Accepted version – final version at: https://www.publish.csiro.au/rj/RJ20034

Carbon farming for resilient rangelands: People, paddocks and policy

Authors

Alex Baumber, Faculty of Transdisciplinary Innovation, University of Technology Sydney, Broadway NSW 2007, Australia

Cathy Waters, NSW Department of Primary Industries, 34 Hampden Street, Dubbo NSW 2830, Australia

Rebecca Cross, School of Geosciences and School of Life and Environmental Sciences, The University of Sydney, Camperdown NSW 2050, Australia

Graciela Metternicht, School of Biological, Earth and Environmental Sciences, PANGEA Research Centre, UNSW Sydney, Kensington NSW 2052, Australia

Marja Simpson, NSW Department of Primary Industries, Orange Agricultural Research Centre, Orange NSW 2800, Australia

Abstract

Carbon farming is a new land use option over extensive areas of the Australian rangelands. This land use change has been promoted by government incentives to mitigate climate change, with the vast majority of Australia's land sector abatement to date being delivered in rangelands. Aside from these mitigation benefits, carbon farming has also demonstrated potential co-benefits that enhance socio-ecological resilience by diversifying land uses and income streams, providing opportunities for sustainable land management to enhance soil and vegetation and creating opportunities for self-organisation and collaboration. However, factors such as policy uncertainty, perceived loss of future land use flexibility and the potential for carbon farming eligibility to create social divisions have the potential to negatively impact on resilience. In this paper, we weigh up these risks, opportunities and co-benefits and propose indicators for measuring the impact of carbon farming on the resilience of rangeland systems. A set of land policy principles for enhancing resilience through carbon farming are also identified.

Summary text for the Table of Contents online

Carbon farming is expanding in Australia's rangelands, driven by government incentives aimed at managing land to promote the regeneration or maintenance of tree cover. While carbon sequestration is the primary objective, other co-benefits for biodiversity, soils and landholder income may enhance socio-ecological resilience of rangeland Australia. This paper analyses these opportunities along with potential risks to resilience that could arise from policy uncertainty, social divisions and perceived loss of future land use flexibility.

Additional key words: sustainable land management, co-benefits, resilience, risk

Introduction

In recent years, carbon farming has rapidly expanded in the southern Australia rangelands. Here, we explore how this expansion of carbon farming practices may affect the socio-ecological resilience of rangeland systems (i.e. their capacity to absorb disturbances and reorganize while maintaining essential functions). Focusing primarily on the rangelands of north-western New South Wales (NSW), we review the risks and opportunities for the socio-ecological resilience of rangeland systems, as well as potential management options and policy principles to respond to these risks and opportunities.

Starting with a profile of carbon farming in Australia, the paper identifies potential benefits and disbenefits highlighted in prior research, with a brief introduction to the concepts of resilience and rangelands as socio-ecological systems. The conceptual framework used to synthesise these opportunities and risks is based on six enabling conditions for general resilience identified from previous research – reserves, diversity, monitoring, scale, feedbacks and social capital (Walker and Salt 2012, Armitage 2007, Erol *et al.* 2010, Carpenter *et al.* 2012). The discussion of these enabling conditions includes a consideration of appropriate policy settings to maximise the opportunities that carbon farming presents for enhancing rangeland resilience while minimising the risks. This analysis has implications for rangeland systems in other countries, such as the United States, where resilience-bsased approaches have been used to evaluate the carbon sequestration potential of different vegetation systems (Dass *et al.*, 2018).

Profiling carbon farming in the Australian rangelands

Carbon farming encompasses a range of land management activities designed to either increase carbon sequestered in vegetation and soils or reduce greenhouse gas emissions from vegetation, soils and livestock (Government of Western Australia 2020; Queensland Government 2020). In recent years, carbon farming has emerged as a significant and rapidly-growing land use option for the Australian rangelands. The expansion of carbon farming in

Australia between 2015 and 2020 was primarily driven by the Australian Government's purchasing of Australian carbon credits (ACCUs) under the AUD2.5 billion Emissions Reduction Fund (ERF). The ERF represents a key mechanism for delivering on Australia's commitment of 26-28% reduction on 2005 emissions levels by 2030 under the 2015 Paris Agreement and employs UNFCCC (United Nations Framework Convention on Climate Change) rules on accounting for emissions reductions and sequestration though reforestation and avoided deforestation. The 2019 announcement of a further AUD2 billion Carbon Solutions Fund will enable a continuation of the investment that has begun under the ERF (Clean Energy Regulator 2019b).

Eligible activities under the ERF include the management of vegetation to offset anthropogenic carbon emissions which predominantly require the prevention of land clearing (avoided deforestation, AD) or regeneration (human induced regeneration, HIR). As of February 2020, AD and HIR account for 24% and 23%, respectively, of all ACCUs issued (Fig. 1; Clean Energy Regulator 2020). Participation in the ERF is largely voluntary, but to ensure emissions reductions are not displaced by increased emissions elsewhere, an involuntary Safeguard Mechanism has also been built into the scheme that requires large emitters to purchase offsets for emissions above specified baseline levels (Clean Energy Regulator, 2019b).

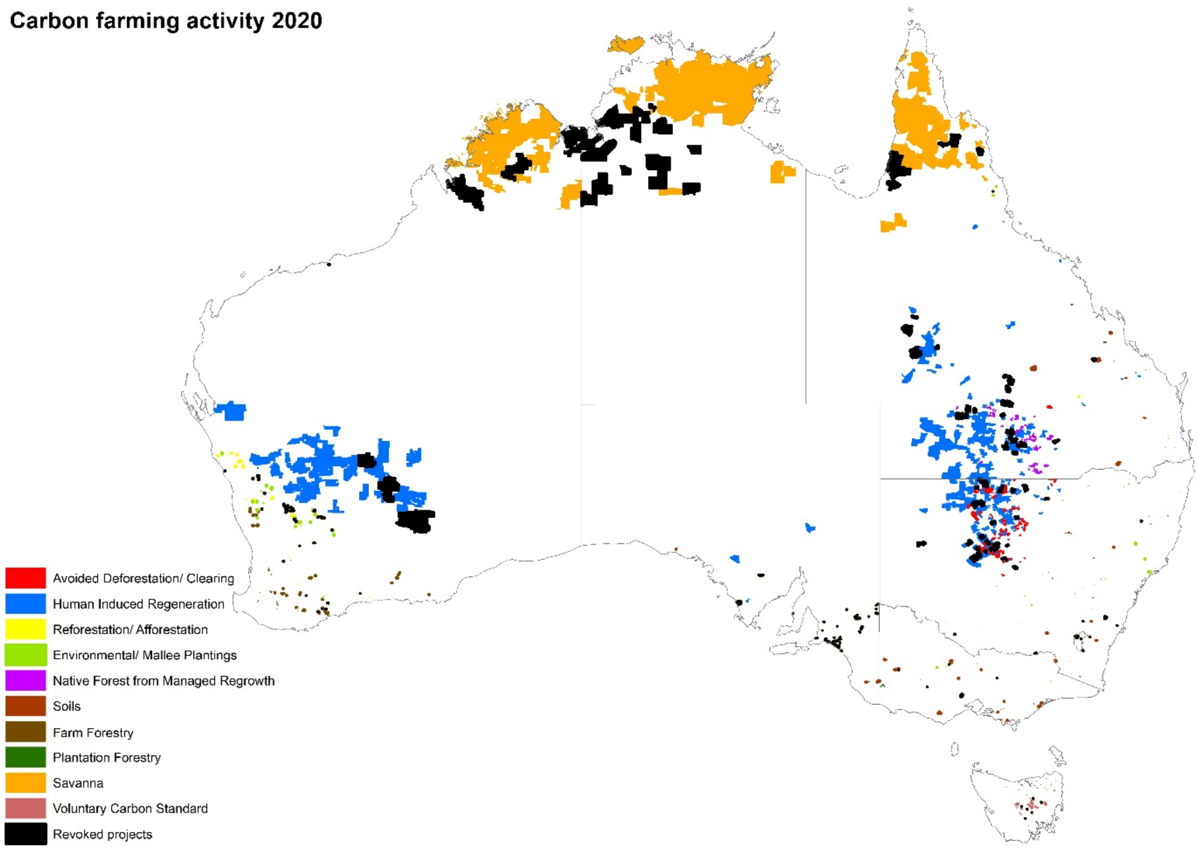
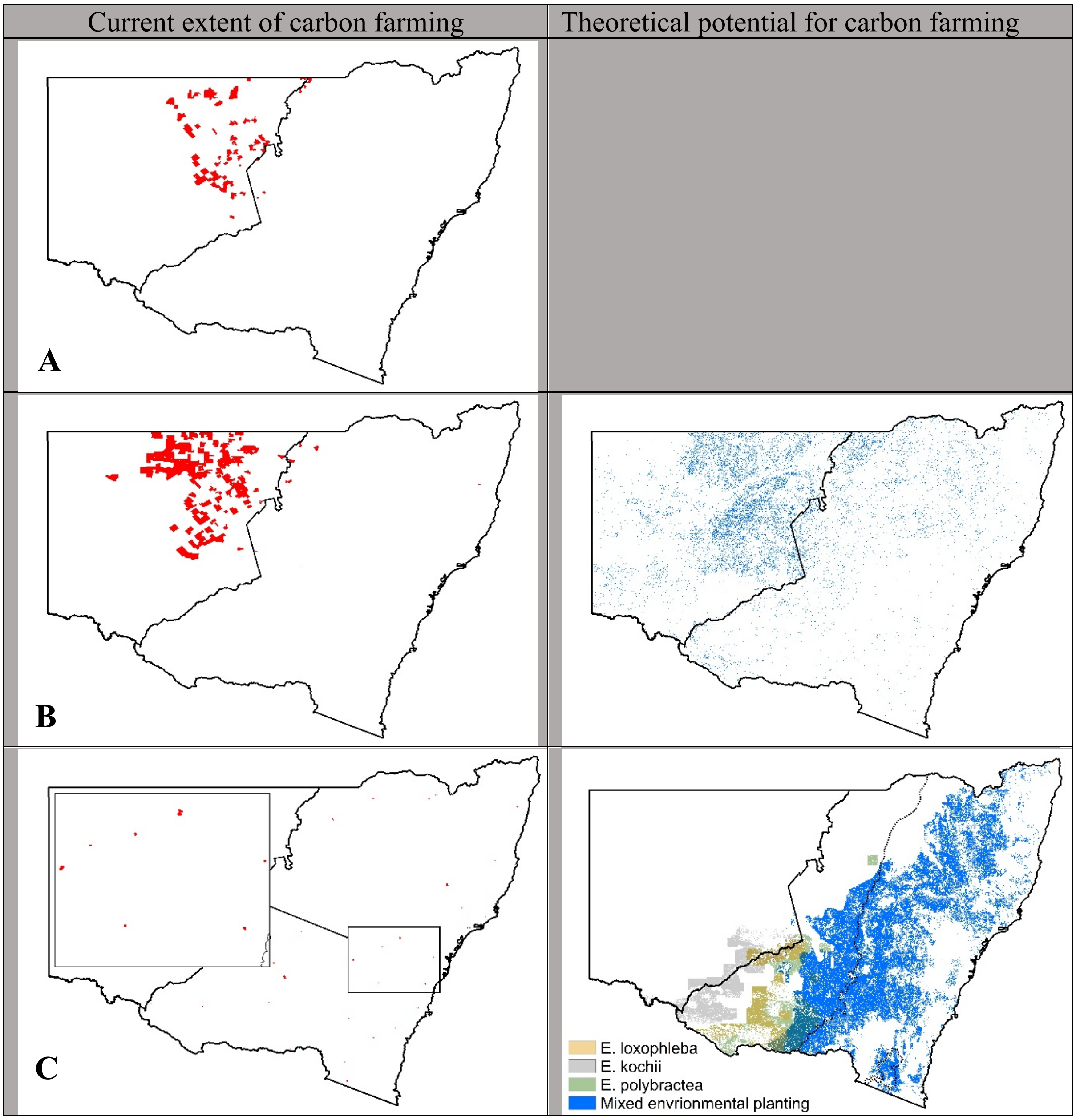


