Challenges, solutions and research priorities for sustainable rangelands

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Abstract. Australia's rangeland communities, industries, and environment are under increasing pressures from anthropogenic activities and global changes more broadly. We conducted a horizon scan to identify and prioritise key challenges facing Australian rangelands and their communities, and outline possible avenues to address these challenges, with a particular focus on research priorities. We surveyed participants of the Australian Rangeland Society 20th Biennial Conference, held in Canberra in September 2019, before the conference and in interactive workshops during the conference, in order to identify key challenges, potential solutions, and research priorities. The feedback was broadly grouped into six themes associated with supporting local communities, managing natural capital, climate variability and change, traditional knowledge, governance, and research and development. Each theme had several sub-themes and

potential solutions to ensure positive, long-term outcomes for the rangelands. The survey responses made it clear that supporting 'resilient and sustainable rangelands that provide cultural, societal, environmental and economic outcomes simultaneously' is of great value to stakeholders. The synthesis of survey responses combined with expert knowledge highlighted that sustaining local communities in the long term will require that the inherent social, cultural and natural capital of rangelands are managed sustainably, particularly in light of current and projected variability in climate. Establishment of guidelines and approaches to address these challenges will benefit from: (*i*) an increased recognition of the value and contributions of traditional knowledge and practices; (*ii*) development of better governance that is guided by and benefits local stakeholders; and (*iii*) more funding to conduct and implement strong research and development activities, with research focused on addressing critical knowledge gaps as identified by the local stakeholders. This requires strong governance with legislation and policies that work for the rangelands. We provide a framework that indicates the key knowledge gaps and how innovations may be implemented and scaled out, up and deep to achieve the resilience of Australia's rangelands. The same principles could be adapted to address challenges in rangelands on other continents, with similar beneficial outcomes.

Introduction

Rangelands play a key role in Australia's environmental, industrial and societal framework, with unique landscapes that cover a large proportion of the continent supporting diverse communities, industries, and a range of ecosystem goods and services. The Australian Rangeland Society broadly defines rangelands as follows (ARS 2019):

> Rangelands include all those environments where natural ecological processes predominate and where values and benefits are based primarily on natural resource areas which have not been intensively developed for primary production. The rangelands of the semiarid and arid zones cover approximately 75 per cent of the Australian continent and equate broadly with the 'Outback'. However, rangelands also occur in higher rainfall areas where limitations other than rainfall restrict use to management of the natural landscape.

The Australian Rangeland Society's definition thus recognises that Australia's rangelands support a broad range of stakeholders utilising the land for multiple purposes. Here, we will refer to rangelands when drawing on general observations, whereas the term Outback will be used when more explicit references are made to Australia's arid and semiarid ecosystems and communities in remote areas.

Australia's rangelands currently support about 2% of Australia's human population. However, the total population on rangelands is decreasing while the proportion of Indigenous peoples is increasing (2016 data; Foran *et al.* 2019). Moreover, the rangelands contribute substantially to Australia's productivity through mining, pastoralism (beef cattle, sheep and goat production; 55.4% of the area by tenure), and tourism. Conservation estates represent 10.5% of the area, and 33.6% is under some form of exclusive Indigenous land tenure; additional conservation and pastoral areas are subject to non-exclusive Indigenous interests and Determined Native Title (for the most complete recent update of this complexity, see table 3 in Foran *et al.* 2019). There are also small (<1% by area), but nationally important, holdings by the Department of Defence, telecommunications infrastructure, and transport corridors (Foran *et al.* 2019).

There is ample evidence that Australia's rangeland ecosystems are under increasing pressure from anthropogenic impacts, both directly through inappropriate land use and indirectly through climate change. Soil degradation is a substantial concern for Australian rangelands as it is elsewhere (Bai *et al.* 2008; Cherlet *et al.* 2018), as is their exposure and sensitivity to climate change (Hughes *et al.* 2016). There is evidence that degradation is linked directly to the vulnerability of ecosystems to global change (Webb *et al.* 2017), including Australian rangelands where areas with reduced vegetation cover show less resilience to drought (Xie *et al.* 2019). Projected changes to rainfall, including increased rainfall variability, and prolonged drought interrupted by floods, as well as rising temperatures and more days with heat stress and high fire risk, therefore pose significant risks to livestock and remote communities in most of Australia's rangeland (Howden 2017).

Various opportunities, however, exist to diversify rangeland use and livelihoods, ranging from sustainable beef production to carbon farming, into management and governance. Sustainable use of native and introduced herbivores, notably goats, may also provide an opportunity for diversification, particularly in light of the promising growth of the rangeland goat industry and increased global demand for goat meat (El Hassan 2019). Likewise, there is great value in developing modern rangeland management that centres on a careful blending of Indigenous and local knowledge with modern science and technology. Management would also benefit from an increased focus on building a sense of identity and culture to create connection with the land and a sense of belonging to a community. This should include increased sharing of knowledge and education to promote awareness of the rangelands locally and beyond. Additionally, there is value in recognising that rangelands around the world are experiencing similar global-change pressures. Placing the Australian rangelands in a global context is crucial to learning from developments elsewhere and communicating

lessons from our rangelands that may inform others (Stafford Smith 2016; Godde *et al.* 2020).

The rangelands thus represent a unique landscape where we can achieve environmental and social sustainability if we work together; however, this requires reciprocal trust among key stakeholders, partners, and members of the society. It is not currently clear how best to achieve this outcome for Australia's rangelands, particularly in light of the changing demographic, declining population size, and the associated loss of managers and custodians of the land.

This paper synthesises input from Australia's professional rangeland community, based on hands-on experience, literature and expert knowledge, to present the most pressing challenges facing Australia's rangelands, and to outline potential solutions and research priorities that will best address these challenges. The longer term aim is to develop a clear framework for how best to ensure resilient and sustainable rangelands that provide cultural, societal, environmental and economic outcomes in light of ongoing global changes. The principles presented here can be adapted to address challenges in rangelands globally, with adaption to local context, including environmental, socio-economic and political conditions.

Methods

We loosely followed a 'horizon scan' approach as described in Sutherland *et al.* (2011) as a process to identify key challenges, potential solutions, and research priorities in rangelands to bridge the gap between research and stakeholders. Prior to the Australian Rangeland Society meeting in Canberra, 2019 (henceforth ARS2019), we asked registered conference participants to answer a series of questions related to rangelands and their own background (i.e. experience level, stakeholder type, profession, etc.; see Supplementary Materials Table S1, available at the journal's website). The results presented here pertain to three of these questions:

1. Identify 3–5 key challenges facing rangelands that you believe are critical to prioritise to ensure long-term sustainable use of rangelands and healthy rangeland communities.
2. Identify, if you can, how you would address the challenges you outlined in Q1.
3. Please identify 3–5 research questions that in your opinion should be prioritised to improve our knowledge of rangelands and how to better manage both the rangelands and their human communities.

