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Opportunities to build resilience of beef cattle properties in the mulga lands of south-western Queensland, Australia

M. K. Bowen[A,*], F. Chudleigh[B], N. M. Sallur[C] and J. Sommerfield[C]

For full list of author affiliations and declarations see end of paper

*Correspondence to:
M. K. Bowen
Department of Agriculture and Fisheries, Rockhampton, Qld 4701, Australia
Email: maree.bowen@daf.qld.gov.au

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ABSTRACT

Beef producers in the mulga lands of south-western Queensland and north-western New South Wales, Australia, face the challenges of inherently low productivity and profitability, exacerbated by widespread pasture degradation and high climate and market variability. Our objective was to use the farm-management economics framework to assess the ability of management strategies and investment options to improve profitability and build the overall resilience of beef cattle properties in the mulga lands. Options were assessed for a hypothetical, representative beef cattle property in south-western Queensland (20 000 ha; initial stocking rate 600 adult equivalents). Firstly, strategies were assessed for their ability to improve profitability when operated as a beef business. Secondly, two alternative investment options were assessed: (1) conversion to rangeland meat goat production; and (2) conversion to carbon farming through carbon sequestration. Herd and economic modelling software were used to conduct property-level, partial discounted cash-flow budgets to assess each strategy over a 30-year investment period. Results indicated very limited potential to improve the profitability and resilience of an existing beef cattle enterprise in the mulga lands. However, full or partial conversion to rangeland meat goat production or carbon farming improved property-level returns and viability.

Keywords: carbon farming, decision making, drought management, extensive grazing systems, farm-management economics, goats, modelling, profitability, rangeland management, rangelands, technology adoption.

Introduction

The Mulga Lands bioregion in Australia covers 25.2 million ha (74% within south-western Queensland, 26% in north-western New South Wales; Thackway and Cresswell 1995), with extensive grazing by cattle and sheep being the primary land use (Commonwealth of Australia 2008; ABS 2021). Livestock producers face major challenges associated with the region's inherently low productivity and profitability (Pressland 1984; Johnston *et al.* 1990; Venn *et al.* 2003). These challenges are exacerbated by widespread, well documented pasture degradation (Mills *et al.* 1989; McKeon *et al.* 2004; Commonwealth of Australia 2008), with this bioregion being recognised as the most extensively degraded landscape in Queensland (Wilson 1999). Additionally, similar to rangelands elsewhere in Australia, the Mulga Lands bioregion experiences substantial climate variability, including extended and extensive droughts (LongPaddock 2021), variable commodity prices and a long-term declining trend in terms of trade (ABARES 2019). To remain in business through these challenges and to build resilience, livestock producers must regularly produce a profit to build capital and equity.

Traditionally, the Merino wool sheep was the dominant production system in the Mulga Lands bioregion (Johnston *et al.* 1990). However, decline in the economic competitiveness of the wool industry caused a decline in sheep numbers over the past six decades, and beef cattle largely replaced wool sheep (ABS 2021; Chudleigh 2021). Livestock producers have also diversified into (1) rangeland goats through either harvesting (capture of wild/feral animals) or managed production (Heywood *et al.* 2000); and (2) carbon farming through carbon sequestration (Baumber *et al.* 2020). Few farm-level studies have been conducted during the past three decades to assess options available to mulga lands beef cattle producers to improve profitability and overall property resilience.

The value of the farm-management economics framework in assessing alternative management strategies for their impact on profit and risk, and thus to support decision-making and improve resilience of extensive livestock producers, has been demonstrated elsewhere in northern Australia (Bowen and Chudleigh 2021*a*, 2021*b*). This approach was also applied two to three decades ago to assess management options for extensive livestock production systems across Australia (e.g. Foran *et al.* 1990; Stockwell *et al.* 1991; Buxton and Smith 1996). The objective of the present study was to use the farm-management economics framework to conduct a contemporary assessment of management strategies and investment options to improve profitability and resilience of a hypothetical beef cattle property representative of the mulga lands of south-western Queensland. This region was considered as an example of low-productivity grazing lands in a semiarid environment.

Materials and methods

Representative property and initial base, beef cattle enterprise

A hypothetical property was constructed to be representative of the Mulga Lands bioregion and of grazing properties within 100 km of the town of Charleville in south-western Queensland. The attributes of this property and herd characteristics were derived from industry surveys and relevant research (Holmes 1980; Passmore 1990; Clarke 1991; O'Rourke *et al.* 1992; Bortolussi *et al.* 1999, 2005; McGowan *et al.* 2014), as well as the expert opinion of scientists, extension officers and nine local producers obtained in discussions during 2019–2020. The property comprised 20 000 ha of mulga (*Acacia aneura*), a native leguminous fodder tree, and associated native pastures on land types comprising soft mulga (50%), hard mulga (25%), and black soil (25%, gidgee (*Acacia cambagei*)/brigalow (*Acacia harphylla*)/yapunyah (*Eucalyptus ochrophloia*); The State of Queensland 2019). The black soil was scattered through the mulga land types. The property was considered deficient in pasture phosphorus (P) for cattle (4–5 mg/kg bicarbonate-extracted P (Colwell 1963) in the top 100 mm of soil; Bowen *et al.* (2020*b*)).

The initial base beef cattle enterprise had a low level of management input. The starting stocking level for the property of 600 adult equivalents (AE), (0.03 AE/ha), was considered representative of that applied by local landholders. The property relied on mechanical harvesting of mulga browse for ca. 6 months every 2 years (on average over 30 years) to provide sufficient fodder for cattle at the applied stocking rate. The beef production system was a self-replacing *Bos indicus* crossbred breeding herd (ca. 50% *B. indicus*). The management features of the initial base herd included continuous mating with two main musters per year to castrate calves, sell steers and identify cull (saleable) breeding cows. Replacement heifers were separated from the breeding herd until first mating at ca. 2 years of age. Steers were sold off their mothers at 10–12 months of age and 220 kg liveweight (i.e. without weaning). The herd received no vaccinations for animal health and no supplements other than hay for steers immediately before sale. The herd model was developed on the basis of long-term expectations of breeder reproductive performance and cattle growth paths in this environment under these low-level management inputs. Key performance and price assumptions for the initial base herd with low-level management are given in Table 1. The expected values for long-term cattle prices were estimated from 10 years of historical price data for Queensland abattoirs (MLA 2019) and at Roma, the closest saleyards to the study area. The latter prices were discounted to correct for the lower weights and condition of cattle from the Queensland mulga lands relative to other more productive areas.

Approach to economic evaluation

The farm-management economics framework (Bowen and Chudleigh 2021*a*) was applied to the hypothetical, representative property to assess: (1) a range of management strategies to improve the profitability of the property when operated as a beef cattle business; and (2) two alternative investment options, rangeland meat goat production and carbon farming. The farm-management economics framework applies the economic principles outlined by Makeham (1971), Makeham and Malcolm (1993) and Malcolm *et al.* (2005). The economic and financial effects of implementing alternative management strategies or investment options were assessed by marginal comparisons to the base property over a 30-year investment period. For each management change or alternative investment, the following were assessed: (1) additional capital and labour required, (2) effects on herd structure, (3) implementation phase, (4) timing of costs and benefits, (5) economic life of the investment, and (6) associated financial impacts and risks. The Breedcow and Dynama (BCD) herd budgeting software (Holmes *et al.* 2017) were used to analyse beef enterprise options. Economic and production models similar to those in the BCD software were developed to assess rangeland meat goat production and carbon farming. For each cattle and goat herd, the optimal (most profitable) age of female culling (sale), and the optimal male sale age and weight, were determined.

The economic criteria 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). The NPV represents the addition to the investors'

Table 1. Underlying assumptions and modelled property-level returns, expressed as the annual operating profit and the rate of return on total capital, for alternative livestock enterprises on a representative property in the mulga lands of south-western Queensland.

