CSIRO PUBLISHING

The Rangeland Journal
https://doi.org/10.1071/RJ20058

Achieving drought resilience in the grazing lands of northern Australia: preparing, responding and recovering

M. K. Bowen[A,C] *and F. Chudleigh*[B]

[A]Department of Agriculture and Fisheries, Rockhampton, PO Box 6014, Red Hill, Qld 4701, Australia.
[B]Department of Agriculture and Fisheries, PO Box 102, Toowoomba, Qld 4350, Australia.
[C]Corresponding author. Email: maree.bowen@daf.qld.gov.au

Abstract. Northern Australia is characterised by high rainfall variability and extended droughts that challenge sustainable and profitable management of grazing properties. To achieve drought resilience, emphasis must be placed on supporting livestock managers to prepare for drought as well as implementing appropriate drought response and recovery actions. Here we describe insights and learnings gained from working with scientists, industry development and extension officers, and property managers, to enable more profitable and drought resilient extensive livestock production systems across northern Australia. We provide examples from the modelling and analysis of hypothetical grazing properties representative of enterprises across northern Australia. To prepare for drought, we principally propose the application of the farm-management economics framework to identify investment strategies which can improve enterprise resilience through building wealth over the longer term. The critical first step in drought preparedness for beef businesses was the implementation of management strategies to achieve the optimal herd structure, steer sale age, and breeder body condition. Other key strategies to improve profitability across northern Australia were (1) addressing a phosphorus deficiency for cattle through effective supplementation and (2) establishing adapted perennial legume-grass pastures to improve steer nutrition. In addition, we identify the benefits of working closely with livestock managers and industry to gain adoption of proven technologies that effectively improve decision-making capacity and the drought preparedness of extensive livestock production systems. The usefulness of the farm-management economics approach to assess the relative value of alternative tactical destocking and restocking decisions during drought response and recovery is also discussed. These latter analyses can highlight important differences between options in terms of future profit and cash flow, as well as the ability to rapidly return the property to the most profitable herd structure and age of turnoff, with consideration of production and financial risk. Additionally, integrating pasture growth models with herd or flock economic models can provide insights into the effects, on profitability and sustainability, of alternative destocking and later restocking strategies over the longer term. Combined, the farm-management economics framework approach can support more informed decision-making by livestock producers and hence enable more profitable and drought resilient extensive livestock production systems. However, achieving drought resilience in the grazing lands of northern Australia will require emphasis on drought preparation, in addition to appropriate action in response and recovery phases of drought. Key to this approach is increasing the adoption of strategies that enhance drought preparedness.

Keywords: beef cattle, decision making, drought management, extensive grazing systems, farm-management economics, goats, modelling, profitability, rangelands, rangeland management, sheep, technology adoption, tropical pastures.

Received 17 June 2020, accepted 27 December 2020, published online 27 February 2021

Introduction

Northern Australia is characterised by high rainfall variability and extended drought periods which challenge the sustainable and profitable management of grazing properties (O'Reagain and Scanlan 2013; Cobon *et al.* 2019; Bowen and Chudleigh 2021). The most effective way to mitigate the personal and society-wide costs of drought has been suggested as provision of support to farmers to improve drought-management decision making (Freebairn 2019). The federal and Queensland governments recognise a need for policy, research and extension to improve decision-making, drought preparedness, and hence drought resilience, of livestock enterprises in Australia (Australian Government 2020; Queensland Government 2020).

Extensive livestock enterprises in northern Australia are challenged by variable commodity prices and by pressures on long-term financial performance and viability due to an ongoing disconnect between asset values and returns, high debt levels and a declining trend in terms of trade (ABARES 2019). Therefore, to remain economically viable and to build resilience, not only to droughts but also to natural disasters and market shocks, grazing enterprises need to increase profit and build wealth (Bowen and Chudleigh 2021). However, to enable property managers to make informed decisions, a framework is required to allow appropriate assessment of the impact of alternative management strategies on profit, risk, and the period of time before benefits can be expected. Farm-management economics methods that determine the extra costs and benefits associated with change over time, at the level of the individual property, are the most appropriate approach to assess the consequences of alternative management strategies (Malcolm 2000; Malcolm *et al.* 2005).

Our objective was to demonstrate the value of the farm-management economics framework to guide informed decisions leading to more profitable and drought resilient extensive livestock production systems across northern Australia. In doing this we have drawn examples from analyses primarily conducted as part of a project funded by the Queensland Government's, Drought and Climate Adaptation Program (DCAP) and published in a series of final reports (Bowen and Chudleigh 2018, in press *a*, in press *b*; Bowen *et al.* 2019*a*, 2019*b*, 2020*a*; Chudleigh *et al.* 2019*b*) available at: https://futurebeef.com.au/projects/improving-profitability-and-resilience-of-beef-and-sheep-businesses-in-queensland-preparing-for-responding-to-and-recovering-from-drought/. Some aspects of this work have also been reported in Chudleigh *et al.* (2019*a*), Bowen *et al.* (2020*b*, 2021) and Bowen and Chudleigh (2021).

Methods – the approach to economic and financial evaluation

We applied the farm-management economics framework at the property level to assess a range of drought management strategies across six regions in northern Australia, using hypothetical, representative grazing properties. In each region, strategies were assessed for their potential to prepare for drought. Analysis of strategies to respond to, and recover from, drought were conducted for the three of the regions, as examples of how to assess these more tactical decisions which will be heavily influenced by the opportunities and prices at the time.

Preparing for drought by improving business profitability and resilience

We advocate the farm-management economics framework as the most appropriate approach to assess alternative management strategies applicable to livestock enterprises in northern Australia (Malcolm 2000; Malcolm *et al.* 2005). This framework incorporates (1) the additional capital and labour required, (2) the effect of the strategy on herd structure and herd value over time, (3) the implementation phase, (4) the timing of costs and benefits, (5) the economic life of the investment, and (6) the assessment of the financial impacts and risks associated with each change in management. In this approach, property-level, herd and flock models, incorporated in the farm-management economics framework, are used to compare productivity and profitability over the same investment period. The investment period selected reflects the economic life of the longer-term investments which is usually 30 years in our work with livestock industries in northern Australia. The benefits of implementing an alternative management strategy are assessed by altering, over time, the herd or flock performance and inputs of the base scenario to construct new scenarios. The economic, financial and risk effects of each of the alternative management strategies are then assessed by comparison with the base production system without the management intervention (i.e. a marginal analysis). Partial discounted cash flow (DCF) techniques are applied to calculate the marginal returns associated with additional capital invested within farm operations.

