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An economic framework to evaluate alternative management strategies for beef enterprises in northern Australia

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Abstract

Context. Beef producers in northern Australia are continually presented with new technologies and opportunities to enhance beef production. They need to be able to accurately and efficiently assess the potential impact of alternative strategies on profitability, risk and the period of time before benefits can be expected.

Aims. Our aim was to demonstrate the value of the farm-management economics framework for assessing alternative management strategies applicable to beef cattle enterprises in northern Australia.

Methods. Beef cattle herd models incorporated into a farm-level partial discounted cash-flow framework were used to evaluate the potential effects of alternative management strategies on the performance of enterprises. This was undertaken using constructed, representative beef enterprises developed for the following three regions in Queensland: Central, Northern Downs and Northern Gulf, and the Katherine region of the Northern Territory. The analysis considered the expected response to change in the management of the base herd. Strategies that targeted (1) overall herd or property performance, (2) breeder reproductive performance, (3) steer growth rates, (4) alternative beef cattle marketing options, or (5) enterprise expansion were assessed. All of the changes considered to the current management strategy of the base herd and property were put forward by industry participants as potentially positive.

Key results. The framework efficiently identified substantial differences in net benefits among strategies and allowed ranking of the alternatives at the property level. Strategies that improved profitability also generally increased management complexity and financial risk. While strategies that could substantially improve profitability were identified, many other strategies were likely to reduce profitability at the property level. Key insights were gained into the time taken to implement the strategies, the complexity of implementation, and the level of financial risk incurred.

Conclusions. This study (1) demonstrated the appropriate framework to compare management options and support decision making, (2) efficiently indicated the potential range of outcomes, and (3) provided insight into the risks associated with development processes and technology adoption.

Implications. This farm-management economics framework could be used to assess alternative strategies for individual beef enterprises and to guide appropriate adoption of technology.

Keywords: beef cattle, extensive beef systems, farm-management economics, profitability, rangelands, tropical pastures.

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Introduction

There are major challenges for beef property managers in northern Australia associated with the large intra-annual and decadal rainfall variability and the resulting major temporal variation in production and profitability (Love 2005; O'Reagain and Scanlan 2013; Cobon *et al*. 2019). The northern beef industry is also challenged by variable commodity prices and by an ongoing disconnect between asset values and returns, high debt levels and a declining trend in terms of trade (McCosker *et al*. 2010; McLean *et al*. 2014; ABARES 2019). Therefore, to remain viable, and to build resilience to droughts, floods and market shocks, beef enterprises need to regularly produce profit and build capital. However, to assess the value of change, due to implementing alternative management strategies and new technologies, producers need to be able to appropriately assess the impact of alternative strategies on profit, risk, and the period of time before benefits can be expected.

The consequences of alternative management strategies are best assessed using farm-management economic models that determine the extra costs and benefits associated with change over time (Makeham 1971; Makeham and Malcolm 1981; Malcolm 2000; Malcolm *et al*. 2005). Although this farm-management economics framework has long been established and accepted as the most appropriate approach to assess alternative strategies for farm businesses, there has been a lack of studies at the farm level to assess the full range of choices available to the managers of northern Australian beef properties.

The objective of the present study was to demonstrate the value of the farm-management economics framework. This framework is based on partial discounted cash flows and taking a marginal, whole-farm perspective, to assess alternative management strategies applicable to contemporary beef enterprises in northern Australia. In doing this, we have selected examples from a series of final project reports (Bowen and Chudleigh 2018; Bowen *et al*. 2019, 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/ (3 September 2020). Aspects of this work have been reported in conference proceedings by Chudleigh *et al*. (2019*a*).