Key parameters required for calculation of property-level returns	Enterprise scenario				
	Beef cattle				Self-replacing rangeland meat goats[A]
	Self-replacing herd with low-level management	Self-replacing herd after implementation of basic herd-management strategies but not mineral supplements	Self-replacing herd after implementation of basic herd management strategies + S and P supplements	Steer turnover	
Average herd mortality rate (%)	7.6	3.5	2.45	6.0	3.6
Breeder mortality rate (%)	12.5	6.0	4.0	n/a	5.0
Weaning rate (%)	47.5[B]	57.3	63.1	n/a	123.7
Male liveweight gain, post-weaning (kg/head.annum)	n/a	115	118	121	24
Male sale age (months) and, in parentheses, liveweight (kg)	12 (220)	18 (292)	18 (295)	18 (292)	23 (57)
Expected average meat price for male and female sales (AU$/kg liveweight)	$2.17	$2.26	$2.26	$2.47	$2.70
Net livestock sales (AU$)	$79 859	$108 753	$121 722	$493 098	$241 370
Husbandry costs (AU$)	$1088	$5657	$8488	$3830	$17 458
Net bull, steer or buck replacement (AU$)	$5638	$4348	$4000	$393 136	$6000
Gross margin (before interest) (AU$)	*$73 132*	*$98 749*	*$109 234*	*$96 132*	*$217 912*
Gross margin (AU$)/DSE after interest	*$10.23*	*$19.84*	*$21.01*	*$17.00*	*$47.44*
Operating overheads (AU$)	$96 600	$97 600	$97 600	$96 600	$106 600
Plant replacement allowance (AU$)	$14 089	$14 089	$14 089	$14 089	$14 089
Allowance for operator's labour and management (AU$)	$40 000	$45 000	$45 000	$45 000	$45 000
Operating profit (AU$)	*−$78 213*	*−$57 948*	*−$47 455*	*−$59 557*	*$52 223*
Rate of return on total capital	*−2.5%*	*−1.9%*	*−1.5%*	*−1.9%*	*1.6%*

[A]The assumption was made that property already had (1) wild dog exclusion fencing and (2) suitable internal fencing and infrastructure to efficiently manage rangeland goats.
[B]Although no weaning activities were undertaken in this herd, the number of calves at 'weaning age' (6 months) was calculated and converted to a 'weaning rate'.
DSE, dry sheep equivalent, used as a basis for comparisons between beef cattle and rangeland goat enterprises at equivalent grazing pressure; n/a, not applicable; P, phosphorus; S, sulfur.

current wealth above or below the gain if they had invested the capital involved in an alternative that earned at the real discount rate applied. The IRR indicates the return on the extra capital invested. The NPV was calculated over the 30-year life of the investment, expressed in present day terms at the level of operating profit. The latter was calculated as Operating profit = (total receipts − variable costs = total gross margin) − overheads. The carbon farming analysis accounted for the extended nature of the contract applied (100-year life) by representing the present value of the investment for Years 31–100, for both 'without-change' and 'with-change' scenarios, as the expected sale value of the property in Year 30. The present value of the property was calculated as the discounted value of the expected future net income streams for each scenario. No real capital gain for the property was included for either the 'without-change' or 'with-change' carbon farming scenarios for the property. Additionally, the present value of the expected costs of managing the carbon farming project from Year 31 to Year 100 were deducted from Year 30 of the NPV calculation. The applied 5% discount rate sufficiently reduces the impact of costs and benefits accruing past Year 30 to make the NPVs of the alternative property management strategies broadly comparable. For all analyses, 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 asset value. Plant replacement was incurred as a capital cost less a salvage value in the year it was 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.

Financial criteria calculated were peak deficit, number of years to peak deficit, and the payback period in years. In all analyses, the beef enterprise started debt-free, but debt was accumulated, and interest paid, as required for implementation of alternative management strategies or investment options. 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 the number of years taken for the cumulative present value to become positive. All analyses included calculation of cumulative and net cash flow measures at the property level.

Analysis of management strategies for the beef cattle enterprise

The constructed base beef production system was used to examine the benefit of implementing management strategies relevant to the region (Table 2). These strategies were assessed in three stages, each with a new base for comparison as strategies were sequentially implemented:

1. *Sequential implementation of basic management strategies.* The base for comparison was the property with low-level management.
2. *Feeding mineral supplements containing sulfur (S), P and nitrogen (N)*. The base for comparison was the property that had already implemented the safe carrying capacity, weaning, pregnancy-testing, basic herd vaccinations and the optimal steer sale age of 18 months.
3. *Additional strategies.* The base for comparison was the property that had already implemented the safe carrying capacity, weaning, pregnancy-testing, basic herd vaccinations, the optimal steer sale age of 18 months, and S and P supplements fed during the pasture-growing period.

Key performance and price assumptions for each modified base herd are given in Table 1. Changes considered to the starting management of the base property and cattle herd were suggested by experienced industry participants as potentially positive changes for the property and herd efficiency. The estimated effect of management strategies on property carrying capacity and on cattle production indices were assigned with reference to published and unpublished research, and the expert opinion of beef producers, scientists, and extension officers with an extensive knowledge of the northern Australian cattle industry. Key parameters are in Tables 1, 2, and details of assumptions and their derivations are given in Bowen and Chudleigh (2021*c*).

Analysis of alternative investment options

Production of rangeland meat goats

First, the representative property was modelled to run as an established meat goat enterprise, in a steady-state analysis, for comparison with (1) the self-replacing cattle herd under various management levels, and (2) a steer turnover enterprise. For the steady-state analysis, it was assumed that wild dog exclusion fencing, internal fencing and infrastructure were in place for efficient management of rangeland goats. Second, the marginal returns were calculated for complete conversion from the self-replacing beef enterprise to the rangeland goat enterprise over a 24-month transition period. The base cattle herd was the enterprise that had implemented basic management strategies and also S and P supplements fed in the pasture-growing period. Investment in a wild dog exclusion fence (required for goats but not for cattle) was AU$500 000 (AU$10 000/km) and specialist goat handling equipment and refurbishment of internal property infrastructure required investment of AU$165 000.

The modelled meat goat enterprise was a self-replacing herd that received basic management, including (1) weaner bucks were not castrated but were separated until sale, and

Table 2. An overview of the management strategies that were modelled for the representative, example beef cattle enterprise in the mulga lands of south-western Queensland.