Fig. 1. Current distribution of different carbon farming projects in Australia. The greatest concentration of Avoided Deforestation (AD) and Human Induced Regeneration (HIR) projects occurs on the rangelands of north-western New South Wales (NSW) and south-western Queensland. Other important rangeland locations for carbon farming include the southern rangelands of Western Australia and Australia's northern tropics, where savannah burning projects cover large areas, albeit accounting for a much smaller proportion of ACCUs than either AD or HIR (9% as of February 2020) *Source:* Clean Energy Regulator, 2020.

Following rapid growth in ERF investment between 2015 and 2018, market opportunities have dampened more recently. The reduced volumes of ACCUs being sold under the ERF has been attributed to the Clean Energy Regulator's unwillingness to pay higher prices and potential sellers being deterred by the administrative complexity of the scheme (Reputex

2020). To increase the value of carbon farming activities, 'core benefits' or 'value-stacking' mechanisms have been identified as having the potential to maximise the opportunities that carbon farming may provide (Lin *et al*. 2013; Kragt *et al.* 2018). Valuing co-benefits (production, environmental and social) from carbon farming is currently being realised at the state level in Australia under the Queensland Government's Land Restoration Fund (LRF) and new third-party schemes such the Reef Credits currently under development (GreenCollar 2020). Should these co-benefit markets continue to grow, further expansion of carbon markets may be expected. Additionally, non-government sources for a demand in carbon credits are becoming an increasingly important driver of carbon markets. Here, voluntary purchases by individuals, businesses or state governments looking to offset their carbon footprint represent this growing demand.

The potential supply of carbon credits from the Australian rangelands is considerable. For example, some 599,515 km^2 could theoretically deliver abatement under the soil carbon methods in NSW alone (Fig. 2). Garnaut (2019; p. 147) has argued that Australia is "uniquely well placed to lead and prosper from the land use transformation" that carbon farming offers. Australia's comparative advantage in land sector emissions reductions and sequestration has also been recognised globally (Lin *et al.* 2013) and within Australia (Dean *et al.* 2015; Fleming *et al.* 2019) as a means to support multi-use landscapes which co-deliver climate mitigation, production and biodiversity benefits (Cunningham *et al.* 2015). In addition, Australia also has a competitive advantage in carbon offsets as it features a policy environment where a combination of market rigour and integrity is supported through eligibility rules, method development, auditing standards and ERF purchasing of ACCUs (CMI 2020). However, policy uncertainty, complex rules and high transaction costs could pose risks to this competitive advantage and limit further expansion of carbon markets and opportunities for some pastoralists (Evans 2018).


Current extent of carbon farming
Theoretical potential for carbon farming
A
B
C
E. loxophleba
E. kochii
E. polybractea
Mixed envrionmental planting

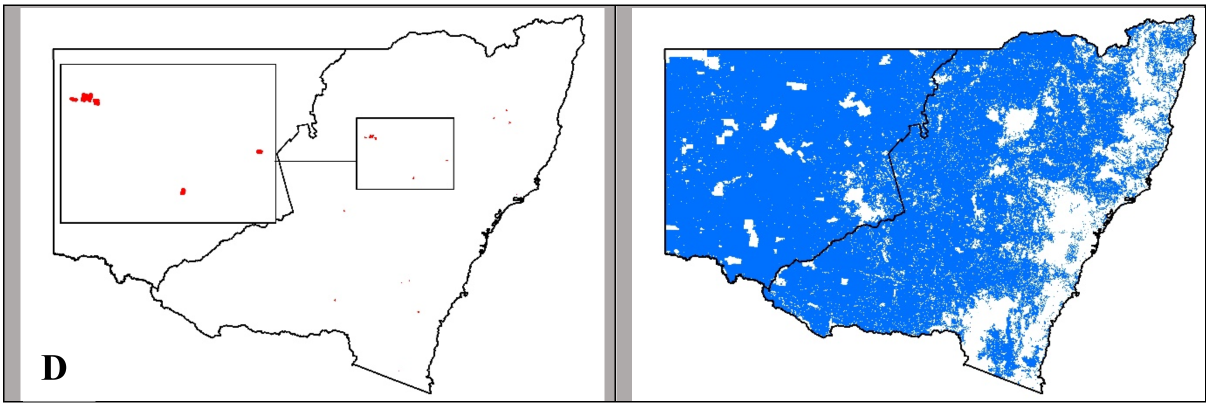


Fig. 2. Current extent (red) and theoretical potential (blue) of Australian government Emissions Reduction Fund (ERF) carbon farming activities in New South Wales: (**A)** Avoided Deforestation (AD)[1.]; (**B)** Human-induced Regeneration (HIR)[1.]; (**C)** Environmental or Mallee Plantings[2.] (EP) and **(D)** Sequestering Carbon in Soils in Agricultural Systems (SOIL). The black line indicates the boundary for western NSW (rangelands) and the black dotted line the 600 mm rainfall isohyet[2.]. Under current eligibility rules, there is no further expansion of AD. There are currently no SOIL or EP projects in the rangelands of western NSW. Details for estimation of theoretical potential are found in Supp. I.

1. The actual extent of a project activity is a sub-set of this area known as the carbon estimation area (CEA) which is defined by rules set out for each ERF method. A project can contain one or many CEA's e.g. may have both AD and HIR projects. These are property boundaries and therefore may be an over-estimate of carbon estimation area.
2. Mallee plantings are restricted to $\leq$ 600 mm long-term average annual rainfall.