Materials and methods

Approach to economic evaluation

The farm-management economics framework used in our study to assess alternative management strategies applies the principles outlined by Malcolm (2000) and Malcolm *et al*. (2005). It incorporates (1) the additional capital and labour required, (2) the effect on herd structure, (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 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 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 modelled four representative beef-cattle properties across diverse production systems and environments in northern Australia, as follows: (1) the productive, subtropical environment of Central Queensland (Qld), (2) the semiarid, Northern Downs of Qld, (3) the monsoonal Northern Gulf of Qld, and (4) the monsoonal Katherine region of the Northern Territory (NT). Of the many possible strategies assessed and presented in the final project report for each of these regions (Bowen and Chudleigh 2018; Bowen *et al*. 2019, 2020*a*; Chudleigh *et al*. 2019*b*), only a limited selection are presented here as (1) examples of how to apply the economic framework, and (2) to demonstrate the range of potential outcomes from implementing commonly applied management strategies in typical scenarios. In doing this, it was important that alternatives to the primary base property (i.e. a 'modified' base) were applied, where relevant, to examine strategies for a region that were of consequence but not appropriately or sensibly included as a characteristic of the primary representative property. For example, prickly acacia infestation was applied to produce a modified base property in the Northern Downs region to allow investigation of optimal management of this woody weed of significance. The use of alternative base properties is an established approach in farm-management economics to allow examination of all relevant alternatives (Malcolm *et al*. 2005).

Representative beef cattle enterprises

The modelled property and herd characteristics for each region were informed by recent industry surveys and regional research (Bortolussi *et al*. 1999, 2005; Henderson *et al*. 2012; Bray *et al*. 2014; McGowan *et al*. 2014; Bowen *et al*. 2015; Cowley *et al*. 2015; Barbi *et al*. 2016; Rolfe 2016; Rolfe *et al*. 2016) as well as collation of expert opinion of beef producers, scientists and beef extension officers with extensive knowledge of the northern Australian cattle industry. The climate and base-enterprise characteristics for each of the four modelled properties are given in Table 1. The long-term, average stocking rate of each property was intended to be representative of properties in the region that operated at long-term sustainable carrying capacity, and accounted for the expected variability in climate over time. The beef production system was a self-replacing *Bos indicus* crossbred (Central Qld and Northern Downs) or Brahman (>75% *B. indicus*; Northern Gulf and Katherine region) breeding and growing activity that relied on the production of weaners by the breeding herd. The Central Qld and the Northern Downs representative properties practiced controlled mating. The Northern Gulf and Katherine region representative properties practiced continuous mating, with two annual musters to wean calves and identify breeding cows for culling. The practice of continuous mating, for the Northern Gulf and Katherine region properties, resulted in a large range in steer liveweight at the primary sale target age of ~29 months. The 17–19% of steers from each year cohort with a lower liveweight (the tail) were sold later at 41 months, but at average liveweight (~400 kg) similar to that of steers sold at 29 months. In all regions, replacement heifers were separated from the breeding herd until first mated at ~2 years of age. Herd models were developed on the basis of long-term, average expectations of breeder reproductive performance and cattle growth paths in each environment. The price basis for cattle was taken from relevant selling centres, using 6.5–11 years of historical price data to derive an expected value for the long-term cattle price. For each

Table 1. Climate and base-enterprise characteristics for four representative beef cattle enterprises across northern Australia
AE, adult equivalent, defined in terms of the feed demand of a 455-kg, non-pregnant, non-lactating cow at maintenance. Feed-on weights are those appropriate for either feedlot entry or commencement of other fattening diets. NT, Northern Territory; P, phosphorus; Qld, Queensland