Management strategy	Summary and key parameters affected by implementation of the strategy
(1) Sequential implementation of basic management strategies. The base for comparison was the property with low-level management	
Safe carrying capacity (stocking rate reduced from 600 to 500 AE)	Additional cattle sales were made over the first 2 years of the analysis to reduce stocking rate by 16.7% and achieve the target safe carrying capacity of 1 AE: 40 ha. By Year 5, female and steer mortality rates were reduced by 2.5 and 1 percentage points respectively, and branding rate was increased by 2 percentage points.
Safe carrying capacity + weaning, pregnancy-testing and basic herd vaccinations	Weaning (at 6 months of age and ca. 167 kg liveweight), pregnancy-testing (to identify cull cows for sale) and basic herd vaccinations (against botulism, leptospirosis, vibriosis and clostridial diseases) were implemented concurrently with herd reduction (600 to 500 AE). Compared with the 500 AE herd (achieved after herd reduction), by Year 5, female and steer mortality rates were reduced by 4 and 0.5 percentage points respectively, weaning rate was increased by 8.28 percentage points, and sale weight of steers at 10–12 months of age was reduced by 15 kg.
Safe carrying capacity + weaning, pregnancy-testing and basic herd vaccinations + increasing age of turnoff from yearling steers to 18 months (the optimal)	The herd was restructured to sell steers at 18 months rather than 12 months, while maintaining equivalent grazing pressure. This was implemented concurrently with the safe carrying capacity, weaning, pregnancy-testing and basic herd vaccinations.
(2) Feeding mineral supplements containing S, P and N. The base for comparison was the property that had already implemented the safe carrying capacity, weaning, pregnancy-testing, basic herd vaccinations and the optimal steer sale age of 18 months	
Dry period S, P, N	Dry period (150 days/annum) supplementation of the entire herd with loose supplement mix containing inorganic S, P and N to reduce breeder and steer mortality rates by 2 and 0.5 percentage points respectively, and increase weaning rate by 6 percentage points.
Growing period S, P	Supplementation of the entire herd during the pasture-growing period (90 days/annum) with loose supplement mix containing inorganic S and P to reduce breeder and steer mortality rates by 2 and 0.5 percentage points respectively, increase weaning rate by 6 percentage points and increase steer sale weight at 18 months by 3 kg.
Dry period S, P, N + growing period S, P	Supplementation of the entire herd with loose mixes containing S, P and N during the dry period (150 days/annum), and S and P during the pasture-growing period (90 days/annum) to reduce breeder and steer mortality rates by 3 and 1 percentage points respectively, increase weaning rate by 10 percentage points and increase steer sale weight at 18 months by 7 kg.
(3) Additional strategies. The base for comparison was the property that had already implemented the safe carrying capacity, weaning, pregnancy-testing, basic herd vaccinations, the optimal steer sale age of 18 months, and S and P supplements fed during the pasture-growing period	
Convert from breeding to steer turnover	Transition over 12 months from a breeder operation to one that purchases 6-month-old (weaner) steers with turnoff (sale) at 18 months.
Controlled mating	
Remove the bulls, only	Remove bulls from the herd for 6 months (June–December) each year.
Sell PTE females, first year only	Remove bulls from the herd each year, as above, in conjunction with pregnancy-testing and sale of PTE females in the first year of the analysis only.
Sell PTE females annually, replace with PTIC	Remove bulls from the herd each year, as above, in conjunction with annual pregnancy-testing, sale of PTE females and then purchase of sufficient PTIC cows to maintain the number of weaners produced each year.
Buffel (*Cenchrus ciliaris*) paddock development (1000 ha)	Aerially seeding a 1000-ha paddock of higher fertility soil types (soft mulga and black soil) with buffel grass to achieve a gradual increase in carrying capacity, so that by Year 30, the carrying capacity of the paddock is double that in Year 1.
Feed whole cottonseed to the breeder herd (50% of years) at either AU$700 or AU$300/t landed	Feeding whole cottonseed to the breeder herd (including heifers) for 180 days every 2nd year on average to reduce female mortality rate by 1.3 percentage points, increase weaning rate by 3.9 percentage points, and increase liveweight of steers by 10 kg at the same age of sale, on average.
Destock in response to drought, through livestock sales (once per decade)	Sale of half of the breeding herd every 10 years on average (Years 5, 15 and 25) in response to a significant dry period, so that 18 months after destocking, forage had responded sufficiently to support average herd numbers (i.e. 500 AE). Savings in annual FORM costs associated with mulga feeding were reduced by 20% from Year 5 to Year 30, and the operator's allowance for the property was reduced by 10% from Year 5.

(*Continued on next page*)

Table 2. (*Continued*)

Management strategy	Summary and key parameters affected by implementation of the strategy
Recover by natural increase in numbers with either 20% or 10% cost savings in mulga feeding from Year 5	18 months after destocking, the cattle herd was rebuilt over time through natural increase (retained progeny) alone, with sensitivity to savings made in FORM tested by halving the assumed level of savings (10% cf. 20%).
Recover through purchase of replacement PTIC breeders	18 months after destocking, sufficient PTIC females were purchased to achieve 500 AE on the property 2 years after destocking.
Recover by taking cattle on agistment, with income valued at AU$3, AU$5 or AU$7/AE.week	18 months after destocking, cattle were taken on agistment, at 90% of the available carrying capacity, while the herd rebuilt through natural increase.
Destock in response to drought, by sending breeders on agistment (once per decade) at a cost of AU$3, AU$5 or AU$7/AE.week.	Destock by sending half of the breeding herd on agistment every 10 years on average (Years 5, 15 and 25) in response to a significant dry period, so that 18 months after destocking forage had responded sufficiently to support average herd numbers (i.e. 500 AE). Savings in annual FORM costs associated with mulga feeding were reduced by 20% from Year 5 to Year 30, and the operator's allowance for the property was reduced by 10% from Year 5.

These strategies are described in detail in Bowen and Chudleigh (2021c).
AE, adult equivalent; FORM, fuel, oil, repairs and maintenance costs; N, nitrogen; P, phosphorus; PTE, pregnancy-tested, 'empty' cows (i.e. not pregnant); PTIC, pregnancy-tested, in-calf cows; S, sulfur.

(2) weaner does were separated from bucks until yearling mating. The goat enterprise was based on rangeland goat genetics, with some crossbred bucks used as sires (i.e. rangeland goats crossed with Kalahari reds, Boer, or Anglo Nubian genotypes). There is a lack of published data on the biology of meat goat production in this region, so the herd characteristics were again informed primarily by expert opinion from discussions in 2019–2020. Key performance parameters and price assumptions are given in Table 1. The expected sale price for goat meat was estimated from long-term price data (MLA 2019), in accord with expectations of local property managers. Grazing pressure equivalence to 500 AE of cattle was determined according to McLennan *et al.* (2020), where an AE or dry sheep equivalent (DSE) rank was assigned as the ratio of the metabolisable energy (ME) requirements for a particular level of production to that of a 'standard animal'. The standard animal for both cattle and goats was defined as having zero weight change, walking 7 km/day on level ground and consuming forage of 55% dry matter (DM) digestibility (7.75 MJ ME/kg DM). A standard bovine animal, representing one AE, was defined as a 450 kg, 2.25-year-old *B. taurus* steer requiring 73 MJ ME/day. A standard goat, representing one DSE, was defined as a 45-kg wether, with no fibre growth above that at maintenance, requiring 8.7 MJ ME/day. This corresponded to a ratio of AE:DSE of 1:8.4.

Carbon farming through sequestration

Potential returns to investment in carbon farming, on 50% or 75% of the property area, were examined for the property when initially fully stocked with a self-replacing herd of either (1) beef cattle or (2) rangeland meat goats. The base cattle herd was the enterprise that had implemented basic management strategies and also S and P supplements fed in the pasture-growing period. The base rangeland meat goat herd had wild dog exclusion fencing and suitable internal infrastructure already in place. A 50% conversion of the property to carbon farming was assumed to be equivalent to 50% of the long-term carrying capacity of the property, whereas 75% conversion was assumed to be equivalent to 80% of the carrying capacity. The difference was due to likely inclusion of some of the higher carrying-capacity land types in 75% of the property area. The area not allocated to the carbon contract was assumed to maintain its carrying capacity. Operating and overhead costs of the livestock enterprises were adjusted accordingly. The area contracted for carbon sequestration was set aside from tree clearing for a 100-year permanence period to align with the most common local practice (Clean Energy Regulator 2021). To simplify the analysis, and match the carbon sequestered to the estimates gained from exclosures by Witt *et al.* (2011), livestock grazing was excluded from the contract area for the entire period. As no data were available to model a dynamic rate of sequestration for the generic property, a constant rate of sequestration of 1.2 t CO_2-equivalent (e)/ha. annum for 25 years was applied, with a total of 30 t CO^2-e/ha accumulated, in accord with published estimates and allowing for a potential negative impact on carbon sequestration of any disturbance events (Fensham and Guymer 2009; Witt *et al.* 2011; Fensham *et al.* 2012; Peters and Butler 2014; Thamo *et al.* 2017). The 25-year period for income (the crediting period) aligned with the conclusion of Witt *et al.* (2011) that mulga land carbon balances are likely to be in equilibrium after 25 years. Additionally, 25 years is the maximum crediting period currently allowed by the Clean Energy Regulator (2021). The initial gross carbon price was assumed to be AU$12.50/t CO^2-e (Cockfield *et al.* 2019) and was maintained in real terms for the 25-year crediting period. Furthermore, following Cockfield *et al.* (2019) and the advice of local landholders, the carbon price achieved at auction (gross price) was reduced by 25%, to allow for project management fees and that 5% of value would be retained by the Clean Energy Regulator (2021).