In our analyses we applied the Breedcow and Dynama (BCD) herd budgeting software (Holmes *et al.* 2017) to conduct the whole-farm economic analysis. These models contain livestock schedules linked to partial DCF budgets that compared the base scenarios with alternative scenarios over 30 years. We developed similar models to those in the BCD software for cattle herds to assess alternative livestock enterprises including rangeland meat goats, meat sheep, self-replacing wool sheep flocks and wool producing flocks based on wether trading. Using these tools, beef, sheep and goat enterprises were modelled individually or as components of a mixed rangelands enterprise.

We conducted analyses for livestock enterprises across northern Australia by modelling representative, example properties for five Queensland regions (Central, Central West, Northern Downs, Northern Gulf, and Mulga Lands) and one in the Northern Territory (Katherine region), (Fig. 1). The representative, modelled property and herd or flock characteristics for each region were informed by recent industry surveys and regional research, as well as the expert opinion of experienced industry professionals, as described in more detail in Bowen and Chudleigh (2021) and in the project reports for each region. Herd and flock models were developed on the basis of long-term, average expectations of female reproductive performance and livestock growth paths in each environment. The price basis for livestock was taken from relevant selling centres using 6.5–11 years of historical price data to derive expected values for the long-term livestock prices. For each representative base property the BCD, herd and economic modelling software (Holmes *et al.* 2017) was used to determine the optimal (most profitable) age of female culling (sale) and the optimal steer or wether sale age. A wide range of relevant management strategies were assessed for each region (Table 1). The strategies selected for analysis in each region were nominated by experienced industry participants as being of most interest and relevance to that region. In some cases, strategies were implemented simultaneously where this was relevant to practical management. Additionally, the characteristics of the base property for each region were varied, where required, to allow investigation of strategies that were of consequence, but not appropriately or sensible included as a characteristic of the primary representative property (e.g. prickly acacia infestation and control in the Northern Downs).

The economic criteria calculated were the net present value (NPV) at the required rate of return (5%; as the real opportunity cost of funds to the producer) and the internal rate of return (IRR). These criteria were calculated to examine the return on the extra capital invested in an alternative management strategy. The NPV was calculated over the 30-year life of the investment, expressed in present day terms at the level of operating profit. The operating profit was calculated as:

$$\begin{aligned}\text{operating profit} &= (\text{total receipts} - \text{variable costs}\\ &= \text{total gross margin}) - \text{overheads}.\end{aligned}$$

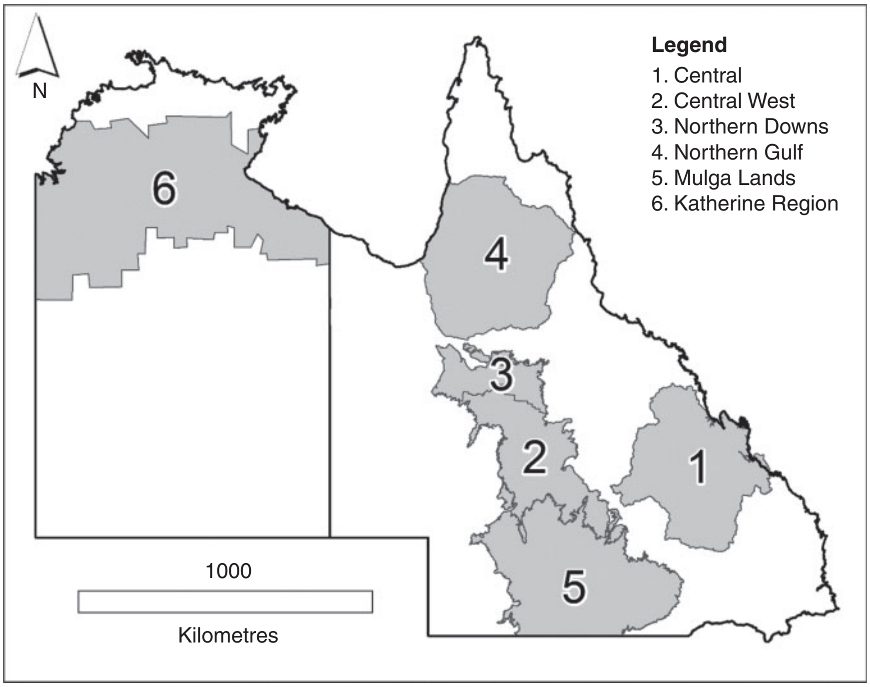

Fig. 1. Location of the key regions, in Queensland and the Northern Territory of Australia, from which the studies in this paper are drawn.

Opening and salvage values for land, plant and livestock were applied at the beginning and end of the discounted cash flow analysis to capture any changes in the opening and residual value of assets. Plant replacement was incurred as a capital cost less a salvage value in the year it was expected to be incurred during the investment period. An amortised NPV was calculated at the discount rate over the investment period to assist in communicating the difference in returns between the base property and the property after the management strategy was implemented. The IRR was calculated as the discount rate at which the present value of extra income equalled the present value of extra expenditure (capital and annual costs), i.e. the break-even discount rate. The financial criteria calculated were peak deficit, the number of years to the peak deficit, and the payback period in years. Peak deficit in cash flow was calculated assuming interest was paid on the deficit and compounded for each additional year in the investment period. The payback period was calculated as the number of years taken for the cumulative present value to become positive. All case studies included the calculation of cumulative and net cash flow measures at the property level.

Responding to, and recovering from, drought

Spreadsheets within the BCD suite of programs (Holmes *et al.* 2017) can be used to assess the relative value of tactical destocking and restocking decisions for alternative classes of livestock. For three Queensland regions (Central, Central West, and Northern Gulf), various destocking and restocking options were assessed with reference to the herd model for the base herd. Alternatives were assessed by comparing the change in costs and benefits associated with implementing an alternative strategy. When the sale of stock to reduce grazing pressure or to relieve financial pressure was assessed, the object was to achieve the grazing or financial objective with least damage to future income. If the issue was grazing pressure, those groups with the lowest gross margin per adult equivalent after interest were sold first. If the issue was financial, those groups with the lowest percent return on livestock and expenses capital were sold first. The profitability criterion for choosing between short-term restocking opportunities was nearly always the gross margin per adult equivalent after interest. If finance was tight to the degree that the available forage could not be completely stocked, then the gross margin expressed as a percent of herd and expenses capital was the more satisfactory criterion.

