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FINAL REPORT

Northern grazing carbon farming – integrating production and greenhouse gas outcomes 1.

AUTHORS AND REPORT STRUCTURE

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PROJECT DESCRIPTION

On-farm practices with potential to reduce methane emissions from cattle and increase carbon stored in soil and vegetation were demonstrated and evaluated in three regions across Australia's northern grazing land. This project (short name Climate Clever Beef) was supported by the Queensland and Northern Territory governments, regional natural resource management groups, 11 grazing businesses and the Australian Government's Action on the Ground program.

The extensive northern Australian grazing industry manages 15 million cattle on 250 million hectares and contributes 79% of Australia's agricultural greenhouse emissions. This project was designed to evaluate the integration of carbon farming practices to increase carbon stored in soil and vegetation and reduce methane emissions to lower the environmental impact of the beef industry, while maintaining herd productivity and business profitability. Additional 'carbon income' may be available to some grazing businesses through participation in the Australian Government's Emissions Reduction Fund (ERF). This project evaluated the magnitude and potential for reduction in methane emissions, improvement in emissions intensity, sequestration of carbon in soil and vegetation and potential to generate carbon credit units, along with identifying some of the practical limitations and tradeoffs for integrating carbon farming into northern Australian beef businesses.

This project targeted three large and diverse regions across northern Australia: the Queensland Gulf, the Queensland Fitzroy Basin and the Northern Territory (Victoria River District, Douglas Daly and Barkly Tableland regions). Eleven grazing businesses across three broad regions were engaged as case studies to undertake demonstrations and evaluations within their businesses. These businesses manage more than 1,281,000 ha and 97,600 cattle.

The project provided an excellent opportunity to capitalize on established networks and genuine producer interest and participation built up in recent initiatives (e.g. CCRP Climate Clever Beef (Bray *et al*. 2014), Northern Grazing Systems project (Phelps *et al*. 2014), RELRP, SCaRP, SavannaPlan, CQ Beef). The project team included research and extension professionals with decades of combined experience working with northern beef producers. The knowledge and analytical tools developed during previous projects identified practices to: reduce the greenhouse gas emissions impact of beef businesses, manage climate variability, improve land condition and increase business profitability. The Climate Clever Beef analytical framework was used in this project to:

1. Collate baseline data to describe the current performance of each collaborating business.
2. Identify promising management options to reduce methane emissions from cattle and/or increase carbon stored in soil and vegetation and improve profitability and productivity.
3. Evaluate the likely impacts of these options on multiple aspects of business performance including impact on greenhouse gas emissions, carbon sequestration, productivity and profitability.

The project engaged with producers and industry advisers by establishing producer demonstration sites in each region, and the project findings have been communicated to over 1800 people and 860 businesses via 48 field days and industry events and 65 publications, including case studies, fact sheets, conference papers, newsletter articles and journal papers. Forty seven people from 19 businesses demonstrated practice change during the project by undertaking businesses analysis and/or changing an aspect of management on their property.

Case studies and fact sheets have documented the results from the analysis of options which are available on the Climate Clever Beef website (http://futurebeef.com.au/resources/projects/climate-clever-beef/), in conference and journal papers and in this final report. A special issue of The Rangeland Journal has been negotiated to provide a long term legacy of the key case studies arising from this project and from other inter-project collaboration.

EXECUTIVE SUMMARY

The northern Australian beef industry is large, managing 15 million cattle on 250 million hectares. The expansive size of the industry means that significant environmental impacts are likely. Of concern are declines in land condition leading to reduced water quality and sediment transport, and emissions of greenhouse gases to the atmosphere. The northern Australian beef industry is estimated to contribute around 79% of Australia's agricultural greenhouse gas emissions (10% to Australia's total greenhouse gas emissions) through livestock emissions as well as impacting carbon stored in soil and vegetation. The northern Australian beef industry thus has a significant role to play through 'carbon farming' to assist Australia to meet its long term emissions reduction targets. However, productivity growth and returns on investment in the northern Australian beef industry are generally static or declining and together with high debt levels and increasing input costs, any new initiatives will require rigorous evaluation to ensure that business profitability is enhanced and financial risks are minimized.

'Carbon farming' was defined for this project as having potential to reduce greenhouse gas emissions, improve emissions intensity or increase carbon stored in soil or vegetation. Carbon farming practices may or may not have potential to generate 'carbon income' through participation in the Australian Government's Emissions Reduction Fund (ERF).

Eleven grazing businesses were engaged across three large and diverse regions to identify, demonstrate and evaluate carbon farming management options to reduce methane emissions from cattle and/or increase carbon stored in soil and vegetation. Innovative engagement processes and decision support tools were used to assess the financial implications, practicality and tradeoffs of integrating carbon farming practices into existing beef businesses. The 11 collaborating businesses represent beef production systems across northern Australia and manage more than 1,281,000 ha and 97,600 cattle. This project was delivered in three large and diverse regions: Queensland Gulf, Queensland Fitzroy and the Northern Territory (Victoria River District, Douglas Daly and Barkly Tableland) regions. The project had support from the Queensland and Northern Territory governments, regional natural resource management groups, 11 grazing businesses and from the Australian Government's Action on the Ground program.

On-farm trials and evaluations demonstrated there were opportunities for beef businesses in northern Australia to minimise the intensity of livestock methane emissions and increase carbon stored in vegetation.

A number of livestock management strategies were identified that led to an improvement in livestock emissions intensity of 10 to 30% including; improving weaning rates, increasing lifetime reproductive performance and improving growth rates. Generally adoption of a suite of management changes and tools were required to achieve the desired outcomes, e.g. pregnancy testing, supplementation, heifer management and pasture improvement. Currently there is little opportunity for most northern beef businesses to register and sell carbon credits from reducing livestock methane emissions due to the inadequate scale of most businesses to offset ERF project management costs and carbon price risk. In many cases, the livestock management options identified improved the productivity and profitability of the business without 'carbon income'. Therefore, if producers are undertaking best management

practices, they are likely to be achieving desirable carbon farming outcomes. Reduction in total emissions was only achieved when stocking rates were reduced, which can have a significant impact on business profitability through reduced sales even if offset by individual livestock productivity improvement.

The retention of regrowth vegetation was found to store substantial amounts of carbon. In regions with significant areas of regrowth (e.g. central and southern Queensland) this option may be highly worthwhile, depending on: the area of regrowth retained, rate of decline in livestock carrying capacity as regrowth grows and carbon price. The implications of this strategy need to be considered in line with the long term goals of the business due to the impact on future livestock productivity and future land use options.

Grazing management strategies that have led to improved pasture condition, increased pasture biomass and reduced drought risk have the ability to substantially increase the average amount of carbon stored in vegetation, particularly in grassland landscapes. This carbon farming practice has significant implications for landscape health, reduced off-farm impacts, long term business profitability and reduction of drought risk, but currently there is no opportunity to generate carbon income due to a lack of a ERF methodology and the perception that higher average pasture biomass is not a secure long term carbon store. This perception could be addressed by policy, leading to a significant improvement in the environmental impact (e.g. water quality, sediment transport, biodiversity) and drought preparedness of the northern Australian beef industry.

The impact of grazing land management and land condition on soil carbon was found to be negligible or inconsistent using SCaRP methodology across many soil types, regions and production systems (apart from converting cropping land to pasture). This suggests that there is little scope for soil carbon sequestration ERF projects on northern Australian grazing land due to high project risk. Although change and trend in soil carbon could not be confidently measured, in general, management strategies that aim to increase the carbon stored in soil are desirable for grazing businesses due to the complementary improvements in pasture quantity and quality, which should lead to improved long term livestock productivity.

The project engaged with producers and industry advisers by establishing producer demonstration sites in three regions. An extension and communication strategy has improved knowledge and awareness of beef producers, agencies, community, agribusiness, rural lenders, academics and policy personnel throughout Australia. Project findings have been communicated to over 1800 people and 860 businesses via 48 field days and industry events and 65 publications, including case studies, fact sheets, conference papers, newsletter articles and journal papers. Forty seven people from 19 businesses demonstrated practice change during the project by undertaking businesses analysis and/or changing an aspect of management on their property.

Key findings from the case studies undertaken in the project include:

Reduce livestock methane emissions

- Improving efficiency of production through increasing weaning rates and/or improving lifetime reproductive efficiency can improve productivity, profitability and livestock emissions intensity for some regions of northern Australia.
- Pregnancy testing can be a powerful tool to evaluate and improve herd reproductive performance and identify unproductive breeders to manage available forage in dry seasons.
- A suite of management changes will likely be required to substantially change productivity, profitability and greenhouse gas outcomes.
- Higher enterprise gross margin often coincides with the lower emissions intensity.
- Total livestock methane emissions can only substantially decline if stocking rates are reduced, which can have a large impact on business profitability even if individual animal productivity improves.
- The viability of livestock management carbon projects will be highly sensitive to herd size and carbon price. Very large herds are required to offset current project management costs, limiting participation for >90% of the industry.
- Beef businesses should focus on cost-effective changes to improve production efficiency and the associated improvement in livestock revenue. Potential carbon income should be considered a bonus and not the basis for management change alone.

Increase carbon stored in soil and vegetation

- Regrowth retention has potential to sequester significant amounts of carbon in vegetation, but pasture biomass will be substantially reduced which will negatively impact on livestock carrying capacity.
- Wet season spelling and stocking rate management can be used to improve pasture biomass and carbon stored in pasture and improve land condition.
- Soil carbon stocks under different management options and land condition states were generally not significantly different nor the trends consistent when assessed using SCaRP methodology. Soil carbon results did not support the widely-held belief that soil organic carbon stocks are higher in locations that are in good land condition.
- Land development and maintaining pasture in good condition is likely to have little impact on soil carbon stocks compared to remnant native vegetation.
- Based on the soil carbon work undertaken in this project (together with evidence from other published scientific studies), it is recommended that northern beef producers exercise caution when considering soil carbon sequestration ERF projects due to the risk of unpredictable (often unresponsive) and inconsistent changes in SOC stocks with change in management (apart from converting cropping land to pasture).
- Despite the limited potential for soil carbon income, our analyses confirm that pasture management to maintain good land condition does have significant productivity, profitability and land management benefits.

Innovative practices /technologies to reduce agricultural greenhouse gas emission /increase carbon stored in soil

Bioeconomic modelling found:

- Moderate stocking rates were better than high stocking rates for total greenhouse gas emissions and emissions intensity and led to higher amounts of carbon stored in vegetation and profitability.
- Regrowth retention for carbon sequestration has potential for substantial carbon income, although livestock income declines over time as pasture productivity declines.
- Pasture spelling can improve pasture condition in poor condition paddocks, but careful consideration of where the livestock are moved to is required, otherwise significant land condition decline in the receiving paddocks can negate the benefits of spelling the poor condition paddocks.
- A suite of management changes is generally required to make a large enough impact on livestock emissions to potentially consider an ERF carbon farming project.

The extension strategy highlighted that:

- Business analysis can be a powerful component of extension activities encouraging practice change.
- Case studies and fact sheets were useful for producers and policy personnel to understand how management change could impact productivity, profitability and greenhouse gas emissions as part of a 'real' grazing business.
- Developing and maintaining trusting relationships with producers and colleagues was extremely important to successfully undertake comprehensive business analyses and facilitate practice change.

The findings from the analysis of options at the demonstration sites have been documented in case studies and fact sheets available on the Climate Clever Beef website (http://futurebeef.com.au/resources/projects/climate-clever-beef/), in conference and journal papers and in this final report. A special issue of The Rangeland Journal scheduled for publication in 2016 has been negotiated to provide a long-term legacy of the key case studies arising from the Climate Clever Beef project and from collaboration with allied projects.

Before this project commenced there was a perception that few carbon farming opportunities were available for the extensive beef industry in northern Australia. Furthermore, it was unclear to most producers and their advisors how (1) a carbon farming practice might be integrated into a beef business or (2) how to assess the business case for participation. Until these issues were addressed, we believed that the uptake of carbon farming practices in the northern beef industry would be low. This project has addressed many of the knowledge gaps and provides clear guidance for northern beef producers considering participation in the carbon economy.

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INTRODUCTION

The northern Australian beef industry is large, managing 15 million cattle on 250 million hectares. The expansive size of the industry means that significant environmental impacts are likely. Of concern are declines in land condition leading to reduced water quality and sediment transport, impacts on biodiversity and emissions of greenhouse gases to the atmosphere. The northern Australian beef industry is estimated to contribute around 79% of Australia's agricultural greenhouse gas emissions through livestock enteric methane as well as impacting carbon stored in vegetation and soil. The northern Australian beef industry thus has a significant role to play in assisting Australia to meet its long term emissions reduction targets.

As with many other agricultural industries, productivity growth and returns on investment are generally static or declining across much of the northern beef industry (McLean *et al*. 2014). Together with high debt levels and increasing input costs, the industry is struggling to improve production efficiency and profitability (Petty *et al*. 2013). Recent benchmarking data (McLean *et al*. 2014) shows that there are businesses that are performing well despite the prevailing conditions, which suggests there are opportunities for the wider industry to improve its profitability, but new initiatives will require rigorous evaluation to ensure the financial risks to businesses are minimal.

Two key profit drivers in extensive beef businesses are 'kilograms of beef produced per adult equivalent per year' and cost of production. Recent animal production and land management research in northern Australia has highlighted several opportunities to lift business performance in a cost-effective way. Common strategies include increasing breeder herd productivity (by increasing weaning rates and reducing mortality rates), improving weight for age, realizing under-utilized carrying capacity, and managing costs. Recommended practices include genetic and fertility selection, infrastructure development, stocking rate management, pasture improvement and/or finishing cattle elsewhere (Bentley *et al*. 2008, Henderson *et al*. 2012, Petty *et al*. 2013, Quigley & Poppi 2013, McGowan *et al*. 2014). These practices also have implications for greenhouse gas emissions and/or carbon sequestration and thus show potential for beef producers to participate in the carbon economy.

Participation in the 'carbon economy' (emissions reduction and sequestration) may provide some opportunities, but evaluating the business case for participation is not without significant challenges. Key challenges include:

- Poor understanding of the impact of management change on livestock business greenhouse gas emissions and carbon sequestration in vegetation and soil and the trade-offs with livestock productivity.
- Lack of market instruments to engage in the carbon economy (no extensive livestock ERF methodologies had been approved at the start of the project in 2012, some methodologies are now available see Table 1).
- Poor financial position of most grazing businesses and lack of financial literacy and skills to evaluate alternative income options.
- Highly volatile livestock markets (live export cessation, drought), high climate variability and little certainty of carbon prices and compliance costs contribute greatly to the risk associated with evaluating and undertaking a 'carbon project'.

- Highly dispersed and 'over-busy' (partly due to drought) business managers mean that extension and education support to undertake significant management change is difficult.

Despite these challenges, recent RD&E projects (e.g. Northern Grazing Systems, Climate Clever Beef and $avannaPlan) have identified and demonstrated practices that improve productivity, land condition and beef business resilience. Importantly, many of the identified practices also have 'carbon farming' implications supported by past and recent Australian Government supported research including RELRP (Reducing Emissions from Livestock Research Program), SCaRP (National Soil Carbon Research Program) and Cooperative Research Centre for Greenhouse Accounting.

In this report, 'Carbon farming' is defined as having potential to reduce greenhouse gas emissions, improve emissions intensity and/or sequester carbon in vegetation or soils. Carbon farming practices evaluated in this project may or may not have potential to generate 'carbon' income from the registration and sale of carbon credit units through the Emissions Reduction Fund (ERF).

In 2011, the Australian Government implemented the CFI (Carbon Farming Initiative) package to enable farmers to participate in a 'carbon market'. The land sector elements of the CFI package were about creating opportunities on the land whilst addressing carbon pollution under the premise that significant opportunities exist within Australia's agriculture sector to reduce carbon pollution and increase the amount of carbon stored on the land. The intent of the CFI program was that those who pursued these opportunities would be rewarded through the CFI, allowing farmers and land managers to create saleable credits for carbon bio-sequestration and pollution reduction activities associated with agricultural production. In 2014, the CFI was transitioned into the Australian Governments Emissions Reduction fund (ERF).

However, at the start of the project in 2012 there was a perception in the northern grazing industry that few carbon farming opportunities and no methodologies were available for extensive beef producers. Since 2012, a number of ERF methodologies, potentially applicable to the northern beef industry, have been developed (Table 1). This uncertainty highlighted a clear need to demonstrate the integration of practices to increase carbon sequestration and reduce greenhouse gas emissions, while maintaining or improving productivity and profitability. Furthermore, it was unclear to most producers and their advisors how:

1. A carbon farming project might be integrated into a beef business, or
2. How to assess the business case for adoption and participation in a carbon farming project.

Unless these issues were addressed, uptake of carbon farming projects and practices in the northern beef industry was likely to be limited.

Table 1 Emission Reduction Fund (ERF) methodologies potentially applicable to the northern beef industry.

Target	Methodology	Status
Soil carbon sequestration	Sequestering carbon in soils in grazing systems	Approved 2014
Livestock methane emissions	Reducing greenhouse gas emissions in beef cattle through feeding nitrate containing supplements	Approved 2014
Woody vegetation carbon sequestration	Native forest from managed regrowth	Approved 2013
Woody vegetation carbon sequestration	Reforestation and afforestation	Approved 2013
Fire emissions	Reduction of greenhouse gas emissions through early dry season savanna burning. High rainfall zone (above 1000 mm of average annual rainfall)	Approved 2012
Fire emissions	Reduction of greenhouse gas emissions through early dry season savanna burning. Low rainfall zone	Approved 2015
Livestock methane emissions	Beef cattle herd management	Approved 2015

PROJECT DEVELOPMENT AND REPORT STRUCTURE

To address the above issues, a multifaceted development project (the 'D' in RD&E) was devised under the Carbon Farming Futures Fund – Action on the Ground program.

