem map - version 12.02	Queensland Department of Environment and Science (2022) https://qldspatial.information.qld.gov.au/catalogue/custom/detail.page?fid={CB642237-0FB9-4F15-A27C-087987077FE8}	Identify areas of interest

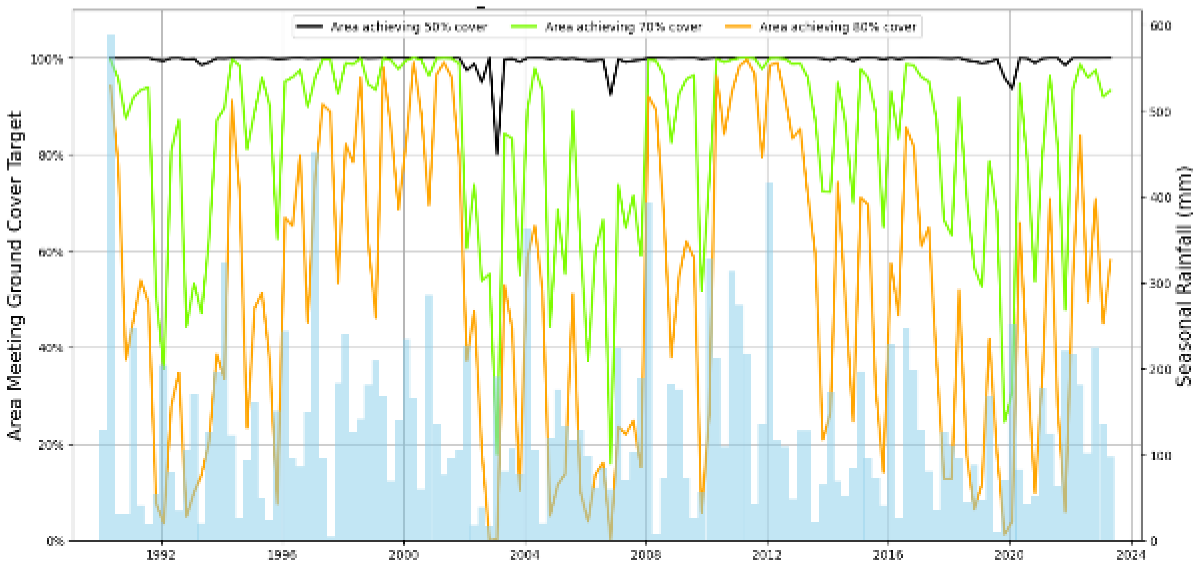
Name	Source	Use
Vegetation management regulated vegetation management map - version 6.06	Queensland Department of Resources (2023) https://qldspatial.information.qld.gov.au/catalogue/custom/detail.page?fid={9CC053EC-585B-4C41-A713-E1D04543CCC2}	Identify areas of interest
SLATS Site Potential (M) version 2.0	Queensland Department of Environment and Science (2022) For details on how it is derived, see Stephen H. Roxburgh, Senani B. Karunaratne, Keryn I. Paul, Richard M. Lucas, John D. Armston, Jingyi Sun, A revised above-ground maximum biomass layer for the Australian continent, Forest Ecology and Management, Volume 432, 2019, Pages 264-275, ISSN 0378-1127, https://doi.org/10.1016/j.foreco.2018.09.011	Identify areas of interest
SLATS Time Since Cleared	Queensland Department of Environment and Science (2022) Unpublished – derived from standard SLATS 1991–2018 clearing layers	Identify areas of interest
SLATS Age since disturbed (areas currently woody)	Queensland Department of Environment and Science (2022) Unpublished – derived from standard SLATS 1991–2018 clearing layers	Identify areas of interest
SLATS above ground tree biomass (t/h)	Queensland Department of Environment and Science (2022) Unpublished – derived from age since disturbed and site potential using the FullCAM Method	Identify areas of interest
SLATS Sentinel-2 - 2020 Foliage Projective Cover (FPC) - Queensland	Queensland Department of Environment and Science (2022) https://qldspatial.information.qld.gov.au/catalogue/custom/detail.page?fid={3B9CFF51-5302-4552-8786-60EF6C429583}	Identify areas of interest; Detect where regrowth of native forest had been suppressed below forest cover levels (<20% foliage projective cover) for at least 10 years
National Forest and Sparse Woody Vegetation Data Version 6.0	Department of Industry, Science, Energy and Resources (2022) https://data.gov.au/data/dataset/national-forest-and-sparse-woody-vegetation-data-version-6-0-2021-release	Detect where regrowth of native forest had been suppressed below forest cover levels (<20% foliage projective cover) for at least 10 years

9.5 CIBO Labs Example Forest Carbon Stock

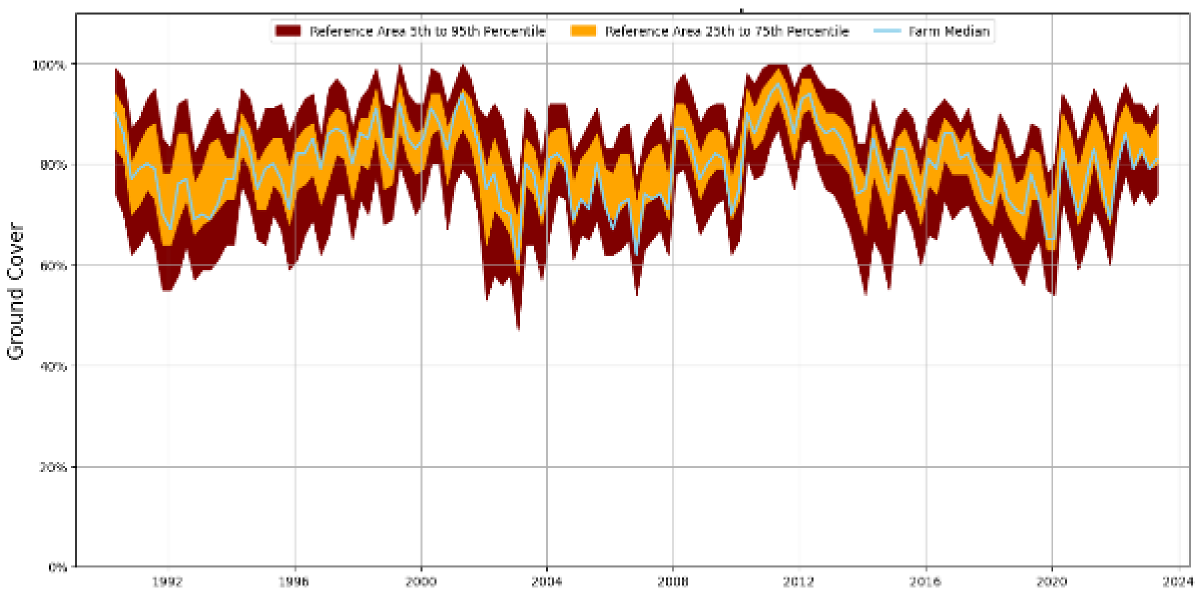
9.6 CIBO Labs Example Woody Cover Change



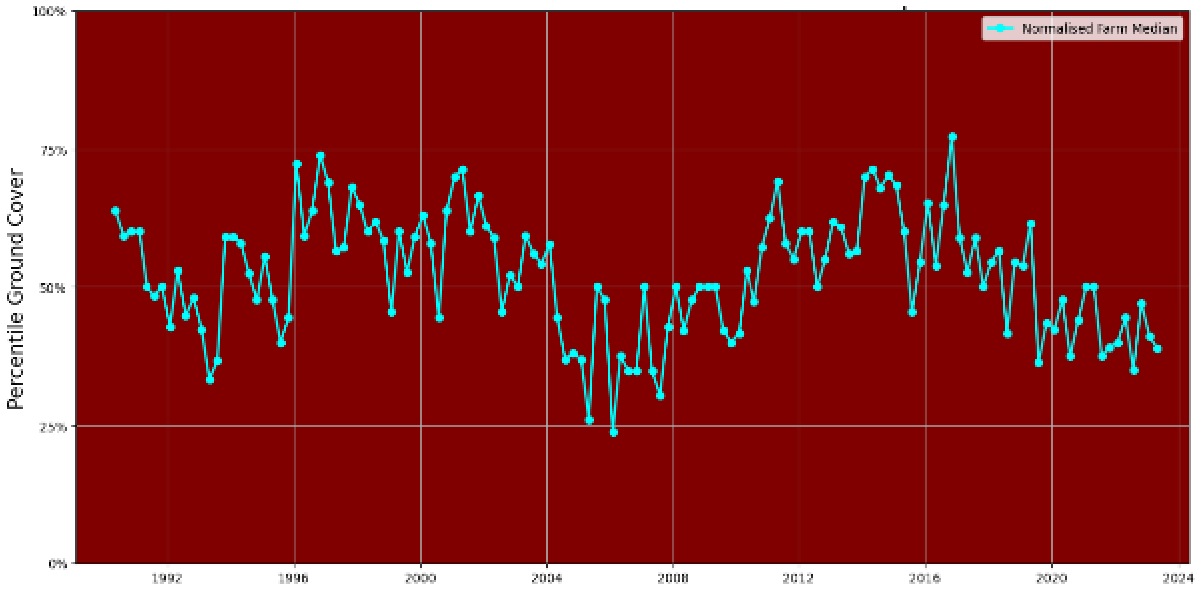
9.7 CIBO Labs Example Ground Cover Targets