This provided an on-farm return of AU$9.30/t CO^2-e. Operational costs to establish and maintain the areas under carbon contract were set at AU$1.5/ha.annum for the first 5 years, with annual maintenance costs being subsequently halved for the remaining 95 years.

Results

Analysis of management strategies for the beef cattle enterprise

The steady-state profit analysis of the initial, base beef cattle enterprise indicated a return of −AU$78 213, (or −2.5%), on total capital invested, with total farm income being insufficient to pay total property costs (Table 1). Of the initial basic management strategies, only targeting the optimal age of steer turnoff had a measurable (greater than ±AU$5000/annum) effect on annual enterprise profit (Table 3). However, total property returns were −1.9% (Table 1). When the property with fully implemented initial basic management strategies was used as a modified base to test the value of feeding mineral supplements, the greatest benefit was due to S and P supplements fed only during the pasture growth period. Property profit increased by AU$7100/annum (Table 3) but total property returns were −1.5% (Table 1). Implementing dry period mineral supplements decreased property returns when fed alone (−AU$2000/annum) and decreased the benefit to growing period supplements when fed in combination (AU$4100 extra profit/annum).

The effect of implementing additional strategies provided very limited opportunity to improve profitability and, hence, viability of the cattle enterprise. All strategies except 'destocking in response to drought' resulted in an unmeasurable (less than ±AU$5000) or large negative effect on annual profit (Table 3). Even destocking in response to drought added to profitability only when savings in fuel, oil, repairs and maintenance associated with feeding mulga browse could be reduced by at least 20%, on average, in combination with a reduction in operator's allowance of 10%.

Analysis of alternative investment options

The steady-state profit analysis of the established rangeland meat goat enterprise indicated the property returned AU$52 223, or 1.6%, on total capital (Table 1). Where full investment in a wild dog exclusion fence around the property boundary and existing infrastructure refurbishment were required to facilitate a change from cattle to goat production, the investment added AU$48 300 profit/annum and generated an IRR of 10.8% (Table 4). However, the investment substantially increased the riskiness and indebtedness of the property, as indicated by the substantial peak deficit (−AU$876 000) and payback period (14 years).

Partial conversion of a beef enterprise to carbon farming substantially improved property profitability, with 75% conversion adding AU$36 800 profit/annum and 50% conversion AU$26 600 profit/annum (Table 4). However, partial conversion of a rangeland meat goat enterprise to carbon farming decreased profitability (−AU$17 400 and −AU$36 800 less profit/annum for 50 and 75% conversion respectively; Table 4).

Discussion

In general, there was limited opportunity to improve profitability, and hence viability and resilience, of the hypothetical beef cattle enterprise. The cumulative effect of implementing a basic level of herd management and other strategies was a property with negative total returns and declining cumulative cash flow over 30 years of analysis. This finding supports earlier studies when Merino wool sheep production was the region's dominant enterprise (Holmes 1980; Johnston *et al.* 1990; Passmore 1990).

Strategies likely to increase the profitability of beef cattle enterprises in the Mulga Lands bioregion were consistent with those for other geographical regions in Queensland and the Northern Territory, and included increasing the age of steer turnoff from weaners to the optimal, and provision of mineral supplements (particularly P) in the pasture growth season where deficiencies occur (Bowen *et al.* 2020*b*; Bowen and Chudleigh 2021*a*). In addition to improving profitability, increasing age of steer turnoff to the optimal can improve drought preparedness because of a reduced breeder herd relative to growing cattle at the same grazing pressure. However, an impediment to this strategy is the substantial peak deficit in cash flow incurred while steers are initially held for longer prior to sale. Soils of the Mulga Lands bioregion are severely deficient in available P and N (Dawson and Ahern 1973; Beale 1994; McLennan *et al.* 1999). Ruminant diets with high proportions of mulga browse exacerbate P and N deficiency, and S and sodium also become limiting (McMeniman *et al.* 1986*a*; Clarke 1991; Pritchard *et al.* 1992). Additionally, the low digestibility (ca. 45% DM digestibility) and low voluntary intake of mulga browse severely curtail performance (McMeniman *et al.* 1986*b*; Pritchard *et al.* 1992). Low levels of strategic mineral supplements such as P and non-protein N (urea) constitute one of the few, low-cost options for northern Australian beef producers to reduce the effects of nutritional deficiencies in pasture and improve breeder productivity (McCosker and Winks 1994; Dixon 1998). However, the present analysis only indicated measurable improvements in whole-farm profitability from supplementing with S and P in the pasture-growing period (AU$7100 extra profit/annum). The poor profitability response to dry period S, P and N supplementation (−AU$2000/annum) is in accord with analysis for the more productive Central Queensland region where, similarly, the costs relative to benefits of dry period supplementation were higher than for P supplementation in

Table 3. Profitability and financial risk of implementing management strategies for a representative, hypothetical beef enterprise in the mulga lands of south-western Queensland.

Strategy	NPV of change (AU$)	Annualised NPV (AU$)	Peak deficit (with interest) (AU$)	Years to peak deficit	Payback period (years)	IRR (%)
(1) Sequential implementation of basic management strategies. The base for comparison was the property with low-level management						
Safe carrying capacity (stocking rate reduced from 600 to 500 AE)	$8000	$500	−$17 000	n/c	n/c	4.3
Safe carrying capacity + weaning, pregnancy testing and basic herd vaccinations	$2700	$200	−$15 000	n/c	n/c	4.6
Safe carrying capacity + weaning, pregnancy testing and basic herd vaccinations + increasing age of steer turnoff from yearling steers to 18 months (the optimal)	$190 700	$12 400	n/c	n/c	n/c	n/c
(2) Feeding mineral supplements containing sulfur (S), phosphorus (P) and nitrogen (N). The base for comparison was the property that had already implemented the safe carrying capacity, weaning, pregnancy-testing, basic herd vaccinations and the optimal steer sale age of 18 months						
Dry period S, P, N	−$31 300	−$2000	−$102 200	20	n/c	n/c
Growing period S, P	$108 800	$7100	n/c	n/c	n/c	n/c
Dry period S, P, N + growing period S, P	$62 600	$4100	−$33 500	6	11	18%
(3) Additional strategies. The base for comparison was the property that had already implemented the safe carrying capacity, weaning, pregnancy-testing, basic herd vaccinations, the optimal steer sale age of 18 months, and S and P supplements fed during the pasture-growing period						
Convert from breeding to steer turnover	−$248 000	−$16 100	−$718 500	29	n/c	n/c
Controlled mating						
Remove the bulls, only	−$45 700	−$3 000	−$99 700	n/c	n/c	n/c
Sell PTE females, first year only	−$30 000	−$1 900	−$34 600	n/c	n/c	n/c
Sell PTE females annually, replace with PTIC	$10 000	$700	n/c	n/c	n/c	n/c
Buffel paddock development (1000 ha)	$26 400	$1700	−$10 600	7	16	14%
Feed whole cottonseed to the breeder herd (50% of years)						
AU$700/t landed	−$777 700	−$50 600	−$1 971 500	n/c	n/c	n/c
AU$300/t landed	−$386 400	−$25 100	−$1 082 100	n/c	n/c	n/c
Destock in response to drought, through livestock sales (once per decade)						
Recover by natural increase in numbers						
20% cost savings in mulga feeding from Year 5	$78 500	$5100	n/c	n/c	n/c	n/c
10% cost savings in mulga feeding from Year 5	$13 500	$900	n/c	n/c	n/c	n/c
Recover through purchase of replacement PTIC breeders	$123 200	$8000	n/c	n/c	n/c	n/c
Recover by taking cattle on agistment						
AU$3/AE.week	−$46 500	−$3000	−$152 600	n/c	n/c	n/c
AU$5/AE.week	−$11 600	−$760	−$52 200	n/c	n/c	n/c
AU$7/AE.week	$23 300	$1500	n/c	n/c	n/c	n/c
Destock in response to drought, by sending breeders on agistment (once per decade)						
AU$3/AE.week	$115 000	$7500	−$25 000	5	6	n/c