The project undertook work in three regions across northern Australia. This report is structured to provide an overview of the project and address the Action on the Ground priorities (reduce methane emissions, increase carbon stored in soil and innovative practices and technologies) by drawing together previous research and key findings and learnings from the case studies.

The Action on the Ground program and project priorities were:

a) Reduce methane emissions

> The project evaluated and trialed on-farm practices that can reduce livestock methane emissions and improve emissions intensity to assist participating land managers gain knowledge and adopt management practices on their properties to reduce livestock methane emissions and/or improve livestock methane emissions intensity.

b) Increase carbon stored in soil

> The project evaluated and trialed on-farm practices that can increase the sequestration of carbon in soil and vegetation to assist participating land managers identify and adopt management practices to increase and maintain carbon sequestered in soil and vegetation on their properties.

c) Innovative practices /technologies to reduce agricultural greenhouse gas emissions /increase carbon stored in soil

The project used innovative tools and bioeconomic models to evaluate and develop a business case for the integration of innovative on-farm practices at the whole-farm scale that can reduce methane emissions from cattle and/or improve emissions intensity, improve and increase carbon stored in soil and vegetation while maintaining or improving livestock productivity and improving business profitability. The business case took into account each property's stage of development.

An underlying objective was to help 'improve business efficiency' and provide demonstrated evidence that integrating a carbon farming practices into a beef business:

- Was economically viable.
- Optimized environmental outcomes.
- Did not compromise sustainable productivity.

The project was designed to deliver the following outcomes for the northern grazing industry, community and government:

1) Identification of the benefits and constraints to implementing carbon farming practices and demonstration of the conditions under which carbon farming practices would be commercially viable.
1) Increased capacity and tools for industry advisors to assist producers to evaluate and implement carbon farming practices.
2) Increased understanding of the realistic and likely magnitude of methane emissions reduction and carbon sequestration in soil and vegetation for diverse regions and production systems.
3) Professional and respected delivery of factual information about the project results, carbon economy, climate change and government policies and programs.

CARBON FARMING OPPORTUNITIES

Across northern Australian grazing land a range of carbon farming practices are potentially available, however regional differences exist due to climate, soil type, property scale, markets and history of land development. The opportunities and constraints are identified in each of the three project regions in Table 2, based on past research and experience. Available management practices are highlighted below.

REDUCE METHANE EMISSIONS

Previous research by CSIRO, DAF, DoR, MLA and RELRP indicated that the following practices would improve sustainable production and reduce methane emissions intensity:

- Identify and remove unproductive breeders to optimize weaning rates.
- Improve liveweight gains and decrease age of turnoff.
- Heifer management to improve lifetime fertility.
- Phosphorus supplementation to improve weaning rates.
- Manage stocking rates to improve land condition and diet quality.
- Feed legume pasture to increase growth rates and reduce lifetime emissions per head.
- Feed nitrate supplements to reduce daily methane emissions.

As an example of what can be achieved, Blanncourt Station in the Queensland Gulf implemented a range of management changes over 15 years (Broad *et al.* 2011) including; reducing stocking rates, wet season spelling, pasture improvement, supplementation and feeding of young cattle to meet weight-for-age targets. This suite of changes increased profitability by 93%, increased beef sold by 80%, improved land condition, reduced total emissions by 15% and improved emissions intensity by 53%.

Table 2 Opportunities and constraints for various carbon farming management practices in different regions.

Region	Reduce methane emissions	Increase carbon in soil	Increase carbon in vegetation
Fitzroy (Qld)	Options for improving breeder herd reproductive rates and increasing growth rates	Significant interest but little scientific evidence of being able to increase soil carbon with management, apart from returning cropping land to pasture.	Retention of brigalow and eucalypt regrowth provide options for sequestration. Opportunity to improve average pasture biomass.
Queensland Gulf	Options for improving breeder herd reproductive rates. Properties generally still developing fences and waters to increase carrying capacity, potentially leading to increased total livestock emissions.	No/little scientific evidence of being able to increase soil carbon by improving management/land condition.	Little regrowth. Opportunity to improve average pasture biomass. Savanna burning may be an option.
Barkly Tableland and VRD (NT)	Options for improving breeder herd reproductive rates. Properties generally still developing fences and waters to increase carrying capacity, potentially leading to increased total livestock emissions.	No/little scientific evidence of being able to increase soil carbon by improving management/land condition.	Opportunity to improve average pasture biomass. Savanna burning may be an option.
Douglas Daly (NT)	Options for increasing growth rates of growing cattle using improved pasture to increase diet quality and carrying capacity.	Significant interest but little scientific evidence of being able to increase soil carbon with management.	Opportunity to improve average pasture biomass. Retention of regrowth may provide options for sequestration but properties generally still developing country. Forest plantations may be an option.

Infrastructure development to increase herd size is a high priority for many producers in northern Australia. This is driven by the need to have as much of the land asset in production as possible. Under previous Australian carbon farming legislation, any rise in total emissions from increasing herd size would have precluded many northern producers from participating in the carbon market. Under current legislation, activities that lead to improvements in emissions intensity (achieved through improved production efficiency) are eligible for participation and methodologies are being developed along these lines. The improvement in the emissions trajectory as a result of productivity improvement is illustrated conceptually in (Figure 1). As a property is developed and technologies are adopted to increase livestock carrying capacity, total greenhouse gas emissions will increase proportionally unless there are simultaneous improvements in emissions intensity.

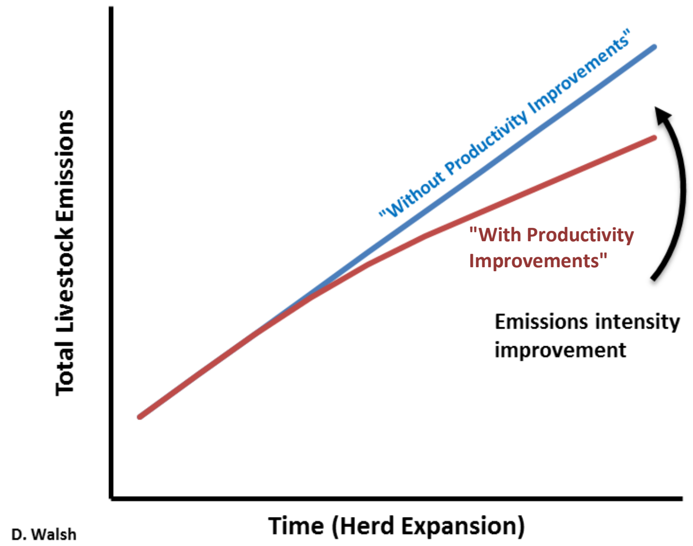

Figure 1 A conceptual representation of how total livestock emissions increase with increasing herd size and how productivity improvements can alter the emissions trajectory (Source D. Walsh).

INCREASE CARBON STORED IN SOIL AND VEGETATION

Research by SCaRP, DERM, DoR, CSIRO, DAF and the CRC for Greenhouse Accounting indicated that carbon sequestration is possible in northern grazing lands by improving land condition to maximize growth of herbaceous and/or woody vegetation and increasing the input of vegetation carbon into the soil (e.g. Ash *et al.* 1995; Holt 1997; Northup *et al.* 1999 and Pringle *et al.* 2011). However the results of recent soil carbon work using SCaRP methodology have shown inconsistent and contradictory responses to management (Allen *et al.* 2010; Allen *et al*. 2014; Bray *et al.* 2010; Pringle *et al.* 2011) and require further evaluation in a range of environments and production systems. Management practices that can theoretically increase carbon stored in soil and vegetation include:

- Sustainable grazing systems that increase ground cover and forage production.
- Rehabilitating degraded land to increase ground cover and perennial species.
- Woody regrowth retention to increase carbon in woody vegetation and potentially soil (Bray and Golden 2009; Donaghy *et al*. 2010).
- Introducing legumes into grass pastures to increase soil carbon (Abberton *et al.* 2010).

INNOVATIVE PRACTICES /TECHNOLOGIES TO REDUCE AGRICULTURAL GREENHOUSE GAS EMISSION /INCREASE CARBON STORED IN SOIL

Despite being recognized as important drivers for sustainable pastoral production, the above practices are not widespread in the northern beef industry due to economic or other barriers to implementation. To encourage adoption, the Climate Clever Beef project (Bray *et al.* 2014) worked with case study properties and regional champions to develop a framework to analyze businesses and identify options to improve business outcomes (Figure 2). This innovative process was used to evaluate and demonstrate the multiple benefits of undertaking a practice on profitability, productivity, land condition, greenhouse gas emissions and climate risk therefore improving the likelihood of implementation of carbon farming practices.

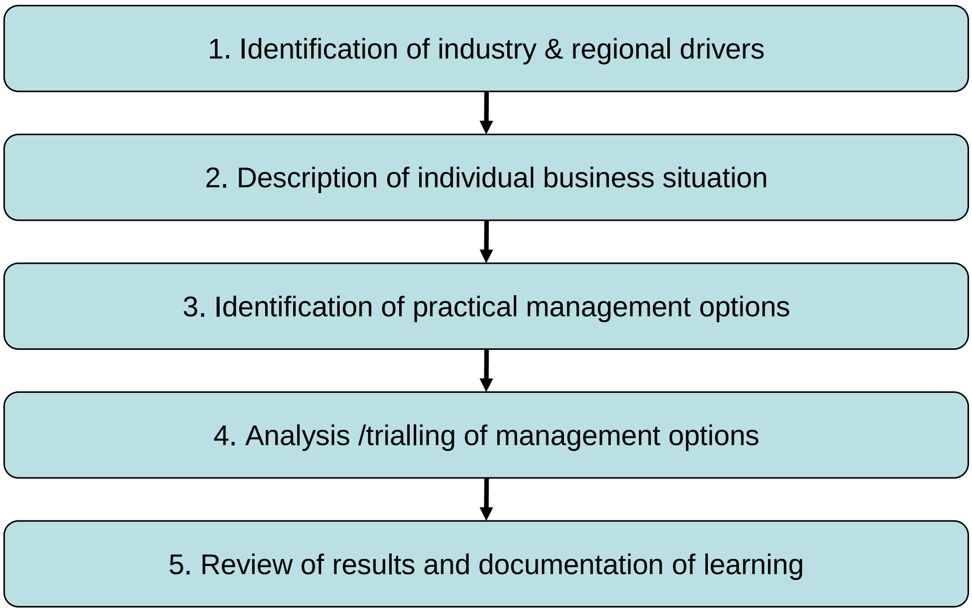

Figure 2 Climate Clever Beef framework used to systematically assess the performance of management options for improving business resilience.

To evaluate carbon farming practices, whole-farm bioeconomic modelling can integrate management practices, livestock, pasture dynamics, tree biomass and soil carbon at the whole property scale and over longer time frames spanning a number of climatic cycles than can be realistically trialled on-farm in a short-term project (e.g. Phelps *et al.* 2014 and Donaghy *et al.* 2010). The project used bioeconomic modelling to integrate on-farm measurements and data to assess to long term 20-30 years impact in three case studies.

METHODOLOGY

REGIONAL APPROACH AND COLLABORATION

Due to the large geographic size of the northern Australian beef industry and to access a range of expertise the project was structured as a collaborative partnership on a regional basis. The project targeted three large and diverse regions across northern Australia (Figure 3):

- Queensland Gulf in north Queensland
- Fitzroy Basin in central Queensland
- Victoria River District (VRD), Douglas Daly and Barkly Tableland in the Northern Territory

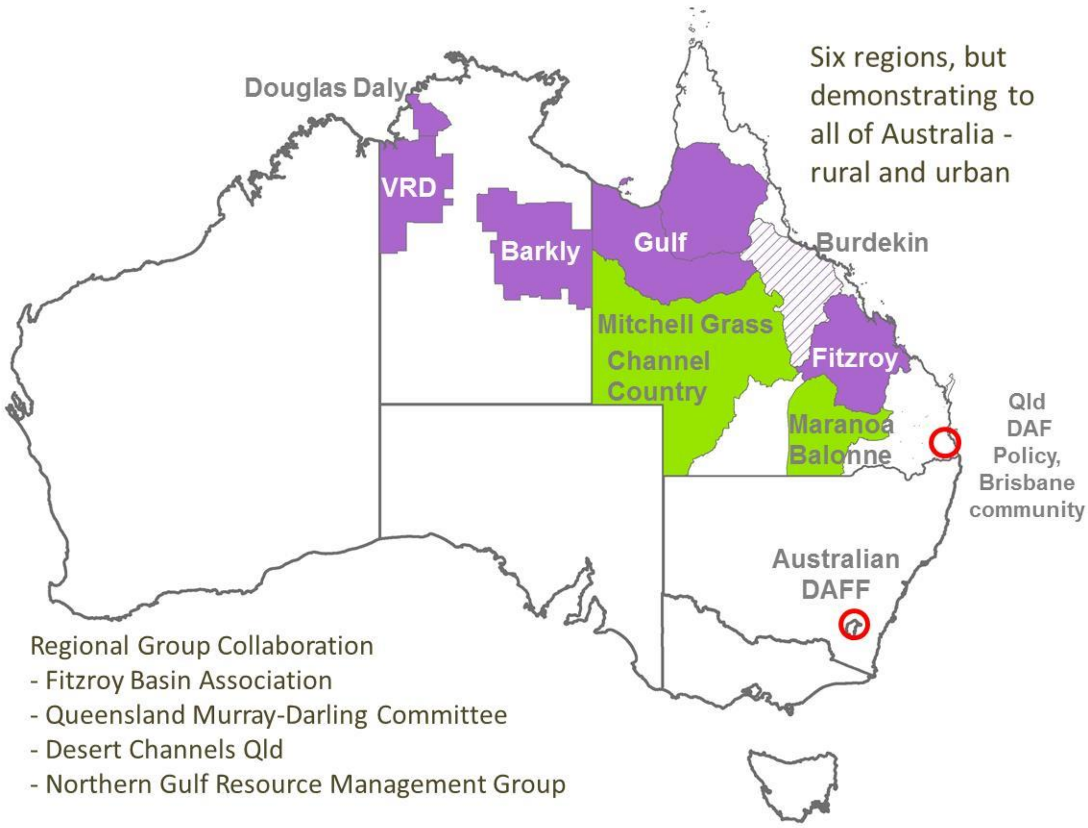

Figure 3 Map of targeted regions (purple colored).

The Maranoa Balonne, Mitchell grass and Channel Country regions were targeted by a similar project supported by the Australian Government (AOTGR1-198) which worked collaboratively with this project.

The benefits of the regional approach included:

- A larger cross section of research and extension teams being involved in understanding the opportunities and constraints of carbon farming.
- Sharing the learnings from different regions across northern Australia.
- Differences in opportunities between regions could be targeted (e.g. regrowth management is an opportunity in central and southern Queensland, soil carbon sequestration opportunities may exist

in mixed farming areas where cropping land is converted to pasture, managing property development leading to increasing herd numbers in the more extensive areas.)

Collaboration was seen as a key project strength across; borders, agencies, regional NRM bodies, projects and beef businesses. Collaborating partners included:

- Department of Agriculture and Fisheries, Queensland
- Department of Primary Industry & Fisheries, Northern Territory
- Department of Science, Information Technology and Innovation, Queensland
- Northern Gulf Resource Management Group, Queensland
- Fitzroy Basin Association, Queensland
- 11 beef businesses

A key consideration of the project was recognition that the findings from the project were also of interest to policy and academics such as:

- Research institutions e.g. Melbourne University, CSIRO
- Policy development teams in State and Australian Governments
- Other government programs (e.g. Filling the Research Gap and Extension and Outreach)
- Industry organizations (e.g. Meat and Livestock Australia)
- Individuals interested in greenhouse gas emissions issues.

This project provided an excellent opportunity to capitalize on the established networks and genuine producer interest and participation built up in recent initiatives (e.g. CCRP Climate Clever Beef, Northern Grazing Systems project, RELRP, SCaRP, SavannaPlan, CQ Beef). The project team included research and extension professionals with decades of combined experience working with northern beef producers.

DEMONSTRATION PROPERTIES

Regional activities were centered around forming collaborative partnerships with beef businesses to host on-ground demonstrations in each region. Regions engaged at least three businesses as demonstration sites with a fourth property as a backup to mitigate against the risk of losing a property mid-way through the project. Overall the project team evaluated options across three regions on 11 properties including:

- Three properties in the Queensland Gulf (two family businesses and one corporate property)
- Two properties in the Fitzroy region in Queensland undertook comprehensive evaluations. Another two properties undertook initial evaluations. The net carbon position of a grazing research trial in the Burdekin catchment was comprehensively evaluated.
- Three property groups were assessed in the Northern Territory: one on the Barkly Tableland, one in the Victoria River District (VRD) and three properties in the Douglas Daly region.

These 11 businesses managed a combined land area in excess of 1,281,000 ha and 97,600 cattle.

Each region had a risk management plan to address the potential for a business/es withdrawing from the project. Generally the risk management strategy was to identify an extra demonstration property than contractually required. This was an important risk management process for the Fitzroy region enabling them to deliver despite encountering some difficulties due to drought, specific landholder circumstances and factors outside the control of the project team.