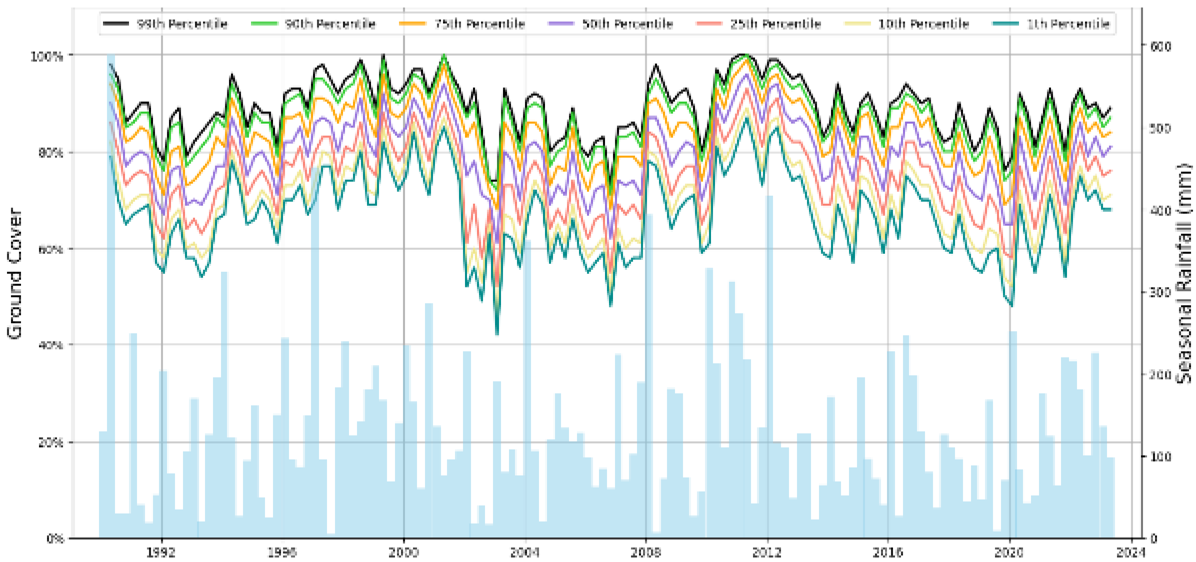
9.8 CIBO Labs Example Ground Cover Benchmarked



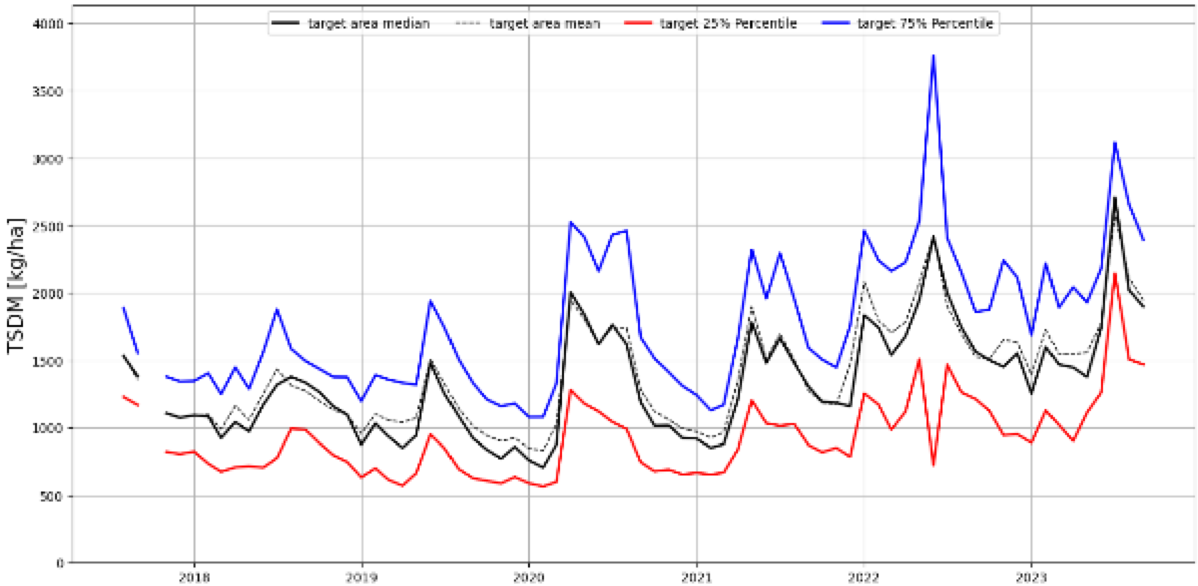
9.9 CIBO Labs Example Ground Cover Normalised Benchmark



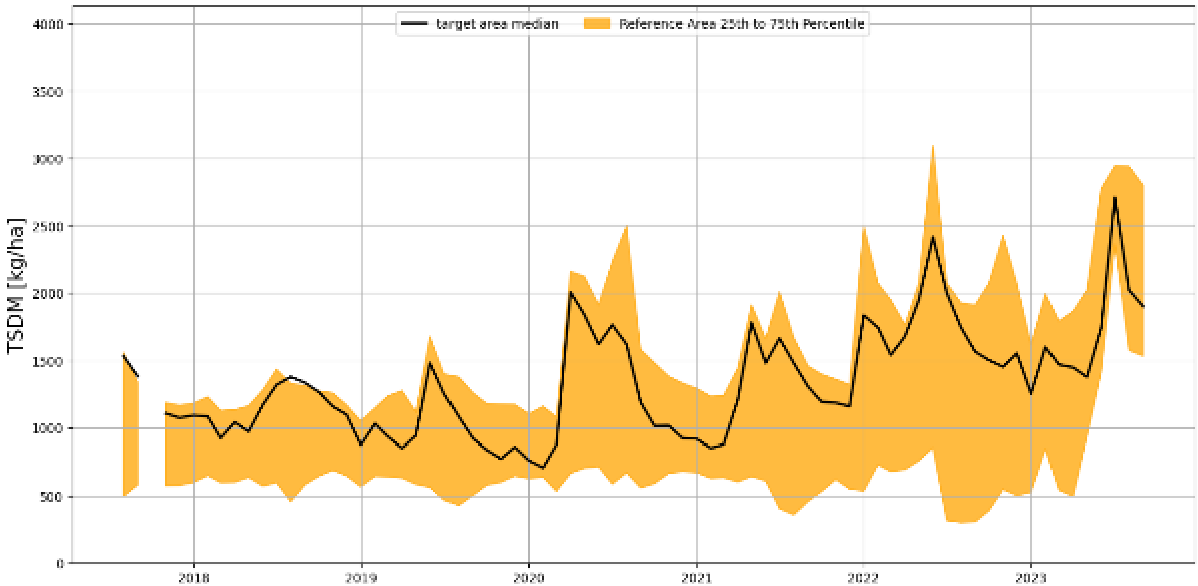
9.10 CIBO Labs Example Ground Cover Percentile Coverage