Accepted version – final version at: https://www.publish.csiro.au/rj/RJ20034

Benefits and disbenefits of carbon farming for rangelands: perceptions and reality

While carbon farming has been identified to have a range of economic, social and environmental impacts on rangeland systems, there is uncertainty around how these impacts may manifest in different contexts and the interactions and relationships between them. As carbon farming is a relatively recent phenomenon in the Australian rangelands, most research into benefits and disbenefits has relied on stakeholder perceptions, modelling or speculations by rangeland experts based on similar practices rather than empirical evidence from carbon farming sites (Baumber *et al.* 2019).

Potential economic benefits identified by previous studies include increases in landholder income, diversification of income sources, increased availability of capital to invest in farm infrastructure and improvement, ability to hire labour, and flow-on effects for surrounding towns and communities (Crossman *et al.* 2011, Evans *et al.* 2015, Salas Castelo 2017, Jassim 2018, Cowie *et al.* 2019, Cross *et al.* 2019). Potential social benefits include improved mental health and community resilience (Cowie *et al.* 2019), innovative community initiatives and networks (Fleming *et al.* 2019), enhanced community development and cultural connection to land for Indigenous communities (Jackson *et al.* 2017) and enhanced potential for inter-generational farm management and succession on agricultural properties (Cross *et al.* 2019). Potential ecological benefits of carbon farming include increased biodiversity, increased habitat provision, improved soil health, structure and water holding capacity, management of erosion and salinity and improved water quality (Baumber *et al.* 2019; Cross *et al.* 2019). The potential for income to be reinvested into regenerative farming practices and improved farm efficiency also has potential sustainability benefits for farm resilience in the long-term (Cross and Ampt 2017, Cross *et al.* 2019).

The Australian Government has promoted co-benefits to landholders, such as "improved quality of your land and water supply, increased biodiversity and shade and shelter for stock" (Clean Energy Regulator 2018) and the Queensland state government has introduced a Land Restoration Fund to incentivise carbon farming projects that offer "co-benefits" of this nature. However, a range of potential "disbenefits" have also been identified from carbon farming that could pose threats to the future expansion of the industry as well as affecting the socio-ecological resilience of rangeland systems. These disbenefits include perceived risks of increases in invasive native scrub (INS) or woody weeds (Jassim 2018, Butler *et al.* 2014, Cross *et al.* 2019) which have the potentilal to reduce land use flexibility due to long-term land management commitments (Kragt *et al.* 2017) and decrease land value (Baumber *et al.* 2011). Further disbenefts may include a perceived risk of fire and pest occurrence (Torabi *et al.* 2016) caused by landholders shifting from pastoralism to carbon farming and moving off site (absenteeism) and social divisions which may also occur with an increasing gap between those who have eligible land for carbon farming and those who do not (Cowie *et al*. 2019; Cross *et al.* 2019).

What is a resilient rangeland?

To understand whether a new practice such as carbon farming might increase or decrease the resilience of a socio-ecological system, it is first necessary to define resilience. Resilience relates to the way that a system deals with disturbances or shocks. Here we follow the definition of resilience as "the capacity of a social-ecological system to absorb disturbance, reorganize, and thereby retain essential functions, structures and feedbacks" (Carpenter *et al.* 2012; p. 3249). Under this definition, resilience is more than just "bouncing back"; it requires an element of adaptation and reorganization. This approach also requires an initial consideration of the "resilience of what" (Walker and Salt 2012); that is, deciding which key functions, structures and relationships the stakeholders within a system might wish to maintain over time in the face of potential disturbances. In the case of Australia's rangelands, important functions may include the provision of habitat for biodiversity, protection of soil and water quality, supporting landholder and community livelihoods, cultural connections to land and interconnections with neighbouring systems or higher system levels through trade, culture and governance.

The impacts of carbon farming on the socio-ecological resilience of the NSW rangelands has previously been explored by Cowie *et al.* (2019), who applied the RAPTA (Resilience Adaptation Pathways and Transformation Approach) framework developed by O'Connell *et al.* (2016). This research included workshops and a survey involving technical experts and local stakeholders to identify key system relationships, potential disturbances, thresholds for system change and possible pathways for the system to respond to these shocks. Key relationships identified by Cowie *et al.* (2019) included those between woody cover, ground cover, total grazing pressure and profitability, which were in turn influenced by factors such as infrastructure, enterprise options and debt levels. The major external shocks of concern included extreme seasonal conditions (both wet and dry periods), commodity price shocks, and government programs aimed at changing land use practices, including carbon farming and other NRM incentives.

Rangelands are complex adaptive systems that may be regarded as operating within certain states, or "basins of attraction" where system elements interact with one another in a set of relationships that are relatively predictable (Walker *et al.* 2004). For example, in a rangeland grazing system, humans move livestock around, livestock eat grass, grass and trees compete for resources. Where climatic or other disturbances act to push a system out of its current state, balancing feedbacks act to pull it back towards a particular set of relationships and values that define its essential functions and structures (Fig. 3). In rangeland systems, such feedbacks may include the persistence of seedbanks within the soil, adaptations that allow trees to re-sprout after fire and human management practices such as proactive adjustment of stocking rates or maintaining financial reserves to enable reinvestment following drought. Provided that such feedbacks remain in place, the present state may be regarded to be relatively resilient, even if the system does not stabilise for any length of time due to the constant interplay between disturbance and recovery.

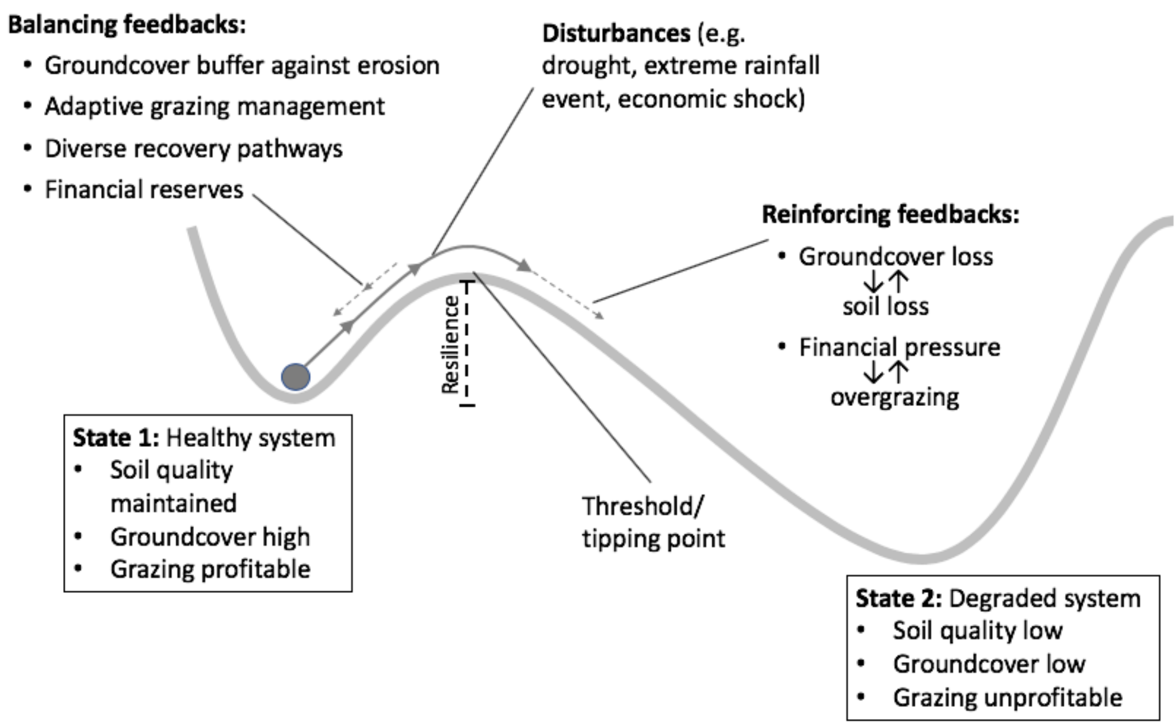


Fig. 3. Conceptual model of system states, thresholds and feedbacks using the analogy of a "ball in a basin" (Levin *et al.* 1998, Walker *et al*. 2004).

While balancing feedbacks may help to maintain essential functions and structures following a disturbance, resilience has its limits. For example, while some tree species such as eucalypts may exhibit adaptations that help them recover after a fire disturbance by resprouting (a strong balancing feedback), other species that lack these adaptations (e.g.