In addition, for the Central West Queensland region, we integrated the GRASP pasture growth model (McKeon *et al.* 2000; Rickert *et al.* 2000) with BCD to allow the long-term effect of alternative destocking and later restocking options to be examined over an historical climate sequence for a beef enterprise. This bio-economic modelling approach allowed consideration of both sustainability and profitability outcomes of alternative grazing management strategies.

Results and discussion

Identifying strategies to prepare for drought

In a series of comprehensive analyses for six regions in northern Australia we have demonstrated the critical importance of making sound decisions to improve enterprise resilience, through building wealth over the longer term (Bowen and Chudleigh 2018, in press *a*, in press *b*; Bowen *et al.* 2019*a*, 2019*b*, 2020*a*; Chudleigh *et al.* 2019*b*;). As detailed in Bowen and Chudleigh (2021), in each region, the analysis identified strategies that substantially improved profit compared with the net profit per

Table 1. Strategies assessed for their ability to improve profitability and drought resilience of representative, example beef enterprises in one or more of six regions across northern Australia

Strategy	Regions					
	Queensland					Northern Territory
	Central	Central West	Northern Downs	Northern Gulf	Mulga Lands	Katherine Region
(1) Overall herd or property performance						
Herd reduction to implement safe carrying capacity	–	–	–	Yes	Yes	–
Weaning and basic vaccinations	–	–	–	–	Yes	–
Optimising cow and heifer culling age	–	–	Yes	–	–	Yes
Phosphorus supplementation to address a deficiency	Yes	–	–	Yes	Yes	Yes
Other inorganic supplements (nitrogen, sulfur)	Yes	–	–	–	Yes	–
Herd segregation	–	–	–	–	–	Yes
Reducing mortality	–	–	–	–	–	Yes
Home-bred bulls	–	–	Yes	Yes	–	Yes
Converting from breeding to steer turnover	–	–	Yes	–	Yes	–
Managing prickly acacia (*Acacia nilotica* subsp. *indica*)	–	–	Yes	–	–	–
Buffel (*Cenchrus ciliaris*) paddock development	–	–	–	–	Yes	–
Alternative livestock enterprises	–	Yes	–	–	Yes	–
Grazing management strategies	–	Yes	–	–	Yes	–
(2) Breeder reproductive performance						
Controlled mating	–	–	–	–	Yes	–
First mating heifers as yearlings	–	–	Yes	–	–	–
Genetic improvement of weaning rate	Yes	–	Yes	Yes	–	Yes
Supplementing first-calf heifers	Yes	–	Yes	Yes	–	Yes
Feeding whole cottonseed to the breeder herd	–	–	–	–	Yes	–
Reducing fetal/calf loss	Yes	–	Yes	Yes	–	Yes
Vaccination against Pestivirus	Yes	–	–	–	–	–
(3) Steer growth rates						
Establishing leucaena (*Leucaena leucocephala* subsp. *glabrata*) -grass pastures	Yes	–	–	Yes	–	–
Establishing desmanthus (*Desmanthus virgatus*)-grass pastures	Yes	–	–	–	–	–
Establishing stylo (*Stylosanthes* spp.)-grass pastures	–	–	–	Yes	–	Yes
Phosphorus fertiliser on existing stylo pastures	–	–	–	Yes	–	–
Forage oats for all steers	Yes	–	–	–	–	–
Molasses production mix for steer tail	–	–	Yes	Yes	–	–
Concentrate feeding the steer tail	–	–	–	–	–	Yes
Silage for all steers	–	–	–	Yes	–	–
Hormonal growth promotant	Yes	–	Yes	–	–	–
Custom feedlotting	Yes	–	–	–	–	–
Sending steers on agistment	–	–	–	Yes	–	Yes
(4) Market alternatives						
Increasing age of steer turnoff to the optimal	–	–	Yes	Yes	Yes	–
Organic beef	Yes	–	–	–	–	–
European Union beef market	Yes	–	–	–	–	–
Wagyu beef	Yes	–	–	–	–	–
(5) Enterprise expansion						
Purchasing a steer growing and finishing property	–	–	Yes	–	–	–
Purchasing a breeder property	–	–	Yes	–	–	–

annum of the base property. Additionally, many strategies reduced profit while some had a negligible effect on profit ($< \pm$AU\$5000/annum), even though they were originally identified by industry professionals or property managers as likely to have a positive impact. For example, property-level economic analysis indicated that more appropriate management strategies could improve profit of the representative beef cattle enterprise in the Fitzroy region of Central Queensland by up to 50% or about \$50000/annum (e.g. establishing perennial, legume-grass pastures such as *Leucaena leucocephala* subsp. *glabrata* (leucaena)-grass systems), (Bowen and Chudleigh 2018). Other commonly applied strategies in that region decreased annual profit by up to 50% or about \$50000/annum (e.g. annual forage crops or custom feedlotting).

An important finding from these combined analyses across regions was that most strategies that increased profit also increased management complexity and risk, e.g. implementing legume-grass pasture systems to improve steer growth rates, or moving from a breeding to a steer turnover/trading operation. The importance of applying a decision-making framework that appropriately highlights the financial aspects and risks associated with the implementation of a management strategy, as well as the potential economic benefits, has been previously advocated by others including Foran *et al.* (1990), Stockwell *et al.* (1991), Lewis *et al.* (2012) and Malcolm *et al.* (2012). Our findings, both here and in other studies (e.g. Bowen and Chudleigh 2019), are in accord with these authors who also identified that capital constraints and perceived risk were likely to be important factors influencing the adoption of alternative management strategies and technologies by livestock producers across Australia.