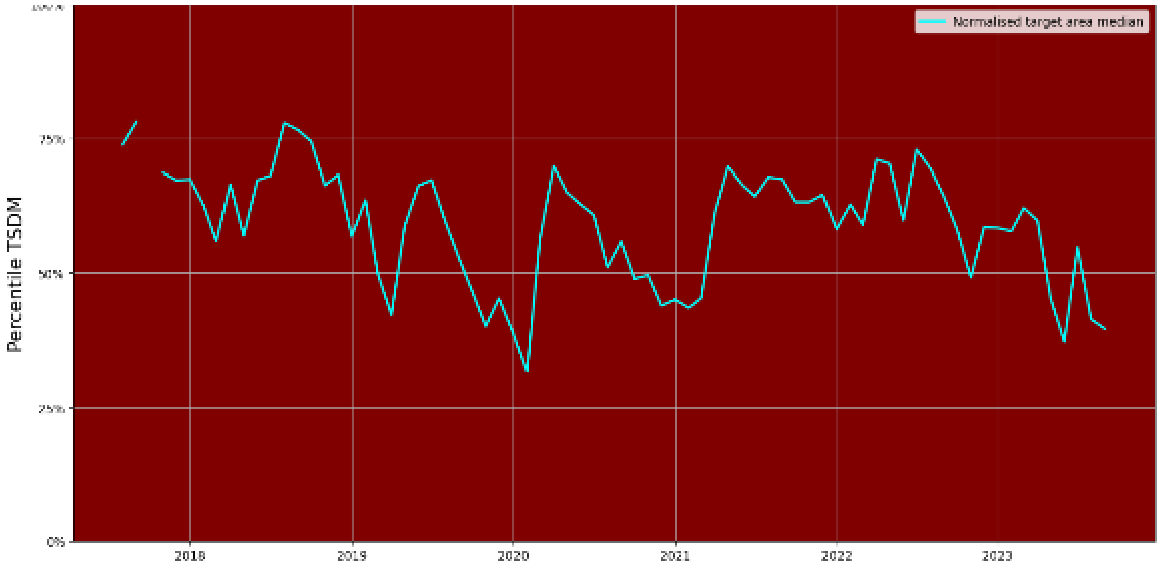
9.11 CIBO Labs Example Total Standing Dry Matter



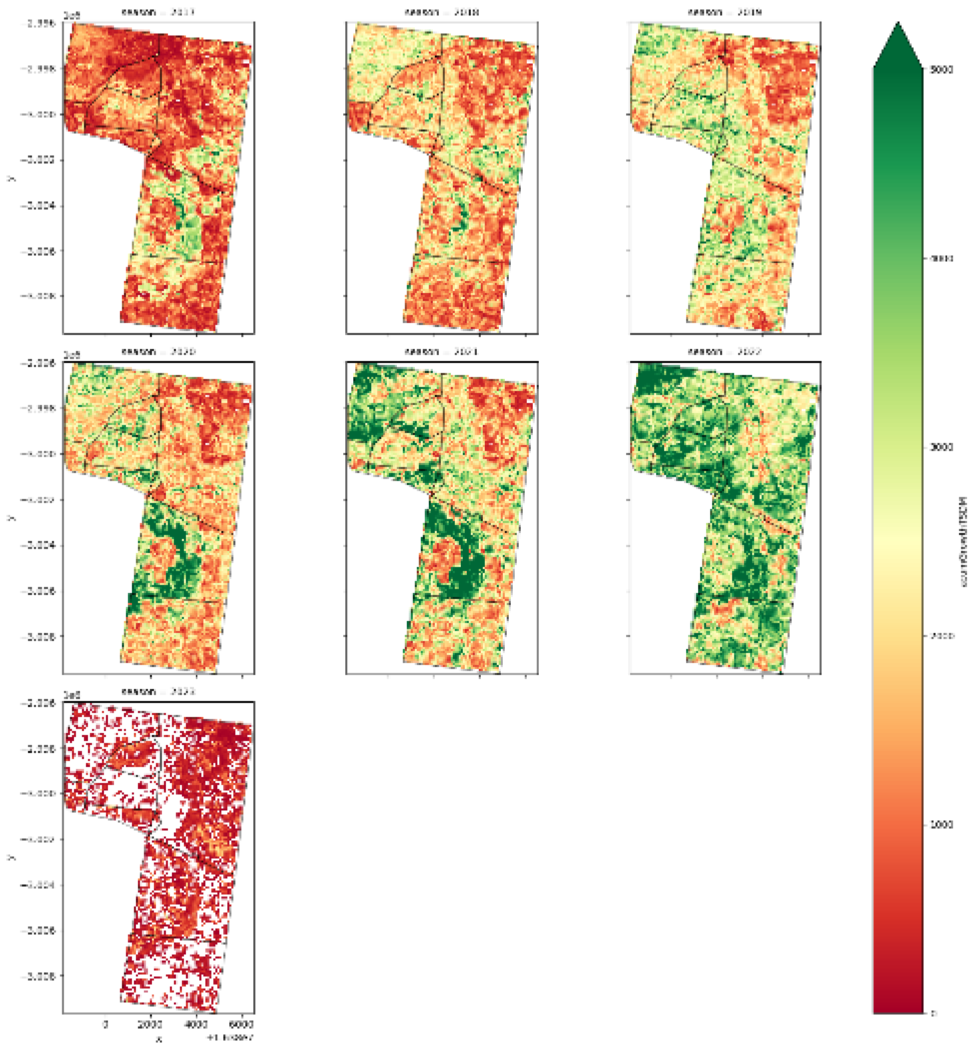
9.12 CIBO Labs Example Total Standing Dry Matter Benchmarked



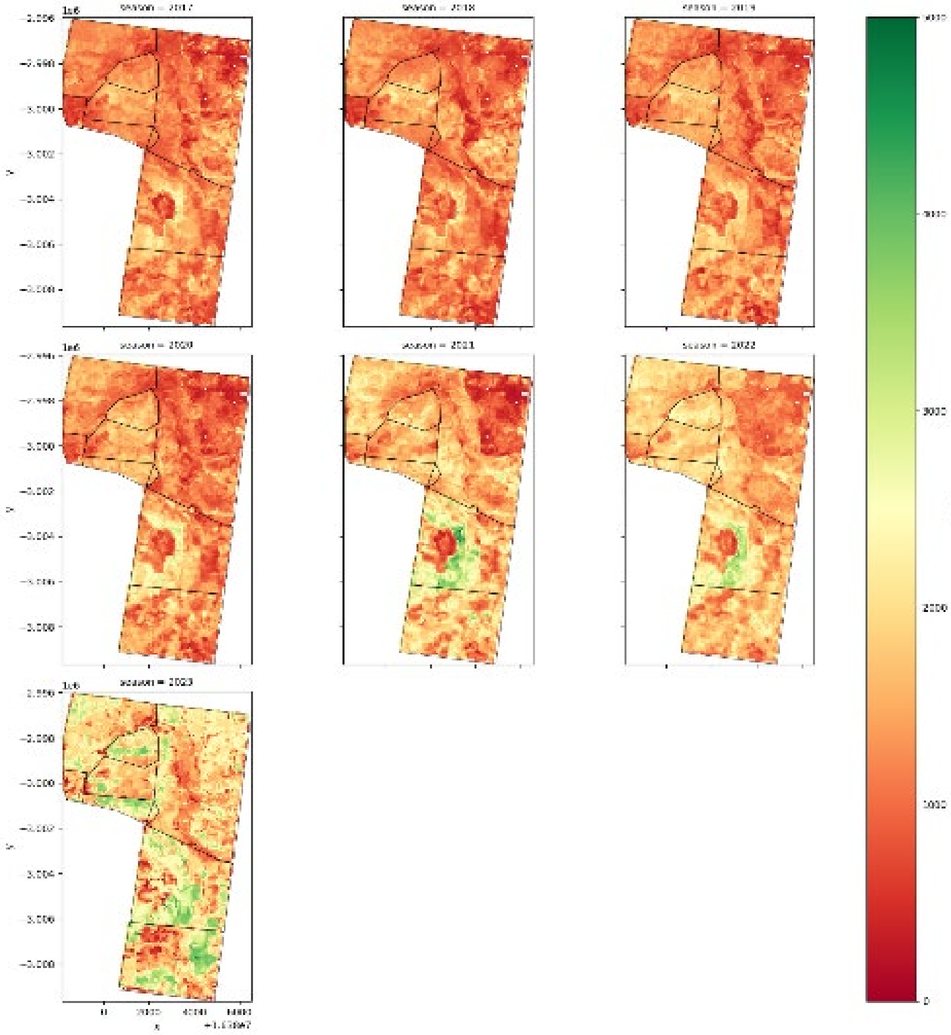
9.13 CIBO Labs Example Total Standing Dry Matter Normalised Benchmark