(*Continued on next page*)

Table 3. (*Continued*)

Strategy	NPV of change (AU$)	Annualised NPV (AU$)	Peak deficit (with interest) (AU$)	Years to peak deficit	Payback period (years)	IRR (%)
AU$5/AE.week	$93 400	$6100	−$38 800	5	7	n/c
AU$7/AE.week	$71 900	$4700	−$52 700	5	8	n/c

NPV is the net present value of an investment, referring to the net returns (income minus costs) over the 30-year life of the investment and represents the extra return added by the management strategy, i.e. it is the difference between the base property and the same property after implementation of the strategy or combination of strategies. The annualised NPV represents the average annual change in NPV over 30 years resulting from the strategy and can be considered as an approximation of the change in profit per year. Peak deficit is the maximum difference in cash flow between the strategy and the base scenario over the 30-year period of the analysis. It is a measure of riskiness. Payback period is the number of years it takes for the cumulative present value to become positive. Other things being equal, the shorter the payback period, the more appealing the investment. IRR is the internal rate of return, i.e. the rate of return on the additional capital invested. It is a discounted measure of project worth. AE, adult equivalent; n/c, not able to be calculated; PTE, pregnancy-tested, 'empty' cows (i.e. not pregnant); PTIC, pregnancy-tested, in-calf cows.

the pasture-growing period (Bowen *et al.* 2020*b*). This issue warrants more detailed investigation across northern Australia's grazing lands.

In the present study, several management strategies that improve the profitability of beef cattle properties in more productive regions of northern Australia resulted in either unmeasurable (less than ± AU$5000 profit/annum) or negative effects on profitability. For example, the decrease in property profitability (−AU$16 100/annum) resulting from converting the mulga lands breeding herd to a steer turnover operation contrasts with results for more productive areas of Queensland (Bowen and Chudleigh 2021*a*). The decreasing rate of steer liveweight gain over time in the low-productivity Mulga Lands bioregion was the major cause of this difference. The rate of steer liveweight gain assumed in this analysis was primarily based on data from local producers. However, it aligns with data for steers grazing low-productivity land types in the Northern Territory (Schatz 2011; Cowley 2012).

Similarly to the results in the present study, analyses for other low-productivity regions in northern Australia have indicated that property profitability can be improved by implementing optimal stocking rates, breeder segregation, better weaner management, and, where needed, closely targeted P supplements. However, as for the current analysis, the addition of controlled mating to these management strategies generally reduced profitability (Chudleigh *et al.* 2017, 2019). The poor nutrition in these low-productivity regions, and consequent poor herd reproductive efficiency, make controlled mating unlikely to improve returns unless high-risk livestock trading activities are incorporated to overcome the large cash flow deficits caused by a change from continuous to controlled mating.

Despite government- and grazier-supported initiatives in the 1990s to (1) promote property amalgamation for improved enterprise efficiency, (2) control total grazing pressure, and (3) objectively assess safe livestock carrying capacities (Johnston *et al.* 1996*a*, 1996*b*; Rose 1998), and the more recent *Queensland Vegetation Management Act 1999* (The State of Queensland 2018), the condition of the Mulga Lands bioregion as a grazing resource appears to be in continued decline (Commonwealth of Australia 2008). A stocking rate reduction to achieve the safe carrying capacity for the hypothetical property was considered the essential first step in our analysis to prevent further degradation. However, despite releasing ca. AU$60 000 worth of livestock capital over the 2 years of adjustment to the lower stocking rate of 500 AE, the long-term economic and financial outlook of the property remained similar to that when running 600 AE. The lack of research data for beef cattle in this region to support assumed improvements in livestock productivity resulting from implementing a safe carrying capacity indicates that this analysis should be considered with caution. Additionally, the use of the average market price to value stock sold as part of the herd reduction may have overstated livestock value, because such stock would be unlikely to be in the same average condition as are normal sale cattle. Regardless, the outcome of this strategy is consistent with that of a similar analysis conducted for a Northern Gulf property in Queensland (Bowen *et al.* 2019). We did not examine further interventions to improve degraded rangeland pastures, other than reducing stocking rate, because evidence suggested that restoration would be unlikely, and because of economic constraints (Johnston *et al.* 1990; MacLeod and Johnston 1990; Commonwealth of Australia 2008).

Livestock enterprise and resource management in this bioregion relies on harvesting mulga browse (Page *et al.* 2008). However, retaining livestock through use of mulga fodder when grass biomass is limiting has been the major contributor to pasture degradation (Pritchard and Mills 1986; Mills *et al.* 1989; Johnston *et al.* 1990). Stocking rates and pasture utilisation rates in the Mulga Lands bioregion are generally higher than values estimated as 'safe' for maintaining pasture condition (McKeon *et al.* 2004; Commonwealth of Australia 2008). Additionally, high pasture utilisation levels may require more frequent and extensive mulga harvesting to maintain livestock numbers (Commonwealth of Australia 2008; Page *et al.* 2008). In our analysis, we examined the effect on property profit of destocking in response to

Table 4. Profitability and financial risk of implementing alternative investment options for a representative, hypothetical beef enterprise in the mulga lands of south-western Queensland.

Strategy	NPV of change (AU$)	Annualised NPV (AU$)	Peak deficit (with interest) (AU$)	Years to peak deficit	Payback period (years)	IRR (%)
(1) Rangeland meat goats						
Convert from a self-replacing beef cattle herd to self-replacing rangeland meat goats, including investment in exclusion fencing and some internal infrastructure	$742 900	$48 300	−$876 000	3	14	11
(2) Carbon farming, through carbon sequestration						
Convert from a self-replacing beef cattle herd to						
Carbon farming on 50% of the property	$409 000	$26 600	n/c	n/c	n/c	n/c
Carbon farming on 75% of the property	$586 200	$36 800	n/c	n/c	n/c	n/c
Convert from a self-replacing rangeland meat goat herd to						
Carbon farming on 50% of the property	−$268 000	−$17 400	−$1 542 500	30	n/c	n/c
Carbon farming on 75% of the property	−$566 300	−$36 800	−$2 834 900	30	n/c	n/c

The base for comparison for all strategies when conversion was from a self-replacing beef cattle herd was the beef enterprise that had implemented the safe carrying capacity, weaning, pregnancy-testing, basic herd vaccinations, the optimal steer sale age of 18 months, and sulfur and phosphorus supplements fed during the pasture-growing period. The base for comparison when conversion was from a self-replacing rangeland meat goat herd was the goat enterprise with wild dog exclusion fencing and suitable internal fencing and infrastructure already in place.
Definitions of economic and financial parameters and abbreviations given in Table 3.

extended dry periods, with a scenario of destocking half of the breeding herd for 18 months every 10 years. This analysis depended on uncertain assumptions of climatic variability and the associated impact on property carrying capacity, prices, and costs. Nevertheless, a key finding was that destocking in response to drought was likely to add to the property profitability if savings in fuel, oil, repairs and maintenance costs associated with feeding mulga browse could be reduced by at least 20%, and operator's allowance (labour costs) reduced by 10%. The most appropriate strategy for individual producers to destock (sale or agistment of cattle on another property), then rebuild herd numbers in the recovery phase (natural increase, purchases, agistment income) will depend on the costs, livestock prices at the time, and the availability and/or demand for agistment.