Diversifying sources of income can have the effect of both smoothing income over time and improving average profitability which, consequently, can reduce risks from climate variability and assist with drought preparedness and resilience (Buxton and Stafford Smith 1996; Freebairn 2019). The benefits to the livestock producer of diversifying the enterprise mix on-farm were highlighted in our analysis for the Central West rangelands region of Queensland (Bowen and Chudleigh in press *a*). In this region, the operating profit generated by existing meat sheep, rangeland meat goat, or self-replacing merino wool enterprises was similar, and slightly better than that of the representative beef enterprise. Given that, over time, wool and meat prices may not move in parallel, combining meat and wool-producing enterprises may improve the stability of farm profit. However, if additional capital is required to diversify, this may affect the profitability of the change and should be considered on an individual-property basis.

Additionally, some livestock producers rely on non-farm income for business survival during drought periods. This aspect was not examined in our studies, but has been identified as particularly important in inherently low-productivity, extensive regions that have an early history of subdividing large properties, e.g. the Northern Gulf and Mulga Lands of Queensland (e.g. Johnston *et al.* 1990). The same issues are not apparent in regions of the Northern Territory with similar extensive, low-productivity land types that have not been subject to the same level of subdivision. There may be a case for the amalgamation of properties in low-productivity regions as a way of improving drought preparedness, but the ongoing disconnect between land value and production potential in these regions will limit the capacity of local landholders to achieve such an outcome. Others, such as Hamblin (2009), argue that more effective agricultural policies are required to instead retire low-productivity areas from agricultural land use where environmental and social decline are endemic.

The critical first step in drought preparedness for beef businesses was the implementation of management strategies to achieve optimal breeder body condition, herd structure, and steer sale age. For instance, our analyses for the representative property in the Northern Gulf of Queensland (Bowen *et al.* 2019*a*) showed that managing breeder nutrition, through grazing management and appropriate use of inorganic nitrogen and phosphorus (P) supplements so that body condition is $\geq$3 (on a 5-point scale) going into a drought, would substantially reduce the mortality rate of mature and aged cows ($\sim$15% of the herd $>$9 years old) that are likely to lose $>$10% liveweight. Further, implementing these strategies allowed the cow cull age to be reduced from 11–12 to 8–9 years. This herd restructuring added \$7000/annum profit to the already sizeable benefits generated by appropriately managing the P nutrition of breeders and reducing mortality risk due to drought.

Modelling exercises using the BCD software have consistently indicated that sale of older steers was more profitable than sale of weaners in northern Australia, with the optimal age varying with region, breeder productivity, steer performance, available markets, and the relative price of weaners and older steers. For example, in the Northern Downs region of Queensland, increasing the sale age of steers from weaners to 31 months provided \$70 000/annum benefit which was relatively substantial compared with other management strategies considered (Bowen *et al.* 2020*a*). An additional benefit, in terms of drought resilience, of moving to an older age of steer sale is the reduction in size of the breeder herd component of the total herd at the same grazing pressure. Decreasing the proportion of breeders in the herd decreases drought risk due to the relatively greater nutritional demands of breeders related to reproduction, and the added complexity and expense of management interventions for heavily pregnant cows or cows with small calves during times of drought.

Other key insights from our analyses for beef enterprises across northern Australia were that consistently profitable strategies included (1) addressing a P deficiency for cattle through effective supplementation, and (2) establishing adapted perennial legume-grass pastures (e.g. leucaena-, desmanthus- or stylo-grass pastures) to improve steer nutrition. Strategies that consistently reduced profitability of beef enterprises included production feeding (e.g. molasses, silage or grain) and use of annual forage crops (e.g. oats) to improve herd or steer nutrition. Strategies to improve the reproductive performance of beef breeders (e.g. genetic improvement of weaning rate and supplementing first-calf heifers) resulted in outcomes which ranged from small positive to large negative effects on enterprise profitability, even where optimistic responses to the technology were applied.

The scenario analysis conducted as part of our DCAP project clearly demonstrated that researching and analysing one management strategy or technology in isolation does not identify the relative benefits compared to (1) other strategies or (2) the current system of management, and does not identify any potential complementary or additive benefits from implementing strategies simultaneously. We are in agreement with Mayberry *et al.* (2021) who advocate for a broader understanding of animal production systems, with a multidisciplinary, systems approach incorporating economics at the farm scale. Additionally, new management strategies and technologies will continue to present themselves. Hence, we recommend that analysis of a range of appropriate strategies and technologies be undertaken to support decision-making and that such analysis should be revisited whenever new opportunities arise. An additional key recommendation from our work is that the farm-management economics framework (as outlined here) be used to undertake individualised analyses for livestock enterprises, wherever possible, with consideration of the goals, skills and resources of the management team. This recommendation has previously been made by others, e.g. Foran *et al.* (1990) and Buxton and Stafford Smith (1996). We recognise that profit does not necessarily drive all goals of livestock producers who are motivated by a complex and diverse range of factors (McCartney 2017; Paxton 2019). However, to remain economically viable, and to build business resilience, producers must regularly produce a profit and build wealth over the longer term.

Tactical decisions – responding to, and recovering from, drought

Analysis of drought-related herd reduction and subsequent rebuilding options was conducted for the Central, Central West and Northern Gulf regions of Queensland (Bowen and Chudleigh 2018; Bowen *et al.* 2019*a*, 2019*b*). It was evident that drought response and recovery options need to be assessed using the relevant input figures for a specific property, and a specific herd or flock structure, at the time of the decision. Providing generic examples for each region could be misleading as the widely varying parameter values for price, forage quality, current status of the various classes of livestock, and the estimate of seasonal outlook could lead to both relative and absolute differences in the recommended class of stock either to be sold or purchased at any time.

Therefore, key findings from tactical herd reduction analyses were that (1) the assessment of the sale of alternative classes of cattle should consider the impact on both future profit and future cash flow, and (2) all classes of cattle should be assessed. The herd rebuilding analyses demonstrated substantial, but not always consistent, differences among various drought recovery strategies on their ability to rapidly return the property to the most profitable herd structure and age of turnoff within the considerations of production and financial risk. Importantly, a dependence entirely on natural increase (retained progeny) to rebuild the herd following drought was shown to seriously reduce the ongoing viability of the property. In our studies, utilising spare grazing capacity by accepting cattle on agistment improved cash balances in the short-term during herd rebuilding. However, agistment income was expected to be less profitable than cattle trading over the longer term, but with less risk. These findings are broadly in accord with results of Buxton and Stafford Smith (1996), who also used the farm-management economics framework to assess tactical stock management decisions for livestock enterprise across Australia's rangelands.