Mulga and Cypress Pine) may experience large mortality events from fire declining resilience under climate change (Nolan *et al.* 2019). Thresholds may exist that, once crossed, produce runaway change as a result of balancing feedbacks being overwhelmed by reinforcing feedbacks that bolster the direction of change. For example, intense rainfall following drought may wash away a critical mass of topsoil, preventing vegetation from re-establishing, making the landscape susceptible to further erosion and “locking” the system into a new degraded state. Furthermore, the disturbance that pushes the system over such a tipping point need not be especially large by historical standards if the resilience of the system has been eroded, such as by a gradual weakening of the balancing feedbacks that work to keep the system in its non-degraded state (e.g. through climate change, loss of income streams or overgrazing).

Enabling factors for rangeland resilience

Various resilience theorists have sought to identify factors that can enhance or reduce resilience in complex systems, including Carpenter *et al.* (2012), (2012), Erol *et al.* (2010) and (2007). Table 1 identifies six types of enabling factors for general resilience, drawn primarily from Carpenter *et al.* (2012), with additional points from other researchers relating to self-organisation, agility, collaboration and social capital (Walker and Salt 2012, Armitage 2007, Erol *et al.* 2010).

Table 1. Enabling factors for general resilience.

Enabling factor	**Description**
Reserves/ buffers/ redundancies	Extra capacity that is held in reserve that can minimise the severity of a disturbance or enable recovery (e.g. capital, labour, water, organic matter, social memory).
Diversity	Includes economic diversity, cultural diversity, biological diversity and response diversity (i.e. having a range of pathways available).
Monitoring/ information flows	Capacity to gather information in a shared, transparent and regular fashion.
Management at the right scale	Striking the right balance between: • Connectedness: Maintaining connections to neighbouring systems and higher system levels to enable exchange, support and replenishment. • Modularity: Enabling autonomous units in which agility, responsiveness and self-organisation is enhanced at the local level and threats are quarantined to stop them spreading.
Feedbacks	Maintain strong balancing feedbacks that push back against a disturbance, as well as the capacity to interrupt reinforcing feedbacks that could lead to undesired runaway change.
Social capital	Includes effective leadership, trusted relationships between key stakeholders, collaboration and reciprocity.

The factors shown in Table 1 are termed *general* resilience factors, and are relevant to a wide variety of complex systems that may incorporate diverse ecological, social and economic features and face a range of possible disturbances (Walker and Salt 2012). The application of these general factors may be appropriate in cases where there is a high degree of uncertainty around the nature, scale and frequency of disturbances. Based on historical trends, Australia's rangelands have characteristically experienced climatic disturbances such as drought, high-rainfall events and heatwaves, the frequency and intensity of which are expected to increase in the future (Godde *et al.* 2020). However, as human-induced climate change progresses, past experiences may no longer be a reliable guide to predicting future climatic extremes and modelling climate change impacts for some important drivers of climate, such as El Niño-Southern Oscillation, are subject to high levels of uncertainty (IPCC 2012).

As with environmental disturbances, socio-economic trends may be partially predicted from past experience (e.g. shifts in commodity prices, migration trends), but new disturbances may emerge under conditions that have not been experienced before. For example, recent social and economic disruptions — without precedent in modern times — include the rise of China as an economic superpower, the structural shift to a "permanent" era of low interest rates and inflation (Garnaut 2019; p. 65), and the emergence of the COVID-19 pandemic during the course of writing this paper. As such, extreme events may be expected to be a defining feature of rangeland systems into the future and current norms related to climatic and economic conditions may continue to be challenged in unpredictable ways.

Where the type, scale and frequency of likely disturbances is relatively well-understood, it may be possible to complement *general* resilience strategies with those aimed at *specified* resilience. Specified resilience strategies often align with the broader general resilience categories shown in Table 1, but allow for a more targeted focus due to a better understanding of the nature of the disturbances faced. For example, insurance may be taken out against specific threats such as flood or fire, stockpiles of food and medicine may be planned based on the likely length of a supply disruption, local communities may be trained to respond to known threats and monitoring may be focused on key thresholds of concern (Carpenter *et al.* 2012).

The application of the RAPTA framework to the NSW rangelands by (Cowie *et al.* 2019) is an example of a *specified resilience* approach, including the identification of likely climatic, economic and policy disturbances, along with key thresholds of concern, such as ground cover levels falling below 50%, three consecutive months with less than 75 mm rainfall and total grazing pressure rates exceeding 30% utilisation of perennial grass cover. Such thresholds can act as triggers for specified actions under an adaptive management approach to maintaining essential functions and structures. However, they should not necessarily be seen as targets to be maintained at all costs, particularly in non-equilibrium systems that periodically experience shifts between multiple stable states while maintaining the critical climatic and soil conditions that determine ecological function and structure (Booker *et al.* 2013).

Potential impacts of carbon farming on rangeland resilience

Each of the general resilience factors from Table 1 is explored below. This includes an analysis of the potential opportunities and risks that carbon farming presents for these resilience factors, as well as policy options to enhance these opportunities and minimise the risks. Table 2 highlights examples of how carbon farming could potentially support or detract from each of these resilience factors, along with potential management and policy responses identified by carbon farming research to date.

[Table 2 goes here – see separate Table 2 file]

Building up reserves, buffers and redundant capacity

Designing policy and management interventions that enhance rangeland resilience requires understanding the different ways in which buffers and reserves affect resilience. At its core, carbon farming is about building up reserves of carbon in vegetation and soils. The ERF incentivises this by purchasing ACCUs periodically via auction and facilitates it by providing a range of approved methodologies and associated tools such as the Full Carbon Accounting Model (FullCAM) used to estimate carbon stores (Richards *et al.* 2004). In addition, carbon farming may also help to build up financial reserves for landholders and increase the amount of native habitat that can act as refugia for biodiversity during droughts and other disturbances.

Building up reserves of carbon in vegetation and soils can enhance resilience in two different ways. Firstly, these reserves may help to dampen the effects of disturbances, such as the role played by ground cover in preventing heavy rainfall from eroding soils. Secondly, reserves provide redundant capacity that is not used under normal conditions but may be available to draw on when resource levels are low, such as increased persistent, palatable, productive perennial grass cover that retain feedbase and ground cover under deteriorating seasonal conditions. Achieving both objectives simultaneously requires nuanced policy settings. For example, building up ground cover to buffer against extreme climatic events is consistent with the principle of "permanence" that underpins both the HIR and AD methods, but if the goal is to build up reserves of biomass to access in times of need, a more flexible, non-permanent approach is required that allows biomass reserves to be drawn down periodically.

The current Australian HIR rules include several elements that enable landholders to enhance both permanent buffering capabilities as well as adaptively managing biomass reserves. The focus of the HIR methodology is on the permanence of woody vegetation, while biomass levels in grasses and soils are able to fluctuate. Furthermore, landholders are able to choose between a 100-year or 25-year permanence period, use HIR areas for limited strategic grazing and implement a "growth pause" in the HIR FullCAM model, where grazing does not suppress forest growth (Department of the Environment and Energy 2016). However, those landholders choosing to sign up for a 100-year permanence period with total exclusion of stock may need to consider whether, from a resilience perspective, the increase in financial reserves from selling carbon credits compensates for a loss of future land use flexibility.

In developing new policy measures to promote the "co-benefits" of carbon farming, the twin goals of buffering against disturbances and enhancing redundant capacity need to be considered. For example, co-benefit payments could be linked to the maintenance of adequate buffers, with Cowie *et al.* (2019) proposing a threshold of 50% ground cover maintained 50% of the time as an indicator of adequate buffering against wind erosion, and 30% perennial grass utilisation as a threshold above which pasture reserves may be depleted. Flexibility and adaptive management could be further enhanced by employing variable ground cover targets that take into account seasonal conditions, such as those employed under the 2004-2008 ground cover incentive scheme in western NSW (Hacker *et al.* 2010), or by using "activity-based" metrics that reward landholders for following certain practices rather than achieving specific outcomes (Baumber *et al.* 2019).

The security of reserves is also a key consideration, with the potential for policy design to offer greater incentives for landholders to provide and maintain reserves that are more secure against disturbances such as fire. Dass *et al.* (2019) present evidence that below-ground carbon in US grasslands may offer more secure sequestration than forests in fire-prone environments. Carbon farming sites that act as refugia for biodiversity in times of extreme drought could also be prioritised for incentive payments (e.g. wet refugia in landscapes, Gill *et al.* 2016).

Enhancing diversity

Carbon farming in the Australian rangelands has the potential to enhance diversity in several ways, including diversifying enterprise options for landholders (Cowie *et al.* 2019) and encouraging the protection and enhancement of biodiversity (Butler *et al.* 2014). However, it is important to note that the ERF auction mechanism is not designed to promote diversity, but rather has a singular focus on carbon that stems from a legislated goal of “purchasing carbon abatement at the least cost” under the *Carbon Credits (Carbon Farming Initiative) Act 2011* (section 20G). This singular focus creates the risk that carbon farming incentives could potentially reduce ecological, economic and social diversity by valuing only one component within complex rangeland ecosystems. Walker and Salt (2006) highlight how policy approaches based on efficiency or optimisation may reduce resilience by over-simplifying complex systems, “keeping only those things that are directly and immediately beneficial” (Walker and Salt 2006, p. 7).