Apart from directly engaging the collaborating businesses, many more producers were engaged through regional champions, established peer networks and extension events. Examples include:

- In the Queensland Fitzroy, the Dunne family (owners of the Oaklands demonstration property) are regarded as regional industry 'champions'. John was the Chair of the Mimosa Creek Landcare Group and Colin is a 'Climate Champion'. The Mimosa Creek Landcare group of approximately 8 businesses was used as a sounding board for the demonstration site encouraging local discussion of carbon farming opportunities. The Landcare group used the demonstration site for a field day drawing in other local businesses. The Oaklands property was selected to be a Beef Australia 2015 property tour, with the landholders keen to showcase the demonstration site.
- In the Northern Territory, the collaborators included a well-known and respected manager on the Barkly Tableland, a relatively new but forward-thinking business in the VRD and three established businesses in the Douglas Daly. The work at the demonstration sites was presented and discussed at regional field days and events.
- In the Queensland Gulf, one of the family property collaborators is a local government councilor and a strong industry advocate. A well-attended field day was held on the property with a range of additional guest speakers discussing: global beef marketing, business financial analysis and a bankers forum. Another property was part of a large corporate business with the objective of impacting many of the other corporate properties in northern Australia. Although not a demonstration property, a Climate Clever Beef field day was held on another well-known property near Hughenden.

The networks around the collaborators and collaborating properties greatly enhanced the successful delivery of information from the project.

BUSINESS BENCHMARKING AND IDENTIFICATION OF OPTIONS

The Climate Clever Beef business analysis framework (Figure 2) was used to produce baseline data for each collaborating property and to identify alternative management options. The economic potential, practicality and impact on greenhouse gas emissions or sequestration of alternative management practices were subsequently evaluated for each option or combination of options. This innovative process combined business records and output from several analysis tools including:

- Business financial benchmarking and analysis (e.g. property records, Business Analyser®, industry consultants, Breedcow & Dynama).
- Herd structure, productivity and herd modelling (e.g. property records, Breedcow & Dynama)
- Livestock emissions and sequestration calculators (e.g. FarmGAS, FullCAM tool, Greenhouse Accounting Frameworks)
- Bioeconomic modelling (e.g. GRASP and Enterprise, excel-based discounted cash flow bioeconomic models)
- Property mapping and assessment of land types, woody vegetation and land condition.

Invariably, the benchmarking process identified the strengths and weaknesses of each business and along with the business long term goals, this information was used to identify management options that had potential to also enhance productivity and profitability, reduce methane emissions or increase carbon stored in soil and vegetation. A key benefit of this activity was that the subsequent evaluations of options were based on 'real' (property relevant) local data which was much more accepted by the collaborators and peers in the region. It should be noted that several producers made significant positive changes to their business as a result of undertaking the business analysis process.

REDUCE METHANE EMISSIONS METHODS

The calculation of livestock methane emissions in northern Australia requires knowledge of seasonal numbers of livestock in each class (e.g. Heifers 1-2 years, Steers calves 0-1 years, etc.), average seasonal liveweight (LW) and liveweight gain (LWG). This information was generally compiled from a combination of property records (paddock records, sales and purchase records), property livestock schedules and herd modelling (e.g. Breedcow & Dynama modelling). One of the lessons learned from this process was that the lack of clean musters, substandard business records, variability in annual herd numbers and turnoff will make it very difficult to analyze baselines and carbon farming project performance for many businesses. The livestock data was then processed using a greenhouse gas emissions calculator (e.g. excel version of FarmGAS (http://www.farminstitute.org.au/calculators/farm-gas-calculator).

Depending on the demonstration site, the current livestock data were compared to measured or projected livestock data for an alternative management option. Data to inform the management options were derived from:

- Historic property records.
- Research literature, reports or regional representative herd models.
- Expert opinion (departmental officers, the collaborator, other group members).
- Property measurements and experience.

For each management option evaluated, total livestock greenhouse gas emissions (t CO_2e) and emissions intensity (t CO_2e per t liveweight sold) were calculated and compared.

All regions assessed livestock methane emissions. Example management strategies assessed include:

- Improved weaning rates by combining the following complementary practices in the VRD:
    - Reduce stocking rate (adult equivalents) by 5% (the property was assumed to be slightly over-stocked based on regional data).
    - Cull breeders that don't reliably produce calves (using pregnancy testing).
    - Best practice weaning (including weaner supplementation).
    - Run heifers in better quality paddocks (including legume augmented paddocks).
    - Keep cull-for-age breeders if they are still healthy and pregnancy-tested in calf.
- Reduced stocking rate, supplementation and spelling to improve herd performance and land condition in the Queensland Fitzroy region.
- Improving per head productivity and herd fertility via infrastructure development, cross-breeding, breeder selection and stocking rate management in the Barkly Tableland region.

- Herd management, spelling and establishing stylo pastures to improve growth rates and weaning rates in the Queensland Gulf region.
- The influence of different herd structures and enterprise mix on emissions performance in the Douglas Daly region.

SOIL CARBON METHODS

Soil carbon sampling during the project followed the SCaRP methodology for grazing land in northern Australia (Allen *et al.* 2010, Pringle *et al*. 2011) to collect, process and analyse the soil samples. In summary, at least ten cores were sampled per plot or paddock to a depth of 30 cm. Bulk density was calculated on intact core samples. Total soil organic carbon (SOC) stocks (t/ha) were calculated for the 0-10cm and 0-30cm depth intervals. The soil sampling was undertaken in collaboration with the National Soil Carbon Program regrowth project in the Fitzroy region.

Key management strategies assessed for impact on soil carbon included:

- Woody vegetation management on Box (eucalypt) woodland (fully cleared, regrowth and remnant) and pasture spelling in the Fitzroy region.
- Brigalow regrowth retention in the Fitzroy region (Gowen and Bray, submitted).
- Pasture development in the Douglas Daly region.
- Legume establishment and land condition in the Queensland Gulf.
- Historical duration and intensity of grazing in the Barkly Tableland (Figure 4) (Walsh and Shotton, 2015).
- Weed control (Prickly Acacia) in the Queensland Gulf.

Figure 4 A curious cow watching Peter Shotton soil sampling at Alexandria on the Barkly Tableland. Soil carbon was assessed in relation to age of water point and intensity of grazing and land condition.

VEGETATION CARBON METHODS

Woody vegetation was assessed in the Fitzroy region at three properties using the TRAPS woodland monitoring methodology (Burrows *et al.* 2002). Woody vegetation carbon stocks were estimated from individual stem basal area using locally relevant allometric equations (Burrows *et al.* 2002; Butler 2013). Tree growth was modelled using measured data, locally relevant tree growth equations (Donaghy *et al*. 2010) and the FullCAM model (Gowen and Bray, submitted).

Pasture vegetation was measured using the Botanal procedure (Tothill *et al.* 1992), cutting pasture quadrats or using GRASP pasture growth modelling (Littleboy and McKeon 1997).

BIOECONOMIC MODELLING METHODS

Two bioeconomic approaches were used: 1. GRASP pasture and animal production modelling based approach, and 2. an excel-based discounted cash flow approach.

In the first approach, the bioeconomic modelling (BEM) framework consisted of the GRASP pasture and animal production model (Littleboy and McKeon 1997) linked to the ENTERPRISE dynamic herd economic model (MacLeod *et al.* 2011). The whole property BEM framework was developed and tested during the Northern Grazing Systems project (Phelps *et al.* 2014; Scanlan *et al.* 2014). GRASP is a point-based model that simulates soil moisture, pasture growth and animal production from daily inputs of rainfall, temperature, humidity, evaporation and solar radiation. The model has been modified recently to enable it to simulate a wider range of stocking rate management strategies, dynamic tree growth and the impacts of pasture spelling. A recent variation to the ENTERPRISE dynamic herd economic model permits allocation of the herd to a maximum of 20 paddocks. The ENTERPRISE model uses the predicted liveweight gain per head from GRASP to estimate branding and mortality rates, and constructs a herd consistent with these rates, the stocking rates from GRASP, and the buying/selling rules within ENTERPRISE. The economic outcome for a given year is assessed using a whole-enterprise budgeting technique with a number of economic metrics generated. Two sites were modelled using this approach:

- Oaklands in the Fitzroy region: modelled regrowth management and spelling regimes on livestock productivity and emissions, land condition and regrowth carbon sequestration (Whish *et al.* submitted).
- Alexandria on the Barkly Tablelands, Northern Territory: modelled impact of stocking rate management on long-term livestock carrying capacity, land condition and pasture biomass (Walsh and Cowley, submitted).

The second bioeconomic modelling approach used discounted cash flow analysis integrating regional costs and prices, livestock productivity, woody regrowth management and impact on pasture productivity (e.g. Donaghy *et al*. 2010). Uncertainty in key variables such as amount of regrowth retained and product prices was incorporated using sensitivity analyses. The resultant measures of enterprise profitability (i.e. net present value (NPV)) were used to compare the regrowth retention options to the current management system. The modelling assumed each scenario was managed in a manner that maintained or enhanced land condition and utilized best management grazing practices. This approach was used at Coonabar in the Fitzroy region to assess regrowth retention options (Gowen and Bray, submitted).

BUSINESS CASE DEVELOPMENT

The final product of the demonstration sites was to develop a case study document that would enable the reader to determine whether an option may be worthwhile pursuing for their business in a particular region. All demonstration sites collated and measured appropriate indicators and documented the costs, benefits, constraints and practical issues associated with carbon farming project implementation.

EXTENSION ACTIVITIES

In terms of community and industry engagement, the project used a suite of engagement and extension techniques across northern Australia. Methods included: engaging regional champions, programmed learning (training packages), information access (e.g. field days/forums, newsletter articles), consultant/mentor (one-on-one), on-property demonstrations and producer group activities. Field days and training packages improved producer awareness, knowledge and confidence while demonstrations and one-on-one delivery aimed to foster practice change. Ongoing support and mentoring with the case study properties and other beef producers enabled the delivery team to understand production, profitability and practicality issues as well as the link between herd productivity and greenhouse gas emissions.

Apart from the direct one-on-one extension with the demonstration property businesses and associated groups, other extension activities included:

- Field days and field day presentations at events held by other organizations or projects (e.g. Northern Gulf Resource Management Group's North Queensland field day seminars), leading to training workshops and one-on-one follow-up.
- Fact sheets and case studies used as handouts and available on the project website.
- Project website providing a project overview as well as hosting the links to fact sheets, case studies, field day notes, newsletter articles, conference papers and posters.
- Industry newsletter articles.
- Media press releases and interviews.
- Webinars.
- Beef Australia 2015 bus tour presentation.
- Presentations at industry forums and conferences attended by landholders and other technical people.
- Supporting Meat & Livestock Australia Farm300 training and activities.
- Collaboration and support for other projects, e.g.
    - Soil carbon research and demonstration. Diane Allen
    - Northern grazing carbon farming – integrating production and greenhouse gas outcomes 2.
    - Spelling Strategies project. Paul Jones and Carly Harris
    - Wambiana Grazing Trial. Peter O'Reagain and John Bushell

- Livestock emissions. Melbourne University Richard Eckard, Natalie Doran-Browne
- Land rehabilitation project. Emma Hegarty, Rebecca Gunther and Southern Gulf Catchments.
- CFI Methodology development. Michael Martin, Richard Chisholm, Sandra Eady and Beverley Henry.
- Sown pasture rundown. Stuart Buck

PROJECT LEGACY

To ensure the project has an enduring legacy a number of options have been pursued:

- The Rangeland Journal special issue has been negotiated to be published late 2016. The issue will contain approximately 10 journal papers from this and associated projects around the theme 'Climate Clever Beef' (Bray *et al.* submitted[a]; Bray *et al.* submitted[b]; Gowen and Bray, submitted; Rolfe *et al.* submitted; Walsh and Cowley, submitted; Whish et al. submitted)
- Conference papers and posters for a range of conferences including: Northern Beef Research Update Conference (2013), Australian Rangelands Conference (2015), Modelling Nutrient Digestion and Utilisation in Farm Animals Conference (2014).
- Journal article in Animal Production Science on the net carbon position of moderate and high stocking rate treatments in the Wambiana grazing trial (Bray *et al.* 2014).
- A special issue of The Rangeland Journal (Savanna Burning: Role and Opportunities in a Rangelands Carbon Economy Volume 36 Number 4 2014) included papers authored by project team members.
- Strong regional, inter-regional and inter-agency collaborative relationships.
- Better informed agency officers.
- Comprehensive final report incorporating an overarching summary report and detailed regional appendices.
- Climate Clever Beef webpages hosted on the FutureBeef website.

ANNUAL PROJECT MEETINGS

Four whole-of-project meetings were held during the project in: Brisbane, the Atherton Tableland in north Queensland, Roma in southern Queensland and Boulia in far western Queensland. The whole project team was invited to participate along with departmental managers, an Action-on-the-Ground (AotG) representative, the project reviewer and guest speakers (e.g. Michael Martin from the methodology development team in the Australian Department of Environment, Rhonda Toms-Morgan on the AotG soil carbon and fire projects in the Maranoa Balonne). AotG representatives were unable to attend any of the annual project meetings apart from the first planning meeting.

The goal of the annual meetings was to:

- Share the progress and future plans for each region (referring to project plan and communications plan documents).
- Discuss the upcoming reporting requirements.
- Get ongoing updates on the CFI, ERF and other policy changes
- Hear about other AotG projects in the region.
- Visit project sites and learn about different production systems in different regions.

PROJECT REVIEWER

The independent reviewer for the project was Dr Mick Quirk. Dr Quirk was invited to be the project reviewer due to his industry expertise and to maintain links and synergies between this project and other current and future industry supported projects. The project reviewer attended all annual project meetings and provided ongoing constructive feedback on the approach and findings of the project.

RESULTS AND DISCUSSION

The project was highly successful at engaging with collaborating properties across northern Australia with 11 properties evaluating and trialing alternative management practices. Results of the demonstrations are presented and discussed under the Action-on-the-Ground priority headings.

REDUCE METHANE EMISSIONS

If livestock productivity is to be maintained or improved at the property scale, reduction in total methane emissions or improvement in emissions intensity are related to:

- Having fewer unproductive livestock on the property (i.e. cows and heifers that do not have a calf) and minimizing impact of extreme climatic conditions leading to low productivity.
- Increasing the number of calves per breeder lifetime (e.g. reducing the time to first joining and weaning a calf every year thereafter).
- Reducing the time to achieve market weight (faster growth).
- Reducing the methane produced per day by using methane reducing technologies (e.g. some feed supplements).

The reducing methane emissions options evaluated in this project can be split into three categories:

1. Improving breeder herd efficiency and growth rates
2. Changing the enterprise mix
3. Innovative supplements and forages

IMPROVING BREEDER HERD EFFICIENCY – IMPROVED WEANING RATES IN THE VRD

Dionne Walsh

Analysis of the case study business indicated that weaning rates were lower than desired, impacting on productivity and profitability. A strategy was devised combining a number of complementary practices:

- Reduce stocking rate (adult equivalents) by 5% (the property was assumed to be slightly over-stocked based on regional data).
- Cull breeders that don't reliably produce calves (using pregnancy testing).
- Best practice weaning (including weaner supplementation).
- Run heifers in better quality paddocks (including legume augmented paddocks).
- Keep cull-for-age breeders if they are still healthy and pregnancy-tested in calf.

For the typical 2,400 km² (240,000 ha) breeder property running 16,600 AE and selling feeder cattle to live export, the combined practices resulted in a smaller breeder herd, but weaned 4% more calves. Due to reduced mortality rates and improved liveweight gains, slightly more liveweight was sold (an extra 10 t per annum, 0.6% increase). Herd gross margin improved by 14% and gross margin per AE by 21%. Taking into account the implementation costs, the profitability of the cattle enterprise increased by ~4%

per annum ($30,000 p.a.). The property experienced a reduction in total greenhouse gas emissions from 31,300 to 28,900 t CO_2e and an improvement in emissions intensity from 17.5 to 16.0 t CO_2e/t LW sold.

The case study was then evaluated for its carbon farming potential assuming the 'Carbon Farming Initiative - Beef Cattle Herd Management' methodology was available. The potential carbon revenue achieved by the reduction in emissions over a seven year project life ranged between $84,000 and $420,000 depending on the carbon price ($5-$25/t CO_2e) (Table 3). When indicative project registration, monitoring, reporting and audit costs (~$9,300 per year) were factored in, the potential profit ranged between $2,000 and $51,000 per annum. On face value such a carbon farming project would appear to be worthwhile for an enterprise of this size, particularly at higher carbon prices.

Table 3 Estimated carbon farming project profit, as a result of reducing emissions from a beef cattle herd in the Victoria River District, Northern Territory. The analysis assumes a 7-year contract period. Project cost estimates provided by Phil Cohn, RAMP Carbon.

	Carbon price ($/t CO_2e)				
	5	10	15	20	25
Potential carbon revenue over 7 years	$84,070	$168,140	$252,210	$336,280	$420,350
Project registration costs	$2,500	$2,500	$2,500	$2,500	$2,500
Project monitoring & reporting costs	$17,500	$17,500	$17,500	$17,500	$17,500
Audit costs (3 audits in 7 yrs)	$45,000	$45,000	$45,000	$45,000	$45,000
Carbon project profit (7 yr project life)	$19,070	$103,140	$187,210	$271,280	$355,350
Carbon project profit per yr	$2,724	$14,734	$26,744	$38,754	$50,764
Carbon project profit per AE per yr	$0.17	$0.93	$1.70	$2.46	$3.22

Sensitivity analysis showed that herd size would need to be at least 2,439 AE to cover the indicative costs of the project at a carbon price of $25/t CO_2e (Figure 5). At $5/t CO_2e, the herd size would need to exceed 12,190 AE to cover project costs. To put this into context, ABARES estimates that 96% of the beef herds in northern Australia are smaller than 5,400 head (Thompson & Martin 2014) which, for this case study property, equates to about 3,600 AE. The analysis suggests that in implementing the described strategy, current carbon project management costs would negate carbon revenue if the price was below ~$11/t CO_2e for the majority of northern beef producers.