Bio-economic modelling, where the GRASP pasture growth model was linked with BCD, for a representative beef cattle property in the Central West region of Queensland over a 30-year historical period (1988–2017) provided insights into both sustainability and profitability consequences of alternative destocking decisions when applied consistently as a strategy (Bowen *et al.* 2019*b*, 2021). This analysis showed that retaining a core herd of breeders, during four droughts within the 30-year historical period, was less profitable and less sustainable than a greater level of destocking and restocking responsiveness to pasture availability. This finding is in accord with results for analysis of beef production systems in South Texas where destocking, compared with maintenance feeding during droughts, resulted in substantial benefits on short-term and long-term profitability (Young *et al.* 2018). In our analysis for the Central West region of Queensland, with its highly variable and unpredictable climate, managing stocking rates with a moderate degree of flexibility in response to pasture availability was the most profitable strategy and also maintained pasture condition which was represented by the modelled percentage of perennial grasses. However, it was essential to economic viability that the property was restocked as soon as safely possible following drought, in line with pasture availability, once good seasonal conditions returned. In this 30-year analysis, where the cattle herd was rebuilt following drought through natural increase alone, negative property level returns resulted. The analysis also indicated that the class of livestock purchased to initially restock the property should be determined as a tactical assessment of choices available at the time, rather than a rigid adherence to immediately returning to the long-term, optimal herd structure.

Although integration of the GRASP pasture growth model with BCD provided useful insights into the effects of alternative grazing management strategies in a region for which the GRASP model was well calibrated, it was not the preferred approach when assessing the plethora of other strategies available to managers of grazing livestock enterprises to improve their profitability and drought resilience. For this purpose, it was considered most appropriate to use the BCD spreadsheets in isolation, which rely on identification of 'best-bet' range of parameters on the basis of local knowledge of experienced property managers, extension officers and scientists. Our experience is that keeping the model as simple as possible, and focusing on the key parameters, facilitates input from, and engagement with, industry and producers. An additional issue is that the GRASP pasture growth model (or alternatives) are not well calibrated and validated for many regions of northern Australia, particularly regions where sown grass or legume-grass pastures have been established (e.g. Central and Northern Gulf regions of Queensland) or where browse from shrubs forms a substantial part of the livestock diet (e.g. Mulga Lands).

Gaining adoption

In our studies, the farm-management economics framework, applied principally through a representative farm modelling approach, proved to be efficient across all regions in identifying strategies likely to improve profit and build resilience to drought. This finding is in accord with others who have applied farm-management economics to analyse options for livestock enterprises in Australia, e.g. Foran *et al.* (1990), Buxton and Stafford Smith (1996), Armstrong *et al.* (2005), Lewis *et al.* (2012), Malcolm *et al.* (2012), and Sinnett *et al.* (2019). Even so, the application of the framework as a regionally representative model appears unlikely to improve the rate of uptake of relevant strategies by individual property managers unless it is accompanied by appropriate development and extension activities. This same assertion has been previously made by others including Stafford Smith and Foran (1988) and Jackson and Malcolm (2018).

In our work, several previously favoured management strategies were discarded by industry professionals after participating in the development of the regional analyses reported here. This indicates that the framework and the collaborative process of conducting the analyses with input from extension officers and scientists as key participants, was successful in achieving understanding, trust and acceptance of the framework, and of results which sometimes challenged existing paradigms. This is a first step towards achieving industry adoption of (1) an appropriate framework to support decision making, and (2) more profitable management strategies and technologies. However, there remain challenges in achieving the ultimate objective of adoption by property managers. Our experience, and that of others (e.g. Stafford Smith and Foran 1988; Jackson and Malcolm 2018) is that the farm-management economics framework cannot do that, when applied in isolation.

Our analyses for livestock enterprises across northern Australia identified that consistently profitable strategies included (1) addressing a P deficiency for cattle through effective supplementation, and (2) establishing adapted perennial legume-grass pastures to improve steer nutrition. Both of these technologies have been well researched and for several decades, identified as very sound investments. Despite this, Niethe (2011) estimated that only ~10% of cattle located in acutely phosphorus deficient regions of northern Australian are appropriately supplemented with P. Additionally, the adoption rate of leucaena, as an example of a perennial legume suited to areas of Northern Australia, has been slow with Buck *et al.* (2019) estimating that plantings have occurred on only ~1.5% of the potential suitable area in Queensland and ~0.5% of the potential area in northern Australia. Either of these two management strategies has the capacity to dramatically alter the drought preparedness of a large number of individual beef properties, and that of the northern beef industry as a whole, if they were more widely adopted.

The slow adoption of profitable strategies across the northern Australian beef industry is not new. Farquharson *et al.* (2003) identified that the most profitable innovation ever likely to be encountered by the northern Australian beef industry, the infusion of *Bos indicus* genetics, took more than 50 years, and possibly more than 60 years, to reach peak adoption in the 1990s and only did so after the minds of beef property managers were focussed on survival by the beef price crash of the 1970s.

There has been a long history of discussions on how to achieve adoption of innovation by farm managers across a range of journals and literature. The contribution of Jackson and Malcolm (2018) is considered most relevant to the present discussion as it applies the farm-management economics framework and identifies the relationships between returns, risks, and learning, to understand innovation adoption. These authors identify several critical factors in the adoption of an innovation including (1) the value of accounting for risk, and (2) the process of learning. They found that a key factor in the learning process was farmers' expectations about the probability of success of the technology. Critical to successful adoption was the engagement of the farmer in a dynamic process of learning, before undertaking the investment. In the study of Jackson and Malcolm (2018), an initial phase of ~3 years of evaluation by farm managers was conducted to allow them to learn about the probability of success of a technology. This phase applied low-cost awareness-raising techniques such as field days and provision of marketing material. The second stage commenced when farmers attitude towards the likelihood of success of the technology was sufficiently positive and typically involved a 1-year, on-farm trial. If the on-farm trial was successful, producer investment in the technology was likely to proceed. If the trial was unsuccessful, the innovation was typically discarded.