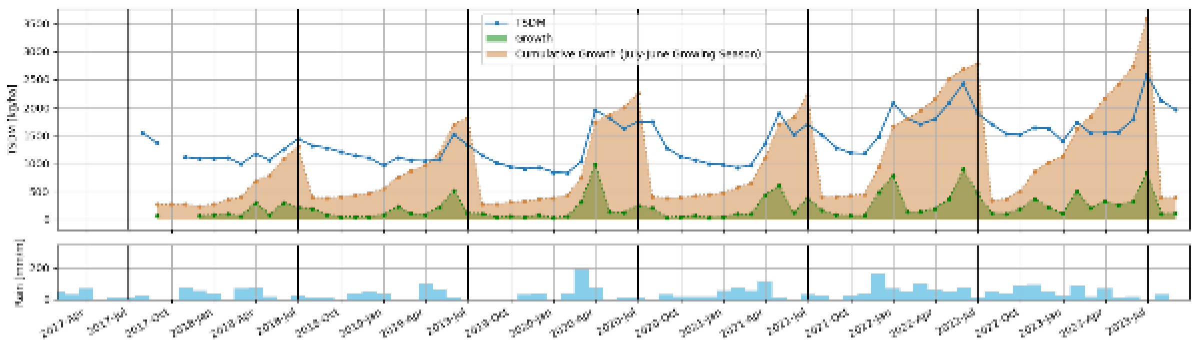
9.14 CIBO Labs Example Cumulative Dry Matter Growth



9.15 CIBO Labs Example Total Dry Matter



9.16 CIBO Labs Example Total Standing Dry Matter Normalised Benchmark



9.17 Potential for soil carbon sequestration in Northern Australian grazing lands: A review of the evidence report

https://futurebeef.com.au/resources/soil-carbon-sequestration-in-northern-grazing-lands/

9.18 Caveats to Stocktake data

StockTake Database Landtypes export file for median Growth 2014. Caveats identified by John Carter - DES

a) The GRASP modelled pasture growth data for a given tree density has been developed from relatively few field measurement studies within Queensland.

b) The GRASP modelled relationships between pasture growth and tree density are general in nature (given the broad spatial extrapolation) and may not reflect a range of site-specific factors that affect tree-grass competition such as soil depth / access to deeper layers of soil water which change the impact of trees on pasture growth.

c) The GRASP modelled relationship between pasture growth and tree density always results in trees as having a negative impact on pasture growth yet trees that are spatially arranged in the landscape or even low-density levels of trees may have a positive impact on pasture production which is not reflected in the GRASP modelling. (Tables produced after 2014, include some adjustment for tree induced microclimate effects impacting pasture growth, but do not fully capture the positive effects of trees).

d) The tables contain pasture production estimates for tree densities that often don't exist in reality (e.g., high tree densities for low rainfall environments, maximum tree basal areas too low for some wet areas). In addition, the table suffers from too few tree density classes to adequately characterise tree density effects on pasture growth in some systems.

9.19 Central Queensland average BioCondition score by grazing business and assessment unit

Grazing business ID	Assessment unit	Number of sites assessed	Average BioCondition score (%)	Average BioCondition score excluding landscape attributes (%)
1	Brigalow remnant	3	62	68
	Brigalow old regrowth (> 15 years)	0	-	-
	Brigalow young regrowth (< 15 years)	2	33	41
	Brigalow cleared pastures AB grazing land condition	3	6	6
	Brigalow cleared pastures CD grazing land condition	0	-	-
	Brigalow Leucaena-grass pastures	2	9	10
2	Brigalow remnant	0	-	-
	Brigalow old regrowth (> 15 years)	4	54	58
	Brigalow young regrowth (< 15 years)	3	27	33
	Brigalow cleared pastures AB grazing land condition	4	14	16
	Brigalow cleared pastures CD grazing land condition	0	-	-
	Brigalow Leucaena-grass pastures	1	10	13
3	Brigalow remnant	5	63	77
	Brigalow old regrowth (> 15 years)	4	46	54
	Brigalow young regrowth (< 15 years)	1	32	39
	Brigalow cleared pastures AB grazing land condition	2	22	28
	Brigalow cleared pastures CD grazing land condition	0	-	-
	Brigalow Leucaena-grass pastures	2	13	16

9.20 Central Queensland native flora data by grazing business and assessment unit.

Grazing business ID	Assessment unit	Number of sites assessed	Native forbes (and other species) species richness	Native grass species richness	Native shrub species richness	Native tree species richness	Number of unique native species
1	Brigalow remnant	3	27	17	16	23	83
	Brigalow old regrowth (> 15 years)	0	-	-	-	-	-
	Brigalow young regrowth (< 15 years)	2	14	5	3	7	29
	Brigalow cleared pastures AB grazing land condition	3	5	0	9	6	20
	Brigalow cleared pastures CD grazing land condition	0	-	-	-	-	-
	Brigalow Leucaena-grass pastures	2	6	0	3	2	11
	Number of unique sites/native species	*10*	*37*	*17*	*21*	*27*	*102*
2	Brigalow remnant	0	-	-	-	-	-
	Brigalow old regrowth (> 15 years)	4	10	2	13	15	40
	Brigalow young regrowth (< 15 years)	3	14	0	8	8	30
	Brigalow cleared pastures AB grazing land condition	4	14	1	8	6	29
	Brigalow cleared pastures CD grazing land condition	0	-	-	-	-	-
	Brigalow Leucaena-grass pastures	1	1	0	1	0	2
	Number of unique sites/native species	*12*	*27*	*3*	*16*	*19*	*65*
3	Brigalow remnant	5	27	11	12	16	66
	Brigalow old regrowth (> 15 years)	4	32	11	9	12	64
	Brigalow young regrowth (< 15 years)	1	3	3	4	4	14
	Brigalow cleared pastures AB grazing land condition	2	9	4	2	3	18
	Brigalow cleared pastures CD grazing land condition	0	-	-	-	-	-
	Brigalow Leucaena-grass pastures	2	10	7	2	0	19
	Number of unique sites/native species	*14*	*53*	*20*	*17*	*16*	*106*
Overall number of unique sites/native species		**36**	**76**	**32**	**33**	**39**	**180**

9.21 Central Queensland native fauna data by grazing business and assessment unit.

Grazing business ID	Assessment unit	Number of sites assessed	Native mammal species richness	Native bird species richness
1	Brigalow remnant	3	10	54
	Brigalow old regrowth (> 15 years)	0	-	-
	Brigalow young regrowth (< 15 years)	2	3	36
	Brigalow cleared pastures AB grazing land condition	3	6	29
	Brigalow cleared pastures CD grazing land condition	0	-	-
	Brigalow Leucaena-grass pastures	2	2	22
	Number of unique sites/native species	*10*	*10*	*68*
2	Brigalow remnant	0	-	-
	Brigalow old regrowth (> 15 years)	4	11	42
	Brigalow young regrowth (< 15 years)	3	7	34
	Brigalow cleared pastures AB grazing land condition	4	5	37
	Brigalow cleared pastures CD grazing land condition	0	-	-
	Brigalow Leucaena-grass pastures	1	0	6
	Number of unique sites/native species	*12*	*12*	*70*
3	Brigalow remnant	5	8	52
	Brigalow old regrowth (> 15 years)	4	7	53
	Brigalow young regrowth (< 15 years)	0	-	-
	Brigalow cleared pastures AB grazing land condition	2	2	19
	Brigalow cleared pastures CD grazing land condition	0	-	-
	Brigalow Leucaena-grass pastures	1	2	16
	Number of unique sites/native species	*12*	*10*	*72*
Overall number of unique sites/native species		**34**	**14**	**113**