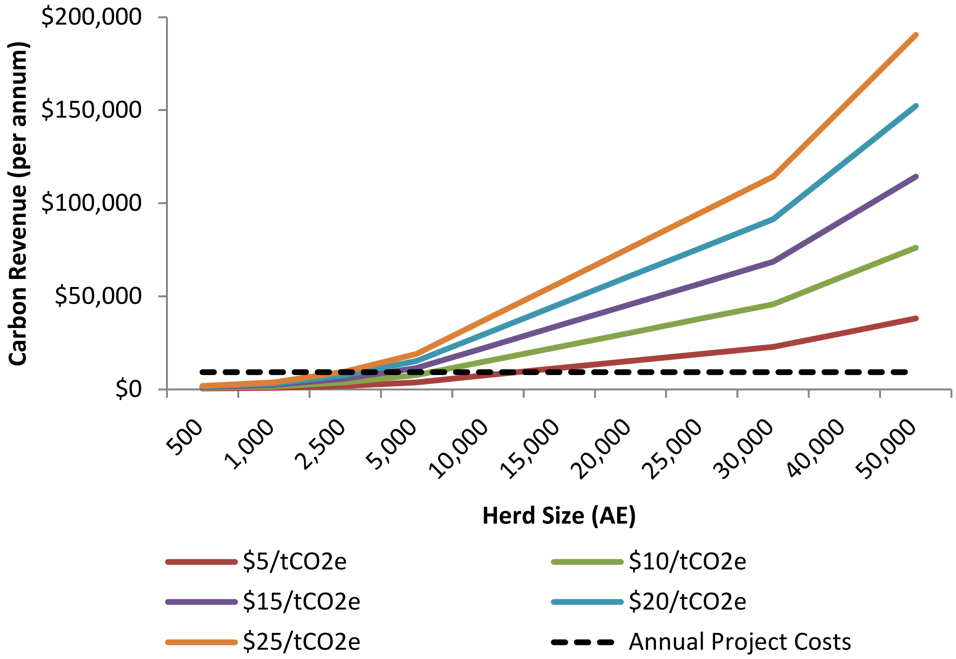

Figure 5 The indicative viability of a livestock emissions abatement project relative to carbon price and herd size.

The key findings from the improved weaning rates scenario in the VRD case study include:

- Improving weaning rates can improve productivity, profitability and livestock emissions intensity.
- Total greenhouse gas emissions typically decline if stocking rates are reduced.
- Carbon farming project profit will be highly sensitive to project management costs and carbon price.
- Carbon farming project viability will be highly sensitive to herd size, with large herds required to offset project management costs.
- Unless project management costs decrease substantially, businesses would need to 'stack' and/or aggregate projects to dilute these costs.
- Beef businesses should focus on cost-effective changes to improve production efficiency and the associated improvement in livestock revenues. Potential carbon income should be considered a bonus and not the basis for management change alone.
- A suite of management changes will likely be required to substantially change productivity, profitability and greenhouse gas outcomes.

IMPROVING BREEDER HERD EFFICIENCY – INFRASTRUCTURE, HERD GENETICS AND GRAZING MANAGEMENT ON THE BARKLY TABLELAND

Dionne Walsh

This case study documented three decades of innovation by a leading producer on the Barkly Tableland region of the Northern Territory. Many of the practices used on the property are now being adopted by other producers, including:

- Developing infrastructure to improve paddock utilization, increase carrying capacity and increase herd size.
- Cross-breeding to improve herd genetics and achieve better animal production and marketability.
- Pregnancy-testing and culling non-performing breeders to increase herd fertility.
- Using safe stocking rates and wet season spelling to maintain good land condition.

The property manager collaborated to undertake a whole property analysis to reconstruct and compare the production, economic and greenhouse gas emissions performance of the business at three points in time (1981, 2006 and 2013).

Since 1981, management changes on the property have resulted in a >50% increase in livestock carrying capacity, a 46% improvement in weaning rate, an 82% reduction in breeder mortality rate and the maintenance of good land condition. Liveweight turn-off per adult equivalent (AE) has increased from 75 kg to 128 kg. Gross margin per AE has improved by almost 300%. Whilst the property has experienced a 50% increase in total greenhouse gas emissions due to increased herd size, the business has achieved a 43% reduction in emissions intensity (t CO_2e/t liveweight sold).

The potential for carbon farming project revenue was subsequently evaluated assuming the 'Carbon Farming Initiative - Beef Cattle Herd Management' methodology was available. For the purposes of the analysis, it was assumed the property could immediately transition from the '1981' baseline to the '2013' productivity. Under this scenario, the potential carbon revenue over a seven year project life ranged between \$124,000 and \$623,000 depending on the carbon price (\$5-\$25/tCO_2e). When indicative project registration, monitoring, reporting and audit costs were factored in, the potential profit ranged between \$8,000 and \$80,000 per annum. On face value such a carbon project would appear to be worthwhile, particularly at higher carbon prices. However, there are two important caveats. Firstly, the case study property has one of the largest herds in northern Australia and the potential carbon revenue is driven by the significant scale of the business. Sensitivity analysis showed that herd size would need to be greater than 6,800 AE just to cover the indicative management costs of the carbon project at a price of \$25/tCO_2e. At \$5/tCO_2e, the herd size would need to exceed 35,470 AE to cover these costs. The second caveat is that not all activities that have led to the emissions intensity improvement can be implemented in a short period of time. Some of the practices that have had the biggest impact on animal productivity and emissions intensity (including cross-breeding and genetic selection) have taken up to 30 years to achieve. Such activities are unlikely to make a measurable difference to emissions intensity over the relatively short timeframe of a 7-year Emissions Reduction Fund (ERF) contract period. Thus, unless ERF contract timeframes are brought into line with the lag time of these practices, the economics of an emissions intensity project such as this will not be viable for most northern beef businesses.

It should be noted that despite its smaller enterprise scale, the VRD increased weaning rates case study performs better from a carbon project perspective than the emissions case study undertaken in the Barkly Tableland region. This difference is explained by the fact that the herd size decreased in the VRD study but increased in the Barkly Tableland study. The majority of the carbon revenue for the VRD property was generated by the reduction in herd numbers rather than the improvement in emissions intensity.

The key findings from the improved infrastructure, herd genetics and grazing management case study in the Barkly Tableland include:

- A suite of management changes have resulted in significant improvements in productivity, profitability and emissions intensity, but total emissions have actually increased in response to increased livestock carrying capacity.
- A large herd size would be required to offset current indicative ERF project costs before a carbon farming project would be worthwhile in this region.

This case study has been submitted to The Rangeland Journal for publication in the Climate Clever Beef special issue (Walsh and Cowley, submitted).

IMPROVING BREEDER HERD EFFICIENCY- INCREASE WEANING RATES IN THE QUEENSLAND FITZROY

Byrony Daniels and Steven Bray

The Oaklands demonstration property in the Queensland Fitzroy region is an organic beef breeding business. Organic certification limits the range of inputs that can be used and the inputs available can be expensive. The higher input costs are offset by higher beef prices received. The current herd situation was compared to an improved management scenario focused on improving weaning rates (Table 4). The base herd scenario (current situation) has 1005 breeders mated and 68% weaning rate. Heifers are joined at two years of age. Spayed heifers go to a separate fattening property. Cull cows are spayed and sold straight to the meatworks after fattening. The weaner steers go to the fattening property.

Management sees the current stocking rate as unsustainable due to low pasture biomass and poor land condition in some paddocks. Furthermore, if the decision was made to retain regrowth for carbon farming, stocking rates would need to be lowered as the growing trees will decrease livestock carrying capacity (Scanlan 2002). The improved management scenario involved lowering stocking rate by 10% (896 breeders) and supplementing the cows for four months in the dry season to increase weaning rate to 75%. The results show that herd gross margin would decline by 7% with the reduced stocking rate even though the gross margin per adult equivalent would improve by 4% (Table 4). The cost of supplement also contributed to offset productivity gains. Reducing stocking rate by 10% reduced livestock emissions by 10%, however combined with providing supplement, herd emissions intensity improved by 8%. At the scale of this enterprise (1005 breeders) there is little opportunity to offset the reduction in gross margin with carbon income from the herd, however carbon income from retaining regrowth may make this option worthwhile. Regrowth management at the property scale was evaluated using bioeconomic modelling in the ‘Innovative practices and technologies’ section.

Table 4 Oaklands herd modelling and greenhouse gas emissions results

Scenario	GM/AE	Herd emissions (t CO_2e)	Emissions intensity (t CO_2e per t LW sold)
Current Situation **1,552 AE**	$125	2,606	13.6 (191 t LW)
Reduce stocking rate by 10% increase weaning rates by 7%, supplement 4 months of year	$130	2,324	12.6 (184 t LW)

Key findings from the Increase weaning rates in the Queensland Fitzroy case study include:

- Reduced sales following stocking rate reductions can be difficult to offset with individual livestock productivity gains.
- Management strategies need to be carefully evaluated for profitability and greenhouse gas emissions benefits.

CHANGING THE ENTERPRISE MIX – AGE OF TURNOFF IN THE QUEENSLAND GULF

Joe Rolfe and Bernie English

In the Queensland Gulf region, business analysis on Karma Waters identified that low branding rates and low annual weight gains were key herd productivity constraints. Changing the turnoff strategy may provide opportunities to increase profitability given these constraints. Herd analysis and modelling compared the current strategy of turning off bullocks at 4–4.5 years with a range of younger steer and weaner turnoff strategies. Gross margins per AE steadily declined as turnoff age decreased, with weaner turnoff gross margins estimated to be nearly $15 per AE behind the current bullock operation (Table 5).

At Karma waters, reducing the turnoff age, reduced the total greenhouse gas emissions from 1,764 t CO_2e per year under the current bullock turnoff strategy, to 1,525 CO_2e per year if the production system moved to selling weaners (Table 5). However, greenhouse gas emissions intensity was 19% better for bullock turnoff compared to weaner turnoff.

Table 5 Impact of turnoff age on gross margin and greenhouse gas emissions at karma Waters in the Queensland Gulf.

	Turnoff 4.5 years	Turnoff 3.5 years	Turnoff 2.5 years	Turnoff 1.5 years	Turnoff Weaners
Gross margin for herd	$65,393	$58,900	$54,514	$43,767	$40,979
Gross margin/AE	$65.39	$58.90	$54.51	$43.77	$40.98
Greenhouse gas (GHG) emissions					
Total GHG emissions (t CO_2e/year)	1,764	1,652	1,587	1,560	1,525
GHG emissions/AE (t CO2e/AE)	1.76	1.65	1.59	1.56	1.53
GHG emissions/turnoff (t CO2e/t liveweight sold)	23.2	23.2	24.6	26.6	28.7

Key findings for the age of turnoff in the Queensland Gulf region include:

- Changing age of turnoff can substantially change profitability and alter total emissions and emissions intensity. Individual property evaluations are thus required to identify the best strategy.
- Higher enterprise gross margin often coincides with the best emissions intensity.

CHANGING THE ENTERPRISE MIX – BACKGROUNDING VERSUS BREEDING IN THE QUEENSLAND GULF REGION

Emma Hegarty and Joe Rolfe

Greenhouse gas emissions intensity was also evaluated for a Queensland Gulf Mitchell grass downs property where the enterprise had been changed from a trading and backgrounding (growing) operation to a breeding operation. The trading operation had a much lower greenhouse gas emissions intensity (average 4.4 t CO_2e/t liveweight sold) compared to the breeder herd operation (average 15.1 t CO_2e/t liveweight sold). The emissions intensity of the breeder herd was poorer due to the higher average liveweight of the livestock carried (cows, bulls and calves) compared to the lower liveweight of growing weaners and yearlings. Changing the enterprise type (breeding versus background) will change the greenhouse gas emissions profile of a business, however the weaners need to be produced somewhere so they carry 'embodied emissions' when they are sold or transferred. Carbon farming methodologies should take this into account.

Key findings from the backgrounding versus breeding in the Queensland Gulf region include:

- Changing the enterprise mix can alter total greenhouse gas emissions and emissions intensity.
- Methodology developers need to consider the 'embodied' emissions in producing weaners which may be purchased and bought into a business.

KEY FINDINGS FOR REDUCING METHANE EMISSIONS

- Improving efficiency of production through increasing weaning rates, early mating and cross breeding is a highly profitable strategy for some regions of northern Australia.

- Changing age of turnoff or enterprise mix can substantially change profitability and alter total emissions and emissions intensity, individual property evaluations are required to identify the best strategy. However the 'embodied' emissions in producing weaners needs to be considered.
- Pregnancy testing to remove unproductive breeders is a useful way to evaluate and improve herd reproductive performance and to manage available forage in dry seasons.
- A suite of management changes will likely be required to substantially change productivity, profitability and greenhouse gas outcomes.
- The gains achieved across the case study properties with markedly different rainfall, country types, and property size suggest similar improvements can be made on-farm across much of northern Australia.
- Total greenhouse gas emissions can decline if stocking rates are reduced. However, reduced sales following stocking rate reduction can be difficult to offset with individual livestock productivity gains.
- Need to consider seasonal conditions and assess climate risk as part of evaluation of the profitability and likely greenhouse emissions benefits of livestock supplementation.
- Higher enterprise gross margin often coincides with the best emissions intensity.
- Carbon farming profits will be highly sensitive to project management costs and carbon price.
- Carbon project viability will be highly sensitive to herd size, with large herds required to offset current indicative project management costs.
- Unless current indicative project management costs decrease substantially, businesses would need to 'stack' and/or aggregate projects to dilute these costs
- Beef businesses should focus on cost-effective changes to improve production efficiency and the associated improvement in livestock revenues. Potential carbon income should be considered a bonus and not the basis for management change alone.

INCREASE CARBON STORED IN SOIL AND VEGETATION

To increase carbon stored in soil and vegetation five broad practices were evaluated:

1. Regrowth management
2. Pasture management and land condition
3. Establishing improved pasture and legumes
4. Weed management
5. Response to land development

INCREASE CARBON STORED IN SOIL AND VEGETATION – EUCALYPT (BOX) REGROWTH MANAGEMENT AND SPELLING IN THE FITZROY REGION

Steven Bray, Bryony Daniels, Paul Jones, Carly Harris and Diane Allen

The Oaklands site in the Fitzroy region of central Queensland had significant areas of 10-year old Box regrowth that was due for reclearing because it was deemed by the landholders to be impacting on livestock productivity. Furthermore, they were aware that land condition in the paddock was fair to poor (B to C condition) and could be improved in order to increase long term carrying capacity. The aim of the trial was to evaluate the potential to retain Box regrowth for carbon income and to wet season spell pastures to improve land condition and pasture productivity.

The treatments measured at Oaklands included: remnant Box woodland, retained 10-year-old Box regrowth, recently cleared 10-year-old Box regrowth, and completely cleared with Graslan herbicide 10 years ago. For each vegetation type, two grazing treatments were applied: continuously grazed and wet season spelled. Utilizing the existing woody vegetation differences allowed comparisons of soil and vegetation carbon to be made during the project.

Tree carbon assessments found that remnant woody vegetation contained 5-8 times more carbon than 10-year-old Box regrowth indicating substantial scope for carbon storage by retaining regrowth vegetation (Figure 6).

The remnant trees grew faster over the three years of measuring than the regrowth plot (4.3 and 0.9 t CO_2e per ha per year respectively), however there were significant numbers of dead trees in the remnant vegetation indicating that the biomass of live trees was fluctuating with climate cycles. Little growth was recorded in the graslan paddock which was maintained with regular burning, while the recently cleared site recorded a carbon stock growth of 1 t CO_2e per ha per year.

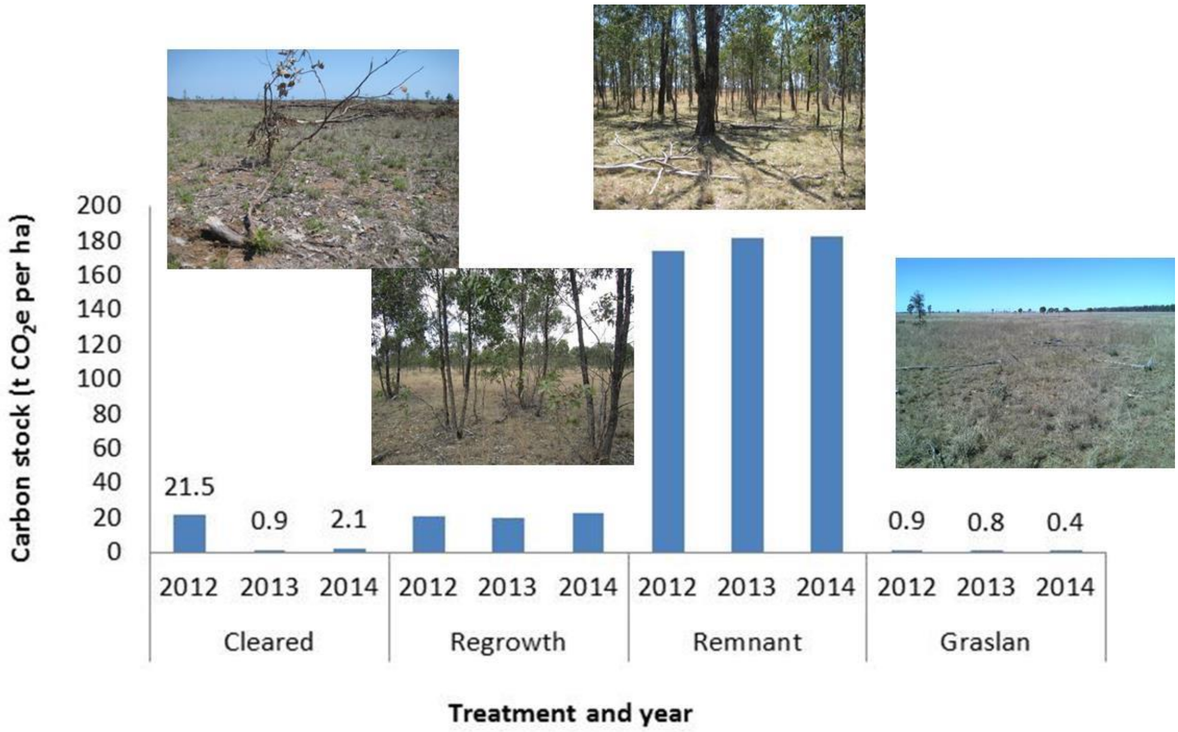

Figure 6 Woody vegetation carbon stock and representative photos for the Box woody vegetation at Oaklands in the Fitzroy region. Recently cleared plots were measured before chaining.