We have observed similar learning processes while undertaking detailed case studies with beef property managers across northern Australia as part of the current DCAP project and previous studies (e.g. Bowen *et al.* 2015; Chudleigh *et al.* 2017). In the current project, three case studies developed with profitable beef properties in regions with acutely-deficient soil P status revealed that (1) feeding the correct amount of P supplement during the northern monsoon is a very challenging task, (2) there is a lack of immediate feedback mechanisms to indicate success or otherwise of the technology, and (3) adoption appears to rely on the sustained accumulation of detailed knowledge over several years before the strategy being implemented. Similar to Jackson and Malcolm (2018), our experience is that a local or on-farm trial outcome is perceived to be highly informative of the true probability of success of a technology. Additionally, a negative or inconclusive trial result will lead to the rejection of the innovation with little likelihood that it will be re-visited. In regard to P adoption, an inconclusive result from on-farm trials is made more likely by the number of property-specific, facilitating processes required for a successful P supplement program run under extensive rangeland conditions. Discussions with the P case study participants in our DCAP project revealed that such a supplementation program both required, and enabled, other complex herd management strategies to be implemented. Further, implementation of these complementary herd management strategies was required to gain full benefit. Hence, we recommend that revisiting P supplementation strategies with non-adopting property managers should involve (1) a close integration of locally relevant data, (2) the skills of industry development officers with detailed technical knowledge of the production and herd management system, and (3) demonstration of economic benefits and investment pathways with use of the farm-management economics framework applied to the locally relevant data. Although likely to generate significant private benefits for the property manager, the public good generated by having such enterprises more prepared for drought and other shocks to the system are likely to be significant and unlikely to be gained by any other process.

Another example of the value of incorporating the farm-management economics framework in the adoption process is provided by the findings of five case studies undertaken as part of a previous project conducted with beef producers in Central Queensland (Bowen *et al.* 2015). The case studies were undertaken with property owners engaged as commercial co-operators to determine the value of high-output forages grown on their properties. The case studies were designed to facilitate further understanding of how the forages contributed to farm returns and were not intended to identify alternatives to their preferred management strategy at the time. Building and discussing models and budgets for their individual property, and integrating that with the findings of the project for other local property and forage combinations, allowed them considerable insight that they had not previously gained. It was later reported by project technical staff (based on unsolicited comment provided by the case study co-operators) that all producer co-operators had made changes to operations (some significant) as a result of the interaction. Even where it was not designed to do so, the integration of the farm-management economics framework in an extension and development process that included intensive and localised data collection, facilitated the adoption of innovation. More broadly, during the course of the 'high-output forages' project, 2144 industry participants received direct information about the project at 121 events which included 29 field days or producer workshops (Bowen and Hopkins 2016). The intended level of practice change as a result of project messages and recommendations was 66% across all surveyed events, and 87% for attendees at full day workshops. Aspects considered key to the effectiveness of the extension program included (1) involvement of beef producer co-operators in the project, (2) the multidisciplinary project team which included technical, extension and economist expertise, (3) demonstration of the financial implications of recommended practice change, and (4) providing a pathway to adoption, including development and demonstration of extension tools, and provision of ongoing support.

Recommended approach to drought management

We recommend the implementation of longer-term and sustained programs for livestock producers, to support and guide decision-making and adoption of relevant innovations in relation to drought preparedness. This assertion has previously been made by others who have reviewed Australian drought policy and management, e.g. White (2000), Botterill (2003), and Howden *et al.* (2014). Most recently, Freebairn (2019) advocated long-term provision of information and education programs for farmers to improve decision making, as a worthwhile policy option for managing drought and other uncertainties. Importantly, we would add, that such packages should focus on assisting decision-making and adoption by individual farm managers in all three 'phases' of drought: preparation, response and recovery. The farm-management economics framework outlined here should be used to lift the capacity of livestock producers to better question, analyse and compare management options, rather than to provide an absolute answer from using the tools. This approach to support producer learning has also been advocated by many others including Stafford Smith and Foran (1988) and Armstrong *et al.* (2005). Further, to achieve a high level of industry adoption of (1) appropriate decision-making frameworks, and (2) drought management strategies, we recommend the application of multidisciplinary, regional project teams with a strong focus on applied research and on the financial implications for producers.

In conclusion, we have demonstrated the importance of improving profitability and wealth generation as an essential step in building drought resilience. Using the farm-management economics framework in drought response and recovery phases will also enhance drought resilience by minimising damage to the business and aiding return to profitable enterprise and herd structures, and long-term cash-flow. The freely available BCD software can be used by advisors to assess alternative strategies for individual beef enterprises and to guide investment decisions. The activities of skilled, local industry development officers to support the learning and decision making of livestock producers is key to adoption of appropriate technologies and drought management strategies.

Conflicts of interest

The authors declare no conflicts of interest.

Acknowledgements

This study was co-funded by the Department of Agriculture and Fisheries, Queensland, and the Queensland Government's, Drought and Climate Adaptation Program. The authors have benefited from numerous discussions and input provided by many producers, scientists and staff of companies providing technical services to the northern livestock industries, and especially beef cattle research and extension specialists within Queensland and Northern Territory Government departments. We thank Terry Beutel for preparing the map showing the location of study regions.

References

ABARES (Australian Bureau of Agricultural and Resource Economics and Sciences) (2019). 'Agricultural Commodities: March quarter 2019.' (Australian Bureau of Agricultural and Resource Economics and Sciences: Canberra, ACT.) Available at: https://www.agriculture.gov.au/sites/default/files/sitecollectiondocuments/abares/agriculture-commodities/AgCommodities201903_v1.0.0.pdf (accessed 5 June 2020).

Armstrong, D., Ho, C., Doyle, P., Malcolm, B., Gibb, I., and Brown, S. (2005). Analysing drought impacts and recovery options by adapting a dairy farming systems modelling approach. *AFBM Journal* **2**, 11–16.

Australian Government (2020). 'Drought Policy.' (Australian Government, Department of Agriculture, Water and the Environment: Canberra, ACT.) Available at: https://www.agriculture.gov.au/ag-farm-food/drought/drought-policy (accessed 5 June 2020).

Botterill, L. C. (2003). Uncertain climate: the recent history of drought policy in Australia. *The Australian Journal of Politics and History* **49**, 61–74. doi:10.1111/1467-8497.00281

Bowen, M. K., and Chudleigh, F. (2018). 'Fitzroy Beef Production Systems. Preparing for, Responding to, and Recovering from Drought.' (The State of Queensland, Department of Agriculture and Fisheries, Queensland: Brisbane.) Available at: https://futurebeef.com.au/projects/improving-profitability-and-resilience-of-beef-and-sheep-businesses-in-queensland-preparing-for-responding-to-and-recovering-from-drought/ (accessed 5 June 2020).