We compiled the survey responses in two spreadsheets, one focused on challenges and solutions and one on research priorities, with 509 responses from >40 participants with a range of backgrounds from rangeland practitioners to government and research. These responses were then grouped into broad themes before the conference for more targeted discussions during the conference, using round-table discussions similar to the World Café concept (The World Café Community Foundation: www.theworldcafe.com). One World Café session was specifically focused on the horizon scan, with participants providing feedback on survey responses (i.e. highlighting particularly critical challenges and research activities, linking challenges and solutions, etc.). Another three sessions focused on governance, traditional knowledge, and social licence, respectively. Each World Café session involved 20–40 participants. The hosts of

World Cafés welcomed participants, outlined the objective(s), and then led a guided discussion on the topic in question. Notes taken during the discussions were used to help frame the key messages presented here. Following the conference, the survey responses and feedback received during World Café sessions was consolidated by a sub-group of the authors into six broad but interlinked themes: livelihood, natural capital, climate variability and change, traditional knowledge, governance, and research and development (R&D). Additional input was then sought from individuals with particular expertise related to one or more of the themes to help synthesise challenges, solutions and research priorities posed in each theme, and identify potentially missing topics, with the resulting knowledge integrated, drawing links between the themes where possible.

Results and discussion

The survey, discussions and experts identified challenges, solutions and research priorities that can be grouped into six broad and intertwining themes: Theme 1, livelihood (supporting local communities); Theme 2, natural capital; Theme 3, climate (variability and change); Theme 4, traditional knowledge; Theme 5, governance; and Theme 6, R&D. The main challenges, solutions and research priorities identified by the survey responses and experts, alongside proposed actions to address these, are discussed below. However, the proposed actions of one theme will likely impact the way we respond to another, with synergistic outcomes when done right. Sustaining local communities (Theme 1) in the long term will inevitably require that the rangelands' inherent natural capital is managed sustainably (Theme 2), particularly in the light of current and projected variability in climate (Theme 3). Establishing guidelines and approaches to address this challenge will benefit from an increased recognition of the value, and contributions, of traditional knowledge and practices (Theme 4), developing better governance that is guided by, and benefits, local stakeholders (Theme 5), and more resources to conduct and implement robust R&D activities (Theme 6).

Theme 1. Livelihood: supporting local communities

The socioeconomics of Australian rangeland communities are strongly dependent on land used in pastoralism, tourism, mining and conservation, and increasingly for Indigenous cultural connection and renewable energy generation (Foran *et al.* 2019; Kelly and Phelps 2019). Although there are numerous potential viable land uses under stable economic, social and environmental conditions, rangelands are vulnerable to major environmental disturbances such as floods and droughts, unstable market forces and other externalities (Phelps and Kelly 2019). Rainfall is likely to become more extreme and unpredictable under climate-change projections (Howden 2017; Godde *et al.* 2020) and the COVID-19 pandemic has highlighted the potential for global events to act as major disruptors of markets and supply chains (Branson 2020; Greenville *et al.* 2020) with the potential to affect livelihoods of communities in rangelands. In the face of disruptive changes and future uncertainties, a key challenge is to embed adaptation and transformation processes into land use to enhance the resilience of rangeland communities. Resilience incorporates the capacity, skills and knowledge

of communities 'to adequately prepare, respond and adapt in the face of rapid change' (Queensland Government 2017) and the ambitions of a community to adapt and transform, progressing towards socially desired goals and values (Maru *et al.* 2014; Phelps and Kelly 2019). Therefore, Theme 1 focuses on adaptation of land management with the potential to enhance the resilience of rangeland communities, in the context of these broad global disruptions. Strategies that can help to achieve greater rangeland resilience include: (*i*) diversifying economies; (*ii*) increasing populations, skills and knowledge; (*iii*) building social capital; (*iv*) building financial capacity; (*v*) restructuring governance arrangements; and (*vi*) active adaptive management of natural and cultural resources (Walker and Salt 2012).

Maintaining and building a greater diversity of enterprise options can increase resilience by enhancing the adaptive capacity of landholders to respond to changing conditions of different agricultural production systems (e.g. sheep, cattle, goats, horticulture) as well as non-grazing income streams such as tourism, mining, renewable energy, stewardship payments or carbon farming (Cowie *et al.* 2019). Similarly, rangeland communities that have employment options across a diverse mix of local industries will be more resilient to economic disturbances. This diversification may help to offset the threat to community resilience caused by declining populations and address a lack of employment opportunities for Indigenous people – a significant, and increasing, proportion of the rangeland population.

Rangeland regions tend to have strong social capital, although it has been eroded by declining populations (Kelly and Phelps 2019). Social capital is critical to resilient communities, including trust, knowledge, leadership and the capacity to collaborate (Walker and Salt 2012), and can be enhanced through approaches such as 'two-eyed seeing' (Bartlett *et al.* 2012) and others outlined in Theme 4. Stronger networks are needed across industry sectors, across regions and countries and across knowledge systems to ensure innovation is based in the best science and most creative thinking.

Social licence represents one key element of social capital, because it relates to whether an industry or activity has the trust of key stakeholders and is seen as legitimate and credible (Thomson and Boutilier 2011). Social licence frameworks were developed in the mining sector and highlight that trust and legitimacy are influenced by factors such as distributional fairness (how the costs and benefits of an activity are shared), procedural fairness (how decisions are made and affected communities are engaged), and confidence in governance (Zhang *et al.* 2015). Other key factors include shared values (e.g. is it appropriate to 'lock up' land for conservation?); incumbency (i.e. are long-standing industries such as grazing more likely to be seen as legitimate?); adaptability (how does an industry respond when its social licence is threatened?); and scale (do you need separate social licences from your local community, from consumers of your products and from the broader majority-urban Australian population?).

Enhancing financial capacity of rangeland regions includes attracting capital investment in addition to maintaining financial reserves to help cope with uncertainties such as drought or loss of key staff. Adequate finances are critical for responding to disturbances, whether that is in the form of cash reserves, insurance, additional capacity of critical infrastructure, or groundcover that buffers against extreme rainfall and provides reserve animal feed in times of drought (Cowie *et al.* 2019). Frequently, tension exists between maximising efficiency in the short term, by putting all reserve capacity to productive use, and enhancing longer term resilience by maintaining reserves (Walker and Salt 2012). Of note in this regard is the use that agricultural industries make of the Farm Management Deposits, a scheme established by the Australian Government to reduce risk, to smooth farm income over time, and as a tax-effective way of maintaining reserves, to manage climate variability (Australian Government 2020). However, the reliance of rangeland regions on grazing has led to high vulnerability to climatic events (Phelps and Kelly 2019), and debt levels in many regional small businesses often preclude them from building reserves. This is a consideration for not only land managers, but also for local government and other policy-makers.

Typically, government investment in rangeland regions is intermittent and linked to drought, disasters such as flooding and bushfires, or other crises that resonate with Australia's larger urban populations. Rangeland industries and communities have long been calling for more sustained and reliable investments based on locally led demands, aspirations and strategies (Kelly and Phelps 2019). Governments should be encouraged to incentivise the building up of reserves of key natural resources (e.g. water, biomass, carbon) as well as investing in safety nets and key infrastructure when times are good, rather than waiting until a drought or other disturbance hits (Hughes *et al.* 2019). Supporting the maintenance of such reserves will reduce calls on public funding in crisis times.