9.22 Southwest Queensland average BioCondition score by grazing business and assessment unit.

Grazing business ID	Assessment unit	Number of sites assessed	Average BioCondition score (%)	Average BioCondition score excluding landscape attributes (%)
4	Brigalow remnant	2	69	72
	Brigalow old regrowth (> 15 years)	0	-	-
	Brigalow young regrowth (< 15 years)	1	28	35
	Brigalow cleared pastures AB grazing land condition	1	20	22
	Brigalow cleared pastures CD grazing land condition	0	-	-
	Soft Mulga remnant	1	86	88
	Soft Mulga selective fodder harvesting	0	-	-
	Soft Mulga regrowth (<15 years)	2	50	61
	Soft Mulga cleared pasture AB grazing land condition	0	-	-
	Soft Mulga cleared pasture CD grazing land condition	1	46	53
5	Brigalow remnant	2	68	80
	Brigalow old regrowth (> 15 years)	0	-	-
	Brigalow young regrowth (< 15 years)	1	35	41
	Brigalow cleared pastures AB grazing land condition	0	-	-
	Brigalow cleared pastures CD grazing land condition	1	25	29
	Soft Mulga remnant	1	79	88
	Soft Mulga selective fodder harvesting	3	66	69
	Soft Mulga regrowth (<15 years)	0	-	-
	Soft Mulga cleared pasture AB grazing land condition	2	21	26
	Soft Mulga cleared pasture CD grazing land condition	1	35	41

Grazing business ID	Assessment unit	Number of sites assessed	Average BioCondition score (%)	Average BioCondition score excluding landscape attributes (%)
6	Brigalow remnant	4	72	80
	Brigalow old regrowth (> 15 years)	0	-	-
	Brigalow young regrowth (< 15 years)	4	38	44
	Brigalow cleared pastures AB grazing land condition	2	30	35
	Brigalow cleared pastures CD grazing land condition	2	34	41
	Soft Mulga remnant	3	83	85
	Soft Mulga selective fodder harvesting	1	69	81
	Soft Mulga regrowth (<15 years)	2	60	73
	Soft Mulga cleared pasture AB grazing land condition	2	36	42
	Soft Mulga cleared pasture CD grazing land condition	2	39	44
7	Brigalow remnant	1	80	80
	Brigalow old regrowth (> 15 years)	0	-	-
	Brigalow young regrowth (< 15 years)	1	39	43
	Brigalow cleared pastures AB grazing land condition	1	19	21
	Brigalow cleared pastures CD grazing land condition	0	-	-
	Soft Mulga remnant	3	78	81
	Soft Mulga selective fodder harvesting	2	71	67
	Soft Mulga regrowth (<15 years)	2	57	61
	Soft Mulga cleared pasture AB grazing land condition	0	-	-
	Soft Mulga cleared pasture CD grazing land condition	0	-	-

9.23 Southwest Queensland native flora data by grazing business and assessment unit.

Grazing business ID	Assessment unit	Number of sites assessed	Native forbes (and other species) species richness	Native grass species richness	Shrub species richness	Tree species richness	Number of unique native species
4	Brigalow remnant	2	16	12	7	10	45
	Brigalow old regrowth (> 15 years)	0	-	-	-	-	-
	Brigalow young regrowth (< 15 years)	1	3	3	3	5	14
	Brigalow cleared pastures AB grazing land condition	1	4	0	1	1	6
	Brigalow cleared pastures CD grazing land condition	0	-	-	-	-	-
	Soft Mulga remnant	1	13	9	5	8	35
	Soft Mulga selective fodder harvesting	0	-	-	-	-	-
	Soft Mulga regrowth (<15 years)	2	16	13	5	8	42
	Soft Mulga cleared pasture AB grazing land condition	0	-	-	-	-	-
	Soft Mulga cleared pasture CD grazing land condition	1	6	8	6	3	23
	Number of unique sites/native species	*8*	*33*	*28*	*17*	*23*	*101*
5	Brigalow remnant	2	21	11	11	11	54
	Brigalow old regrowth (> 15 years)	0	-	-	-	-	-
	Brigalow young regrowth (< 15 years)	1	10	5	4	5	24
	Brigalow cleared pastures AB grazing land condition	0	-	-	-	-	-
	Brigalow cleared pastures CD grazing land condition	1	18	5	0	1	24
	Soft Mulga remnant	1	11	5	4	6	26
	Soft Mulga selective fodder harvesting	3	17	10	8	14	49
	Soft Mulga regrowth (<15 years)	0	-	-	-	-	-
	Soft Mulga cleared pasture AB grazing land condition	2	14	5	0	7	26
	Soft Mulga cleared pasture CD grazing land condition	1	8	6	1	2	17
	Number of unique sites/native species	*11*	*53*	*26*	*14*	*23*	*116*

Grazing business ID	Assessment unit	Number of sites assessed	Native forbes (and other species) species richness	Native grass species richness	Native shrub species richness	Native tree species richness	Number of unique native species
6	Brigalow remnant	4	30	19	12	14	75
	Brigalow old regrowth (> 15 years)	0	-	-	-	-	-
	Brigalow young regrowth (< 15 years)	4	29	13	9	7	58
	Brigalow cleared pastures AB grazing land condition	2	8	5	3	5	21
	Brigalow cleared pastures CD grazing land condition	2	20	12	1	2	35
	Soft Mulga remnant	3	22	14	2	3	41
	Soft Mulga selective fodder harvesting	1	5	11	5	3	24
	Soft Mulga regrowth (<15 years)	2	8	10	2	4	24
	Soft Mulga cleared pasture AB grazing land condition	2	13	10	2	4	29
	Soft Mulga cleared pasture CD grazing land condition	2	15	11	2	1	29
	Number of unique sites/native species	*22*	*65*	*40*	*19*	*17*	*141*
7	Brigalow remnant	1	7	4	4	4	19
	Brigalow old regrowth (> 15 years)	0	-	-	-	-	-
	Brigalow young regrowth (< 15 years)	1	6	8	3	2	19
	Brigalow cleared pastures AB grazing land condition	1	7	4	1	1	13
	Brigalow cleared pastures CD grazing land condition	0	-	-	-	-	-
	Soft Mulga remnant	3	14	16	6	6	42
	Soft Mulga selective fodder harvesting	2	11	12	1	6	30
	Soft Mulga regrowth (<15 years)	2	15	10	4	6	35
	Soft Mulga cleared pasture AB grazing land condition	0	-	-	-	-	-
	Soft Mulga cleared pasture CD grazing land condition	0	-	-	-	-	-
	Number of unique sites/native species	*10*	*34*	*29*	*12*	*9*	*84*
Overall number of unique sites/native species		**51**	**95**	**54**	**33**	**32**	**214**

9.24 Southwest Queensland native fauna data by grazing business and assessment unit.

Grazing business ID	Assessment unit	Number of sites assessed	Native bird species richness
4	Brigalow remnant	2	27
	Brigalow old regrowth (> 15 years)	0	-
	Brigalow young regrowth (< 15 years)	1	9
	Brigalow cleared pastures AB grazing land condition	1	10
	Brigalow cleared pastures CD grazing land condition	0	-
	Soft Mulga remnant	1	16
	Soft Mulga selective fodder harvesting	0	-
	Soft Mulga regrowth (<15 years)	2	27
	Soft Mulga cleared pasture AB grazing land condition	0	-
	Soft Mulga cleared pasture CD grazing land condition	1	18
	Number of unique sites/native species	*8*	*47*
5	Brigalow remnant	2	14
	Brigalow old regrowth (> 15 years)	0	-
	Brigalow young regrowth (< 15 years)	1	15
	Brigalow cleared pastures AB grazing land condition	0	-
	Brigalow cleared pastures CD grazing land condition	1	12
	Soft Mulga remnant	1	18
	Soft Mulga selective fodder harvesting	3	21
	Soft Mulga regrowth (<15 years)	0	-
	Soft Mulga cleared pasture AB grazing land condition	2	10
	Soft Mulga cleared pasture CD grazing land condition	1	11
	Number of unique sites/native species	*11*	*45*

Grazing business ID	Assessment unit	Number of sites assessed	Native bird species richness
6	Brigalow remnant	4	37
	Brigalow old regrowth (> 15 years)	0	-
	Brigalow young regrowth (< 15 years)	4	21
	Brigalow cleared pastures AB grazing land condition	2	21
	Brigalow cleared pastures CD grazing land condition	2	9
	Soft Mulga remnant	3	40
	Soft Mulga selective fodder harvesting	1	11
	Soft Mulga regrowth (<15 years)	2	14
	Soft Mulga cleared pasture AB grazing land condition	2	13
	Soft Mulga cleared pasture CD grazing land condition	2	17
	Number of unique sites/native species	*22*	*78*
7	Brigalow remnant	1	32
	Brigalow old regrowth (> 15 years)	0	-
	Brigalow young regrowth (< 15 years)	1	20
	Brigalow cleared pastures AB grazing land condition	1	19
	Brigalow cleared pastures CD grazing land condition	0	-
	Soft Mulga remnant	3	29
	Soft Mulga selective fodder harvesting	2	45
	Soft Mulga regrowth (<15 years)	2	26
	Soft Mulga cleared pasture AB grazing land condition	0	-
	Soft Mulga cleared pasture CD grazing land condition	0	-
	Number of unique sites/native species	*10*	*69*
Overall number of unique sites/native species		**51**	**96**