Predicted growth rates from the FullCAM model and growth at other eucalypt woodland sites in central Queensland were similar to the measured data.

Soil carbon was sampled using SCaRP methodology in collaboration with the soil carbon in regrowth AotG project. Soil carbon stocks varied between the treatments, but due to the large within-treatment variability, differences were not significant nor consistent between the grazing and woody vegetation treatments (Figure 7).

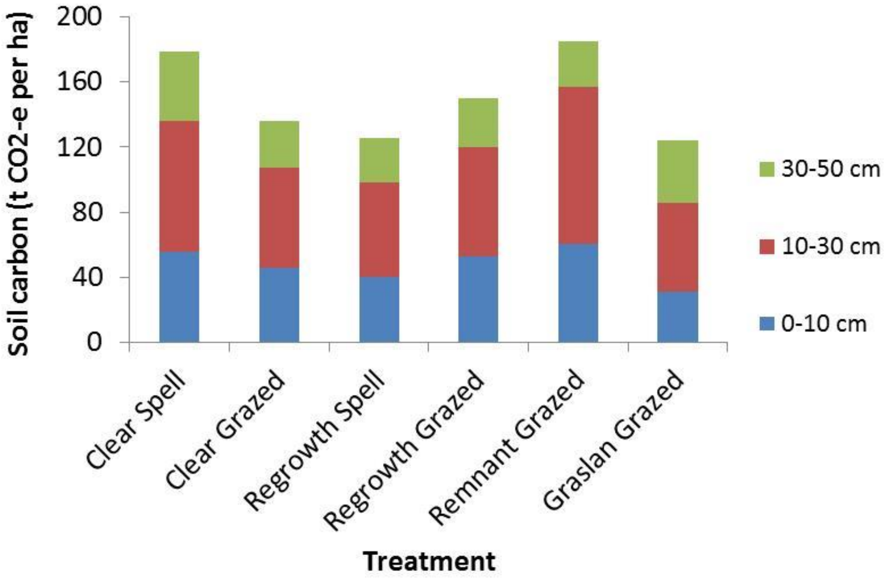

Figure 7 Soil carbon stocks at the Oaklands site. Differences between treatments were not significant nor consistent between vegetation types or continuously grazed and spelled systems. Clear = recently cleared.

Pasture biomass and land condition were measured in collaboration with the Spelling Strategies project (Harris *et al.* 2015). Pasture biomass improved with spelling and with lower woody biomass (Table 6). Land condition appeared to be slowly improving with wet season spelling but mainly in the recently cleared treatment. Pasture assessments at the end of the project indicated spelling doubled pasture biomass in the recently cleared plot, improved ground cover and led to a slight improvement in land condition.

Table 6 Pasture yield, crown cover, ground cover and land condition change (between 2012 and 2014) in the grazed and spelled systems on the remnant and recently cleared treatments (Harris *et al.* 2015). Negative change in land condition score indicates land condition has improved.

Treatment	**Change in yield (kg/DM)**	**Change in % crown cover**	**Change in % ground cover**	**Change in land condition**
Recently cleared and grazed	920.0	0.5	0.3	-0.5
Recently cleared and spelled	2324.6	1.5	0.1	-0.9
Remnant and grazed	-316.4	-0.4	-4.1	0.1
Remnant and spelled	54.3	0.5	1.8	-0.1
Average- overall	398.1	0.1	-6.2	-0.2
Spelled	857.4	0.3	-5.3	-0.4
Grazed	-61.3	-0.1	-7.1	0.0

In the plots where no spelling occurred there was no recorded change in land condition. The results from the Oaklands demonstration site are consistent with the slow change in land condition recorded at the Monteagle and Wambiana sites in the MLA Wet Season Spelling Strategies project (Jones *et al.* 2015).

Regrowth management and spelling strategies were further evaluated at the whole property scale using bioeconomic modelling (see Innovative practices and technologies section).

Key findings of the eucalypt (Box) regrowth management and spelling case study in the Fitzroy region included:

- Regrowth has potential to sequester significant amounts of carbon in vegetation.
- Soil carbon results showed no consistent nor statistically significant differences in the various grazing and woody vegetation treatments.
- Spelling can be used to improve pasture biomass and slowly improve land condition.

This case study has been submitted to The Rangeland Journal for publication in the Climate Clever Beef special issue (Whish *et al.,* submitted).

INCREASE CARBON STORED IN SOIL AND VEGETATION – BRIGALOW REGROWTH MANAGEMENT IN THE FITZROY REGION

Steven Bray, Byrony Daniels, Rebecca Gowen and Diane Allen

The Coonabar case study considered the effect of retaining Brigalow regrowth strips for carbon farming on grass production, livestock carrying capacity and profitability. Brigalow regrowth strips have been retained across the property. Current vegetation and soil carbon stocks were assessed and bioeconomic modelling was used evaluate the opportunity and constraints for retaining a range of percentage area of regrowth. The producers also wanted to know whether the income from a carbon farming regrowth project could offset the animal production losses should the regrowth strips be retained. Vegetation treatments included remnant Brigalow, regrowth Brigalow (25 years old) and Graslan cleared strips (Figure 8).

Figure 8 Looking along edge of a regrowth strip (left), tree density within a regrowth strip (centre) and tree density within a remnant uncleared strip (right).

The remnant woody vegetation currently has 4 times more carbon than the retained regrowth per hectare indicating an opportunity for further carbon sequestration in the retained regrowth (Figure 9). The regrowth strip contained 32 t CO_2e/ha in the trees approximately 25 years after it was initially cleared, increasing by 3.3 t CO_2e/ha per year between 2012 and 2014. The remnant vegetation also increased in carbon stock between 2012 and 2014 at a rate of 3.6 t CO_2e/ha per year. Dead trees were present in the mature remnant vegetation indicating that live tree biomass was fluctuating with climate cycles. There is currently little woody biomass in the cleared 'grass' strip compared to the regrowth and remnant vegetation although some scattered regrowth was present.

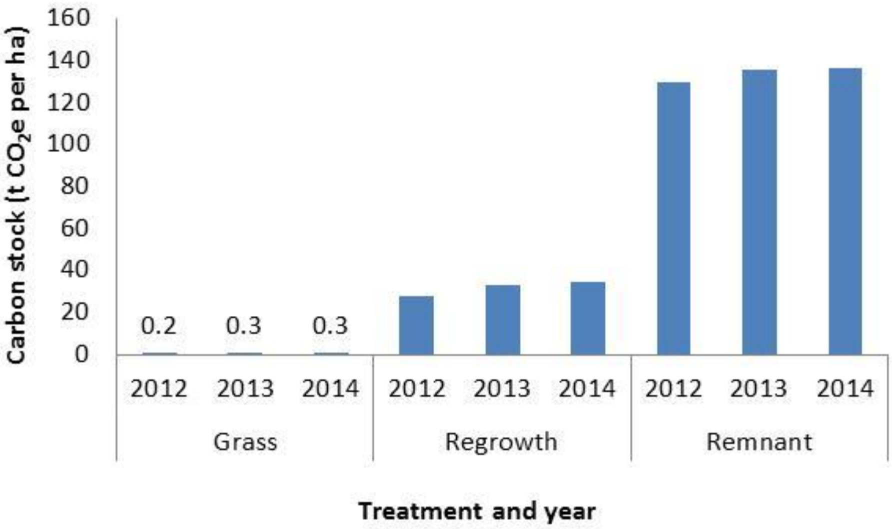

Figure 9 Tree carbon stock in each treatment and year at Coonabar.

When the regrowth strips were initially retained, it was thought by the landholders that there should be little impact on cattle production (maybe even beneficial for production). As the regrowth has grown, the impact on grass production has become more apparent, with grass yield less within the regrowth strips and often a noticeable difference in greenness, with the grass near and amongst the regrowth senesced and brown, while the grass in the cleared strips tending to be greener (Figure 10). When the grass biomass was measured, the cleared grass strip had about twice the amount of grass that was present in the regrowth strip, which was twice the amount of grass in the remnant strip. A decline in grass biomass of this magnitude would impact livestock carrying capacity, particularly if the regrowth is retained and allowed to grow to a level consistent with remnant vegetation biomass.

Figure 10 Grass biomass near and amongst the regrowth strip is lower and the pasture often appears more senesced and brown compared to the grass away from the regrowth at Coonabar.

Soil carbon was measured using SCaRP methodology in collaboration with the soil carbon regrowth project, to assess whether there was any difference between the vegetation types. There was no statistical difference in soil organic carbon stock between the three woody vegetation treatments (Figure

11) which indicated that land development and maintaining pasture in good condition made little difference to soil carbon stocks.

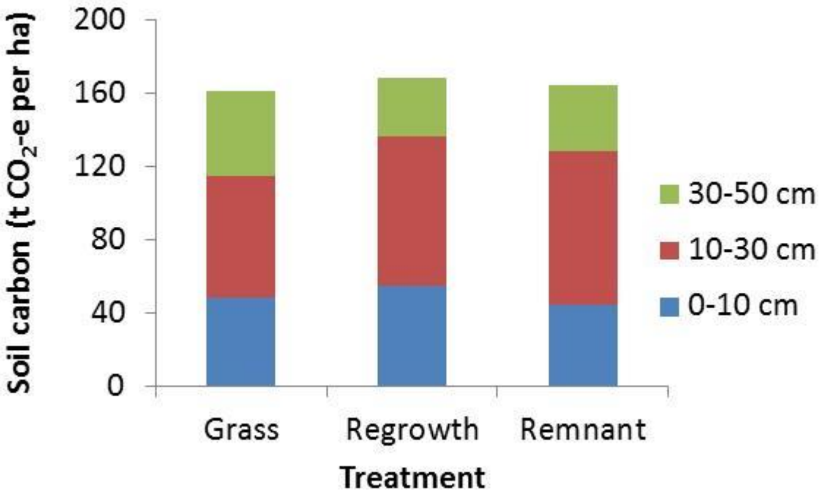

Figure 11 Soil organic carbon stock in each treatment at Coonabar.

Key findings for the Brigalow regrowth management in the Fitzroy region case study include:

- Regrowth retention has potential to sequester large amounts of carbon in woody vegetation.
- Pasture biomass is substantially impacted by regrowth retention which negatively impacts on livestock carrying capacity.
- Land development and maintaining pasture in good condition made little difference to soil carbon stocks.

This case study has been submitted to The Rangeland Journal for publication in the Climate Clever Beef special issue (Gowen and Bray, submitted).

INCREASING CARBON STORED IN SOIL AND VEGETATION – ESTABLISHING SOWN PASTURE AND LEGUMES

Joe Rolfe and Bernie English

The Karma Waters demonstration site in the Queensland Gulf used stock water development, wet season pasture spelling, Stylo pastures, conservative stocking rates and phosphorus supplementation as the key management strategies to improve weaning, mortality and growth rates. Diet quality data (from NIRS faecal samples) highlighted the value of improved Stylo pastures coming into the drier months, with protein levels often at 6–7% and digestibility above 51% in November across several paddocks. This diet quality is above the maintenance levels of growing cattle and weight gain in steers would be expected. It is not uncommon to see native pasture protein and digestibility levels drop below 5% and 48% respectively in the dry season on similar country, resulting in weight loss across all classes of cattle. The dry season faecal tests often indicate phosphorus is limiting production and weight gain in the Stylo paddocks where late season digestibility and protein are above animal maintenance requirements, so a phosphorus supplementation program has been established. Stylo pastures and phosphorus supplementation would be contributing to improved livestock emissions intensity through improved weaning rates, liveweight gain and earlier turnoff, however, it was unknown whether the improved land condition as a consequence of Stylo establishment and pasture management was impacting on soil carbon stocks.

Soil carbon and nitrogen stocks under native pastures with Stylos were compared to native pasture. The native pasture–Stylo paddock received a spell every second year and was in good A- condition while the native pasture paddock was continuously grazed and in fair to poor condition (B–C). Soil carbon was examined at depths of 0–10 cm, 10–30 cm and 0-30cm. There was no significant difference in soil carbon between the two sites for any depth increment. There was no significant difference between the two sites for nitrogen in the 0–10 cm soil layer (Table 7), however, there was a significant difference between the two sites in the 10–30 cm soil layer. The native pastures site had considerably lower soil nitrogen than the native pasture–Stylos site indicating that the Stylos may be fixing nitrogen which was accumulating in the 10-30cm soil layer. The extra nitrogen would likely improve pasture productivity and quality.

Table 7 Soil nitrogen at Karma Waters (t N/ha) for three depth increments.

Depth	Stylo	No Stylo
0-10 cm	1.69	1.64
10-30 cm	1.21	0.92
0-30 cm	2.9	2.56

The results of this case study were supported by sampling in the Douglas Daly region which found no consistent differences in soil carbon between native pasture and improved pasture sites. The unresponsiveness of soil carbon to management and land condition will reduce the likelihood of producers making decisions to change management based on soil carbon outcomes, as the soil carbon differences are often minimal and not necessarily positive at some sites.

Key findings for the establishing sown pasture and legumes case studies included:

- There was no consistent evidence to indicate that soil carbon will increase with the establishment of improved pastures.
- The unresponsiveness of soil carbon to management means that a soil carbon 'carbon farming' project will be risky.
- Accumulation of soil nitrogen was found at one site with legumes which will likely increase pasture productivity but also nitrous oxide emissions.

INCREASING CARBON STORED IN SOIL AND VEGETATION – MANAGING LAND CONDITION ON THE BARKLY TABLELAND

Dionne Walsh and Peter Shotton

Soil organic carbon (SOC) stocks were measured to assess change with land condition, grazing duration and grazing intensity at an existing NT DPIF grazing land management demonstration site at Alexandria. The site in East Ranken paddock was established in 2010 to demonstrate sustainable stocking rates and pasture spelling (Walsh 2011). Land condition indicators and pasture productivity were measured annually along 5km long transects radiating out from three bores of different ages. The oldest of these bores was established in 1910, the second oldest in 2005 and the youngest in 2010.

The soil sampling confirmed previous work in the region that showed that SOC is naturally quite low (typically <0.5%) in the productive vertosols of the Barkly Tableland region. Average SOC stocks were typically in the order of 9-17 t C/ha in the top 30cm (Figure 12). Few statistically significant differences in average total SOC stocks were found between the different age bores (grazing duration) or distance from water (grazing intensity). Somewhat surprisingly, the highest SOC stocks (23.8 t C/ha) were found at 100m from the oldest bore, which is probably due to the long-term accumulation of cattle dung and/or high turnover of short-lived plants in this heavily impacted zone. Soils from long-term ungrazed enclosures did not have significantly more SOC than adjacent heavily grazed areas suggesting that up to 100 years of grazing has had no discernible negative impact on SOC stocks at the site. If typical, the results suggest that there is no potential to earn carbon income from the management of land condition on cracking clay soils in the Barkly Tableland region.

These results are supported by soil sampling at Karma Waters, Oaklands and Coonabar in this project and other recent soil carbon projects (e.g. Allen *et al.* 2014, Bray *et al.* 2010; Bray *et al.* submitted; Pringle *et al.* 2011).

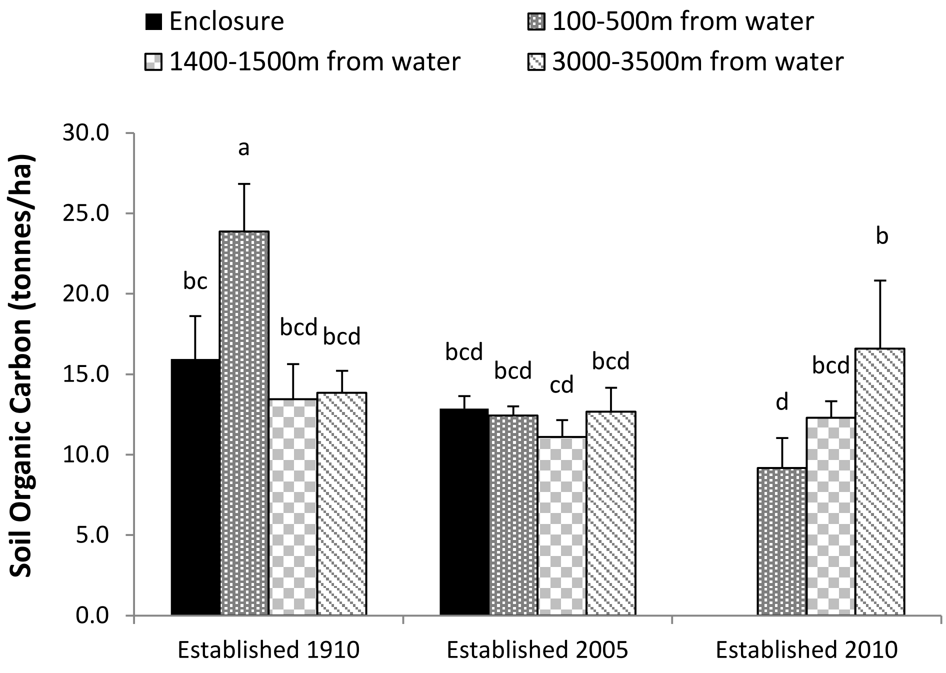

Figure 12 Soil organic carbon stocks (0-30cm) for three water points in East Ranken paddock, Alexandria Station. Error bars are the 95% confidence interval. Means with different letters are significantly different to each other (P<0.05).