Further research into case studies of communities that have shown resilience and an ability to adapt to changing circumstances, including disasters, is needed to enhance understanding on how adaptation and transformation processes and social licence may lead to resilient rangeland communities (Mayer 2019). This should include measurements of the key variables that influence diversification of economies, population and migration, social capital, governance and policy experimentation, to determine how best to incentivise the building of resilience and social licence. It would also need to focus on specific disturbances that have affected Australia's rangelands and compare those communities that have shown resilience (i.e. been able to adapt and change while maintaining essential functions and structures) with those that have undergone a shift to a less desirable state with entrenched social, economic or environment problems. Possible candidates for case-study research include recent drought, floods, bushfires, COVID-19 disruptions or the 2008 global financial crisis. Key premises are that diversity, buffers (or reserves) and social capital all enhance resilience at times of disturbance and that the complexity and nuances of how different regions operate needs to be better understood. There may be a specific role for linking social capital between the resident rangeland population and external experts in the face of a declining population (Phelps and Kelly 2020). Post-COVID-19, rangeland towns with sufficient baseline services could become central to a risk-spreading strategy for city offices, with small teams based in towns such as Longreach or Katherine able to continue core business in the event of pandemic outbreaks in major urban centres such as Brisbane.

Policy experimentation is required to determine how land managers and other rangeland stakeholders might respond to different incentives, penalties and supporting mechanisms (e.g. information, training, standardisation, R&D). This experimentation could take the form of a suite of 'safe-to-fail experiments' that are applied for short durations in different locations, to learn more about stakeholder responses and to allow ongoing adjustment of policy-settings. This approach recognises that there is no such thing as a 'failsafe' policy for enhancing rangeland resilience. One advantage that Australia has in this respect is the distribution of its rangelands across multiple state and territory jurisdictions, which enables different policy settings to be trialled in different locations and learning to be shared between governments through a process of 'triple-loop learning' (McLoughlin *et al.* 2020).

Actions that would help to address challenges related to Theme 1

1. Policy and strategies fostering investment in safety nets and key infrastructure when times are good, rather than waiting until a drought or other disturbances hits rangelands.
2. 'Safe-to-fail' policy experimentation to determine how land managers and other rangeland stakeholders might respond to different incentives, penalties and supporting frameworks.
3. Research to identify key variables that contribute to social licence, such as distributional fairness, procedural fairness and confidence in governance.
4. Studies to determine whether the social-licence factors identified in sectors such as mining are relevant to other industries such as grazing and conservation-based management, and comparative case studies between long-established practices and newer practices (e.g. grazing vs carbon farming) and between local and more distant communities (e.g. rangeland vs urban communities).

Theme 2. Natural capital

Managing natural capital for sustainability, improved productivity and resilience remains one of the most challenging issues in the rangelands. The survey respondents identified a range of issues facing the management of natural capital and proposed actions to meet them. The challenges can be clustered in three main categories: degradation of natural capital, deterioration of water resources, and biodiversity loss.

The introduction of European herbivores and overgrazing are recognised as the major drivers of degradation of natural capital in the Australian rangelands (Abel *et al.* 2006; Alemseged and Hacker 2014). Overgrazing has led to the loss of perennial grasses, encroachment of woody weeds, and a subsequent cascade of losses in landscape function, including erosion and declines in soil structure, nutrient cycling and water infiltration (Ludwig *et al.* 1997; Sparrow *et al.* 2003; WLLS 2014). Feral hoofed animals (e.g. goats, camels, donkeys), rabbits and increased populations of native macropods have contributed significantly to total grazing pressure at times and resulted in further degradation of resources (Fisher *et al.* 2004). As a result, management of total grazing pressure is a major challenge that requires a high level of collaboration among pastoralists, conservationists and other key stakeholders.

There is also a need to understand the rangelands as a complex social-ecological system that has interacting social and ecological components, including those that depend on or affect natural capital (e.g. grazing, pests and weeds, fires) (Walker and Janssen 2002). Identifying thresholds of concern is necessary for management and prevention of degradation of ecosystems and landscape function (Walker and Meyers 2004). Further, resilience of the rangelands depends in part on attributes related to natural capital, including connectivity, diversity, and availability of reserves across the landscape (Walker *et al.* 2012; O'Connell *et al.* 2015).

Incorporation of Aboriginal values is also of great significance as discussed further by Ridges *et al.* (2020). The rangelands have evolved under Aboriginal management, which included, among other practices, regular use of fire for purposes such as cultural outcomes, hunting strategies, control of vegetation density and regenerating grasslands. Since European colonisation, fire in the landscape has been significantly altered, contributing to impacts on ecosystems of varying degrees across different regions (Turner *et al.* 2008; Williams *et al.* 2009). This has further added to the problem of encroachment of trees and shrubs (Noble 1997; Norton and Reid 2013), which has been intensified by significant rainfall events (Bastin 2008) and overgrazing of perennial grasses. This in turn has led to more degradation of resources and even more aggressive and unsustainable grazing strategies to mitigate the loss of income (Ludwig *et al.* 1997).

Research should focus on best management practices (including grazing management and rehabilitation methods) for restoration and maintenance of landscape function, biodiversity, soil carbon, soil structure and other important elements related to natural capital, while maximising production and profitability. Where required, research should also explore transformative changes beyond what is currently accepted as best practice.

Water management is vital for the rangelands, which are characterised by infrequent and sporadic rainfall events. Management of water resources is a complex issue because of contrasting objectives of users in rangelands (e.g. production vs environmental flows). Issues such as water availability, quality and allocation are becoming increasingly challenging with the rapid change in climate and the increase in frequency, duration and intensity of droughts. Excessive extraction of artesian water has resulted in significant declines in groundwater availability (Noble *et al.* 1998; Hill 2011; Smerdon *et al.* 2012). An increase in dams and changes to overland flow patterns are altering flow regimes of streams. Water infrastructure is recognised as an important means of improving grazing distribution over landscapes (Hunt *et al.* 2014). However, it should be balanced with maintenance of areas of landscape remote from water (>8–10 km) primarily to protect grazing-sensitive species (James *et al.* 1999; Fensham and Fairfax 2008). Recent unprecedented fish kill in the Menindee Lakes provides a stark warning of the dire need to transform the management of water allocations in the rangelands and surrounding catchments. A $20 million Basin research plan administered by the Murray–Darling Basin Authority is currently taking place in response to the fish deaths (Littleproud and Pasin 2019). Social-ecological system thinking should also prevail here. Water-management plans within the Australian rangelands need to take into

consideration all stakeholders, industry, community and environmental impacts. For example, inland rivers are vital both for ecosystems and for people on the rangelands, and there is a need to prioritise water use, water quality and water management in a way that connects the environment and river communities. Research that focuses on sustainable extraction limits and ways of maintaining hydrological processes is needed. In addition, assessment of the impact of increased infiltration in catchments is necessary, including impacts on year-round and extreme flows, water quality, sedimentation of watercourses, and salinity. The intergovernmental agreement protecting the free-flowing rivers of the Lake Eyre Basin and providing a framework for evidence-based regulations is one approach that could be adapted across other rangeland river systems (LEBCG 2000; Andrews 2017; LEBMF 2017).