9.25 Flora and fauna species identified on Central Queensland grazing properties

Native flora

Abutilon calliphyllum
Abutilon otocarpum
Abutilon oxycarpum
Acacia blakei subsp. *blakei*
Acacia excelsa
Acacia harpophylla
Acacia leiocalyx subsp. *leiocalyx*
Acacia macradenia
Acacia oswaldii
Acacia podalyriifolia
Acacia salicina
Acalypha eremorum
Achyranthes asperaBra
Aeschynomene brevifolia
Alectryon diversifolius
Allocasuarina luehmannii
Alphitonia excelsa
Alstonia constricta
Alternanthera denticulata
Alternanthera nana
Amaranthus interruptus
Amyema quandang var. *bancroftii*
Amyema quandang var. *quandang*
Ancistrachne uncinulata
Aristida calycina var. *calycina*
Aristida holathera var. *holathera*
Aristida leptopoda
Aristida queenslandica var. *dissimilis*
Arundinella nepalensis
Atalaya hemiglauca
Backhousia angustifolia
Bertya pedicellata
Boerhavia dominii
Bothriochloa bladhii subsp. *bladhii*
Bothriochloa decipiens var. *decipiens*
Brachychiton australis
Brachychiton rupestris
Brachyscome dentata
Brunoniella australis
Calandrinia pickeringii
Calotis cuneata
Calotis cuneifolia
Capparis arborea
Capparis canescens
Capparis loranthifolia var. *bancroftii*
Capparis mitchellii
Capparis sarmentosa
Carex inversa
Carissa ovata
Cassia tomentella
Casuarina cristata
Cheilanthes sieberi subsp. *sieberi*
Chloris divaricata
Chloris pectinata
Chloris ventricosa
Citrus glauca
Cleistochloa subjuncea
Clematicissus opaca
Clerodendrum floribundum
Codonocarpus attenuatus
Commelina diffusa
Corchorus tomentellus
Corymbia trachyphloia subsp. *trachyphloia*
Croton insularis
Croton phebalioides
Cyanthillium cinereum
Cymbopogon refractus
Cyperus fulvus
Cyperus gracilis
Dactylymenia laingii
Denhamia cunninghamii
Denhamia oleaster
Denhamia parvifolia
Desmodium brachypodum
Dianella caerulea
Dianella revoluta
Dichanthium sericeum subsp. *sericeum*
Digitaria brownii
Digitaria diffusa
Digitaria divaricatissima
Dinebra decipiens
Diospyros humilis
Dipteracanthus australasicus subsp. *corynothecus*
Ehretia membranifolia
Einadia nutans
Elaeodendron australe var. *integrifolium*
Enchylaena tomentosa
Enneapogon lindleyanus
Enneapogon truncatus
Enteropogon paucispiceus
Eragrostis alveiformis
Eremophila debilis
Eremophila mitchellii
Eriochloa procera
Eriochloa pseudoacrotricha
Erythroxylum sp. (Splityard Creek L.Pedley 5360)
Eucalyptus crebra
Eucalyptus populnea
Euphorbia dallachyana
Euphorbia tannensis subsp. *eremophila*
Eustrephus latifolius
Everistia vacciniifolia
Evolvulus alsinoides
Flueggea leucopyrus
Geijera parviflora
Glinus lotoides
Glycine clandestina
Glycine tabacina
Goodenia glabra

Grevillea striata
Grewia latifolia
Heteropogon contortus
Hibiscus vitifolius
Indigofera colutea
Ipomoea plebeia
Jasminum didymum subsp. *racemosum*
Jasminum simplicifolium subsp. *australiense*
Juncus usitatus
Lepidium africanum
Lobelia concolor
Lomandra confertifolia subsp. *pallida*
Lysiana subfalcata
Lysiphyllum carronii
Lysiphyllum hookeri
Maireana microphylla
Malvastrum americanum var. *stellatum*
Melaleuca bracteata
Melaleuca lanceolata
Melaleuca squamophloia
Melia azedarach
Murdannia graminea
Neptunia gracilis forma gracilis
Nyssanthes erecta
Oplismenus aemulus
Owenia acidula
Owenia venosa
Panicum decompositum var. *decompositum*
Panicum effusum
Parsonsia eucalyptophylla
Parsonsia lanceolata
Paspalidium caespitosum
Paspalidium distans
Phyllanthus virgatus
Pithocarpa cordata
Pittosporum spinescens
Pittosporum viscidum
Planchonella cotinifolia var. *pubescens*
Plantago cunninghamii
Portulaca pilosa
Pseuderanthemum variabile
Psydrax odorata
Pterocaulon ciliosum
Rhagodia spinescens
Rhynchosia minima
Rostellularia adscendens
Salsola australis
Santalum lanceolatum
Scleria mackaviensis
Sclerolaena tetracuspis
Secamone elliptica
Senecio brigalowensis
Senna artemisioides subsp. *zygophylla*
Senna coronilloides
Sesbania cannabina var. *cannabina*
Sida corrugata
Sida hackettiana
Sida sp. (Charters Towers E.J.THompson+ CHA456)
Solanum ellipticum
Solanum mitchellianum
Solanum parvifolium subsp. *parvifolium*
Spermacoce multicaulis
Sporobolus caroli
Tetragonia tetragonoides
Trianthema triquetra
Tribulus micrococcus
Turraea pubescens
Verbena africana
Vittadinia pterochaeta
Vittadinia sulcata
Walwhalleya subxerophila
Zaleya galericulata subsp. *galericulata*

Non-native flora (excluding 3P species)

Abildgaardia vaginata
Alectryon oleifolius
Alternanthera pungens
Apophyllum anomalum
Chloris inflata
Cirsium vulgare
Corchorus trilocularis
Crotalaria incana subsp. *incana*
Cyperus concinnus
Echinochloa crus-galli
Eragrostis cilianensis
Glandularia aristigera
Gomphocarpus physocarpus
Gomphrena celosioides
Indigofera brevidens
Lepidium bonariense
Leucaena leucocephala subsp. *leucocephala*
Malvastrum coromandelianum
Marsdenia micradenia
Marsdenia microlepis
Marsdenia viridiflora subsp. *viridiflora*
Melinis repens
Notelaea microcarpa
Opuntia aurantiaca
Opuntia leucotricha
Opuntia streptacantha
Opuntia stricta
Opuntia tomentosa
Parsonsia straminea
Phyla canescens
Physalis lanceifolia
Plectranthus parviflorus
Portulaca oleracea
Rivina humilis
Salvia reflexa
Schkuhria pinnata
Setaria pumila subsp. *pumila*
Sida spinosa
Sonchus oleraceus
Urochloa mosambicensis
Urochloa panicoides var. *panicoides*

Verbesina encelioides var. *encelioides*
Xanthium occidentale
Zinnia peruviana
Zygophyllum apiculatum

Non-native 3P flora

Cenchrus ciliaris
Clitoria ternatea
Leucaena leucocephala
Megathyrsus maximus var. *pubiglumis*
Panicum antidotale
Stylosanthes scabra
Trifolium glomeratum
Trifolium repens var. *repens*

Native mammal species

Aepyprymnus rufescens
Macropus dorsalis
Macropus giganteus
Macropus parryi
Macropus robustus
Macropus rufogriseus
Perameles nasuta
Pseudomys patrius
Rattus fuscipes
Sminthopsis crassicaudata
Sminthopsis macroura
Sminthopsis murina
Tachyglossus aculeatus
Trichosurus vulpecula