Characteristic	Representative property			
	Central Qld	Northern Downs, Qld	Northern Gulf, Qld	Katherine region, NT
Climate	Subtropical	Semiarid	Monsoonal	Monsoonal
Median rainfall[A] (mm/year)	620	420	840	1040
Pasture type	Native and sown (primarily buffel grass (*Cenchrus ciliaris*))	Native (primarily Mitchell grass (*Astrebla* spp.))	Native	Native
P-deficiency status	Adequate	Adequate	Deficient	Acutely deficient
P supplementation	Nil	Nil	Adequate	Inadequate; low levels in dry season only
Property size (ha)	8700	16 000	30 000	147 000
Carrying capacity (AE)	1500	2000	1500	7400
Weaning rate (%)	78	65	58	54
Average herd-mortality rate (%)	2.9	2.0	2.5	4.5
Steer liveweight gain, post-weaning (kg/head.annum)	180	140	113	90
Steer turnoff age (months) and, in parentheses, liveweight (kg)	27 (495)	31 (474)	83% of year cohort: 29 (418); 17% of year cohort: 41 (414)	81% of year cohort: 29 (368); 19% of year cohort: 41 (388)
Target market for steers	Feed-on	Feed-on	Live export	Live export

[A]Median for the 30-year climate normal period (1961–1990) at Rolleston (Central Qld), Richmond (Northern Downs, Qld), Georgetown (Northern Gulf, Qld), and Katherine (Katherine region, NT) (BOM 2020).

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 sale age.

(1) Central Qld

The representative property was located centrally in the region, near Rolleston. The breeding herd utilised less productive, non-arable land types within the region (State of Queensland 2019), which were predominantly open eucalypt woodlands but were considered to be adequate in phosphorus (P) status (average >8 mg/kg bicarbonate-extracted P (Colwell 1963) in the top 100 mm of soil; McCosker and Winks 1994). The steers and heifers grazed more productive and arable Brigalow land types supporting sown buffel grass (*Cenchrus ciliaris*) pastures also adequate in P. A detailed description of the herd structures and dynamics, cattle management activities, treatments and cost assumptions required as inputs for the analysis are given in the final project report (Bowen and Chudleigh 2018).

(2) Northern Downs, Qld

The representative property was located near Julia Creek in north-western Qld. The cattle herd grazed primarily native Mitchell grass (*Astrebla* spp.) pastures on Open Downs and Ashy Downs land types (State of Queensland 2019), which were considered, on average, adequate in P (average >8 mg/kg bicarbonate-extracted P (Colwell 1963) in the top 100 mm of soil; McCosker and Winks 1994). The base property was considered to have a very low level of infestation with the woody weed prickly acacia (*Acacia nilotica* subsp. *indica*), except for the scenario where the economic consequences of prickly acacia control were examined. For the latter scenario, the modified base property was assumed to have the following areas of infestation severity: (1) 5%, high; (2) 15%, moderate; (3) 60%, low; and (4) 20%, very low infestation. The corresponding percentages of pasture production within each of these categories, expressed as % of potential production without prickly acacia infestation, were (1) 10%, (2) 50%, (3) 75%, and (4) 100%. An additional modified base property with a weaner steer turnoff production system, rather than the optimum age of sale at 31 months (Table 1), was used to demonstrate the value of selecting the optimal age of steer turnoff. A detailed description of the herd structures and dynamics, cattle management activities, treatments and cost assumptions required as inputs for the analysis are given in the final project report (Bowen *et al*. 2020*a*).

(3) Northern Gulf, Qld

The representative property was located near Georgetown in northern Qld. The cattle herd grazed low-productivity land types such as Sandy Forest, Range Soil and Sand Ridge (State of Queensland 2019), which were considered deficient in P (on average 4–5 mg/kg bicarbonate-extracted P (Colwell 1963) in the top 100 mm of soil; McCosker and Winks 1994). The entire cattle herd was fed recommended amounts of P supplement to address the deficiency. A detailed description of the herd structures and dynamics, cattle management activities, treatments and cost assumptions required as inputs for the analysis are given in the final project report (Bowen *et al*. 2019).

(4) Katherine region, NT

The representative property was located 600 km from Darwin and within 300 km of Katherine. Pastures were primarily native tropical tall grasses growing on acutely P-deficient soil types (2–3 mg/kg bicarbonate-extracted P (Colwell 1963) in the top 100 mm soil; acute P-deficiency category; McCosker and Winks 1994). The entire cattle herd grazed acutely P-deficient land types. The base herd received a low amount of P supplement that was included into non-protein-nitrogen dry-season supplements. A modified base herd, developed to assess the benefits of P supplementation, were not fed any supplements during either the wet or dry seasons. A detailed description of the herd structures and dynamics, and cattle management activities, treatments and cost assumptions required as inputs for the analysis are given in the final project report (Chudleigh *et al*. 2019*b*).