Biodiversity in Australia's rangelands is vital for provision of ecosystem services and for increasing resilience of pastoral businesses. Biodiversity also has cultural significance and underpins the tourism industry. A loss in biodiversity can erode the resilience of ecosystems and the broader social ecological systems that depend on their services (Fischer *et al.* 2006; Oliver *et al.* 2015). Since European settlement, there has been a considerable loss of biodiversity from the rangelands as a result of changed management combined with climate change (Woinarski and Fisher 2003). In addition to formal public and private reserves, conservation of biodiversity on pastoral lands is necessary to ensure connectivity and provide protection of species not currently represented in these reserves. This also provides ecosystem services at a broad scale (Morton *et al.* 1995; Fischer *et al.* 2006). Recognition of the role of pastoralists in land stewardship, and collaboration between pastoralists, conservationists, traditional owners and other key stakeholders on the land is therefore key to increasing biodiversity and associated ecosystem services in the rangelands (Baumber *et al.* 2020).

Research priorities include looking at options to value natural capital, and providing payments or encouraging markets for ecosystem services, including carbon and biodiversity. There is also scope for research to evaluate the secondary benefits of increased biodiversity, such as the role of improved diet for livestock in controlling worms, clostridial diseases and other animal health issues, and to assess how native fauna can coexist with domestic livestock.

Actions that would help to address challenges related to Theme 2

1. Promoting the importance of natural capital for continued production and profitability in rangelands, including in heterogeneous landscapes that incorporate both conservation and anthropogenic objectives; and providing incentives or payments for conservation of biodiversity and ecosystem services on agricultural landscapes.
2. Developing market-based approaches for control of non-native and unwanted herbivores (camels and pigs), extending the markets already available for goats, and working towards a national or international market brand that emphasises low emissions, low inputs, and free-range production.
3. Implementing sustainable grazing practices, including: managing total grazing pressure and regenerating native ground-cover (perennial grasses); using landscape-rehabilitation

techniques and approaches such as water ponding, water spreading and contour banks; and learning from traditional knowledge around the use of fire, and potentially utilising these practices to manage the land.
4. Improving guidelines and machine learning to know when to destock or use supplementary feed. This entails real-time, technology-based monitoring of stock condition and natural capital, and projections of feed supply and demand.
5. Reducing permits to harvest water and prioritising environmental water needs where necessary, as well as limiting unregulated water use (including both overland capture and bore extraction); and carefully rethinking the location and spread of water-points within landscapes, and possibly increasing dams.
6. Increasing the resources for national parks to perform necessary management activities (pest management, fencing, maintaining facilities, monitoring, etc.); and implementing broad-scale control of weeds and pest animals and spreading awareness of their impacts on native flora and fauna.

Theme 3. Climate: variability and change

The survey and World Café sessions highlighted climate variability and change as a key threat, with potential actions to manage for climate variability and change including: preparing and managing for climate variability through better seasonal and long-range climate forecasts, more proactive grazing management strategies, and monitoring of resource condition; adapting to climate change through, for example, increasing income diversification and better managing extreme events; exploring mitigation options, especially the impacts and opportunities from abatement activities and trade-offs in terms of income and social and environmental benefits. Here, we put these potential actions and associated challenges and opportunities in the context of what is already known.

Climate variability is a defining feature of most rangelands (Sloat *et al.* 2018). Even in the absence of anthropogenic climate change, understanding and managing this variability provides challenges for rangeland managers. This is especially the case for livestock production, which needs to balance production for a profitable enterprise with long-term sustainability of the resource base. Management is particularly challenged by the temporal interaction of rainfall variability, forage production and livestock production, which creates forage pulses and multi-year system lags and dynamics in flocks and herds. Drought episodes and their impact on socioeconomics and landscapes have been well described, as have the options for learning from these events (Stafford Smith *et al.* 2007). However, managers of livestock enterprises repeatedly struggle to manage sustainably in the face of drought, and this is exacerbated by the lack of coherent national policy on drought (Botterill *et al.* 2017) as well as an appropriate context specificity given the wide range of conditions across the rangelands. This implies the need for flexibility in policy application and management over both space and time.

Various management guidelines and tools to support better management of climate variability have been developed over recent decades. For example, guidelines for better management of grazing and pasture utilisation in the face of a highly variable climate, underpinned by years of field and analytical research

(e.g. Buxton and Stafford Smith 1996; O'Reagain *et al.* 2014), are readily available on various drought and climate websites (e.g. Queensland Government's Long Paddock site, https://www.longpaddock.qld.gov.au/dcap/; NSW Government's DroughtHub, https://droughthub.nsw.gov.au/). There is also an array of tools such as seasonal forecasts and outlooks (e.g. Bureau of Meteorology, http://www.bom.gov.au/climate/ahead/) and remote sensing to inform grazing management (e.g. Ground Cover Report in Long Paddock, https://www.longpaddock.qld.gov.au/forage/report-information/ground-cover/). However, guidelines and specific products such as seasonal climate forecasts can be hard to integrate into management or business planning, or are misaligned with observed seasonal conditions or critical decision points, leading to low application rates (Stafford Smith *et al.* 2000; Marshall *et al.* 2011) and distrust of forecast tools (Paxton 2019).

Compounding the challenge in managing existing climate variability is the impact of climate change. Most projections show that climate change will have a negative net biophysical impact on Australian rangelands, particularly through increased incidence, intensity and/or duration of drought and heatwaves (McKeon *et al.* 2009; Crimp *et al.* 2010). This is a result of increased temperatures and reduced, or increasingly variable, rainfall, especially in southern Australia. The rainfall trends in northern Australia are less certain. Although broad-scale trends are apparent, management decisions require modelling to be undertaken at regional scales. Responding to climate change requires proactive adaptation, yet communities in rangelands generally have low adaptive capacity (Nelson *et al.* 2010). Marshall (2015) identified that only 16% of beef producers in northern Australian rangelands had sufficient adaptive capacity to manage the impacts of climate change. Barriers to adaptation include scepticism about the human influence on climate, with changes often perceived to be part of longer term natural cycles (Berry and Metternicht 2017).

Apart from building adaptive capacity in rangeland managers and communities, technologies and innovative management practices are needed to help buffer the biophysical impacts of climate change. Response to gradual changes in climate can be achieved through incremental practices and technologies. However, bigger changes in mean temperature or rainfall, or an increase in intensity or frequency of extreme events, will require transformational changes (Cobon *et al.* 2009; Ash *et al.* 2012). This may entail different enterprise options, including diversification of income. In Australia, greater intensity of extreme events (e.g. the recent drought across much of eastern Australia or the severe flooding in February 2019 in north-western Queensland) has provided insights into the challenges faced by rangeland communities.