Because of the limited opportunity identified in our analysis to improve the profitability and viability of the beef cattle enterprise, alternative investment options were examined. The first examined was conversion to the production of rangeland meat goats. This generated substantially more profit (AU $48 300 extra profit/annum; 11% IRR) than did any strategy examined to improve performance of the existing cattle enterprise. However, performance of this investment is heavily dependent on the assumptions that the estimated relative and absolute goat meat price will be maintained over the long term. Although profitable over 30 years, an important constraint was the level of debt required (−AU$876 000 peak deficit) and the long interval (14 years) before the property was expected to return to the same financial position as that without change. This financial risk is challenging for property managers where high costs of wild dog exclusion fencing must be funded wholly by the property. Similar results were obtained for conversion from beef to goat production for a representative property in the central-western rangelands of Queensland (Bowen and Chudleigh 2021*d*).

An aspect of goat production systems in the mulga lands is that goats select proportionally more browse than do other livestock species (Hacker and Alemseged 2014; Pahl 2019). Furthermore, evidence suggests that goats can digest and utilise mulga browse more effectively than do cattle or sheep because of adapted rumen micro-organisms that improve nitrogen digestion and retention (Brooker *et al.* 1994; Miller *et al.* 1995). Our estimate of the number of goats able to be run on the representative property was conservative, because we assumed grazing pressure equivalency of cattle and goat animal units, based on energy requirements. This conservative approach was taken in the absence of data to indicate substitution ratios between cattle and goats, and to reduce the risk of pasture overutilisation. Overutilisation by goats can occur on commercial properties because of high reproductive rates (124% weaning rate in this analysis), and possibly the greater drought resilience and survival of goats compared with cattle or sheep. This latter attribute is considered to be partially a consequence of the more flexible diet of goats and their better ability to utilise browse and select for diet quality. In the current analysis, the rate of sale of surplus goats was sufficient to avoid increasing grazing pressure compared with the beef cattle enterprise. Lack of reliable data for managed rangeland meat goat production in this bioregion demands caution in extrapolating these results. However, given profitability of the goat enterprise, it appears that rangeland goats could have an important role in maintaining profitable and resilient mulga land production systems. This would require ongoing demand for goat meat and improved knowledge of effective goat management systems.

Although historically dominant in the mulga lands, Merino wool sheep production is now uncommon (ABS 2021). For this reason, as well as the lack of interest by the local advisory group in examining sheep (wool or meat) enterprises for this mulga-dominant property, sheep were not included in this study. Analyses for the central-western rangelands of Queensland indicated that existing Merino wool sheep enterprises were profitable and resilient on the basis of contemporary prices (Bowen and Chudleigh 2021*d*). However, changing from a beef cattle to a sheep enterprise generally requires even greater capital investment than that for a change to goats, and, consequently, increased financial risk and indebtedness (Bowen and Chudleigh 2021*d*).

The second alternative examined in the present study, partial conversion of a beef enterprise to carbon farming, substantially improved property profitability over 30 years, with 75% land-area conversion being superior to 50% conversion. However, partial conversion of a rangeland meat goat enterprise to carbon farming decreased profitability over 30 years, despite carbon farming improving cash flows in the short to medium term. The analysis indicated that the opportunity cost of the investment will be a key factor determining whether carbon farming is attractive. With an unprofitable enterprise in place (e.g. beef production in this analysis), the opportunity costs of investing in carbon farming are low and provide a greater incentive for carbon farming. It appears likely that the widespread adoption of carbon farming in the rangelands (Baumber *et al.* 2020) has been predominately due to the extended droughts and low commodity prices of the past decade. These circumstances have reduced the opportunity costs, and/or increased the discount rates, of some landholders to the point that carbon farming became attractive. A sequence of more favourable seasonal conditions and continuation of higher commodity prices could slow the conversion of large parts of the mulga lands to carbon farming. Even so, the relative profitability of carbon farming indicates that its adoption on portions of properties is likely to be considered closely by many landholders. This is particularly likely if carbon prices were to increase in real terms over time. However, managers must not only apply the correct methodology when assessing the potential for carbon sequestration, but also an appropriate framework to assess the economic and financial value of carbon farming. Furthermore, the tax implications for this non-primary production income stream, and the uncertainty of impacts of long-term carbon contracts on property sale value, were not included in our analysis but should be considered by property managers.

Carbon farming and rangeland goat production provide a diversified income for a beef property, potentially stabilising income over time as well as improving average profitability. This can reduce risks from climate variability and assist with drought preparedness and resilience (Buxton and Smith 1996; Freebairn 2019; Bowen and Chudleigh 2021*d*). However, as identified previously (Bowen and Chudleigh 2021*a*, 2021*b*), individual properties may have characteristics different from those assumed in this analysis. Furthermore, the goals, resources, and skills of property managers will influence decision-making and adoption of alternative management strategies. We recommend that the farm-management economics framework applied in our analysis be considered at an individual property level to account for property and manager-specific factors and to better guide decision-making in rangelands generally.

The poor returns from beef cattle production have led some producers in the mulga lands to rely on non-farm income for business survival. This has been identified as important in inherently low-productivity regions with a history of subdividing large properties (Johnston *et al.* 1990; Fargher *et al.* 2003). There was considerable interest in the 1980s and 1990s in promoting property amalgamation in the mulga lands to take advantage of economies of size, and thereby improve profitability, and to reduce the economic incentive for adoption of exploitative grazing strategies (Holmes 1980; Passmore and Brown 1991). However, the disconnect between land value and production potential has limited the capacity of local landholders to achieve such an outcome. Bowen *et al.* (2020*a*) found no positive effect of purchasing additional grazing land even when more productive land was purchased, when a 5% discount rate was applied to indicate the opportunity cost of the additional capital. A similar outcome would be expected for the mulga lands property. Fargher *et al.* (2003) and Hamblin (2009) have argued that, in regions where environmental and social decline are endemic, more effective land management policies should be implemented to retire low-productivity land from grazing, with support given to grazing businesses to restructure.

Conclusions

This study provided insights into the opportunities to improve profitability and resilience of a hypothetical grazing enterprise in a low-productivity, semi-arid rangeland environment. The finding of low inherent productivity and profitability of beef cattle production in the Mulga Lands bioregion is in accord with previous studies when Merino wool sheep production was dominant (Holmes 1980; Johnston *et al.* 1990; Passmore 1990). Our study indicated very limited potential to improve the profitability or resilience of the existing beef cattle enterprise. However, full or partial conversion to rangeland goat production or carbon farming improved property returns and viability.

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, Australia) Available at https://www.agriculture.gov.au/sites/default/files/sitecollectiondocuments/abares/agriculture-commodities/AgCommodities201903_v1.0.0.pdf [Accessed 24 August 2021]

ABS (Australian Bureau of Statistics) (2021) 7121.0 Agricultural Commodities, Australia, 2019-20. Available at http://www.abs.gov.au/ausstats/abs@.nsf/mf/7121.0 [Accessed 24 August 2021]

Baumber A, Waters C, Cross R, Metternicht G, Simpson M (2020) Carbon farming for resilient rangelands: people, paddocks and policy. *The Rangeland Journal* **42**, 293–307. doi:10.1071/RJ20034

Beale IF (1994) Management of mulga (*Acacia aneura*) scrublands in southwest Queensland. In 'Forage tree legumes in tropical agriculture'. (Eds RC Gutteridge, HM Shelton) pp. 325–337. (CAB International: Wallingford, UK)

Bortolussi G, Hodgkinson JJ, Holmes CR, McIvor JG, Coffey SG (1999) Report on the Northern Australian Beef Industry Survey Activity. South-West Region Report. CSIRO Division of Tropical Agriculture, Brisbane, Qld, Australia.