Alternative management strategies examined and the criteria used to compare the scenarios

Example management strategies of relevance to each region were modelled for each of the four beef cattle properties and targeted (1) overall herd or property performance, (2) breeder reproductive performance, (3) steer growth rates, (4) market alternatives, or (5) enterprise expansion (Table 2). All of the changes considered to the current management strategy of the base herd were put forward by experienced industry participants as potentially positive changes for herd and property efficiency.

The estimated effect of management strategies on property carrying capacity and on cattle liveweight, liveweight gain, mortality, conception and weaning rates were assigned with reference to published and unpublished research, as well as collation of expert opinion of beef producers, scientists and beef extension officers with extensive knowledge of the northern Australian cattle industry. For each representative property, equivalent grazing pressure was maintained for all scenarios by adjusting cattle numbers, as required. Key parameters are given in Table 2 and details of the assumptions and their derivations are given by Bowen and Chudleigh (2018) for Central Qld, Bowen *et al*. (2020*a*) for Northern Downs, Bowen *et al*. (2019) for Northern Gulf, and Chudleigh *et al*. (2019*b*) for the Katherine region. The full detail is not presented here; however, demonstrating the application of the farm-management economics framework to compare alternative strategies was the primary focus of the present paper rather than the absolute values of the outcomes. We advocate the application of this framework to consider alternative assumptions and strategies, other than those considered here, as new or alternative data become available and also to conduct analysis on an individual-property basis. In the present analysis, the assumptions for each scenario, including the scale and implementation of the strategy, varied for each region as considered most relevant and appropriate. For individual beef producers, comparison of relevant strategies within the region will be most relevant. Hence, differences among regions in assumptions were considered to be of lesser importance for the present study.

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). The IRR indicates the return on extra capital invested and the NPV represents the addition to the investors' current wealth above or below that which they would gain if they invested the capital involved in an alternative that earned at the real discount rate applied. 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:

$$\text{Operating profit} = (\text{total receipts} - \text{variable costs} \\ = \text{total gross margin}) - \text{overheads.}$$

Opening and salvage values for land, plant and livestock were applied at the beginning and end of the DCF 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 (hereafter, annualised) NPV was calculated at the discount rate over the investment period to assist in communicating the difference in returns between the baseline 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), that is, 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 that 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.

Results

The net profit per annum (undiscounted) for the representative base property in each region (Table 1) ranged from –AU$23 500 in the Northern Gulf to AU$673 000 in the Katherine region (Table 3). The modelled change in marginal returns (NPV and IRR) and the financial risk (peak deficit, years to peak deficit and payback period) of implementing the alternative management strategies for the base property in each of four regions are given in Table 3.

(1) Central Qld

In Central Qld, the strategy producing the greatest increase in whole-farm profit was that of establishing leucaena–grass pastures to run all steers from weaning to feed-on weight (feedlot entry; 495 kg liveweight), giving AU$46 100 extra profit/annum, 37% IRR (for comparable results, see Bowen and Chudleigh (2019)). However, financial risk was also increased substantially, as indicated by the peak deficit of –AU$190 500 and the 7 years until the investment was paid back. The strategies of (1) converting the *B. indicus* crossbred herd to Wagyu genetics, while assuming that price premiums were reduced from Year 10, (2) growing forage oats for steers, and (3) supplementing first-calf heifers to improve

Table 2. An overview of the management strategies that were modelled for one or more of four representative beef cattle enterprises (Central Queensland (C-Q), Northern Downs of Queensland (ND-Q), Northern Gulf of Queensland (NG-Q), Katherine region of the Northern Territory (K-NT))