Key findings from the managing land condition on the Barkly Tableland case study included:

- No consistent evidence was found to support the widely-held belief that soil organic carbon stocks are higher in locations that are in good land condition.

- Based on the soil carbon work undertaken in this project (together with evidence from other published scientific studies), it is recommended that northern beef producers exercise caution when considering soil carbon sequestration ERF projects due to the risk of unpredictable (often unresponsive) and inconsistent changes in SOC stocks with change in management.
- Despite the limited potential for soil carbon income, our analyses confirm that pasture management to maintain good land condition can have significant productivity, profitability and land management benefits.

This case study has been published (Walsh and Shotton, 2015).

INCREASE CARBON STORED IN SOIL AND VEGETATION – WEED MANAGEMENT IN THE QUEENSLAND GULF

Emma Hegarty and Joe Rolfe

The case study property in the Queensland Gulf Mitchell grass downs is continually striving to improve the productive capacity and efficiency of the land resource. This is being achieved through wet season spelling, forage budgeting and woody weed control.

Soil carbon was assessed at two sites that reflect the soil type and pasture species seen across the property. Site 1 represented Mitchell grass downs country that was cleared of the woody weed prickly acacia (which the property manager estimated had been there for 20 years) in 2011 and has since been relatively free of this woody weed. Site 2 was Mitchell grass downs country (with no history of prickly acacia infestation). There was no significant difference in soil organic carbon between the two sites indicating the presence of prickly acacia did not change the amount of soil organic carbon held in the soil. This finding should be tested at other sites before wider conclusions can be drawn.

INCREASE CARBON STORED IN SOIL AND VEGETATION – RESPONSE TO LAND DEVELOPMENT IN THE DOUGLAS DALY

David Ffoulkes and Peter Shotton

Soil carbon was measured at six paired sites in the Douglas Daly region of the Northern Territory. The paired sites consisted of uncleared bush compared to cleared native pasture or developed improved pasture. There was no consistent trend between uncleared bushland and pasture sites indicating that soil carbon is not adversely affected by clearing and pasture development. However, there may be some significant differences in SOC between sown pasture species at the 10-20cm soil depth layer indicating that some pasture species may have potential to sequester more carbon into the soil than others. Inter-year and intra-year (season) sampling of the same sites produced variable results reducing confidence in findings from a single sampling date or attempts to monitor soil carbon trends over time. This has significant implications for verification of soil carbon stocks as part of a carbon farming soil carbon sequestration project.

Soil carbon stocks between remnant native vegetation and cleared native and improved pasture were also assessed in the Queensland Fitzroy (Figure 7 and Figure 11) and in the Maranoa Balonne and support the findings of no consistent differences in soil organic carbon in the Douglas Daly region.

Key findings for the response to land development in the Douglas Daly case study included:

- There was no consistent difference between uncleared remnant vegetation and developed pasture indicating that soil carbon is not adversely affected by clearing and pasture development.

KEY FINDINGS FOR INCREASING CARBON STORED IN SOIL AND VEGETATION

- Regrowth retention has potential to sequester significant amounts of carbon in vegetation.
- Soil carbon results were not significantly different, nor consistent between grazing and woody vegetation treatments.
- Pasture biomass is substantially impacted by regrowth retention and negatively impacts on livestock carrying capacity.
- No consistent differences in soil carbon were found between uncleared remnant vegetation and good condition developed pasture, indicating that soil carbon is not adversely affected by clearing and pasture development.
- No consistent evidence to indicate that soil carbon will increase with establishment of improved pastures.
- Pasture spelling can be used to improve pasture biomass and slowly improve land condition.
- No consistent evidence was found to support the widely-held belief that soil organic carbon stocks are higher in locations that are in good land condition.
- Based on the soil carbon work undertaken in this project (together with evidence from other published scientific studies), it is recommended that northern beef producers exercise caution when considering soil carbon sequestration ERF projects due to the risk of unpredictable (often unresponsive) and inconsistent changes in SOC stocks with change in management.
- Despite the limited potential for soil carbon income, our analyses confirm that pasture management to maintain good land condition can have significant productivity, profitability and land management benefits.

INNOVATIVE PRACTICES /TECHNOLOGIES TO REDUCE AGRICULTURAL GREENHOUSE GAS EMISSIONS / INCREASE CARBON STORED IN SOIL

Bioeconomic modelling (BEM) analyses integrating livestock, vegetation, prices and land condition were used to evaluate a suite of management changes at the whole-property scale. These analyses assessed the impact of implementation on animal productivity, profitability, greenhouse gas emissions and carbon stored in vegetation and soil over a 20-30 year period. The purpose of the BEM was to evaluate the long-term performance of these strategies over a wider range of seasonal conditions than was possible during the project period.

INNOVATIVE PRACTICES AND TECHNOLOGIES – EVALUATING REGROWTH RETENTION AND WET SEASON SPELLING STRATEGIES

Giselle Whish, Lester Pahl and Steven Bray

Regrowth retention to sequester carbon and strategies to implement wet season pasture spelling to improve land condition and livestock productivity and profitability were evaluated at Oaklands in the Fitzroy region using a bioeconomic modelling framework to assess the biological, economic and carbon implications associated with integrating carbon farming practices at the whole-farm scale.

Five regrowth management scenarios (0 to 100% of regrowth cleared) were evaluated and six pasture spelling scenarios (varied in how cattle from the spelled paddocks were distributed across the property or sold) were compared in separate modelling exercises.

When regrowth was retained (less regrowth was cleared and less controlled burns), the amount of pasture grown and the number of cattle carried on the property over 20 years decreased. An average herd of 1302 AE was achieved when 100% of the property's regrowth was cleared and managed. The herd declined by 25% to 1038 AE when 0% regrowth was cleared. As more regrowth was cleared and managed there were increases in herd size, cattle sales, average annual profit, enterprise gross margin and gross margin/AE. For example, the average annual profit and enterprise gross margin for 100% clearing of regrowth was $70,000 higher than that for no clearing of regrowth. Net carbon outcomes between regrowth clearing scenarios were dominated by the amount of carbon sequestered by trees, where carbon sequestered in trees was a magnitude greater than carbon emitted from livestock (Figure 13). A carbon price of only $3 per t CO_2e sequestered by trees was needed to compensate for lost income from cattle sales over 20 years when all regrowth was retained and allowed to grow unchecked on the Oaklands property. If the Oaklands property was independent of other family owned properties, and sold 300kg steers instead of weaner steers, a carbon price of $5 per t CO_2e sequestered by trees was needed to compensate for lost income from cattle sales. A key consideration for a family business and the business' long term goals and aspirations would be the impact of reduced livestock production and the requirement to retain trees once the trees reach maximum carbon stocks and were no longer generating additional carbon income.

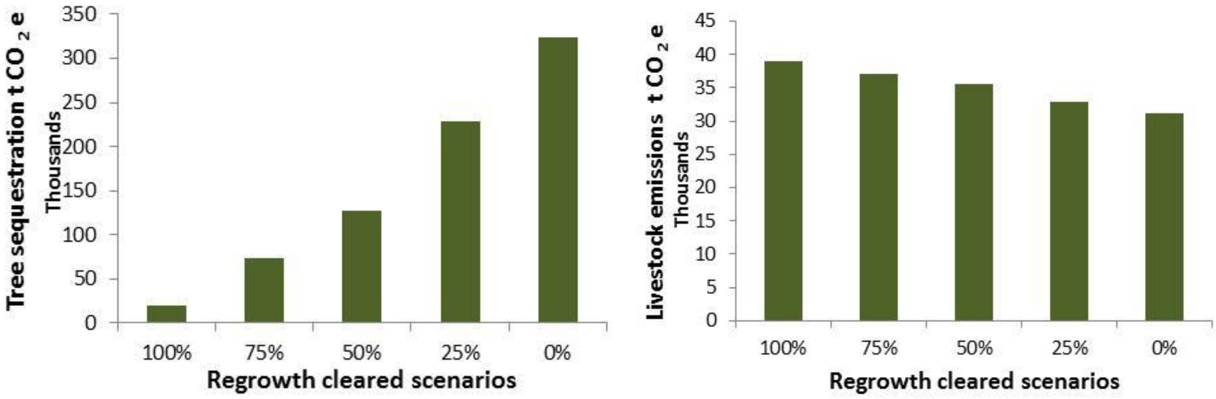

Figure 13 Sequestration in retained regrowth and livestock emissions of 20 years at Oaklands.

The biophysical and economic outcomes of 20-years of rotational pasture spelling on the Oaklands property were dependent on the proportion of the property spelled, the stocking rate, timing of spell, and the interaction of spelling and regrowth management practices. Pasture condition was better (20% increase in perennial grasses), and the amount of total standing dry matter (pasture) was higher (14%

increase) for all three spelling scenarios which had lowered stocking rates during the first 12 years (livestock from the spelled paddock were sold when spelling began, livestock were then purchased to return to the original stocking rates 12 years later - after 3 spelling cycles). Both pasture condition and cattle productivity declined in three of the five B condition paddocks when cattle from spelled paddocks were added for four or eight consecutive growing seasons (indicating low pasture resilience for coping with short term higher stocking rates). Adding cattle from the spelled paddock to the Graslan paddock stocked with heifers was not the only factor that caused overgrazing in this paddock. Reduced pasture fuel loads meant the burning regime was ineffective for controlling the regrowth, causing a downward spiral of overgrazing and increased regrowth, leading to a significant loss of pasture condition.

The impacts of the rotational spelling scenarios had a relatively small effect on the overall herd productivity and profitability of Oaklands. The marginal changes to financial outcomes (less than 5% of total gross margin) are due to the relatively small changes to the herd size which did not vary greatly at the whole-property scale between spelling scenarios due to the low proportion of the property area spelled (20% of the property), the herd size in the spelled paddocks (15% of total herd) and the use of fixed maintenance stocking rates in simulations. The lower stocking rate spelling scenarios (stock from spelled paddock sold for 12 years) and the scenario where spelled stock were distributed within the system achieved the highest gross margin per AE.

The changes in carbon stocks associated with pasture spelling on Oaklands did not impact the financial outcomes of rotational spelling as there were no regrowth retention areas designated for carbon farming, and neither the carbon sequestered in high pasture biomass nor that emitted from cattle in the form of methane are currently able to derive carbon income. However, rotational spelling in conjunction with a reduced stocking rate did achieve the best outcomes in terms of improvements in pasture condition, carbon stored in pasture biomass, liveweight gain, lower livestock methane emissions and better gross margin per AE. Distributing stock from the spelled paddocks across the better condition paddocks (in an attempt to utilize the resilience of the better condition pasture) achieved the worst pasture and animal productivity outcomes and carbon outcomes. The poor outcomes for B condition paddocks were predominantly due to the significant loss of the pasture condition in one particular paddock after 20 years.

Key findings from the evaluating regrowth retention and wet season spelling strategies case studies include:

- Regrowth retention for carbon sequestration has potential for substantial carbon income, although livestock income declines over time as pasture productivity declines.
- Pasture spelling can improve pasture condition in poor condition paddocks, but careful consideration of where the livestock are moved to is required, otherwise significant declines in land condition in those paddocks can negate the benefits of spelling poor condition paddocks.
- Modelling indicated there was little resilience in B-condition pasture to cope with higher stocking rates while other pastures are spelled, particularly where regular controlled burns are required to manage regrowth.

This regrowth options case study has been submitted to The Rangeland Journal for publication in the Climate Clever Beef special issue (Whish *et al*., submitted).

INNOVATIVE PRACTICES AND TECHNOLOGIES – NET CARBON POSITION OF LIVESTOCK GRAZING STRATEGIES AT WAMBIANA

Steven Bray and Natalie Doran-Browne

The Wambiana grazing trial in the Burdekin catchment of northern Queensland provided an opportunity to retrospectively assess carbon stocks and greenhouse gas emissions associated with a northern Australian livestock grazing system. Livestock, pasture, woody vegetation, soil and fire were assessed under alternative grazing management strategies (moderate and heavy stocking rate) over a 16 year period. The results showed that tree biomass and woody vegetation dynamics dominate the carbon stocks and fluxes in grazed savanna woodlands (Figure 14 and Figure 15). During the trial, both moderate and heavy stocking rate treatments had a positive net carbon balance (reported as t CO_2e) with the moderate stocking rate treatment having a better 'net carbon position' (19 t CO_2e per ha) than the heavy stocking rate treatment (9 t CO_2e per ha), primarily due to less livestock emissions and greater pasture biomass (Figure 16). These results add to the previously published benefits on land condition and economic return of grazing at moderate stocking rates compared to heavy stocking rates (O'Reagain *et al.* 2011 and 2014; Scanlan *et al.* 2013).

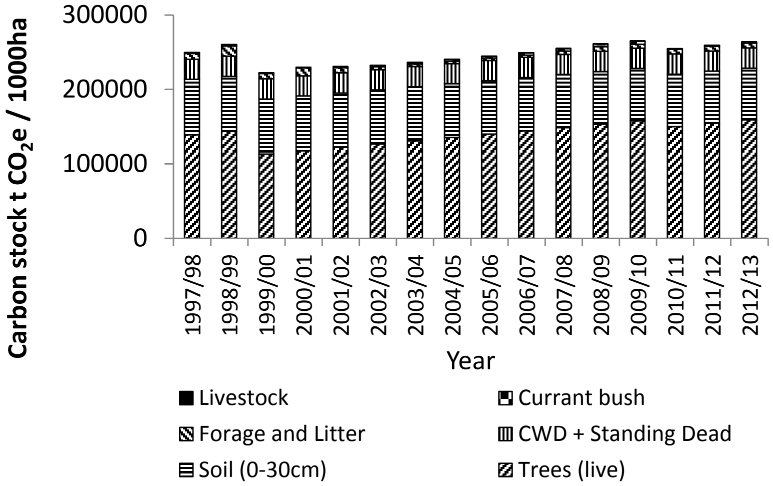

Figure 14 Carbon stocks (t CO_2e per 1000 ha) for six biomass pools during the 16 year (1997 to 2013) Wambiana grazing trial for the Heavy stocking rate treatment.

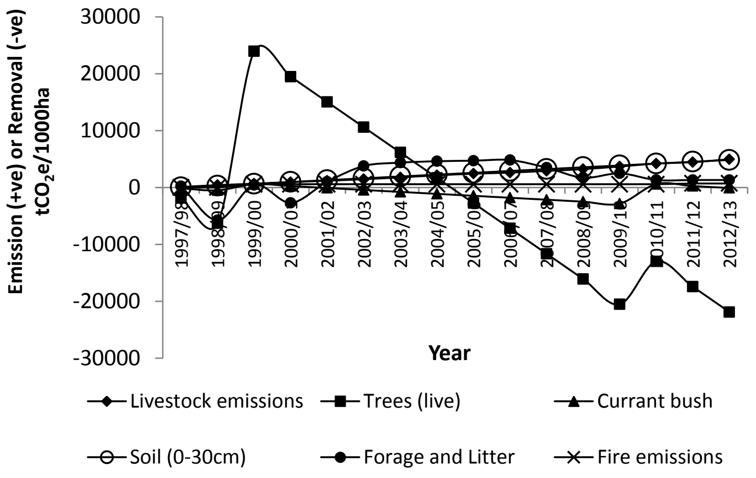

Figure 15 Cumulative carbon fluxes and emissions (t CO_2e per 1000 ha) during the 16 year (1997 to 2013) Wambiana grazing trial in the Heavy stocking rate treatment. Positive (+ve) values indicate emission to the atmosphere and negative (-ve) values indicate removal from the atmosphere relative to the starting year.

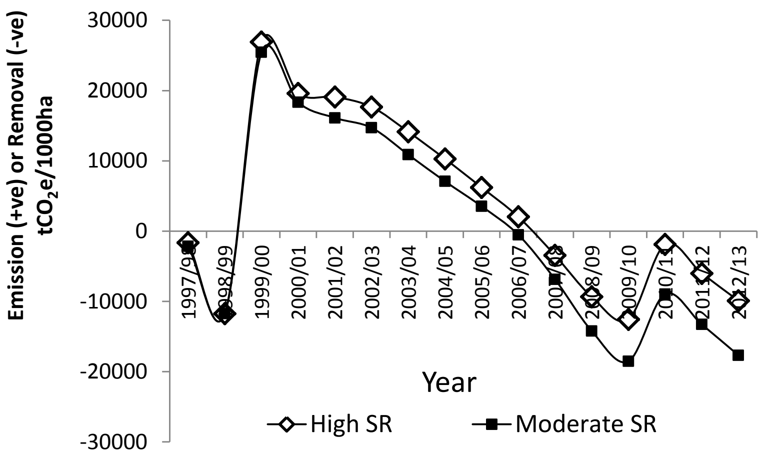

Figure 16 Summary of the carbon flux and emissions (t CO_2e per 1000 ha) during the 16 year (1997 to 2013) Wambiana grazing trial in the heavy and moderate stocking rate treatments. Positive (+ve) values indicate emission to the atmosphere and negative (-ve) values indicate removal from the atmosphere relative to the starting year.

This work was published in the Animal Production Science journal (Bray *et al.* 2014).

Key findings for the net carbon position of livestock grazing strategies at Wambiana case study included:

- Vegetation dynamics can dominate the net carbon position of a grazing business because livestock methane emissions are relatively small on a per hectare basis on extensive beef properties.
- Moderate stocking rates are better than high stocking rates for greenhouse gas emissions, carbon in pasture vegetation and profitability.