One of the opportunities for diversifying income is through climate-change mitigation activities. Through mitigation policy initiatives such as the Emissions Reduction Fund and carbon-farming, rangeland enterprises can secure a different income stream through vegetation and soil management to increase carbon sinks. There can be trade-offs and synergies with mitigation activities (Cowie *et al.* 2019). For example, there is a perception that carbon farming activities may lead to greater absenteeism and an inability to undertake collaborative management activities such as prescribed fire or biosecurity control

(Cowie *et al.* 2019). In this way, an individual enterprise may benefit from carbon farming income but there may be social and environmental disadvantages at the regional level.

Other emission-reduction opportunities include aiming for carbon neutrality in rangeland livestock operations through technologies to reduce methane emissions from livestock, and vegetation management (Mayberry *et al.* 2019). Indeed, the main sources of greenhouse gas emissions from the Australian livestock sector are land clearing and enteric methane. In addition to mitigating greenhouse-gas emissions, carbon neutrality may help the sector to maintain a social licence to operate in an environment where agricultural production comes under greater scrutiny with more pressure to demonstrate sustainable land management.

Actions that would help to address challenges related to Theme 3

1. Building greater adaptive capacity in rangeland managers and communities to manage impacts of climate variability and change. The challenge of low adaptive capacity has been clearly identified and pathways to build adaptive capacity have been proposed, but there is little evidence of widespread adoption. Structured frameworks such as RAPTA (resilience, adaptation and transformation) can be used both to identify adaptation pathways and to build adaptive capacity (Cowie *et al.* 2019; O'Connell *et al.* 2019), but they are not on their own sufficient.

2. Providing technical information (e.g. climate data, seasonal forecasts, forage tools) that is better contextualised to individual property decisions. There are large quantities of climate data, technical information, simulation models, calculators and factsheets available to rangeland managers. However, much of this information is discounted because it is not positioned in a 'place-based' context, nor does it incorporate local knowledge (Leith and Vanclay 2017). Overcoming this challenge is not simply a matter of identifying user needs; a deeper understanding of behavioural barriers to uptake and trigger points for engagement is required (McCartney 2017; Paxton 2019).

3. Better accommodating extremes in projections and adaptation responses. Typically, analysis of climate change impacts has focused on mean changes in climate variables, using Intergovernmental Panel on Climate Change emission scenarios. However, the impacts of climate change, and hence the adaptation required, are increasingly being first experienced through extreme events. Incorporating changes in climate variability and extremes in climate projections and adaptation responses is a priority.

4. Carbon neutrality is a goal of the red meat sector in Australia and increasingly an ambition of state and local governments. How this can be achieved in rangeland enterprises requires more context-specific options that surpass the current generic recommendations, mechanisms that allow market development and federal and state ambitions to be realised.

Theme 4. Traditional knowledge

Responses from the survey conducted before the conference showed broad agreement around the need to establish guidelines

and approaches to promote recognition of the value, and contributions, of traditional knowledge and practices. The survey identified five areas of interest within this theme: (*i*) valuing traditional peoples, their knowledge and management practices; (*ii*) empowering, recognising and enabling Indigenous land management; (*iii*) promoting greater collaboration and co-management with other stakeholders; (*iv*) promoting economic opportunities; and (*v*) increasing participation of Indigenous people in land management.

A World Café session explored this specific theme with ~30 people from a wide range of backgrounds. The discussion was broad, and ultimately focused on the first point because the group thought that by valuing traditional knowledge and practices and working meaningfully with Aboriginal people, the other four points will be progressed. Ridges *et al.* (2020) complement this view, and argue that it is time to move beyond simply incorporating Aboriginal ecological knowledge into western science perspectives, to genuinely incorporate Aboriginal values into land-management practices given that core concepts of Kinship, Country, Lore and Dreaming strongly align with resilient social-ecological systems. Examples exist where Aboriginal values have changed land-management practices in Australia (e.g. Ens *et al.* 2015), showing that biocultural values have provided significant contributions to conservation priorities, especially around fire management, threatened fauna, and water rights and planning. These values lead to more holistic socio-ecological systems approaches. The challenge then is how to enable communities to foster and grow the characteristics of resilient social-ecological systems outlined by Biggs *et al.* (2015). As put by one participant, 'How do we get rangeland practitioners and researchers doing, living and reporting on integrating culture?'

Participants also debated on the importance of listening, given that the need for truth-telling persists. Not all of the reasons for misunderstanding between Aboriginal people and scientists are because of concepts and values – it also concerns history, and understanding of that history, and the legacy of the trauma associated with that history. It was further emphasised that respectful, shared experiences can enable place identity, and boost social, mental and spiritual wellbeing. In turn, this fosters valuing and engaging in the culture itself, keeping in mind that culture is not just a set of protocols to abide by. The benefit of engaging in the culture is that it enables the deep exchange of concepts and values that leads to shared understanding. There is no standard guide or method for achieving this. By investing in relationships, true co-design of projects based on shared understanding can take place.

The group considered five questions:

1. The rangelands are a shared space that is appreciated by stakeholders in different ways. Traditional knowledge is just one of many forms of knowledge we value. How do we achieve knowledge-integration?
2. How do we value traditional knowledge and the living culture embedded within? How do we increase the appeal of culture itself?
3. How do we move beyond treating traditional knowledge as 'data' and move to meaningful cultural knowledge exchange based on the principles of 'two-eyed seeing' (Bartlett *et al.* 2012)?

4. How do we appreciate and practice the sharing of knowledge and perspective?
5. What could a vision of valued traditional knowledge look like for the Australian rangelands?

From these questions, the group came up with a simple guiding principle that could resolve the challenges: to work on a joint vision and find the common ground (e.g. look after Mother Earth), work alongside each other and embrace the two-eyed seeing approach (Bartlett *et al.* 2012). The next generation is critical to sustained land management based on two-eyed seeing. If we want to teach people about Aboriginal culture, it is best to do it early and with the knowledge holders on country via the approaches outlined in the options for action that follow.

Actions that would help to address challenges related to Theme 4

1. Acknowledge that traditional knowledge is not just data, it is a lived knowledge and it is about the culture and the experience. There is a need to overcome the compartmentalised western version of knowledge and enable an experiential knowledge founded in deep cultural connections and values. As one participant said, 'To value traditional knowledge, you've got to value and love the culture that goes with it.'
2. Create the time and space to connect by meeting on Aboriginal people's traditional lands or participating in ceremony. It takes time for respectful, meaningful shared connections to develop (Miller 2014). Create shared experiences and enable story-telling, then watch and reflect on what is happening.
3. Be prepared to listen to the silence and the landscape also, as this helps with connection to place. One participant noted how listening is just as important as speaking and that not all interaction has to be talk. Listening to people but also to the landscape (Goggin *et al.* 2017).
4. Building emotional connections that foster positive relationships among all participants will enhance the value of those partnerships. When this is achieved, genuine two-eyed seeing is enabled; that is, a problem will be understood from both a scientific and a cultural perspective (Bartlett *et al.* 2012).
5. Support Aboriginal people to play a greater role in leadership in a western science sense, so that they can help bridge gaps in understanding. As one person explained, 'Often there are two people talking, but there is a piece of glass between them. They see the lips move but do not hear the words.' Having knowledge-bridge builders is essential.
6. Research that aligns with general government program delivery in Aboriginal communities, and that translates into real-world outcomes that bring benefits to them. Including Aboriginal culture in research and operational programs can produce secondary benefits and increase its impact. The research activities outlined in Box 1 would help to fill this gap.