Exotic mammal species

Mus musculus
Oryctolagus cuniculus

Native bird species

Acanthagenys rufogularis
Acanthiza apicalis
Acanthiza chrysorrhoa
Acanthiza nana
Accipiter cirrhocephalus
Alectura lathami
Alisterus scapularis
Anthus cervinus
Anthus novaeseelandiae
Antigone rubicunda
Aprosmictus erythropterus
Aquila audax
Ardeotis australis
Artamus cinereus
Artamus personatus
Artamus superciliosus
Cacatua galerita
Cacatua sanguinea
Cacomantis flabelliformis
Cacomantis pallidus
Calyptorhynchus banksii
Centropus phasianinus
Chalcites basalis
Chalcites osculans
Cincloramphus mathewsi
Circus assimilis
Cisticola exilis
Colluricincla harmonica
Coracina maxima
Coracina novaehollandiae
Coracina tenuirostris
Corcorax melanorhamphos
Corvus orru
Coturnix ypsilophora
Cracticus nigrogularis
Cracticus torquatus
Cryptoblepharus pulcher
Dacelo novaeguineae
Dicaeum hirundinaceum
Dicrurus bracteatus
Dromaius novaehollandiae
Elanus axillaris
Entomyzon cyanotis
Eolophus roseicapillus
Eopsaltria australis
Eudynamys orientalis
Eurystomus orientalis
Falco berigora
Falco cenchroides
Geopelia humeralis
Geopelia striata
Gerygone olivacea
Grallina cyanoleuca
Grantiella picta
Gymnorhina tibicen
Gymnorhina tibicen dorsalis
Haliastur sphenurus
Hirundapus caudacutus
Hirundo neoxena
Isoodon macrourus
Lalage leucomela
Lalage tricolor
Lichenostomus virescens
Lichmera indistincta
Malurus cyaneus
Malurus lamberti
Malurus melanocephalus
Manorina flavigula
Manorina melanocephala
Meliphaga lewinii
Merops ornatus
Mirafra javanica
Morelia spilota
Myiagra inquieta
Myiagra rubecula
Myzomela sanguinolenta
Nymphicus hollandicus
Ocyphaps lophotes
Oriolus sagittatus
Pachycephala olivacea
Pachycephala rufiventris
Pardalotus striatus
Petrochelidon nigricans
Phaps chalcoptera
Philemon citreogularis
Philemon corniculatus
Platycercus adscitus
Plectorhyncha lanceolata
Podargus strigoides
Pomatostomus temporalis
Pomatostomus temporalis temporalis
Psephotus haematonotus

Ptilonorhynchus maculata
Pyrrholaemus sagittatus
Rhipidura fuliginosa
Rhipidura leucophrys
Scythrops novaehollandiae
Sericulus chrysocephalus
Smicrornis brevirostris
Sphecotheres vieilloti
Strepera graculina
Struthidea cinerea
Taeniopygia bichenovii
Taeniopygia guttata
Threskiornis spinicollis
Trichoglossus chlorolepidotus
Trichoglossus haematodus
Turnix varius
Tyto javanica
Vanellus tricolor
Wallabia bicolor
Zosterops lateralis

Exotic bird species

Acridotheres tristis
Streptopelia chinensis

9.26 Flora and fauna species identified on Southwest Queensland grazing properties

Native flora

Abutilon fraseri
Abutilon leucopetalum
Abutilon malvifolium
Abutilon oxycarpum var. *incanum*
Abutilon oxycarpum var. *subsagittatum*
Acacia aneura
Acacia excelsa
Acacia harpophylla
Acacia longispicata
Acacia sparsiflora
Acalypha eremorum
Alectryon diversifolius
Alectryon oleifolius
Alphitonia excelsa
Alstonia constricta
Alternanthera denticulata
Alternanthera nana
Amphipogon caricinus
Amyema congener
Amyema maidenii
Ancistrachne uncinulata
Archidendropsis basaltica
Aristida calycina
Aristida caput-medusae
Aristida jerichoensis
Aristida leptopoda
Aristida platychaeta
Asteraceae
Astrebla elymoides
Astrebla lappacea
Astrebla pectinata
Astrebla squarrosa
Atalaya hemiglauca
Atriplex lindleyi subsp. *conduplicata*
Boerhavia dominii
Boraginaceae
Brachyachne convergens
Brachychiton populneus
Brachychiton rupestris
Brachychiton x turgidulus
Brunoniella australis
Bursaria incana
Calandrinia
Callitris glaucophylla
Calotis cuneata
Calotis cuneifolia
Calotis hispidula
Calotis lappulacea
Camptacra barbata
Capparis anomala
Capparis lasiantha
Capparis mitchellii
Carissa ovata
Cheilanthes sieberi
Chenopodiaceae
Chenopodium desertorum
Chloris divaricata
Chloris ventricosa
Chrysocephalum apiculatum
Citrus glauca
Codonocarpus attenuatus
Commelina diffusa
Convolvulaceae
Corymbia clarksoniana
Corymbia tessellaris
Crassula tetramera
Croton phebalioides
Cymbopogon obtectus
Cymbopogon refractus
Cynanchum viminale subsp. *brunonianum*
Cyperus fulvus
Cyperus gracilis
Dactyloctenium radulans
Daucus glochidiatus
Denhamia cunninghamii
Denhamia oleaster
Desmodium brachypodum
Desmodium varians
Dianella longifolia
Dichanthium sericeum
Digitaria brownii
Digitaria divaricatissima
Dinebra decipiens var. *asthenes*
Dinebra decipiens var. *peacockii*
Dissocarpus biflorus var. *cephalocarpus*
Dysphania carinata
Ehretia membranifolia
Einadia hastata
Einadia nutans
Einadia polygonoides
Enchylaena tomentosa
Enneapogon lindleyanus
Enteropogon acicularis
Enteropogon ramosus
Eragrostis brownii
Eragrostis elongata
Eragrostis lacunaria
Eragrostis megalosperma
Eremophila bowmanii
Eremophila deserti
Eremophila glabra
Eremophila latrobei
Eremophila longifolia
Eremophila mitchellii
Eriochloa pseudoacrotricha
Eucalyptus chloroclada
Eucalyptus melanophloia
Eucalyptus populnea
Eucalyptus thozetiana
Euphorbia drummondii
Euphorbia tannensis subsp. *eremophila*
Evolvulus alsinoides
Fimbristylis dichotoma
Flindersia maculosa
Geijera parviflora
Glycine

Goodenia fascicularis
Goodenia glabra
Grevillea striata
Hakea leucoptera
Hakea lorea
Hibiscus brachysiphonius
Hibiscus sturtii
Hydrocotyle acutiloba
Hypoestes floribunda
Iseilema vaginiflorum
Jasminum didymum
Leichhardtia viridiflora
Maireana enchylaenoides
Maireana microphylla
Melhania oblongifolia
Minuria integerrima
Monachather paradoxus
Neobassia proceriflora
Notelaea microcarpa
Nyssanthes erecta
Oxalis
Pandorea pandorana
Panicum decompositum
Panicum effusum
Parsonsia eucalyptophylla
Paspalidium caespitosum
Paspalidium constrictum
Paspalidium rarum
Paspalum
Perotis rara
Petalostigma pubescens
Phyllanthus carpentariae
Phyllanthus collinus
Phyllanthus fuernrohrii
Phyllanthus virgatus
Pittosporum angustifolium
Plantago debilis
Polymeria pusilla
Portulaca bicolor
Portulaca filifolia
Prostanthera suborbicularis
Pseuderanthemum variabile
Psydrax oleifolia
Pterocaulon sphacelatum
Ptilotus leucocoma
Ptilotus obovatus
Ptilotus polystachyus
Ranunculus sessiliflorus
Rhagodia spinescens
Rhaphidospora bonneyana
Rostellularia adscendens
Rutidosis helichrysoides
Salsola australis
Santalum lanceolatum
Sclerolaena anisacanthoides
Sclerolaena bicornis
Sclerolaena bicornis var. *horrida*
Sclerolaena birchii
Sclerolaena convexula
Sclerolaena muricata
Sclerolaena stelligera
Sclerolaena tricuspis
Senecio brigalowensis
Senna artemisioides subsp. *artemisioides*
Senna artemisioides subsp. *zygophylla*
Seringia collina
Setaria paspalidioides
Setaria surgens
Sida atherophora
Sida brachypoda
Sida cunninghamii
Sida fibulifera
Sida sp. (Musselbrook M.B.Thomas+ MRS437)
Sida trichopoda
Sigesbeckia orientalis
Solanum ellipticum
Solanum esuriale
Solanum ferocissimum
Solanum jucundum
Solanum parvifolium
Sporobolus actinocladus
Sporobolus caroli
Sporobolus contiguus
Sporobolus creber
Teucrium junceum
Teucrium puberulum
Themeda triandra
Thyridolepis mitchelliana
Trachymene ochracea
Tragus australianus
Trianthema triquetra
Tripogon loliiformis
Urochloa gilesii
Urochloa piligera
Urochloa pubigera
Ventilago viminalis
Vittadinia
Walwhalleya subxerophila