KEY FINDINGS FOR INNOVATIVE PRACTICES / TECHNOLOGIES TO REDUCE AGRICULTURAL GREENHOUSE GAS EMISSION / INCREASE CARBON STORED IN SOIL

- Vegetation dynamics can dominate the net carbon position of a grazing business because livestock methane emissions are relatively small on a per hectare basis on extensive beef properties.

- Regrowth retention for carbon sequestration has potential for substantial carbon income, although livestock income declines over time as pasture productivity declines.
- Moderate stocking rates are better than high stocking rates for greenhouse gas emissions, carbon in vegetation and profitability.
- Pasture spelling can improve pasture condition in poor condition paddocks, but careful consideration of where the livestock are moved to is required otherwise significant declines in land condition in those paddocks can negate the benefits of spelling.
- Lower average stocking rates to achieve carbon or land condition outcomes can be a significant cost to producers if not offset by alternative income (e.g. carbon income).
- Modelling indicated there was little resilience in fair B-condition pasture to cope with higher stocking rates while other pastures are spelled, particularly where regular controlled burns are required to manage regrowth.

REGIONAL DIFFERENCES

Case studies and evaluations were undertaken on 11 beef grazing properties across three regions in northern Australia. There were regional differences in the opportunities for carbon farming (e.g. not all regions have woody regrowth) however, overall there was little difference in response to similar management options between regions. The business response to improving herd productivity and profitability was similar across regions and generally, improved herd efficiency led to improved greenhouse gas emissions intensity. Due to the high sensitivity of grazing businesses to input costs, the implementation of new management strategies needs to be carefully considered in all regions on a business-by-business basis.

Soil carbon responses to management practices in extensive beef regions in northern Australia as measured using SCaRP methodology were found to be inconsistent and variable, leading to the conclusion that there is little opportunity to generate carbon income from a soil carbon ERF project in northern Australian grazing land as the business risk will be too high.

The biggest difference between regions was one of scale, particularly when considering beef herd management activities for carbon farming. Suites of management practices (as opposed to a single change) were able to substantially improve emissions intensity (e.g. by 10-30%), however very large herd sizes are required to offset current indicative ERF project costs. This means that for most family businesses there is little opportunity for carbon farming profits and any livestock practice change needs to be carefully evaluated to ensure it is profitable from solely livestock income. Some opportunities to dilute carbon project costs may be available if businesses are able to ‘stack’ a number of carbon farming projects (e.g. nitrate feeding, herd management, fire abatement and/or regrowth management) or aggregate projects with other businesses.

Key findings from the regional differences assessment were:

- A suite of management changes are required to make a large enough impact to potentially consider registering a carbon farming project.

- To dilute current indicative carbon project costs, producers will need to consider ‘stacking’ multiple projects or aggregate projects with other businesses.
- Soil carbon responses to management practices as measured using SCaRP methodology were found to be inconsistent and variable, leading to the conclusion that there is little opportunity to generate carbon income from a soil carbon ERF project in northern Australian grazing land as the business risk will be too high.

EXTENSION AND COMMUNICATION ACTIVITIES AND LEGACY PRODUCTS

The project used a suite of engagement and extension techniques across northern Australia to raise awareness with over 1800 people and 860 businesses across northern Australia. 47 people from 19 businesses demonstrated practice change during the project by undertaking businesses analysis and/or changing an aspect of management on their property. Engagement and extension methods include engaging regional champions, programmed learning (training packages), information access (e.g. field days/forums, newsletter articles), consultant/mentoring (one-on-one), on-property demonstrations and producer group activities. Ongoing support and mentoring with the 11 case study properties and other beef producers enabled the delivery team to understand production, profitability and practicality issues as well as the link between herd productivity and greenhouse gas emissions.

Across the three years of the project, the project team has interacted with industry stakeholders via:

- The establishment and promotion of 11 demonstration sites
- 12 project case studies and fact sheets
- 22 field days/paddock walks
- 22 industry events/forums/briefings/seminars
- 11 conference papers/posters
- 33 newsletter/on-line articles
- 2 webinars
- 13 radio and TV interviews
- 9 journal papers

Using the above extension and communication activities the project has met or exceeded its extension and communication targets (Table 8).

Table 8 Extension and communication achievement and targets.

Type of impact	Impact	Original Targets
Increased awareness about the project and carbon issues	Direct interaction with 1800 people and 860 businesses Broad media awareness - >29,000 people	Direct interaction – 595 Broad awareness - 2050
Demonstrated increase in KASA (Knowledge, Attitudes, Skills & Aspirations)	91 people representing at least 45 businesses	93 producers
Demonstrated Practice Change, influenced by the project	47 people representing at least 19 businesses	24 producers

In the Queensland Gulf, post-workshop evaluations and on-line surveys identify enterprise issues, evaluate success of the forums, track implementation and identify where more information/follow up is needed. On-property follow-up to support practice change has been conducted on 20 breeding enterprises by the Queensland Gulf team since forums were held in 2012. A range of practices are currently being implemented on these enterprises including: breeder segregation systems (12 properties), wet season pasture spelling (14 properties), wet season phosphorus supplementation (11 properties), pasture improvement (8 properties) and improved weaner feeding programs (9 properties).

Overall the feedback across all regions indicated that the project helped producers to improve their knowledge of carbon farming and increased their knowledge of on-farm management to either decrease methane emissions or increase carbon in soil and vegetation. The business analysis approach used by the project helped producers identify weaknesses and strengths in the business and identify and evaluate strategies to target the underperforming areas to improve herd and business performance (Rolfe *et al.* submitted). However, producers identified that the business analysis was not solely responsible for the change occurring, suggesting instead that extension, producer group discussion or other external activities are also very important for producers to gain the knowledge and confidence to undertake practice change.

The project team was keen to ensure the project had a legacy past the end of the funding period and therefore has focused on a range of legacy products, including:

- 12 case studies and fact sheets.
- Climate Clever Beef website.
- 20 conference and scientific journal papers.
- The Rangeland Journal Special Issue – Climate Clever Beef (scheduled for publishing in 2016).
- Development of many long lasting relationships with producers and other colleagues across a range of agencies and organizations.

Key findings from the extension and communication activities include:

- Business analysis can be a powerful component of extension activities encouraging practice change.

- Case studies and fact sheets were useful for producers and policy personnel to understand how management change could impact productivity, profitability and greenhouse gas emissions as part of a 'real' business.
- Developing and maintaining trusting relationships with producers and colleagues is extremely important to successfully undertake comprehensive business analyses and facilitate practice change.

IMPLICATIONS FOR AUSTRALIAN AGRICULTURE

The northern Australian beef industry is large, managing 15 million cattle on 250 million hectares. The expansive size of the industry means that significant environmental impacts are likely. Of concern are declines in land condition leading to reduced water quality and sediment transport and emissions of greenhouse gases to the atmosphere. The northern Australian beef industry is estimated to contribute around 79% of Australia's agricultural greenhouse gas emissions (10% to Australia's total greenhouse gas emissions) through livestock emissions as well as impacting carbon stored in soil and vegetation. The northern Australian beef industry thus has a significant role to play through 'carbon farming' to assist Australia to meet its long term emissions reduction targets. However, productivity growth and returns on investment in the northern Australian beef industry are generally static or declining and together with high debt levels and increasing input costs, any new carbon farming activities will require rigorous evaluation to ensure that business profitability is improved and financial risks are minimized.

'Carbon farming' was defined for this project as having potential to reduce greenhouse gas emissions, improve emissions intensity or increase carbon stored in soil or vegetation. Carbon farming practices may or may not have potential to generate 'carbon income' through participation in the Australian Government's Emissions Reduction Fund (ERF).

On-farm trials and evaluations on 11 beef businesses in northern Australia demonstrated there were opportunities to minimise the intensity of livestock methane emissions and increase carbon stored in vegetation.

A number of livestock management strategies were identified, which led to an improvement in livestock emissions intensity of 10 to 30% including: improving weaning rates, increasing lifetime reproductive performance and improving growth rates. Generally adoption of a suite of management changes and tools were required to achieve the desired outcomes (e.g. pregnancy testing, supplementation, heifer management and pasture improvement). Currently, there is little opportunity for most northern beef businesses to profitably generate and sell carbon credits from reducing livestock methane emissions because the scale of most businesses is not adequate to offset current indicative project management costs and carbon price risk. In many cases, the livestock management options identified improved the productivity and profitability of the business without 'carbon income'. Therefore, if producers are undertaking best livestock management practices, they are likely to be achieving desirable carbon farming outcomes. Reduction in total emissions was only achieved when stocking rates were reduced which can have a significant impact on business profitability through reduced sales, even if individual livestock productivity is improved.

The retention of regrowth was found to store substantial amounts of carbon in vegetation. In regions with significant areas of regrowth (e.g. central and southern Queensland) this option may be highly worthwhile depending on the area of regrowth retained, rate of decline in livestock carrying capacity as regrowth grows and carbon price. The implications of this strategy need to be considered in line with long-term business goals due to the impact on future livestock productivity and future land use options.

Grazing management strategies that lead to improved pasture condition, pasture biomass and reduced drought risk have the ability to substantially increase the average amount of carbon stored in vegetation, particularly in grassland landscapes. This carbon farming practice has significant positive implications for landscape health, reduced off-farm impacts, long term business profitability and reduction of drought risk, but currently has no opportunity to generate carbon income due to a lack of a ERF methodology and the perception that higher average pasture biomass is not a secure long-term carbon store. This carbon farming opportunity could be addressed by policy and lead to a significant improvement in the environmental impact of the northern Australian beef industry and address a number of the Governments priorities:

- Reef water quality
- Drought preparedness
- Sustainable landscapes
- Carbon storage
- Leasehold land monitoring

The impact of grazing land management and land condition on soil carbon was found to be negligible or inconsistent using SCaRP methodology across many soil types, regions and production systems. This has led to the conclusion that there is limited scope for soil carbon sequestration ERF projects across the majority of northern Australian grazing land due to high project risk. Although consistent and strong changes in soil carbon with land condition were not found, in general, management strategies that aim to increase the carbon stored in soil are desirable for grazing businesses due to the complementary improvements in pasture quantity and quality which should lead to improved long term livestock productivity.

The findings from the analysis of options at the demonstration sites have been documented in case studies and fact sheets available on the Climate Clever Beef website (http://futurebeef.com.au/resources/projects/climate-clever-beef/), in conference and journal papers and in this final report. A special issue of The Rangeland Journal has been negotiated to provide a long-term legacy of the key case studies arising from this project and from inter-project collaboration.

ENDORSEMENT

I endorse this report. It clearly describes how a combination of approaches was implemented within 3 regions of northern Australia to meet the project's objectives. As a result, beef producers in northern Australia can now make a much more informed and systematic assessment of:

- the management options for reducing methane emissions, improving livestock emissions intensity, and/or increasing sequestration of carbon in vegetation and soil;
- the impact of these options on business profitability with and without associated carbon income;
- the likelihood of significant and sustainable carbon income from these options, given the magnitude and consistency of impacts, the ease of measurement and compliance, and the costs of selling carbon credits.

By necessity, some of the demonstrations and analyses were relatively short-term and/or partially based on best estimates of biological rates. However, the approach was robust enough to provide very useful guidance on (1) those management options for deriving carbon income that are worthy of further evaluation and (2) the factors which will negate or limit the implementation of different options.

The project leader and team are to be congratulated for tackling such an ambitious project and for not shying away from the complexity of the questions the project addressed – the management options that potentially lead to carbon-based income in these production systems are often multifaceted and their impacts on business performance, both with and without carbon income, are equally complex.

The project has produced important information and much food-for-thought for beef producers and those who advise them. The project outputs should therefore be communicated widely and with some urgency.

Dr. Michael Quirk
(Livestock production and NRM specialist)
Project Reviewer

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The 11 grazing businesses are specifically acknowledged for their trust in the project team and participation in the project. Without their support, this project would not have been possible. Being able to put carbon farming practices in the context of real businesses is a powerful development and extension mechanism.

Dr Mick Quirk as project reviewer is thanked for his participation in annual meetings and providing insightful feedback and guidance through the project.

PUBLICATION LIST

JOURNAL AND CONFERENCE PAPERS

Allen, D.E., Pringle, M.J., Bray, S., Hall, T.J., O'Reagain, P.O., Phelps, D., Cobon, D.H., Bloesch, P.M., and Dalal, R.C. (2013) What determines soil organic carbon stocks in the grazing lands of north-eastern Australia? *Soil Research* **51**(8), 695-706.

Bray, S., Allen, D., Harms, B., Reid, D., Fraser, G., Dalal, R., Walsh, D., Phelps, D., and Gunther, R. (Submitted) Is land condition a useful indicator of soil organic carbon stock in Australia's northern grazing land? *The Rangeland Journal.*

Bray, S., Doran-Browne, N., and O'Reagain, P. (2014) Northern Australian pasture and beef systems. 1. Net carbon position. *Animal Production Science* **54**(12), 1988-1994.

Bray, S., Walsh, D., Phelps, D., Rolfe, J., Broad, K., Whish, G., and Quirk, M. (Submitted) Climate Clever Beef: practical measures to reduce carbon emissions in northern Australia. *The Rangeland Journal.*

Gowen, R., and Bray, S. (Submitted) Bioeconomic modelling of woody regrowth carbon offset options in productive grazing systems. *The Rangeland Journal.*

Doran-Browne, N.A., Bray, S.G., Johnson, I.R., O'Reagain, P.J., and Eckard, R.J. (2014) Northern Australian pasture and beef systems. 2. Validation and use of the Sustainable Grazing Systems (SGS) whole-farm biophysical model. *Animal Production Science* **54**(12), 1995-2002.

Havard, G., Eady, S., Bray, S., and Cruypenninck, H. (2013) A method to refine the geographical scale of greenhouse gas emissions for the northern beef industry. In 'NBRUC.' Cairns)

Herd, R.M., Oddy, V.H., and Bray, S. (2015) Baseline and greenhouse-gas emissions in extensive livestock enterprises, with a case study of feeding lipid to beef cattle. Animal Production Science 55(2), 159-165.

Rolfe, J., Larard, A., English, B., Hegarty, E., McGrath, T., Gobius, N., De Faveri, J., Srhoj, J., Digby, M., and Musgrove, R. (Submitted) Rangeland profitability in the northern Gulf region of Queensland:

Understanding beef business complexity and the subsequent impact on land resource management and environmental outcomes. *The Rangeland Journal*

Walsh, D., and Cowley, R. (Submitted) Optimising beef business performance in northern Australia: what can thirty years of commercial innovation teach us? *The Rangeland Journal.*

Walsh, D., and Shotton, P. (2015) Cattle grazing found to have had no negative effect on soil carbon stocks at a site in the Northern Territory. In '18th Biennial Conference of the Australian Rangeland Society.' pp. 61: Alice Springs NT,)

Walsh, D. (2013) "Better farming" or "carbon farming"? Show me the money! Northern Beef Research Update Conference, Cairns 12-15/8/13. http://www.nbruc.org.au/

Whish, G., Pahl, L., and Bray, S. (Submitted) Productivity and economic implications of integrating carbon farming practices into a beef grazing property in central Queensland: Regrowth. . *The Rangeland Journal*.