To ensure that carbon farming enhances the diversity of habitat types, enterprise options and community development pathways in the Australian rangelands, targeted policy measures are required that go beyond the least-cost abatement model of the ERF. Globally, there are precedents for auction-based schemes to be modified to promote a diversity of objectives, as has occurred with the US Conservation Reserve Program (Baumber *et al.* 2019). However, the ERF’s legislated requirement to deliver least-cost abatement makes such an option unlikely in Australia. Instead, complementary co-benefit schemes provide a promising option, such as the Queensland Government’s Land Restoration Fund and its associated co-benefits standard for assessing carbon farming projects (Queensland Government 2020). Australian state governments are well placed support this further market expansion, as they not only have constitutional responsibility for natural resource management (NRM) and regional development, but they also represent one of the fastest-growing sources of demand for carbon credits to offset emissions from vehicle fleets, desalination plants and other activities (Clean Energy Regulator 2019b).

Aside from incentivising the co-benefits of carbon farming, regulators may also need to impose constraints on activities that simplify diverse ecosystems. Precedents for such limitations can be found in other market-based environmental policy schemes, such as the restrictions that prevent biofuels being counted towards EU renewable energy targets if they are grown on land converted from primary forest or biodiverse grassland (European Parliament and Council of the European Union 2009). Plantations in Australia are already restricted from earning carbon credits in areas with greater than 600mm annual average rainfall to manage competition for water resources (Department of the Environment and Energy 2019). This restriction helps to improve the competitiveness of assisted regeneration methods such as HIR, which are preferable from a diversity perspective to monocultural plantations (Evans 2018).

The biggest risk of landscape simplification in Australian rangelands comes from invasive native scrub (INS) or woody weeds. Regional NRM agencies have long recommended active management of INS to prevent the formation of dense monocultures that reduce pastural production, inhibit pasture growth and make soils susceptible to erosion (Central West LLS and Western LLS 2014). However, evidence is currently mixed as to whether carbon farming increases INS. A survey by Cowie *et al.* (2019) found mixed perceptions in western NSW, with government stakeholders, landholders with HIR projects and pastoralists (non-carbon farmers), tending to hold the view that carbon farming contributes to INS, while researchers and carbon farming service providers disagreed with this proposition.

The above examples provide evidence that further restrictions may need to be considered if carbon farming approaches that simplify complex ecosystems start to become widespread. Moreover, if a link can be established between carbon farming and increases in INS that simplify landscapes, it may be necessary to modify eligibility rules to prevent forms of INS that simplify rangeland ecosystems from earning ACCUs.

Monitoring key variables and sharing information

Carbon farming has the potential to enhance monitoring and information-sharing across Australian rangelands due to the need for regular, systematic collection of data on vegetation growth rates and the impact of management actions on sequestration levels as part of auditing and compliance under the ERF. Carpenter *et al.* (2012) argue that monitoring and sharing information can enhance general resilience by enabling adaptive management and providing early warnings that critical thresholds may be crossed. Reid *et al.* (2014) have also highlighted the important role played by monitoring and learning in enhancing rangeland resilience.

Table S2 (Supplementary Information) provides a review of remote sensing-based projects and initiatives with the potential to provide information for monitoring key variables associated with co-benefits of carbon farming. Though not developed specifically for carbon farming or to assess soil rehabilitation outcomes at carbon farming sites, they can be combined with expert and local knowledge through modelling to then be applied to planning or incentive schemes. Some of the most promising tools listed in Table S2 (SI) are those relating to the TERN Landscape (formerly TERN AusCover) initiative. Of these data layers , woody cover, seasonal cover and seasonal persistent green data could be used to develop proxies for vegetation quality and soil condition. Woody vegetation height and structure data could be used to develop proxy indicators for habitat value, as done by Dean *et al.* (2015) for rangelands.

While data collection related to carbon farming is currently skewed towards factors that influence carbon sequestration (e.g. tree growth, ground cover and type), such monitoring events provide opportunities to collect a wider array of data to elicit key thresholds that can be used to assess and monitor resilience of carbon farming sites across the NSW rangelands (Table 3). In this way, risks may be managed as monitoring of key variables can provide an early warning of system changes which may led to land degradation. The introduction of incentives schemes for co-benefits such as the Queensland Land Restoration Fund (LRF) has the potential to increase the collection of data on soil condition and biodiversity, helping to support adaptive management and the progressive development of monitoring platforms that can meet assessment, inventory and monitoring information needs across multiple scales. Good practices and lessons exist to that end from the USDA Bureau of Land Management (Toevs *et al.* 2011) that focus on data-driven adaptive management.

Table 3. Key system thresholds identified through expert analysis (*Adapted from:* Cowie *et al*. 2019)

Category	**Thresholds** (anticipated system response)[1.]
Ground cover and type	**> 50% bare ground** (reduced rates of wind erosion) > **three months below 75mm results** (increased perennial grass mortality)
Woody cover and type	**Probability of >75mm rainfall in two successive wet summers** (recruitment and growth of woody vegetation increased)
Number of livestock	**> 30% perennial grass utilisation** (conservation of perennial pasture species)
Unmanaged herbivores	**> 30% perennial grass utilisation** (conservation of perennial pasture species) **>50% bare ground (50% of the time half the ground is covered)** (reduced rates of wind erosion)
Total grazing pressure	**> 30% perennial grass utilisation** (conservation of perennial pasture species) **Demand for feed-base (pasture) exceeds feed supply** (limited rest and recovery of pasture species from herbivores; reducing ground cover; alternating pasture composition with reduced productive, palatable perennial species)

1. System responses need to be considered within the local context (e.g. current landscape condition and levels of degradation, seasonal conditions and vegetation/soil type).

Information transparency is critical to ensuring that monitoring efforts enhance general resilience (Carpenter *et al.* 2012). In this regard, carbon farming offers an advantage over other rangeland land use options, as public registers for carbon farming projects have been established at both the state and federal level. Federally, the Clean Energy Regulator publishes an ERF register that includes a project summary along with the project owner's name and property details for all ERF-funded projects (Clean Energy Regulator 2020). Under its Land Restoration Fund (LRF), the Queensland Government has established a LRF register that will also include details on specific co-benefits classes and methods used to monitor such co-benefits (Queensland Government 2020).

Transparency could be further increased through the sharing of monitoring results from properties being managed for carbon sequestration and other co-benefits. The transparency provided by ERF and LRF registers has the potential to enhance shared understanding around carbon sequestration and other co-benefits. Anecdotal evidence from landholders indicates that such transparency could in some cases clash with established social norms around privacy and commercial confidentiality in rangeland Australia (Cross *et al.* 2019). For example, the ERF register makes it possible for landholders to estimate their neighbours' income from carbon farming much more easily than for grazing or other rangeland enterprises. Future options that could attempt to strike a balance between transparency and privacy include sharing de-identified data, such as monitoring results that have names and locations removed, or using de-identified data to calibrate online estimators of carbon sequestration and co-benefits, such as the prototype LOOC-C tool launched by the CSIRO in 2019 (CSIRO 2020).

Management at appropriate scales

This resilience principle brings together a need for openness, nestedness and modularity, which often need to be balanced against one another when managing for socio-ecological resilience (Carpenter *et al.* 2012). Openness refers to strong interconnections between neighbouring systems, while nestedness relates to the way that sub-systems link to higher system levels. Strong links to neighbouring systems and higher system levels can provide vital support following a disturbance (e.g. neighbours and governments providing disaster relief after a flood, drought or storm). Modularity involves creating localised domains of management that are weakly connected to neighbouring sub-systems, which enables for greater autonomy and self-organisation and more rapid responses that are tailored to local conditions (Armitage 2007). Weaker connections to neighbouring systems may also quarantine a system from disturbances that have the potential to spread across system boundaries, such as fire, disease, social conflict or economic shocks (Walker and Salt 2012).

The policy environment surrounding carbon farming in the Australian rangelands shows elements of modularity, openness and nestedness (Fig. 4). Carbon farming sites, particularly under the HIR methodology, are separated from neighbouring paddocks using fencing to keep out domestic stock, and in some cases other herbivores such as kangaroos and goats. Self-organisation is facilitated by the removal of 'unmanaged' grazing pressure, mechanical clearing and/or fire. However, graziers managing such sites share social, economic and environmental connections to neighbouring properties and they are linked to higher system levels through the ERF (national level), emerging co-benefit schemes such as the LRF (state level) and global carbon accounting and trading systems operated under UNFCCC rules.