Theme 5. Governance

Good governance is critical to well-functioning societies that use resources sustainably. It was clear from the survey responses that this is a key area for improvement to ensure the future of Australia's rangelands. The key challenges identified in the survey included developing policies and legislations that work

Box 1.

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1. Co-designing research outcomes. Create an Indigenous research methodology that enables Indigenous people to control, develop and review culturally and locally meaningful definitions of Indigenous land management methodology and outcomes.

2. Knowledge-gap filling. Improve the documentation and mapping of Indigenous knowledge and values so they can be integrated into rangelands management. Include priorities, management actions, and threats (local and landscape level) to these values.

3. Establishing management benefits. Document the benefits and impacts of Indigenous cultural practices and knowledge through rigorous cultural and ecological science, to demonstrate the contribution Indigenous culture can make to rangeland values.

4. Modelling potential economic benefits. Initiate case studies that track and report on the economic benefits of integrating culture into rangeland management. For example, (*a*) if people connect with culture in rangelands management, what is the economic impact it has on the health and criminal justice system?; (*b*) what are the economic benefits to communities who undertake cultural practices on private conservation areas to achieve biodiversity outcomes?; (*c*) how can Indigenous involvement in rangeland management become economically self-sustaining?

5. Building pathways to integration. Undertake trials that demonstrate how outcomes from Research Activities 1, 2 and 3 can be integrated with existing land-management programs.

6. Documenting cultural and social benefits. Partner Indigenous management practices with other Indigenous programs (such as heritage management, back-to-Country events, resource use and cultural practice) to document cultural and social wellbeing benefits for rangelands management.

7. Enabling a role for science in Indigenous land management. Outcomes identified in Research Activity 1 may require science to be realised. Document examples of this activity where Indigenous and scientific knowledge have worked together to achieve outcomes desired by Indigenous people.

8. Implementing MER (monitoring, evaluation and reporting) for Indigenous cultural land management. Use bio-cultural assessment and planning tools to establish minimum and best practice standards for conducting pre- and post-project assessments and for monitoring of Indigenous land management outcomes. Develop tools to assist Indigenous people to implement culturally meaningful assessment and monitoring methods. These activities would enhance the skills and knowledge of Indigenous and non-Indigenous stakeholders through community-led cross-cultural mentoring.

9. Tertiary training of researchers in Indigenous culture. Develop degree pathways to support Indigenous students entering STEM degree programs**.** Teach non-Indigenous students about Indigenous culture in STEM degree programs, emphasising the value of alternative knowledge systems and their impact on our society and environment.

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for the rangelands, empowering rangeland communities, supporting rangeland industries and the environment, while allowing multiple uses and incentivising good management practices.

However, creating consistent good governance and policy delivery in remote Australia (specifically referred to as the Outback for an Australian narrative; Traill and Stafford Smith 2020) has particular difficulties not faced by communities in the more densely settled farming districts, regional towns and cities (e.g. Stafford-Smith and Cribb 2009; Walker *et al.* 2012; Foran *et al.* 2019). At the state and national level, the sparse populations of the Outback suffer from an inevitable 'democracy deficit', with only 2% of the population in more than three-quarters of the continent. Federal and state governments inevitably focus on the issues faced by the great majority of the urbanised population. With essentially no electoral power, it is very difficult for people in the rangelands to push effectively for policies designed specifically for remote Australia.

There are two consistent consequences of this at national and state levels (Walker *et al.* 2012). One is that policies are generally developed with a mental model suited to delivery into more heavily populated areas with different social and physical infrastructure. The other is the tendency for sporadic, rather unpredictable interventions into specific Outback issues when these happen to reach the national consciousness. Both approaches have had mixed success, sometimes resulting in dramatic failures (e.g. closer agricultural settlement policies outside the Goyder line in South Australia, various Indigenous interventions), yet there is limited reflective analysis of the relationship between intended and actual outcomes of policies. Without this, past mistakes are likely to be repeated. Policy interventions need research to support monitoring, evaluation and learning to catch and rectify poor outcomes early.

The situation is also complex for local government. Remote local governments are closer to local electorates than state and federal levels of government and, as in more populated areas, are key to much service delivery. However, viewed with mental models from populated areas, it is hard to maintain effective services for tiny populations living in vast landscapes (Stafford Smith *et al.* 2008; Dollery *et al.* 2010). The Outback has evolved a wide diversity of local government models, including: local councils without any town (Murchison Shire in Western Australia); councils with vast areas and tiny populations (e.g. Barcoo Shire Council, with 6 Mha – the size of Tasmania – and ~270 residents); Aboriginal town councils partitioned from a surrounding mainstream local council with largely white electors (Cape York Peninsula); an unelected state government authority that delivers local government services (the Outback Communities Authority for all of the South Australian pastoral zone); and areas that have no local government or equivalent (Stafford Smith and Cribb 2009). Fragmented funding sources mean that small councils may need to report on nearly as many grants as a large one. This is especially true for local councils with large Indigenous populations that must deal with complex multi-cultural issues in delivering services with funds sourced from bureaucracies that have complex reporting arrangements. Various policy approaches can assist with these challenges to effective governance of services. Devolved grants allow more locally appropriate determination of what is needed and, if amalgamated across sectoral silos, reduce the overheads of grant applications and acquittals (Houghton 2018). A focus on economies of scope – the efficiencies from one organisation delivering multiple services that benefit from common capacities, such as personal connections across a suite of remote communities,

or the ability to piggy-back multiple services on a single long-distance trip – can be key for small communities (Outback Alliance 2018). These contrast with economies of scale in larger populations, where specialist organisations increase their efficiency by increasing the scale of providing particular services, an approach that often fails in remote areas where doubling the service population may involve travelling an additional 1500 km (Stafford Smith and Cribb 2009).

However, the more general underlying governance issue is addressing how demand for services is expressed in remote regions, and how it is supplied (Walker *et al.* 2012). In Indigenous communities (Moran 2008) or Outback settlements more generally (Stafford Smith *et al.* 2008), governance processes that can be more responsive to context are required. One suggestion has been to establish a national Outback Commission that has the mandate and authority to focus on remote Australia and its regions (Walker *et al.* 2012). This is a worthy goal but one for which political support would likely be hard to win. Marshall and Stafford Smith (2010) suggest that a pathway in this direction could be to mandate regional alliances among regional development, natural resource management and local government bodies to start to play this role regionally. Such alliances have already occurred spontaneously in some rangeland regions (e.g. Eyre Peninsula). These could work together in a national alliance modelled on the Rangelands NRM Alliance, supporting policy development and service delivery in the Outback.