Special Issue of The Rangeland Journal - "Savanna burning: role and opportunities in a rangelands carbon economy". 7 papers published on savanna burning, above-ground carbon, soil carbon and prospects in the emerging carbon economy in northern Australia.
http://www.publish.csiro.au/nid/202/aid/4722.htm

CASE STUDIES AND FACT SHEETS

- Alexandria Station retrospective business analysis http://futurebeef.com.au/wp-content/uploads/Alexandria-Optimising-Production-Final-2014.pdf
- Ruby Downs Station soil carbon fact sheet http://futurebeef.com.au/wp-content/uploads/Ruby-Downs-Case-Study-Final-2014.pdf
- Alexandria Station soil carbon fact sheet http://futurebeef.com.au/wp-content/uploads/2014-Alexandria-Soil-Carbon-Fact-Sheet-Web-version.pdf
- Alexandria Station wet season spelling and stocking rate fact sheet http://cdn2.futurebeef.com.au/wp-content/uploads/Alexandria-Spelling-and-SR-Final-2013.pdf
- Victoria River District "improved weaning rates" fact sheet http://cdn.futurebeef.com.au/wp-content/uploads/VRD-Improving-Weaning-Rates-Final-2013.pdf
- Case study - Brigalow regrowth options evaluated at Coonabar
- Case study – Regrowth management in eucalypt country at Oaklands
- Case study – Pasture spelling to improve land condition at Oaklands
- Case Study—Karma Waters
- Case Study—Oakleigh
- Case Study—Mitchell Grass Downs
- Fact Sheet—Estimated greenhouse gas emissions from Gulf beef enterprises
- Fact Sheet—Monitoring pasture productivity on Karma Waters
- Fact Sheet—Native pastures respond to wet season spelling
- Fact Sheet—Soil carbon storage in the Rangelands
- Fact Sheet—Stylos increase liveweight gains on Karma Waters

MEDIA AND OTHER ARTICLES

- Interview NT Country Hour 22/5/12 on the announcement of the project funding. http://www.abc.net.au/rural/nt/content/201205/s3508485.htm
- Joint presentation by Dan Sedon (Manager Limbunya Station) and Dionne Walsh (DPIF) at the Kidman Springs Field Day held on 1/8/12. http://www.nt.gov.au/d/Primary_Industry/index.cfm?newscat1=Kidman%20Springs%20Field%20Day&newscat2=&header=2012%20Kidman%20Springs%20Field%20Day
- Interview NT Country Hour 2/8/12 on prescribed burning practices in the northern pastoral industry and the implications for emissions and carbon farming. http://www.abc.net.au/rural/nt/content/201208/s3559223.htm
- Kidman Springs Field day article on the Future Beef website 24/8/12. http://futurebeef.com.au/resources/newsletters/futurebeef-ebulletin/territory-pastoralists-give-thumbs-up-to-kidman-springs-field-day-2012/
- Article on the Kidman Springs Field Day presentations published in the August-September 2012 Katherine Rural Review newsletter. http://www.nt.gov.au/d/Content/File/p/NL/KRR/310_12_krr.pdf
- Media coverage of NT DPIF research on savanna burning and its implications for carbon farming published on the Beef Central website 26/9/12. http://www.beefcentral.com/production/article/2218
- Plenary session on "Fire in a carbon economy" at the 17th Biennial Australian Rangeland Society Conference, Kununurra, WA, 27/9/12. Presentations were given on soil and vegetation carbon sequestration and emissions abatement. Conference proceedings: http://www.austrangesoc.com.au/userfiles/file/2012%20ARS%20Conference/ARS%20Proceedings%20v4.pdf
- Articles on the Carbon Farming Initiative workshop and Kidman Springs Field Day presentations published in the September 2012 Barkly Beef newsletter. http://www.nt.gov.au/d/Content/File/p/NL/BB/bb2012_09.pdf
- Two live presentations of a Future Beef webinar about the wet season spelling demonstration site at Alexandria station 10-13/12/12 by Dionne Walsh and Ross Peatling (manager of Alexandria station). Presentation available for viewing at http://futurebeef.com.au/resources/multimedia/#wetseasonspelling
- Climate Clever Beef project summary published on the NT Landcare Facilitator's LandcareNT blog 8/2/13. Article re-published in the Junction Journal on the 15/2/13. http://landcarent.blogspot.com.au/2013/02/carbon-farming-pastoral-business-case.html?utm_source=BP_recent
- Interview NT Country Hour 25/1/13 on the Climate Clever Beef project. http://www.abc.net.au/rural/nt/content/201301/s3676722.htm
- Interview NT Country Hour 19/4/13 on carbon farming and the Climate Clever Beef project (result of presentation at the Douglas Daly Field Day). http://www.abc.net.au/rural/nt/content/201304/s3740850.htm
- Article in the Alice Springs Rural Review - "Better farming" or "carbon farming" – where are the opportunities for additional cash flow? September 2013, Vol. 53: 1, 3-4. http://www.nt.gov.au/d/Content/File/p/NL/ASRR/ASRR_0913.pdf
- Presentation given by Dionne Walsh at the NT DPIF Knowledge Seminar series. "Is there a business case for NT cattle producers to "farm carbon"?" Presented to a live audience and streamed on-line. On-line recording available at http://ourcomms.ntschools.net/p4byt936g69/?launcher=false&fcsContent=true&pbMode=normal
- Barkly Beef Newsletter article published on the soil carbon results from Alexandria September 2014. http://www.nt.gov.au/d/Content/File/p/NL/BB/2014-09-bb.pdf
- Katherine Rural Review newsletter articles - soil carbon results from Alexandria and Kidman Springs Field Day (including the savanna burning presentation). http://www.nt.gov.au/d/Content/File/p/NL/KRR/KRR%20321.pdf
- Cattle versus carbon: the tug of war begins https://futurebeefnew-daff.netdna-ssl.com/wp-content/uploads/CQ-BEEF-Issue-181.pdf
- Why soil organic matter matters https://futurebeefnew-daff.netdna-ssl.com/wp-content/uploads/CQBEEF-16-ScreenRes.pdf

- Soil carbon: the basics https://futurebeefnew-daff.netdna-ssl.com/wp-content/uploads/CQBEEF-16-ScreenRes.pdf
- Factors which influence soil carbon levels https://futurebeefnew-daff.netdna-ssl.com/wp-content/uploads/CQBEEF-16-ScreenRes.pdf
- Can money be made out of Brigalow day? https://futurebeef.com.au/events/coonabar-climate-clever-beef-project-site/
- Coonabar Climate Clever Beef Come and hear the results of our two projects: Sown Pasture Rundown and Climate Clever Beef http://www.frcc.org.au/event/coonabar-climate-clever-beef/
- Climate Clever Beef Cattle versus carbon: Finding the win-win http://www.futurefarmers.com.au/young-carbon-farmers/wp-content/uploads/sites/2/2014/05/Steven-Bray_Cattle-versus-carbon_19-03-2014.pdf
- Oaklands: Producing Certified Organic Beef in a challenging environment. Beef Australia 2015 http://beefaustralia.com.au/wp-content/uploads/Oaklands.pdf
- Faecal testing and feed quality benefits http://www.farmweekly.com.au/news/agriculture/cattle/beef/faecal-testing-and-feed-quality-benefits/2640008.aspx
- Sown pasture rundown and Climate Clever Beef Berrigurra https://futurebeef.com.au/events/sown-pasture-rundown-and-climate-clever-beef-berrigurra/
- CQ Breeder management day http://www.beefcentral.com/news/beef-central-news-briefs-25-july-2013/
- Breeder Management field day booklet 2013 https://futurebeefnew-daff.netdna-ssl.com/wp-content/uploads/Oaklands-Breeder-Management-Field-Day-Booklet.pdf
- Information Sheet (2013) Case Study: Understanding land-use effects on carbon stored in the soil. NT Government.
- Douglas Daly Research Farm field day presentation on soil carbon sequestration including results of Climate Clever Beef project in Douglas Daly District, by David Ffoulkes, 9 April 2015. Attended by 41 people including 9 local pastoralists.
- Production feeding break-even including feed intakes and animal performance
- Feedlot break-even including feed intakes and animal performance
- Karma Waters ProfitProbe (2011)
- Karma Waters profit drivers summary (2012)
- Soil carbon analysis on Karma Waters
- Progress reports were delivered at NGRMG and CCB team meetings
- Breeder Management Information Day flyer (Wetherby)
- Breeder Management Information Day flyer (Rocky Springs)
- Breeder Management Systems in Northern Australia forum flyer (Karma Waters)
- Breeder Management Systems in Northern Australia forum flyer (Alehvale)
- Participant feedback from the Karma Waters and Alehvale Breeder Management Systems for Northern Australia forums
- Paddock Walk (Karma Waters)
- Industry presentation Burn out and beyond – balancing grass, cash and cattle, Northern Gulf Grazier's Forum (Mount Surprise)
- Tackling the Tough Times forum flyer (Karma Waters)
- Participant feedback from the Karma Waters Tackling the Tough Times forum
- Industry presentation Carbon and cattle – find the win-win, FNQ Rotary Field Days (Mareeba)

- Industry presentation Viability in the beef industry, Northern Gulf Grazier's Forum flyer (Georgetown)
- Bull$, Beef and Pastures forum flyer (Whitewater)
- My Grazing Business – Tough Times, Sensible Solutions workshop flyer (Georgetown)
- Business, Breeder and Pasture Management in the Northern Gulf forum flyer (Lanes Creek)
- Beef Industry Update forum flyer (Dunluce)
- Participant feedback from the Beef Industry Update forum (Dunluce)
- Article in Issue 36 of the Gulf Croaker, Autumn 2013
- Article in the North Queensland Register, May 2013
- Articles in Issue 32 of the Northern Muster, August 2013
- Article in the North Queensland Register, April 2014
- Article in the North Queensland Register, May 2014
- Article in Gulf Vision, June 2014
- Article in the North Queensland Register, June 2014
- Article in the North Queensland Register, August 2014
- Article in the North Queensland Register, September 2014
- Articles in the North Queensland Register, October 2014
- Article in Gulf Vision, December 2014
- Article in Issue 36 of the Northern muster, December 2014
- Article in Issue 36 of the Northern muster, December 2014
- Draft of article to be released in Issue 37 of the Northern Muster, April 2015

REFERENCES

Abberton, MT Enhancing the role of legumes: potential and obstacles. In: Abberton, MT, Conant, R, Batello, C eds. (2010) Grassland carbon sequestration: management, policy and economics. FAO, Rome, pp. 177-187.

Allen, D.E., Pringle, M.J., Bray, S., Hall, T.J., O'Reagain, P.O., Phelps, D., Cobon, D.H., Bloesch, P.M., and Dalal, R.C. (2014) What determines soil organic carbon stocks in the grazing lands of north-eastern Australia? *Soil Research* 51(8), 695-706.

Allen DE, Pringle MJ, Page KL, Dalal RC (2010) A review of sampling designs for the measurement of soil organic carbon in Australian grazing lands. *The Rangeland Journal* 32, 227-246.

Ash AJ, et al. (1995) Improved rangeland management and its implications for carbon sequestration. In: '5th International Rangeland Congress'. pp. 19-20. (Salt Lake City, Utah).

Bentley, D., Hegarty, R.S., and Alford, A.R. (2008). Managing livestock enterprises in Australia's extensive rangelands for greenhouse gas and environmental outcomes: a pastoral company perspective. *Australian Journal of Experimental Agriculture*. 48: 60-64.

Bray, S., Allen, D., Harms, B., Reid, D., Fraser, G., Dalal, R., Walsh, D., Phelps, D., and Gunther, R. (Submitted [a]) Is land condition a useful indicator of soil organic carbon stock in Australia's northern grazing land? *The Rangeland Journal.*

Bray, S., Doran-Browne, N., and O'Reagain, P. (2014) Northern Australian pasture and beef systems. 1. Net carbon position. *Animal Production Science* 54(12), 1988-1994.

Bray SG, Golden R (2009) Scenario analysis of alternative vegetation management options on the greenhouse gas budget of two grazing businesses in north eastern Australia. *The Rangeland Journal* 31, 137-142.

Bray, S., Harms, B., Fraser, G., and Rutherford, M. (2010) Assessment of soil carbon stocks in response to land condition in Queensland's northern grazing land: Appendix A. In 'Keys to Healthy Savanna Lands Final Report '. (Ed. K Broad) pp. 21-47. (DEEDI: Kairi).

Bray, S.G., Walsh, D., Phelps, D., Rolfe, J., Rohan, P., Daniels, B., Stokes, C. & Ffoulkes, D. (2014). 'Climate Clever Beef. On-farm demonstration of adaptation and mitigation options for climate change in northern Australia'. Final report B.NBP.0564. (Meat & Livestock Australia, North Sydney.) 181pp.

Bray, S., Walsh, D., Phelps, D., Rolfe, J., Broad, K., Whish, G., and Quirk, M. (Submitted [b]) Climate Clever Beef: practical measures to reduce carbon emissions in northern Australia. *The Rangeland Journal.*

Broad, K., Bray, S., English, B., Matthews, R., and Rolfe, J. (2011) Adapting to beef business pressures in the Gulf. In 'Proceedings of the Northern Beef Research Update Conference.' pp. 176. (North Australia Beef Research Council: Darwin).

Burrows WH, et al. (2002) Growth and carbon stock change in eucalypt woodlands in northeast Australia: ecological and greenhouse sink implications. *Global Change Biology* 8, 769-784.

Butler, D. (2013) Draft methodology submitted to the CFI Domestic Offsets Integrity Committee (DOIC). A methodology using plot-based inventory to quantify greenhouse gas abatement achieved by human-induced native forest regrowth on cleared land; including allometric equations for north-eastern Australia (Northern Territory, Queensland and New South Wales). Queensland Department of Environment and Resource Management.

Donaghy, P., Bray, S., Gowen, R., Rolfe, J., Stephens, M., Hoffmann, M., and Stunzer, A. (2010) The Bioeconomic Potential for Agroforestry in Australia's Northern Grazing Systems. *Small-scale Forestry* 9(4), 463-484.

Gowen, R., and Bray, S. (Submitted) Bioeconomic modelling of woody regrowth carbon offset options in productive grazing systems. *The Rangeland Journal.*

Harris, C., Jones, P. and Bray S. (2015) Wet season spelling: a producer demonstration site. In 'Proceedings of the Australian Rangeland Society 18th Biennial Conference.' pp. 42. (Australian Rangeland Society: Alice Springs).

Henderson, A., Perkins, N., and Banney, S. (2012). ‘Determining property-level rates of breeder cow mortality in northern Australia.’ Final report B.NBP.0664. (Meat & Livestock Australia: North Sydney.)

Holt JA (1997) Grazing pressure and soil carbon, microbial biomass and enzyme activities in semi-arid northeastern Australia. Applied Soil Ecology 5, 143-149.

Jones, P., Harris, C. and Silcock, R. (2015) Spelling strategies for recovery of pasture condition. In 'Proceedings of the Australian Rangeland Society 18th Biennial Conference.' pp. 46. (Australian Rangeland Society: Alice Springs).

Littleboy, M. and McKeon, G.M. (1997). Subroutine GRASP: Grass production model. Documentation of the Marcoola version of Subroutine GRASP. Appendix 2 of Evaluating the risks of pasture and land degradation in native pasture in Queensland. Final Project Report for Rural Industries and Research Development Corporation project DAQ124A.

McGowan, M. *et al.* (2014). ‘Northern Australian beef fertility project: CashCow.’ Final Report B.NBP.0382. (Meat & Livestock Australia: North Sydney.)

McLean, I., Holmes, P., and Counsell, D. (2014). ‘The Northern beef report. 2013 Northern beef situation analysis’. Final Report B.COM.0348. (Meat & Livestock Australia: North Sydney).

MacLeod, N.D., Scanlan, J.C., Whish, G.H., Pahl, L.I. and Cowley, R.A. (2011) Application of bio-economic simulation models for addressing sustainable land management issues for northern Australia. In proceedings of 19th International Congress on Modelling and Simulation, Perth, Australia, 12–16 December 2011, 801-807. (http://mssanz.org.au/modsim2011).

Northup, B.K., Brown, J.R., and Holt, J.A. (1999) Grazing impacts on the spatial distribution of soil microbial biomass around tussock grasses in a tropical grassland. *Applied Soil Ecology* 13(3), 259-270.

O’Reagain, P., Bushell, J., Holmes, B. (2011) Managing for rainfall variability: long-term profitability of different grazing strategies in a northern Australian tropical savanna. Animal Production Science 51, 210–224.

O’Reagain, P., Scanlan, J., Hunt, L., Cowley, R., and Walsh, D. (2014) Sustainable grazing management for temporal and spatial variability in north Australian rangelands – a synthesis of the latest evidence and recommendations. *The Rangeland Journal* **36**(3), 223-232.

Petty, S., Hunt, L., Cowley, R., MacDonald, N., and Fisher, A. (2013). ‘Guidelines for the development of extensive cattle stations in northern Australia: Insights from the Pigeon Hole Project.’ (Ed. I. Partridge). (Meat & Livestock Australia Limited: North Sydney.)

Phelps, D., Broad, K., Cowley, R., Emery, T., English, B., Hamilton, J., Jones, P., Karfs, R., MacLeod, N., Matthews, R., Pahl, L., Paton, C., Rohan, P., Rolfe, J., Stockdale, M., Scanlan, J., Walsh, D. & Whish, G. (2014). ‘Developing improved grazing and related practices to assist beef production enterprises across northern Australia adapt to a changing and more variable climate (Climate Savvy Grazing)’. Final report B.NBP.0616. (Meat & Livestock Australia, North Sydney).

Pringle MJ, Allen DE, Dalal RC, Payne JE, Mayer DG, O'Reagain P, Marchant BP (2011) Soil carbon stock in the tropical rangelands of Australia: Effects of soil type and grazing pressure, and determination of sampling requirement. *Geoderma* 167-168, 261-273.

Quigley, S., and Poppi, D. (2013). 'Factors associated with divergent postweaning liveweight gain in northern Australian beef cattle'. Final report B.NBP.0629. (Meat & Livestock Australia: North Sydney).

Rolfe, J., Larard, A., English, B., Hegarty, E., McGrath, T., Gobius, N., De Faveri, J., Srhoj, J., Digby, M., and Musgrove, R. (Submitted) Rangeland profitability in the northern Gulf region of Queensland: Understanding beef business complexity and the subsequent impact on land resource management and environmental outcomes. *The Rangeland Journal*.

Scanlan, J.C. (2002) Some aspects of tree-grass dynamics in Queensland's grazing lands. *The Rangeland Journal* 24(1), 56-82.

Scanlan, J.C., MacLeod, N.D., O'Reagain, P.J. (2013) Scaling results up from a plot and paddock scale to a property – a case study from a long-term grazing experiment in northern Australia. The Rangeland Journal 35, 193–200.

Scanlan, J.C., McIvor, J.G., Bray, S.G., Cowley, R.A., Hunt, L.P., Pahl, L.I., MacLeod, N.D., and Whish, G.L. (2014) Resting pastures to improve land condition in northern Australia: guidelines based on the literature and simulation modelling. The Rangeland Journal 36(5), 429-443.

Tothill, J.C., Hargreaves, J.N.G., Jones, R.M., and McDonald, C.K. (1992) BOTANAL - A comprehensive sampling and computing procedure for estimating pasture yield and composition. 1. Field sampling. *Tropical Agronomy Technical Memorandum* No. 78.

Walsh, D. & Cowley, R.A. (2011). Looking back in time: can safe pasture utilisation rates be determined using commercial paddock data in the Northern Territory? *The Rangeland Journal*. 33: 131–142.

Walsh, D., and Cowley, R. (Submitted) Optimising beef business performance in northern Australia: what can thirty years of commercial innovation teach us? *The Rangeland Journal*.

Walsh, D., and Shotton, P. (2015) Cattle grazing found to have had no negative effect on soil carbon stocks at a site in the Northern Territory. In '18th Biennial Conference of the Australian Rangeland Society.' pp. 61: Alice Springs NT.

Whish, G., Pahl, L., and Bray, S. (Submitted) Productivity and economic implications of integrating carbon farming practices into a beef grazing property in central Queensland: Regrowth. *The Rangeland Journal*.