Bowen, M. K., and Chudleigh, F. (2019). Productivity and profitability of alternative steer growth paths resulting from accessing high-quality forage systems in the subtropics of northern Australia: a modelling approach. *Animal Production Science* **59**, 1739–1751. doi:10.1071/AN18311

Bowen, M. K., and Chudleigh, F. (2021). An economic framework to evaluate alternative management strategies for beef enterprises in northern Australia. *Animal Production Science* **61**, 271–281. doi:10.1071/AN20125

Bowen, M. K., and Chudleigh, F. (In press *a*). 'Rangelands of Central-western Queensland. Building Resilient and Diverse Livestock Production Systems.' (The State of Queensland, Department of Agriculture and Fisheries, Queensland: Brisbane, Qld.)

Bowen, M. K., and Chudleigh, F. (In press *b*). 'Mulga Lands Beef Production Systems. Preparing for, Responding to, and Recovering from Drought.' (The State of Queensland, Department of Agriculture and Fisheries, Queensland: Brisbane, Qld.)

Bowen, M. K., and Hopkins, K. (2016). Report on extension activities for the project High-output Forage Systems for Meeting Beef Markets – Phase 2. Project B.NBP.0636 Final Report. (Meat & Livestock Australia: Sydney, NSW.)

Bowen, M. K., Chudleigh, F., Buck, S., Hopkins, K., and Brider, J. (2015). 'High-output forage systems for meeting beef markets – Phase 2. Project B.NBP.0636 Final Report.' (Meat & Livestock Australia: Sydney, NSW.)

Bowen, M. K., Chudleigh, F., Rolfe, J. W., and English, B. (2019*a*). 'Northern Gulf Beef Production Systems. Preparing for, Responding to, and Recovering from Drought.' (The State of Queensland, Department of Agriculture and Fisheries, Queensland: Brisbane, Qld.) Available at: https://futurebeef.com.au/projects/improving-profitability-and-resilience-of-beef-and-sheep-businesses-in-queensland-preparing-for-responding-to-and-recovering-from-drought/ (accessed 5 June 2020).

Bowen, M. K., Chudleigh, F., Whish, G., and Phelps, D. (2019*b*). 'Central West Mitchell Grassland Livestock Production Systems. Preparing for, Responding to, and Recovering from Drought.' (The State of Queensland, Department of Agriculture and Fisheries, Queensland: Brisbane, Qld.) Available at: https://futurebeef.com.au/projects/improving-profitability-and-resilience-of-beef-and-sheep-businesses-in-queensland-preparing-for-responding-to-and-recovering-from-drought/ (accessed 5 June 2020).

Bowen, M. K., Chudleigh, F., and Perry, L. (2020*a*). 'Northern Downs Beef Production Systems. Preparing for, Responding to, and Recovering from Drought.' (The State of Queensland, Department of Agriculture and Fisheries, Queensland: Brisbane.) Available at: https://futurebeef.com.au/projects/improving-profitability-and-resilience-of-beef-and-sheep-businesses-in-queensland-preparing-for-responding-to-and-recovering-from-drought/ (accessed 5 June 2020).

Bowen, M. K., Chudleigh, F., Dixon, R. M., Sullivan, M. T., Schatz, T., and Oxley, T. (2020*b*). The economics of phosphorus supplementation of beef cattle grazing northern Australian rangelands. *Animal Production Science* **60**, 683–693. doi:10.1071/AN19088

Bowen, M. K., Chudleigh, F., and Phelps, D. (2021). Bio-economic evaluation of grazing management options for beef cattle enterprises during drought episodes in semi-arid grasslands of northern Australia. *Animal Production Science* **61**, 72–83. doi:10.1071/AN19691

Buck, S., Rolfe, J., Lemin, C., and English, B. (2019). Adoption, profitability and future of leucaena feeding systems in Australia. *Tropical Grasslands-Forrajes Tropicales* **7**, 303–314. doi:10.17138/tgft(7)303-314

Buxton, R., and Stafford Smith, M. (1996). Managing drought in Australia's rangelands: four weddings and a funeral. *The Rangeland Journal* **18**, 292–308. doi:10.1071/RJ9960292

Chudleigh, F., Cowley, T., Moravek, T., McGrath, T., and Sullivan, M. (2017). Assessing the value of changing beef breeder herd management strategy in northern Australia. *In*: 'Proceedings of the 61st Australasian Agricultural and Resource Economics Society (AARES) Annual Conference', Brisbane, Queensland, Australia. Available at: https://ageconsearch.umn.edu/record/258661?ln=en (accessed 5 June 2020).

Chudleigh, F., Bowen, M., and Holmes, B. (2019*a*). Farm economic thinking and the genetic improvement of fertility in northern beef herds. *In*: 'Proceedings of the 63rd Australasian Agricultural and Resource Economics Society (AARES) Annual Conference'. Melbourne, Victoria, Australia. Available at: https://ageconsearch.umn.edu/record/285095?ln=en (accessed 5 June 2020).

Chudleigh, F., Oxley, T., and Bowen, M. (2019*b*). 'Improving the performance of beef enterprises in northern Australia.' (The State of Queensland, Department of Agriculture and Fisheries: Brisbane, Qld.) Available at: http://era.daf.qld.gov.au/id/eprint/6153/1/Improving-the-performance-of-beef-production-systems-in-northern-Australia.pdf (accessed 16 February 2021).

Cobon, D. H., Kouadio, L., Mushtaq, S., Jarvis, C., Carter, J., Stone, G., and Davis, P. (2019). Evaluating the shifts in rainfall and pasture-growth variabilities across the pastoral zone of Australia during 1910–2010. *Crop & Pasture Science* **70**, 634–647. doi:10.1071/CP18482

Farquharson, B., Griffith, G., Barwick, S., Banks, R., and Holmes, B. (2003). Estimating the returns from past investment into beef cattle genetic technologies in Australia. Economic Research Report No. 15. (NSW Agriculture: Armidale, NSW.)