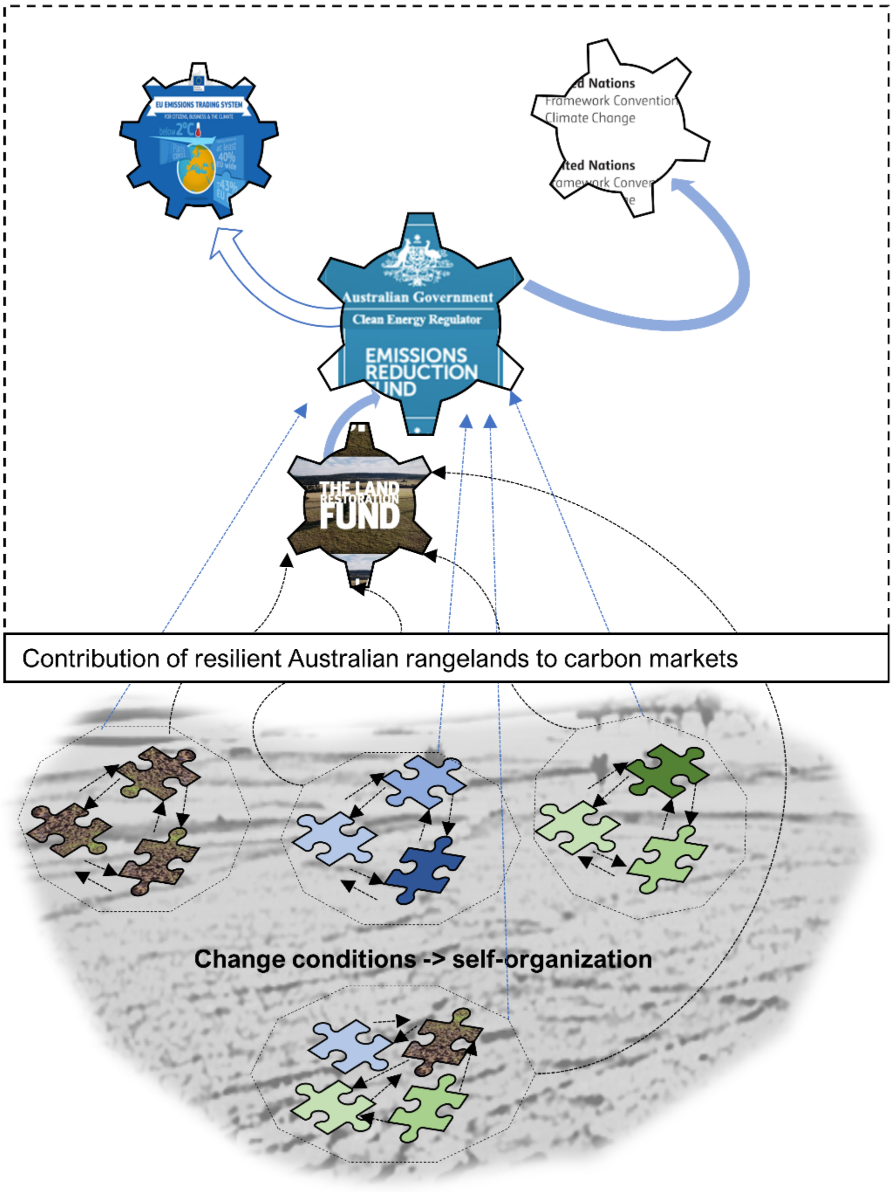


Fig. 4: schematic representation of modularity, openness, nestedness and self-organisation of Australian carbon farming.

A key question for carbon farming is whether resilience can be enhanced by increasing the level of connectedness to neighbouring or higher system levels. Ross Garnaut has argued that linking Australia to overseas carbon markets, such as the EU Emissions Trading Scheme, would enable Australian landholders to sell carbon credits for higher prices and to become a carbon credit exporting "superpower" (Garnaut 2019). However, while this may benefit landholder resilience by increasing incomes and financial reserves, it may also expose the Australian carbon market to future risks such as having to comply with rules that are set by external bodies or having to compete with international credits with lower prices but lacking in co-benefits for biodiversity, soils or communities. If such risks transpire, this could make it harder to strategically promote the most desirable forms of carbon farming (e.g. those offering environmental or social co-benefits). For example, the EU has historically set restrictive rules around reforestation credits due to concerns about their permanence and additionality in other jurisdictions with weaker regulations (European Commission 2012).

A scenario where Australia is required to tighten its rules to link to other markets such as the EU (e.g. through additional monitoring across extensive rangelands properties) could increase transaction costs and ultimately reduce the amount of forest land being restored (and the co-benefits that may come with that). While not necessarily implying that Australia's system should never be linked to global carbon markets, this scenario highlights the need to maintain a degree of national autonomy to set rules based on local conditions and policy objectives.

One option for balancing modularity and openness is to use voluntary carbon schemes to provide links to overseas carbon markets. This may allow Australian carbon farmers to sell credits for higher prices on overseas markets without requiring all carbon farmers to follow rules set in other jurisdictions or having to compete with cheaper, poorly-regulated credits from other countries. Another advantage of voluntary schemes is that they may enable carbon farmers to obtain a price premium for biodiversity, cultural or other co-benefits in cases where purchasers of carbon offsets value such factors. In this regard, two of the voluntary schemes that can be used to certify carbon offsets under Australia's National Carbon Offset

Standard, CCBA (Climate, Community & Biodiversity Alliance) and SocialCarbon, include benchmarks and indicators relating to environmental and social co-benefits: (Baumber *et al.* 2019).

Feedbacks

As socio-ecological systems mature, feedback loops often become weaker and less direct, due to such reasons as system managers experiencing less of the impact of their actions, or regulatory restrictions making it more difficult for managers to respond quickly (Walker and Salt 2012). In turn, this can reduce the ability of system managers to implement balancing feedbacks that help to keep the system in its current state, such as graziers removing stock from a paddock in response to information about declining ground cover or increased pasture utilisation. Carbon farming may help to strengthen feedback loops if it is linked to increased monitoring and information sharing, but may weaken such loops if it reduces landholder flexibility over future management decisions.

One issue related to feedbacks that is yet to receive attention in the development of carbon farming policy is the timing of carbon payments and how these link to drought cycles. Drought relief in Australia has been criticised for perpetuating unsustainable land management practices by masking feedbacks to landholders that indicate their land management practices may not be viable (Walker 2019). In their 2019 ABARES report on the impact of drought on Australian agriculture, Hughes *et al.* (2019) argue that, in order to build resilience, farm policy needs to shift towards investment in structural adjustment and change at times when the land is not in drought. The Australian Government controls the timing of carbon farming investment through the ERF and could investigate ways in which it could be strategically aligned to drought cycles or targeted at regions where structural adjustment is most required. Such considerations may also be relevant to co-benefit payment schemes under development by state governments.

Social capital: Leadership, trust and collaboration

While conventional market economics is underpinned by the assumption that people act according to rational self-interest, resilience-based approaches emphasise the importance of trust, leadership and collaboration in building "social capital" (Walker 2019). Australia's National Strategy for Disaster Resilience emphasises that trust is particularly important in relation to information sources and that leadership is something that can be enacted by a wide variety of stakeholders within their own sphere of influence, rather than being the responsibility of political or institutional leaders (COAG 2011). In the case of carbon farming, leadership may be shown by various stakeholders, including graziers who become early adopters of carbon farming, regional NRM agencies (e.g. Local Land Services in NSW), the "aggregators" who act as brokers between landholders and carbon markets and trusted advisors such as rural financial planners, bankers, accountants and consultants.

There is some distrust in government due to policy uncertainty brought about by the politically-contentious nature of climate change policy in Australia and a lack of clear and reliable information for landholders about the pros, cons, rules and risks associated with carbon farming (Cowie *et al.* 2019). Specific measures aimed at enhancing these information flows may help to overcome misinformation and enhance trust between key stakeholders. Lessons in building trust for new land use practices may also be gained from other sectors such as mining and renewable energy, where examples of trust-building measures include deliberately making and keeping small promises, prioritising quality of contact with local communities over quantity of contact, and viewing moments of crisis as opportunities to demonstrate that proponents are acting in the community's best interest (Baumber 2017).

One challenge associated with market-based instruments (MBIs) such as the ERF is their potential to reduce trust and collaboration by "crowding out" altruistic behaviour and creating divisions between those who get paid and those who do not. Crowding out refers to the phenomenon whereby people who see others getting paid for something that was previously being done for free, such as maintaining or restoring native vegetation, become unwilling to continue providing these services without similar payments (Chervier *et al.* 2019). While evidence of this occurring in relation to carbon farming is yet to be reported, it is something that needs to be monitored based on experiences with MBIs in other sectors.