Governance cannot be divorced from flows of financial resources. Despite federal and state government investment into the Outback, it is evident that there are much larger flows of capital out of the region, whether from mining, low local multipliers, or through exported resources (Rola-Rubzen and McGregor 2009). Understanding these flows and how they could be influenced to increase benefit to the rangelands would be useful research goals to underpin past recommendations for an Outback Capital Fund and better reported recurrent expenditure in rangelands from the Commonwealth Grants Commission (Dillon and Westbury 2007; Stafford Smith and Cribb 2009).

Rapid advances in information and communications technology (e.g. NBN, Zoom, WhatsApp) have special application in the governance of rangelands, demonstrating that remoteness need not be a barrier to holding (virtual) council meetings, for example. Research is still needed on how these tools can be best deployed to build people's capacity, to market rangeland assets and products, and to improve governance effectiveness and efficiency (at all levels of government). Indeed, it was noted during the conference that there are other possible 'out of the box' developments (see Walker 2020) that may be prospective, such as non-monetary exchange systems that facilitate social capital in uncertain times, novel arrangements for stock management, and extending and enabling mobility and resilience.

Achieving better governance, and resultant improvements in policy delivery, depends on creating and maintaining public interest and support, and the resulting political focus. That foundation of support critically requires a strong and positive public narrative about the region to engender and maintain public and political support (Traill and Stafford-Smith 2020).

Actions that would help to address challenges related to Theme 5

1. The consistent delivery of a strong and positive public narrative about the nature, communities and wealth of the Outback.
2. Targeted workshops with decision makers, key stakeholders and community representatives to focus on developing policies and legislation that truly work for the Outback.
3. Increased market access, decision-support guidelines and services, and increased public awareness, within and beyond the rangelands, to reduce the disconnect between policy makers and local communities.
4. More research into the impacts of current and past government policies in the rangelands to determine the relationship between intended and actual outcomes of policies.
5. Elaboration of practical and ideal options for Outback governance to underpin some form of Outback commission: a regional or national governance model specific to the Outback.
6. Actions identified to help the translation of research into practice, supporting the need for a transformational change to diversify production systems.

Theme 6. Research and development

The previous sections have discussed specific areas of research prioritisation. In this section, we address issues that (*a*) transcend the individual topics already covered, or (*b*) relate more to how to conduct R&D for the benefit of the rangelands than to its specific content.

Like other rangelands of the world, Australian rangelands face the ongoing impacts of global change, and there is a struggle to articulate a narrative that overcomes the challenges of distant governance; yet they possess remarkable natural, human and cultural resources, and knowledge that is useful to a changing world (Stafford Smith 2016). Australian rangelands face variable biophysical conditions and remoteness from population centres, but possess a rich cultural history and the potential to draw on the resources of an affluent country, with which come particular concerns about maintaining the social licence to operate. The challenges and opportunities of these complex socio-ecological systems, which function differently from socio-ecological systems in more densely settled areas, are not new but have not been resolved through incremental action to date. Consequently, R&D content and process need to support transformative change towards resilient rangelands by creating value from their comparative advantages and through awareness of the governance realities within which they operate (Foran *et al.* 2019). It is crucial that external rangeland professionals and the resident rangeland population engage in developing research programs that build trust, knowledge and capacity in the pursuit of transformation (Phelps and Kelly 2020).

Survey participants identified 13 issues related to R&D, which could be grouped into four broad sub-themes. These argue: (*i*) that R&D should be better targeted to support policy decision making, especially in addressing contentious challenges; (*ii*) that this requires more of a focus on understanding and monitoring for the tipping points in the rangelands social-ecological system functioning that result in change that is hard to

reverse; (*iii*) that managing the Outback to avoid these changes requires more R&D engagement with Outback users, evolving a more systematic alliance between research and stakeholders, especially Indigenous people as partners; and (*iv*) that all of this needs a vibrant research sector with the right skills and adequate funding for collaborative research, monitoring and learning.

However, the wider survey input, and the theme of ARS2019, emphasised that these priorities should be framed by the need for transformational change towards resilience. Transformational change requires many innovations to be explored, then the successful ones to be scaled. Barriers to scaling can be difficulties in developing or spreading knowledge about the successes, but can also be institutional arrangements, or cultural norms and mental models that inhibit uptake of the innovation. These may be addressed by 'scaling out' (spreading innovations among peers, with adaptation to context as necessary), 'scaling up' (addressing institutional arrangements, rules and regulations), or 'scaling deep' (changing cultures, investing in systemic learning) (Moore *et al.* 2015). Given the challenges of distant governance, addressing cross-scale institutional obstacles (scaling up) is often particularly important for rangelands, although scaling deep to develop a genuine engagement with Indigenous and other local cultural knowledge is also an important opportunity.

How do these scaling modes affect R&D?

1. *Innovations for resilience.* Many resilience-oriented areas of research have already been identified in the previous sections, aimed at innovations in land management across many sectors, such as: coping with climate-related stresses; embedding Aboriginal values into land-management practice, building community resilience; diversifying livelihoods and enterprises; understanding thresholds towards degradation and recovery; sustaining social licence to operate in old and new markets; and appropriate policy experimentation. In general, R&D needs to take a systemic approach to developing these specific innovations, with monitoring and evaluation that identifies the contexts in which particular innovations will or will not work. It also needs to engage land managers, communities or policy decision makers in this research, to ensure its salience, credibility and legitimacy.

2. *Scaling out.* In order to ensure that successful innovations are used by more people, speeding up learning by others with similar problems and contexts is essential. Specific examples have been provided in earlier sections where principles and practices could be applied across many landscapes, using accelerated peer-to-peer learning. These include managing total grazing pressure, applying remote sensing in management, and supporting regeneration. Performing the initial research with stakeholders helps to ensure relevance, but there is a growing modus operandi of 'innovation hubs' (Westley *et al.* 2015), where local ideas are tested collaboratively by stakeholders and researchers, and the research is designed and its lessons captured in a structured way that encourages innovation and rapid learning, instead of ad hoc extension and frequent re-inventing of wheels. This requires strong, stakeholder-mediated links among diverse Outback research systems.

3. *Scaling up.* Considering that many innovations require changes in institutional or regulatory arrangements to scale, focusing research on informing Outback policy in collaboration with policy stakeholders will help uptake. Previous sections have identified many relevant areas such as: ensuring that incentives associated with carbon farming, drought management, renewable energy deployments and telecommuting are aligned with also creating community resilience; providing data that help to value social and natural capital, and document the cultural, social, economic and management benefits of working with traditional ecological knowledge; and evaluating the advantages of effective technology deployments in the Outback. R&D should create partnerships with policy decision makers and the Outback community that enable effective policy experiments to be scaled without conflict.