Foran, B. D., Stafford Smith, D. M., Niethe, G., Stockwell, T., and Michell, V. (1990). A comparison of development options on a northern Australian beef property. *Agricultural Systems* **34**, 77–102. doi:10.1016/0308-521X(90)90095-8

Freebairn, J. (2019). Drought assistance policy options. *AFBM Journal* **16**, 17–23.

Hamblin, A. (2009). Policy directions for agricultural land use in Australia and other post-industrial economies. *Land Use Policy* **26**, 1195–1204. doi:10.1016/j.landusepol.2009.01.002

Holmes, W. E., Chudleigh, F., and Simpson, G. (2017). Breedcow and Dynama Herd Budgeting Software Package. A Manual of Budgeting Procedures for Extensive Beef Herds. Ver. 6.02. (State of Queensland, Department of Agriculture and Fisheries: Brisbane, Qld.) Available at: https://breedcowdynama.com.au/ (accessed 16 February 2021).

Howden, M., Schroeter, S., Crimp, S., and Hanigan, I. (2014). The changing roles of science in managing Australian droughts: an agricultural perspective. *Weather and Climate Extremes* **3**, 80–89. doi:10.1016/j.wace.2014.04.006

Jackson, T., and Malcolm, B. (2018). Using returns, risks and learning to understand innovation adoption. *Australasian Agribusiness Review* **26**, 32–47.

Johnston, B. G., MacLeod, N. D., and Young, M. D. (1990). An economic perspective on future research directions for the Australia sheep-grazed rangelands. *Australian Rangeland Journal* **12**, 91–115. doi:10.1071/RJ9900091

Lewis, C., Malcolm, B., Farquharson, R., Leury, B., Behrendt, R., and Clark, S. (2012). Economic analysis of improved perennial pasture systems. *AFBM Journal* **9**, 37–55.

Malcolm, B. (2000). Farm management economic analysis: a few disciplines, a few perspectives, a few figurings, a few futures. *In*: 'Proceedings of the Annual Conference of Australian Agricultural and Resource Economics Society'. (Australian Agricultural and Resource Economics Society: Sydney, NSW.) Available at: https://ageconsearch.umn.edu/bitstream/171920/2/malcolm.pdf (accessed 5 June 2020).

Malcolm, B., Makeham, J., and Wright, V. (2005). 'The Farming Game, Agricultural Management and Marketing.' (Cambridge University Press: Cambridge, UK.)

Malcolm, B., Ho, C. K. M., Armstrong, D. P., Doyle, P. T., Tarrant, K. A., Heard, J. W., Leddin, C. M., and Wales, W. J. (2012). Dairy directions: a decade of whole farm systems analysis of dairy systems. *Australasian Agribusiness Review* **20**, 39–58.

Mayberry, D., Hatcher, S., and Cowley, F. (2021). New skills, networks and challenges: the changing face of animal production science in Australia. *Animal Production Science* **61**, 201–207. doi:10.1071/AN20115

McCartney, F. (2017). 'Factors Limiting Decision Making for Improved Drought Preparedness and Management in Queensland Grazing Enterprises: Rural Specialists' Perspectives and Suggestions.' (The State of Queensland, Department of Science, Information Technology and Innovation: Brisbane, Qld.) Available at: https://www.longpaddock.qld.gov.au/dcap/grazing-industry/ (accessed 5 June 2020).

McKeon, G. M., Ash, A. J., Hall, W. B., and Stafford-Smith, M. (2000). Simulation of grazing strategies for beef production in north-east Queensland. *In*: 'Applications of Seasonal Climate Forecasting in Agricultural and Natural Systems – The Australian Experience'. (Eds G. Hammer, N. Nichols, and C. Mitchell.) pp. 227–52. (Kluwer Academic Press: Dordrecht, Netherlands.)

Niethe, G. E. (2011). New R & D for better herd health and productivity. In 'Proceedings of the Northern Beef Research Update Conference'. 3–4 August 2011, Darwin, NT, Australia. pp. 34–40.

O'Reagain, P. J., and Scanlan, J. C. (2013). Sustainable management for rangelands in a variable climate: evidence and insights from northern Australia. *Animal* **7**, 68–78. doi:10.1017/S175173111100262X

Paxton, G. (2019). 'Towards Greater Drought Preparedness in Queensland Grazing: Lessons From Qualitative Interviews and Discourse Analysis.' (The State of Queensland, Department of Environment and Science: Brisbane, Qld.) Available at: https://www.longpaddock.qld.gov.au/dcap/grazing-industry/ (accessed 5 June 2020).

Queensland Government (2020). 'The Drought and Climate Adaptation Program'. (Queensland Government: Brisbane, Qld.) Available at: https://www.longpaddock.qld.gov.au/dcap/ (accessed 5 June 2020).

Rickert, K. G., Stuth, J. W., and McKeon, G. M. (2000). Modelling pasture and animal production. *In*: 'Field and Laboratory Methods for Grassland

and Animal Production Research'. (Eds L 't Mannetje, and R. M. Jones.) pp. 29–66. (CABI Publishing: New York, USA.)

Sinnett, A., Malcolm, B., Lewis, C., and Ho, C. (2019). The whole farm case study as the unit of analysis for research in farm management economics. *In*: 'Proceedings of the 63rd Annual Conference of the Australian Agricultural and Resource Economics Society (AARES)'. 12–16 February 2019, Melbourne, Australia. (Australian Agricultural and Resource Economics Society: Melbourne.) Available at: https://ideas.repec.org/p/ags/aare19/285098.html (accessed 5 June 2020).

Stafford Smith, D. M., and Foran, B. D. (1988). Strategic decisions in pastoral management. *Australian Rangeland Journal* **10**, 82–95. doi:10.1071/RJ9880082

Stockwell, T. G. H., Smith, P. C., Stafford Smith, D. M., and Hirst, D. J. (1991). Sustaining productive pastures in the tropics. 9. Managing cattle. *Tropical Grasslands* **25**, 137–144.

White, D. H. (2000). Drought policy, monitoring and management in arid lands. *Annals of Arid Zone* **39**, 105–129.

Young, A. M., Clayton, M. K., Paschal, J. C., and Klose, S. L. (2018). Economic impact of beef cattle best management practices in south Texas: stocking strategies during drought. *Journal of Applied Farm Economics* **2**, 1–7.