The introduction of environmental MBIs can lead to social divisions within a community if the allocation of payments is seen as unfair or the land use activity being promoted does not align with community perceptions of how land should be used. Cowie *et al.* (2019) identified some concerns around the potential for carbon farming in the NSW rangelands to increase the gap between the "haves" who have eligible land for AD or HIR, and the "have nots" who are ineligible. Other concerns relate to the potential for carbon farming to increase landholder absenteeism, which can reduce the population engaging in local community activities and supporting local businesses, as well as causing pest or fire impacts for neighbouring properties due to a lack of active property management.

Kerr *et al.* (2017) recommend careful consideration of existing social norms before implementing MBIs aimed at community-scale behaviour change. If there is no existing social norm in favour of the desired action, then payment may be an effective way to increase that behaviour, but payments cannot in themselves be expected to create a new social norm in favour of the behaviour. Conversely, if there is an existing social norm around the behaviour, payment schemes need to be designed carefully so that they are seen to be recognising and supporting that norm rather than replacing it. Important considerations include the inclusion of local people in the design of the scheme to ensure it is seen as fair, as well as autonomy for local people to operate the scheme. Future research is needed to evaluate whether the potential for local people to influence ERF rules is linked to their perceptions of whether carbon farming is fair, inclusive and aligned with accepted norms and values around how land should be used. The Clean Energy Regulator (2019a) has recognised this need to draw on and enhance social capital by involving local communities in co-designing guidelines and providing feedback to refine systems and processes around carbon farming rules.

Concluding remarks

The emergence of carbon farming has increased income-generating opportunities for landholders in some parts of the Australian rangelands, as well as enabling practices with the potential to deliver a range of environmental and social co-benefits. However, depending on how it is implemented and incentivised, carbon farming also has the potential to erode the socio-ecological resilience of rangelands, with careful management and policy responses required. This has implications not only for Australia, but also for other countries that possess extensive rangeland areas that have been identified as having carbon sequestration potential, such as the United States and China.

This review has indicated that carbon farming aligns with many of the enabling factors for general resilience, including increasing the diversity of livelihood options, protecting habitat for biodiversity, buffering soils through increased groundcover, increasing biomass reserves that may enable landholders to better survive and recover from drought, and collecting and sharing new monitoring data that could improve decision-making and responsiveness.

However, there are also some inherent risks in relying on a market-based instrument such as the ERF to deliver rangeland resilience. The principle of least-cost carbon abatement that underpins the ERF has the potential to preferentially value carbon at the expense of other ecosystem components, to reduce redundant capacity that does not appear to be of immediate value, and to overlook social capital by focusing on individual economic self-interest. These risks need to be carefully monitored and managed if carbon farming is to truly enable greater rangeland resilience.

If carbon farming is to fulfil its potential in enhancing rangeland resilience, an adaptive approach is required in which critical factors are monitored and modifications are made to the suite of policy measures being applied where necessary. Some important thresholds for ecosystem health relate to ground cover and grazing pressure, but it is also important for future social and ecological research to evaluate whether carbon farming is contributing to potential risks around INS, the simplification of diverse ecosystems, landholder absenteeism, community divisions and the crowding out of voluntary behaviours. Policy options to be considered for the future include complementary incentive schemes that value co-benefits, modifications to ERF eligibility rules to prevent the simplification of ecosystems and/or to require active management, striking the right balance between maintaining the autonomy of Australia's carbon markets and connecting it to markets overseas, and policy measures aimed at building social capital. Careful consideration of these factors will increase the likelihood that carbon farming fulfils its potential as an enabler of greater socio-ecological resilience in the Australian rangelands.

Acknowledgements

Accepted version – final version at: https://www.publish.csiro.au/rj/RJ20034

This research was undertaken as part of the New South Wales Department of Primary Industries Climate Change Research Strategy, "Accessing carbon markets" project funded by the NSW Climate Change Fund.

Conflict of interest statement

The authors declare no conflicts of interest

References

Armitage, D., 2007. Building Resilient Livelihoods through Adaptive Co-Management: The Role of Adaptive Capacity, in: Armitage, D., Berkes, F., Doubleday, N. (Eds.), Adaptive Co-Management. UBC Press, Vancouver, pp. 62-82.

Baumber, A., 2017. Social licence and energy cropping: What's trust got to do with it? Biomass & Bioenergy TBC, TBC.

Baumber, A., Metternicht, G., Cross, R., Ruoso, L.-E., Cowie, A.L., Waters, C., 2019. Promoting co-benefits of carbon farming in Oceania: Applying and adapting approaches and metrics from existing market-based schemes. Ecosystem Services 39, 100982.

Baumber, A.P., Merson, J., Ampt, P., Diesendorf, M., 2011. The adoption of short-rotation energy cropping as a new land use option in the New South Wales Central West. Rural Society 20, 266-279.

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

Butler, D.W., Halford, J.J., Evans, M.C., 2014. Carbon farming and natural resource management in eastern Australia. Queensland Department of Science, Information Technology, Innovation and the Arts, Brisbane.

Carpenter, S.R., Arrow, K., Barrett, S., Biggs, R., Brock, W., Crépin, A.-S., Engström, G., Folke, C., Hughes, T.P., Kautsky, N., Li, C.-Z., McCarney, G., Meng, K., Mäler, K.-G., Polasky, S., Scheffer, M., Shogren, J., Sterner, T., Vincent, J., Walker, B., Xepapadeas, A., de Zeeuw, A., 2012. General Resilience to Cope with Extreme Events. Sustainability 4, 1-12.

Central West LLS, Western LLS, 2014. Managing invasive native scrub to rehabilitate native pastures and open woodlands. Central West Local Land Services and Western Local Land Services, Dubbo and Cobar, NSW, Australia, p. 123.

Chervier, C., Le Velly, G., Ezzine-de-Blas, D., 2019. When the Implementation of Payments for Biodiversity Conservation Leads to Motivation Crowding-out: A Case Study From the Cardamoms Forests, Cambodia. Ecological Economics 156, 499-510.

Clean Energy Regulator, 2018. Human-induced regeneration of a permanent even-aged native forest. Clean Energy Regulator, Canberra.

Clean Energy Regulator, 2019a. Compliance policy for education, monitoring and enforcement activities, http://www.cleanenergyregulator.gov.au/About/Policies-and-publications/Compliance-policy-for-education-monitoring-and-enforcement-activities#4.1, Accessed 21 April 2020, Last updated 7 February 2019.

Clean Energy Regulator, 2019b. Statement of opportunities in the ACCU market – March 2019.

Clean Energy Regulator, 2020. Emissions Reduction Fund project register.

CMI, 2020a. Carbon Market Industry. Australian Carbon Industry code of conduct https://marketplace.carbonmarketinstitute.org/code/ [Accessed: 23 April 2020]

CMI, 2020b. Carbon Farming Industry Roadmap. Carbon Market Institute http://carbonmarketinstitute.org/wp-content/uploads/2017/11/Carbon-Farming-Industry-Roadmap.pdf [Accessed: 25 April 2020]

COAG, 2011. National Strategy for Disaster Resilience. Council of Australian Governments, Canberra, p. 25.

Cockfield, G., Shrestha, U. and Waters C. 2019. Evaluating the potential financial contributions of carbon farming to grazing enterprises in Western NSW. The Rangeland Journal 41: 211-223.

Cowie, A.L., Waters, C.M., Garland, F., Orgill, S.E., Baumber, A., Cross, R., O'Connell, D., Metternicht, G., 2019. Assessing resilience to underpin implementation of Land Degradation Neutrality: A case study in the rangelands of western New South Wales, Australia. Environmental Science & Policy 100, 37-46.

Cross, R. and Ampt, P. 2017. Exploring agroecological sustainability: Unearthing innovators and documenting a community of practice in Southeast Australia. Society & Natural Resources 30(5): 585-600.

Cross, R., Metternicht, G., Baumber, A., Waters, C., and Kam, H., 2019. Improving access to carbon farming markets: Stakeholder needs analysis. Report for NSW DPI 'A Decision support tool to enhance carbon farming opportunities' November 2019 University of New South Wales and NSW Department of Primary Industries.

Crossman, N.D., Bryan, B.A., Summers, D.M., 2011. Carbon payments and low-cost conservation. Conservation Biology 25, 835-845.

Cunningham, S. C., Mac Nally, R., Baker, P.J., Cavagnaro, T.R., Beringer, J., Thompson, J.R., Thompson, R.M. 2015. Balancing the environmental benfits of reforestation in agricultural regions. Perspective. Plant Ecology, Evolution and Systematics 17, 301-317.

CSIRO, 2020. LOOC-C: A landscape options and opportunities for carbon abatement calculator. CSIRO.