Bortolussi G, McIvor JG, Hodgkinson JJ, Coffey SG, Holmes CR (2005) The northern Australian beef industry, a snapshot. 2. Breeding herd performance and management. *Australian Journal of Experimental Agriculture* **45**, 1075–1091. doi:10.1071/EA03097

Bowen MK, Chudleigh F (2021*a*) 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 MK, Chudleigh F (2021*b*) Achieving drought resilience in the grazing lands of northern Australia: preparing, responding and recovering. *The Rangeland Journal* **43**, 67–76. doi:10.1071/RJ20058

Bowen MK, Chudleigh F (2021*c*) 'Mulga Lands production systems. Preparing for, responding to, and recovering from drought', (The State of Queensland, Department of Agriculture and Fisheries, Queensland: Brisbane, Qld, Australia) 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 23 August 2021]

Bowen MK, Chudleigh F (2021*d*) Can a return to small ruminants increase profitability and drought resilience in the semiarid rangelands of northern Australia? *Animal Production Science* **(Online early)**, doi:10.1071/AN21422

Bowen MK, Chudleigh F, Rolfe JW, English B (2019). '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, Australia) 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 27 August 2021]

Bowen MK, Chudleigh F, 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, Qld, Australia) 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 14 February 2022]

Bowen MK, Chudleigh F, Dixon RM, Sullivan MT, Schatz T, 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

Brooker JD, O'Donovan LA, Skene I, Clarke I, Blackall L, Muslera P (1994) *Streptococcus caprinus* sp. nov. A tannin resistant ruminal bacterium from feral goats. *Letters in Applied Microbiology* **18**, 313–318. doi:10.1111/j.1472-765X.1994.tb00877.x

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

Chudleigh F (2021) 'Meat sheep, meat goats and wool sheep in Queensland: overview and prospects.' (State of Queensland, Department of Agriculture and Fisheries: Brisbane, Qld, Australia) Available at http://era.daf.qld.gov.au/id/eprint/8032/1/Chudleigh_2021_Meat%20sheep%20meat%20goats%20wool%20sheep%20overview%20and%20prospects.pdf [Accessed 24 August 2021]

Chudleigh F, Cowley T, Moravek T, McGrath T, 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, Qld, Australia. Available at https://ageconsearch.umn.edu/record/258661?ln=en [Accessed 19 October 2021]

Chudleigh F, Oxley T, Bowen M (2019) 'Improving the performance of beef enterprises in northern Australia', (The State of Queensland, Department of Agriculture and Fisheries: Brisbane, Qld, Australia) Available at https://www.daf.qld.gov.au/_data/assets/pdf_file/0008/1439720/Improving-the-performance-of-beef-production-systems-in-northern-Australia.pdf [Accessed 19 October 2021]

Clarke R (1991). 'Beef cattle production in south-west Queensland', (The State of Queensland, Department of Primary Industries: Brisbane, Qld, Australia)

Clean Energy Regulator (2021) Australian Government, Clean Energy Regulator, Canberra, ACT, Australia. Available at http://www.cleanenergyregulator.gov.au/ [Accessed 15 September 2021]

Cockfield G, Shrestha U, Waters C (2019) Evaluating the potential financial contributions of carbon farming to grazing enterprises in Western NSW. *The Rangeland Journal* **41**, 211–223. doi:10.1071/RJ18032

Colwell JD (1963) The estimation of phosphorus fertiliser requirements of wheat in southern New South Wales by soil analyses. *Australian Journal of Experimental Agriculture and Animal Husbandry* **3**, 190–197. doi:10.1071/EA9630190

Commonwealth of Australia (2008) 'Rangelands 2008 – Taking the pulse', (ACRIS Management Committee, National land and Water Resources Audit: Canberra, ACT, Australia)

Cowley T (2012) Modelling the profitability of different calving periods in northern Australian breeding operations targeting the 350 kg live export market. Master of Rangeland Management Thesis, University of Queensland, School of Agriculture and Food Sciences, Brisbane, Qld, Australia.

Dawson NM, Ahern CR (1973) Soils and landscapes of mulga lands with special reference to south western Queensland. *Tropical Grasslands* **7**, 23–34.

Dixon R (1998) Improving cost-effectiveness of supplementation systems for breeder herds in northern Australia. Project DAQ.098 Final Report. Meat and Livestock Australia, Sydney, NSW, Australia.

Fargher JD, Howard BM, Burnside DG, Andrew MH (2003) The economy of the Australian rangelands: myth or mystery? *The Rangelands Journal* **25**, 140–156. doi:10.1071/RJ03012

Fensham RJ, Guymer GP (2009) Carbon accumulation through ecosystem recovery. *Environmental Science and Policy* **12**, 367–372. doi:10.1016/j.envsci.2008.12.002

Fensham RJ, Fairfax RJ, Dwyer JM (2012) Potential aboveground biomass in drought-prone forest used for rangeland pastoralism. *Ecological Applications* **22**, 894–908. doi:10.1890/11-1123.1

Foran BD, Stafford Smith DM, Niethe G, Stockwell T, 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. *Australian Farm and Business Management Journal* **16**, 17–23.

Hacker RB, Alemseged Y (2014) Incorporating farmed goats into sustainable rangeland grazing systems in southern Australia: a review. *The Rangeland Journal* **36**, 25–33. doi:10.1071/RJ13035

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

Heywood J, Hodgkinson K, Marsden S, Pahl L (2000) 'Graziers' experience in managing mulga country', (The State of Queensland, Department of Primary Industries: Brisbane, Qld, Australia)

Holmes WE (1980) Property build-up in a semi-arid grazing area: a study of south-west Queensland sheep-cattle graziers' aspirations for property enlargement, their reasons for desiring more land, and the causes of their past failures. MAgrSc Thesis, University of Melbourne, Melbourne, Vic., Australia.

Holmes WE, Chudleigh F, Simpson G (2017) 'Breedcow and Dynama herd budgeting software package. A manual of budgeting procedures for extensive beef herds. Version 6.02.' (State of Queensland, Department of Agriculture and Fisheries: Brisbane, Qld, Australia). Available at https://breedcowdynama.com.au/ [Accessed 25 August 2021]

Johnston BG, MacLeod ND, Young MD (1990) An economic perspective on future research directions for the Australia sheep-grazed rangelands. *Australian Rangelands Journal* **12**, 91–115. doi:10.1071/RJ9900091

Johnston PW, McKeon GM, Day KA (1996*a*) Objective 'safe' grazing capacities for southwest Queensland, Australia: development of a model for individual properties. *The Rangeland Journal* **18**, 244–258. doi:10.1071/RJ9960244

Johnston PW, Tannock PR, Beale IF (1996*b*) Objective 'safe' grazing capacities for south-west Queensland, Australia: model application and evaluation. *The Rangeland Journal* **18**, 259–269. doi:10.1071/RJ9960259

LongPaddock (2021) 'Drought declarations archive.' (The State of Queensland 1995-2021, Queensland Government: Brisbane, Qld, Australia) Available at https://www.longpaddock.qld.gov.au/drought/archive/ [Accessed 24 August 2021]

MacLeod ND, Johnston BG (1990) An economic framework for evaluating rangeland restoration options. *The Australian Rangelands Journal* **12**, 40–53. doi:10.1071/RJ9900040

Makeham JP (1971) 'Farm management economics', (Gill Publications: Armidale, NSW, Australia)

Makeham JP, Malcolm LR (1993) 'The farming game now', (Cambridge University Press: Cambridge, UK)

Malcolm B, Makeham J, Wright V (2005) 'The farming game, agricultural management and marketing.' (Cambridge University Press: Cambridge, Melbourne, Vic., Australia)

McCosker T, Winks L (1994) 'Phosphorus nutrition of beef cattle in northern Australia', (Department of Primary Industries: Brisbane, Qld, Australia)

McGowan M, McCosker K, Fordyce G, Smith D, O'Rourke P, Perkins N, Barnes T, Marquart L, Morton J, Newsome T, Menzies D, Burns B, Jephcott S (2014) Northern Australian beef fertility project: CashCow. Project B.NBP.0382 Final Report. Meat and Livestock Australia, Sydney, NSW, Australia.