4. *Scaling deep.* Perceptions and mental models of the Outback need to change in many ways to underpin other transformations. Aspects noted in previous sections include: the overall narrative surrounding the Outback (discussed further by Traill and Stafford Smith 2020); valuing and working deeply with Aboriginal people as part of a shared living culture to establish and maintain Outback resilience; reconnecting consumers outside the Outback to stories associated with the products they consume (whether from livestock, tourism, energy, water or mining); and creating a sustainable-production, Outback brand (supporting and supported by all production sectors). R&D must provide more insights into behavioural barriers to change, the factors contributing to social licence to operate, and effective communication about the Outback.

In addition to resourcing the R&D itself, these four elements require the support of training and capacity building of Outback inhabitants and policy makers in working with research, and underpinning data collection and information systems that are well targeted to the needs above.

Synthesis

The six themes that emerged from the surveys and conference World Café session lead to a suite of R&D needs, which can be organised in terms of their contribution to providing the innovation and the scaling that might enable transformation in the rangelands (Fig. 1). However, respondents highlighted other changes needed to facilitate transformation. Identification of these other changes is important, because R&D can be designed to improve the likelihood of them happening, and conversely, they may create an environment in which R&D is more effective.

1. Establish an Outback commission arrangement with diverse stakeholders. There have been intermittent calls for some form of representative Outback entity for many years, to act as an aggregator of Outback needs inasmuch as they differ substantially from more settled regions, and to provide a knowledgeable view on how to implement context-sensitive Outback policy. In the present context, this could help in the co-design of relevant research that will support transformation towards a resilient Outback, and help to negotiate contentious issues such as the net pros and cons of different mining activities, and other areas affecting social licence to operate. This would require community engagement in the
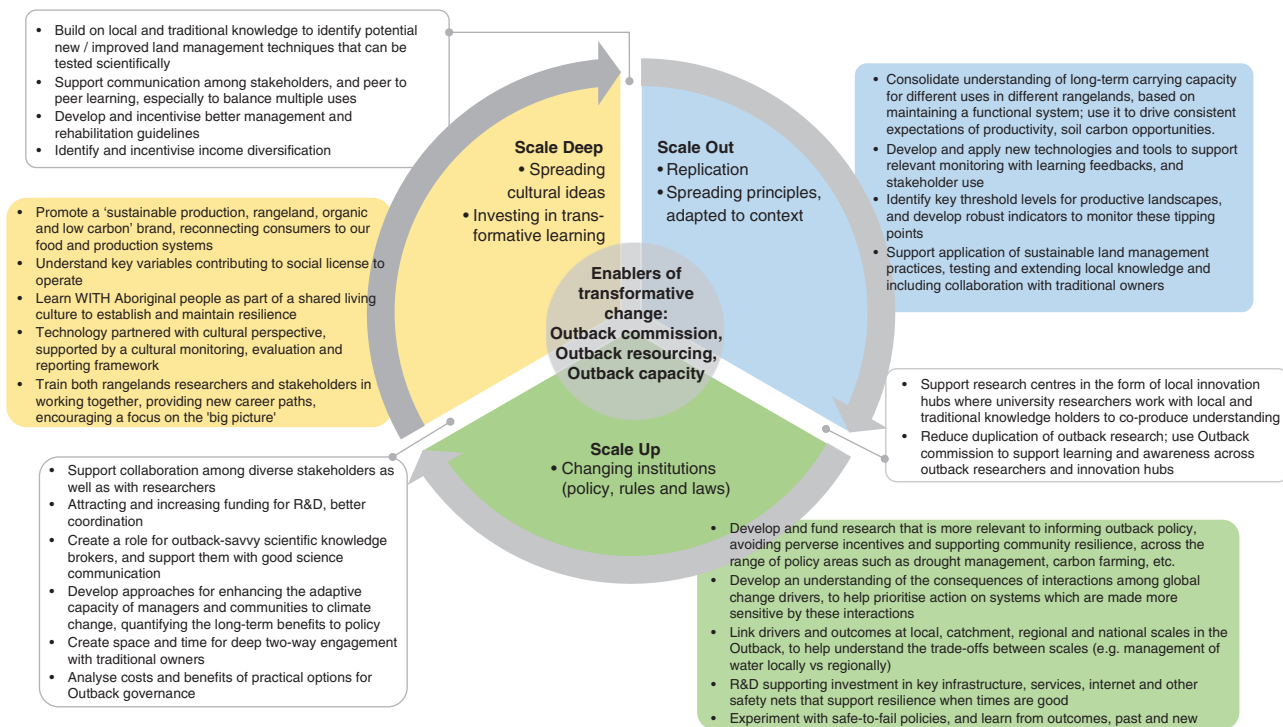
Fig. 1. Scaling of innovations to enable transformational change towards resilient rangelands. The suite of R&D needs identified in the survey and during the World Café event of the ARS2019 conference grouped in terms of their contribution to providing the innovation and the scaling that might enable transformation in the rangelands. Complementary information is available in Supplementary Materials Table S2.

Outback commission activities and could help to navigate the issues involved in scaling up transformative innovations. R&D could support the potential for establishing an Outback commission by analysing its potential role, and costs and benefits.

2. Provide a stronger funding base for Outback activities. As noted under Theme 5, there have also been calls for better funding arrangements for the Outback, in both recurrent and capital funding sources. At present, the majority of capital derived from production in the Outback (most especially from mining) is rapidly lost to the region, with small to non-existent local economic multipliers. As a result, much Outback operating funding comes from Commonwealth Grants Commissions distributions, which neither fully benefit Outback regions, nor are robust to changing national policy. Establishing better reporting on these recurrent funds and establishing an Outback Capital Trust Fund based on royalties would provide more certainty for many of the transformative activities discussed herein, including R&D, and could be guided by an Outback commission. A capital trust fund should invest in all forms of Outback capital – physical, human, social, environmental and cultural. R&D could support the potential for this change through analysing models and potential net benefits to the nation of establishing such instruments.

3. Build greater capacity in the Outback. As highlighted throughout this paper and in other papers in this special issue (e.g. Taylor *et al.* 2020), greater capacity is needed in many forms in the Outback, including: human capacity and training

to address the transformative policy and management issues raised herein; technological capacity to apply new technologies for creating new livelihoods; information systems capacity to acquire and deliver the data needed for better decision-making; communications capacity to develop and disseminate a new narrative about the Outback; and, above all, the cultural capacity to connect all people with an Aboriginal approach to belonging on the Australian landscape. Clearly, an Outback commission arrangement and funding would help to build these capacities. Again, R&D has a role to play in quantifying the capacity building needed to capture its benefits.

Together, an Outback commission, Outback resourcing and Outback capacity building would drive research to enable Outback communities to become more resilient, maintaining diverse, profitable livelihoods while implementing practices to improve natural and cultural capital and increase resilience to drought, climate change and changing societal expectations.

Conflicts of interest

The authors declare no conflicts of interest.

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