Dass, P., Houlton, B.Z., Wang, Y.P., Warlind, D. 2018. Grasslands may be more reliable carbon sinks than forests in California. Environmental Research Letters 13, 074027.

Dean, C., Kirkpatrick, J.B., Harper, r.J., Eldridge, D.J. 2015) Optimising carbon sequestration in arid and semiarid rangelands. *Ecological Engineering* 71:148-163.

Department of the Environment and Energy, 2016. FullCAM Guidelines: Requirements for using the Full Carbon Accounting Model (FullCAM) in the Emissions Reduction Fund (ERF) methodology determination: Carbon Credits (Carbon Farming Initiative) (Human Induced Regeneration of a Permanent Even Aged Native Forest—1.1) Methodology Determination 2013, Version 2.0. Department of the Environment and Energy, Canberra, p. 41.

Department of the Environment and Energy, 2019. Emissions Reduction Fund Method: Plantation Forestry. Department of the Environment and Energy, Canberra, p. 3.

Erol, O., Sauser, B.J., Mansouri, M., 2010. A framework for investigation into extended enterprise resilience. Enterprise Information Systems 4, 111-136.

European Commission. 2012. "Questions & Answers on Accounting Rules and Action Plans on Greenhouse Gas Emissions and Removals Resulting from Activities Related to Land Use, Land Use Change and Forestry (LULUCF). MEMO/12/176." Last Modified 22 October 2015, accessed 1 July. http://europa.eu/rapid/press-release_MEMO-12-176_en.htm?locale=en.

European Parliament, and Council of the European Union. 2009. "Directive 2009/28/EC." *Official Journal of the European Union* L140:16-62.

Evans, M.C., J. Carwardine, R.J. Fensham, D.W. Butler, K.A. Wilson, H.P. Possingham, and T.G. Martin. 2015. "Carbon farming via assisted natural regeneration as a cost-effective mechanism for restoring biodiversity in agricultural landscapes." *Environmental Science & Policy* 50:114-129.

Evans, Megan C. 2018. "Effective incentives for reforestation: lessons from Australia's carbon farming policies." *Current Opinion in Environmental Sustainability* 32:38-45. doi: https://doi.org/10.1016/j.cosust.2018.04.002.

Fleming, A., C. Stitzlein, E. Jakku, and S. Fielke. 2019. "Missed opportunity? Framing actions around co-benefits for carbon mitigation in Australian agriculture." *Land Use Policy* 85:230-238.

Garnaut, Ross. 2019. *Superpower: Australia's Low-Carbon Opportunity*. Melbourne: LaTrobe University Press.

Gill, T., Horn, G., Gibson, R., 2016. Spatial Analysis of Landsat Imagery, Final Project Report. Office of Environment and Heritage, NSW Government, Sydney, p. 38.

Godde, C., Dizyee, K., Ash, A., Thornton, P., Sloat, L., Roura, E., Henderson, B. and Herrero, M. 2019. "Climate change and variability impacts on grazing herds: Insights from a system dynamics approach for semi-arid Australian rangelands". *Global change biology*, *25*(9): 3091-3109

Government of Western Australia (2020). Carbon farming https://www.agric.wa.gov.au/climate-land-water/land-use/carbon-farming[Accessed 26 March 2020

Hughes, Neal, David Galeano, and Steve Hatfield-Dodds. 2019. The effects of drought and climate variability on Australian farms. Canberra: ABARES.

IPCC. 2012. Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation: A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change edited by C.B. Field, V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor and P.M. Midgley. Cambridge, UK and New York, NY, USA: Cambridge University Press.

Jackson, S., L. Palmer, F. McDonald, and A. Bumpus. 2017. "Cultures of carbon and the logic of care: the possibilities for carbon enrichment and its cultural signature." *Annals of the American Association of Geographers* 107 (4):867-882.

Jassim, D. 2018. "Community perceptions of carbon sequestration projects under the Emissions Reduction Fund in Australia: A case study of the Mulga Lands bioregion, south-west Queensland." Unpublished honours thesis, School of Earth and Environmental Sciences, The University of Queensland.

Kerr, J.M., M.K. Lapinski, R.W. Liu, and J. Zhao. 2017. "Long-Term Effects of Payments for Environmental Services: Combining Insights from Communication and Economics. x." *Long-Term Effects of Payments for Environmental Services: Combining Insights from Communication and Economics. Sustainability* 9 (9):1627. doi: https://doi.org/10.3390/su9091627.

Kragt, Marit, Nikki Dumbrell, and Louise Blackmore. 2017. "Motivations and barriers for Western Australian broad-acre farmers to adopt carbon farming." *Environmental Science & Policy* 73:115-123. doi: 10.1016/j.envsci.2017.04.009.

Levin, Simon A., Scott Barrett, Sara Aniyar, William Baumol, Christopher Bliss, Bert Bolin, Partha Dasgupta, Paul Ehrlich, Carl Folke, Ing-Marie Gren, C. S. Holling, Annmari Jansson, Bengt-Owe Jansson, Karl-Goran. Maler, Dan Martin, Charles Perrings, and Eytan Sheshinski. 1998. "Resilience in natural and socioeconomic systems." *Environment and Development Economics* 3 (02):221-262. doi: doi:10.1017/S1355770X98240125.

Nolan, R.H., Sinclair, J., Waters, C.M., Mitchell, P., Eldridge, D.J., Paul, K.I., Roxburgh, S., Bulter, D.W. and Ramp, D. (2019). Risks to carbon dynamics in semi-arid woodlands of eastern Australia under current and future climates *Journal of Environmental Management* 235: 500–510

O'Connell, D., N. Abel, N. Grigg, Y. Maru, J. Butler, A. Cowie, S. Stone-Jovicich, B. Walker, R. Wise, A. Ruhweza, L. Pearson, P. Ryan, and M. Stafford Smith. 2016. Designing Projects in a Rapidly Changing World: Guidelines for Embedding Resilience, Adaptation and Transformation Into Sustainable Development Projects (Version 1.0). Washington, D.C.: Global Environment Facility.

Queensland Government. 2020. Land Restoration Fund Co-benefits Standard version 1.2. Brisbance: Queensland Government Land Restoration Fund.

Reid, R. S., Fernández-Giménez, M. E., & Galvin, K. A. 2014. "Dynamics and resilience of rangelands and pastoral peoples around the globe". *Annual Review of Environment and Resources*, 39: 217-242.

Reputex 2020. Reputex Energy. ACCU contract prices rise, but Regulator takes the low road at ERF Auction 10 https://www.reputex.com/research-insights/accu-contract-prices-rise-but-regulator-takes-the-low-road-at-erf-auction-10/ [Accessed: 23 April 2020]

Richards, G.P. and Evans, D.M.W. 2004. "Development of a carbon accounting model (FullCAM Vers. 1.0) for the Australian continent." *Australian Forestry*, 67(4): 277-283, DOI: 10.1080/00049158.2004.10674947

Salas Castelo, E.M. 2017. "The role of factors that influence the adoption of the Australian Carbon Farming Initiative Emissions Reduction Fund: a mixed methods study." PhD, James Cook University, Queensland, Australia.

Toevs, G. R., Karl, J. W., Taylor, J. J., Spurrier, C. S., Bobo, M. R., and Herrick, J. E. 2011. "Consistent indicators and methods and a scalable sample design to meet assessment, inventory, and monitoring information needs across scales". *Rangelands* 33:14-20.

Torabi, Nooshin, Luis Mata, Ascelin Gordon, Georgia Garrard, Wayne Wescott, Paul Dettmann, and Sarah A. Bekessy. 2016. "The money or the trees: What drives landholders' participation in biodiverse carbon plantings?" *Global Ecology and Conservation* 7:1-11. doi: https://doi.org/10.1016/j.gecco.2016.03.008.

Walker, B. 2019. *Finding Resilience*. Clayton South, VIC, Australia: CSIRO Publishing.

Walker, B., C. S. Holling, S. R. Carpenter, and A. Kinzig. 2004. "Resilience, adaptability and transformability in social–ecological systems." *Ecology and Society* 9 (2):5.

Walker, B., and D. Salt. 2006. *Resilience Thinking: Sustaining Ecosystems and People in a Changing World*. Washington, DC: Island Press.

Walker, B., and D. Salt. 2012. *Resilience Practice: Building Capacity to Absorb Disturbance and Maintain Function*. Washington DC: Island Press.

Accepted version – final version at: https://www.publish.csiro.au/rj/RJ20034

Waters, C.M., McDonald, S.E., Reseigh, J., Grant, R., and Burnside, D. (2020). Insights on the relationship between total grazing pressure management and sustainable land management: key indicators to verify impacts. *The Rangeland Journal* 41: 535-556.

Accepted version – final version at: https://www.publish.csiro.au/rj/RJ20034