McKeon GM, Hall WB, Henry BK, Stone GS, Watson IW (2004). 'Pasture degradation and recovery in Australia's rangelands: learning from history', (The State of Queensland, Department of Natural Resources, Mines and Energy: Brisbane, Qld, Australia)

McLennan S, Dixon R, Hendricksen R, Dodt R (1999) Nutrition of cattle in western Queensland. A report to the Western Queensland Regional Beef Research Committee (WQRBRC) outlining current knowledge, gaps in the knowledge and the suggested direction for future research into the nutrition of beef cattle in western Queensland. The State of Queensland, Department of Primary Industries, Brisbane, Qld, Australia.

McLennan S, McLean I, Paton C (2020) Re-defining animal unit equivalence (AE) for grazing ruminants and its application for determining forage intake, with particular relevance to northern Australian grazing industries. Project B.GBP.0036 Final Report. Meat and Livestock Australia, Sydney, NSW, Australia.

McMeniman NP, Beale IF, Murphy GM (1986*a*) Nutritional evaluation of south-west Queensland Pastures. I. The botanical and nutrient content of diets selected by sheep grazing on Mitchell grass and mulga/grassland associations. *Australian Journal of Agricultural Research* **37**, 289–302. doi:10.1071/AR9860289

McMeniman NP, Beale IF, Murphy GM (1986*b*) Nutritional evaluation of south-west Queensland pastures. II. The intake and digestion of organic matter and nitrogen by sheep grazing on Mitchell grass and mulga grassland associations. *Australian Journal of Agricultural Research* **37**, 303–14. doi:10.1071/AR9860303

Mills JR, Turner EJ, Caltabiano T (1989) Land degradation in south-western Queensland. Project Report QO89008. Department of Primary Industries, Brisbane, Qld, Australia.

Miller SM, Brooker JD, Blackall LL (1995) A feral goat rumen fluid inoculum improves nitrogen retention in sheep consuming a mulga (*Acacia aneura*) diet. *Australian Journal of Agricultural Research* **46**, 1545–1553. doi:10.1071/AR9951545
MLA (Meat and Livestock Australia) (2019) Market information statistics database. Available at http://statistics.mla.com.au/Report/List [Accessed 25 August 2021]
O'Rourke PK, Winks L, Kelly AM (1992) 'North Australia beef producer survey 1990', (Queensland Department of Primary Industries and Meat Research Corporation: Brisbane, Qld, Australia)
Page MJ, Witt GB, Noël MV, Slaughter G, Beeton RJS (2008) Economic and environmental analysis of fodder harvesting practices associated with mulga (*Acacia aneura*) and fire management practices in the mulga lands of south western Queensland. Final Report to Australian Government, Department of the Environment, Water, Heritage and the Arts. School of Natural and Rural Systems Management, The University of Queensland, Brisbane, Qld, Australia.
Pahl L (2019) Macropods, feral goats, sheep and cattle. 2. Equivalency in what and where they eat. *The Rangeland Journal* **41**, 519–533. doi:10.1071/RJ19059
Passmore JGI (1990) 'Economic profile of graziers in the Queensland Mulga Region', (Queensland Department of Primary Industries: Brisbane, Qld, Australia)
Passmore G, Brown CG (1991) Analysis of rangeland degradation using stochastic dynamic programming. *The Australian Journal of Agricultural Economics* **35**, 131–157. doi:10.1111/j.1467-8489.1991.tb00502.x
Peters PJ, Butler DW (2014) 'Mulga: regrowth benefits management guideline.' (The State of Queensland, Department of Science, Information Technology, Innovation and the Arts: Brisbane, Qld, Australia) Available at https://www.qld.gov.au/_data/assets/pdf_file/0025/68191/mulga-management-guideline.pdf [Accessed 15 September 2021]
Pressland AJ (1984) Productivity and management of western Queensland's rangelands. *The Australian Rangelands Journal* **6**, 26–45. doi:10.1071/RJ9840026
Pritchard DA, Mills JR (1986) Drought and its significance. In 'The Mulga Lands'. (Ed. PS Sattler) pp. 11–13. (Royal Society of Queensland: Brisbane, Qld, Australia)
Pritchard DA, Martin PR, O'Rourke PK (1992) The role of condensed tannins in the nutritional value of mulga (*Acacia aneura*) for sheep. *Australian Journal of Agricultural Research* **43**, 1739–1746. doi:10.1071/AR9921739
Rose A (1998) 'The Economics of stocking strategies in south-west Queensland: an overview of current knowledge.' (The State of Queensland, Department of Natural Resources, Queensland: Charleville, Qld, Australia)
Schatz T (2011) The effects of weaning weight on postweaning growth in the VRD. In 'Proceedings of Northern Beef Research Update Conference', 3–4 August 2011, Darwin, NT, Australia. (Eds R Dyer, R Holroyd, J King, J Kyte, T Schatz) p. 134. (North Australian Beef Research Council: Park Ridge, Qld, Australia)
Stockwell TGH, Smith PC, Stafford Smith DM, Hirst DJ (1991) Sustaining productive pastures in the tropics. 9. Managing cattle. *Tropical Grasslands* **25**, 137–144.
Thackway R, Cresswell ID (Eds) (1995) 'An interim biogeographic regionalisation for Australia: a framework for establishing the National System of Reserves, Version 4.0', (Australian Nature Conservation Agency: Canberra, ACT, Australia)
Thamo T, Pannell DJ, Kragt ME, Robertson MJ, Polyakov M (2017) Dynamics and the economics of carbon sequestration: common oversights and their implications. *Mitigation and Adaptation Strategies for Global Change* **22**, 1095–1111. doi:10.1007/s11027-016-9716-x
The State of Queensland (2018) Vegetation management Act 1999. Current as at 3 July 2017 – revised version. The State of Queensland, Brisbane, Qld, Australia. Available at https://www.legislation.qld.gov.au/view/pdf/2017-07-03/act-1999-090 [Accessed 27 August 2021]
The State of Queensland (2019) 'Land types of Queensland. Version 3.1', (Queensland Department of Agriculture and Fisheries: Brisbane, Qld, Australia) Available at https://futurebeef.com.au/knowledge-centre/land-types-of-queensland/ [Accessed 25 August 2021]
Managing woodlands for income maximisation in western Queensland, Australia: clearing for grazing versus timber production. *Forest Ecology and Management* **185**, 291–306.
Wilson BA (1999) Chapter 6. Mulga Lands. In 'The conservation status of Queensland's bioregional ecosystems'. (Eds P Sattler, R Williams) pp. 1–35. (Environmental Protection Agency: Brisbane, Qld, Australia)
Witt GB, Noël MV, Bird MI, Beeton RJS, Menzies NW (2011) Carbon sequestration and biodiversity restoration potential of semi-arid mulga lands of Australia interpreted from long-term grazing exclosures. *Agriculture, Ecosystems and Environment* **141**, 108–118. doi:10.1016/j.agee.2011.02.020

Data availability. The majority of the data that support this study are available from the final project report (Bowen and Chudleigh 2021c), which is available online 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/. Additionally, the herd and flock models used in the analysis can be obtained from the authors upon reasonable request.

Conflicts of interest. The authors declare no conflicts of interest.

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Author affiliations
[A]Department of Agriculture and Fisheries, Rockhampton, Qld 4701, Australia.
[B]Retired. Formerly Department of Agriculture and Fisheries, Toowoomba, Qld 4350, Australia.
[C]Department of Agriculture and Fisheries, Charleville, Qld 4470, Australia.