Non-native flora (excluding 3P species)

Chloris virgata
Cucumis myriocarpus subsp. *myriocarpus*
Eragrostis trichophora
Glandularia aristigera
Harrisia martinii
Malvastrum americanum
Megathyrsus maximus
Melinis repens
Opuntia stricta
Opuntia tomentosa
Portulaca oleracea
Portulaca pilosa
Salvia reflexa
Sonchus oleraceus
Urochloa mosambicensis

Non-native 3P flora

Cenchrus ciliaris

Native bird species

Acanthagenys rufogularis
Acanthiza apicalis
Acanthiza chrysorrhoa
Acanthiza nana
Acanthiza uropygialis

Accipiter cirrocephalus
Aegotheles cristatus
Anthus novaeseelandiae
Aprosmictus erythropterus
Apus pacificus
Aquila audax
Ardeotis australis
Artamus cinereus
Artamus minor
Artamus superciliosus
Barnardius zonarius
Cacomantis pallidus
Caligavis chrysops
Centropus phasianinus
Chalcites basalis
Cheramoeca leucosterna
Chlamydera maculata
Cincloramphus mathewsi
Cisticola exilis
Climacteris affinis
Colluricincla harmonica
Coracina maxima
Coracina novaehollandiae
Coracina papuensis
Corvus coronoides
Corvus orru
Coturnix ypsilophora
Cracticus nigrogularis
Cracticus torquatus
Dacelo novaeguineae
Daphoenositta chrysoptera
Dicaeum hirundinaceum
Dromaius novaehollandiae
Elanus axillaris
Emblema pictum
Entomyzon cyanotis
Eolophus roseicapilla
Eopsaltria australis
Falco berigora
Falco cenchroides
Gavicalis virescens
Geopelia humeralis
Gerygone fusca
Grallina cyanoleuca
Gymnorhina tibicen
Hirundo neoxena
Lalage tricolor
Lichmera indistincta
Lophochroa leadbeateri
Malurus assimilis
Malurus cyaneus
Malurus leucopterus
Manorina flavigula
Manorina melanocephala
Megalurus timoriensis
Melanodryas cucullata
Melithreptus brevirostris
Melopsittacus undulatus
Merops ornatus
Microeca fascinans
Mirafra javanica
Neochmia modesta
Ninox boobook
Northiella haematogaster
Nymphicus hollandicus
Ocyphaps lophotes
Oreoica gutturalis
Oriolus sagittatus
Pachycephala rufiventris
Pardalotus striatus
Petrochelidon ariel
Petrochelidon nigricans
Petroica goodenovii
Phaps chalcoptera
Philemon citreogularis
Philemon corniculatus
Platycercus adscitus
Plectorhyncha lanceolata
Pomatostomus temporalis
Pyrrholaemus sagittatus
Rhipidura albiscapa
Rhipidura leucophrys
Smicrornis brevirostris
Strepera graculina
Struthidea cinerea
Taeniopygia bichenovii
Taeniopygia guttata
Todiramphus sanctus
Trichoglossus moluccanus
Turnix varius
Turnix velox

Exotic bird species

Acridotheres trist

9.27 Wirra Accounting for Nature Information Statement

https://www.accountingfornature.org/auacc45?rq=Wirra

9.28 Minimum number of assessment sites required for M2M grazing businesses to be certified under Accounting for Nature's, '*Method to assess the Econd and Pcond of permanent and perennial pastures*'

	Business ID:	1			2				3					4			5			6				7	8		
Dominant land use	Property ID:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
Woody vegetation	1. Rainforests and scrubs	1		1		1		1																			
	2. Wet eucalypt open forests																										
	3. Eucalypt woodlands to open forests (mainly Eastern)	1	1	1	1	1	1	1		1			1			1						1			1		1
	4. Eucalypt open forests to woodlands on floodplains	1		1				1					1						1	1	1						
	5. Eucalypt dry woodlands on inland depositional plains			1	1		1			1			1	1	1	1	1		1			1	1	1	1	1	
	6. Eucalypt low open woodlands usually with spinifex understorey																										
	7. Callitris woodland - open forests												1														
	8. Melaleuca open-woodlands on depositional plains																										
	9. Acacia aneura dominated open forests, woodlands and shrublands																1		1	1				1			
	10. Other acacia dominated open forests, woodlands and shrublands	1			1	1	1		1	1	1	1		1	1	1	1	1	1	1	1	1		1			
	11. Mixed species woodlands - open woodlands (inland bioregions) includes wooded downs																				1						
	12. Other coastal communities or heaths																										
	13. Tussock grasslands, forblands																1				1			1			
	14. Hummock grasslands																										
	15. Wetlands (swamps and lakes)																										
	16. Mangroves and saltmarshes																										
Grazing land	1. Rainforests and scrubs	1				1																					
	2. Wet eucalypt open forests																										
	3. Eucalypt woodlands to open forests (mainly Eastern)	1	1	1	1	1	1	1		1						1	1					1			1		1
	4. Eucalypt open forests to woodlands on floodplains	1		1				1												1	1				1	1	
	5. Eucalypt dry woodlands on inland depositional plains	1			1		1			1				1	1	1	1		1		1	1	1	1	1	1	1
	6. Eucalypt low open woodlands usually with spinifex understorey																										
	7. Callitris woodland - open forests															1											
	8. Melaleuca open-woodlands on depositional plains							1																			
	9. Acacia aneura dominated open forests, woodlands and shrublands															1	1		1	1				1			
	10. Other acacia dominated open forests, woodlands and shrublands	1			1	1	1		1	1	1	1		1	1	1	1	1	1	1	1	1		1			
	11. Mixed species woodlands - open woodlands (inland bioregions) includes wooded downs																				1						
	12. Other coastal communities or heaths																										
	13. Tussock grasslands, forblands	1													1		1				1			1			
	14. Hummock grasslands																										
	15. Wetlands (swamps and lakes)																										
	16. Mangroves and saltmarshes																										
	Minimum assessment sites if each property were a separate project	50	10	30	30	30	30	30	10	30	10	10	20	20	25	40	45	10	35	30	45	30	10	40	25	15	15
	Minimum assessment sites per grazing business (Aggregate-scale project)	55			55				40					45			50			70				40	25		

9.29 Cost estimate to assess 10, 25, 50 and 100 sites under Accounting for Nature's, 'Method to assess the Econd and Pcond of permanent and perennial pastures'. Assessments occur every five years. Accounting for Nature account verification and certification costs have not been included

			Number of units*			
	Cost unit	Cost per unit ($)	10 sites	25 sites	50 sites	100 sites
	Steel picket	6.5	10	25	50	100
	4WD vehicle hire ($/day)	130	6	9	14	24
	Diesel ($/L)	2	160	240	320	400
Senior ecologist ($90/hour)	Registration map ($/day)	720	1	1	2	2
	Final project map ($/day)		1	1	2	2
	AfN account datasheet setup ($/day)		1	2	3	4
	Data entry/check unknown species ($/day)		1	1	2	2
	Meetings and communications ($/day)		1	1	1	1
Senior ecologist and a junior offsider ($120/hour)	Travel ($/day)	960	2	2	2	4
	Site scope/map access tracks ($/day)		2	3	4	4
	Assessment days ($/day)		2	4	8	16
		Total cost	**$10,525**	**$14,773**	**$23,425**	**$35,530**

*Assumes close spatial proximity for businesses made up of multiple properties. Add two travel days travel for each trip that needs to be undertaken separately. Hourly ecologist rate based on a central Queensland quote.

9.30 Integrating conservation with agricultural production: linear strips of native vegetation support declining woodland birds and provide benefits to pasture

Provided separately.

9.31 Frameworks for Carbon Sequestration with Improved Accessibility for Graziers

Provided separately.

9.32 Emission Reduction Framework for Leucaena

Provided separately.