These strategies are described in detail in Bowen and Chudleigh (2018) for C-Q, Bowen *et al*. (2020*a*) for ND-Q, Bowen *et al*. (2019) for NG-Q and Chudleigh *et al*. (2019*b*) for the K-NT. HGP, hormonal growth promotant; N, nitrogen; P, phosphorus

Management strategy	Summary and key parameters affected by implementation of the strategy
	(1) Overall herd or property performance
P supplementation, entire herd (K-NT)	Year-round supplementation of entire herd (which is currently receiving no P) with loose supplement mix containing inorganic P (and N in dry season) to increase breeder and steer growth rates (by 38%), increase weaning rate (by 10 percentage points) and reduce breeder and steer mortality rate (by 7 percentage points)
Herd segregation, AU$100 000 capital expenditure (K-NT)	Segregation and targeted management of breeders based on lactation and pregnancy status to reduce breeder and steer mortality rates (by 6–7 percentage points) and reduce supplementation costs for retained females >2 years by 10% and labour costs by 5%
Home-bred bulls (NG-Q, K-NT)	Objective selection of home-bred bulls, instead of purchasing bulls, so that bull to cow mating ratio was maintained and no aspect of herd performance (reproduction or growth) was changed
Managing prickly acacia (*Acacia nilotica* subsp. *indica*), property level (ND-Q)	Property-level prickly acacia control to prevent decline in property carrying capacity where 80% of the property area has some level of infestation categorised as 'low' or greater, and assuming 5 years before the onset of a sequence of wet years capable of causing the rapid increase of prickly acacia
Converting from breeding to steer turnover (ND-Q)	Transition from a breeder operation to one that purchases 6-month (weaner) steers with turnoff (sale) at 31 months
	(2) Breeder reproductive performance
Genetic improvement of weaning rate (C-Q, NG-Q)	Existing herd bulls were replaced over time following the normal replacement schedule but with bulls that provided a 6 percentage-point improvement in breeder weaning rates and which were purchased at the same price as regular bulls
Supplementing first-calf heifers (C-Q, NG-Q, K-NT)	An energy and protein supplement (relevant to region) was fed to first-calf, lactating heifers to improve their liveweight and hence re-conception rate by 2 (C-Q), 6 (NG-Q) and 6 (K-NT) percentage points, respectively
	(3) Steer growth rates
Establishing leucaena (*Leucaena leucocephala* subsp. *glabrata*)-grass pastures for all steers (C-Q)	Increasing steer growth rates by planting sufficient area (433 ha) of the tree legume, leucaena, into strips of existing buffel grass (*Cenchrus ciliaris*) pastures to run all steers from weaning and achieve turnoff 6 months earlier at the same target feed-on weight
Establishing stylo (*Stylosanthes* spp.)-grass pastures (NG-Q, K-NT)	Increasing steer growth rates (by 40% NG-Q, 27% K-NT) by establishing the shrubby legume, stylo, into existing native grass pastures (500 ha NG-Q, 7100 ha K-NT)
Forage oats for all steers (C-Q)	Growing sufficient forage oats (160 ha; possible in 67% of years) to run all steers in their 2nd dry season after weaning to increase growth rates and achieve turnoff 5 months earlier at the same target feed-on weight
Molasses production mix for steer tail (NG-Q)	Annual supplementation of the tail (lower liveweight group) of the steer cohort (17% of all steers) a molasses production mix for 90 days to increase their liveweight by 63 kg
Concentrate feeding the steer tail (K-NT)	Annual supplementation of the tail (lower-liveweight group) of the steer cohort (19% of all steers) a concentrate ration for 150 days to increase liveweight by 54 kg
Silage for all steers (NG-Q)	Growing forage sorghum annually to produce sufficient silage to feed all steers for 90 days from 18 months (308 kg liveweight) to increase liveweight by 108 kg
HGP for all steers (ND-Q)	Provision of HGP to all steers continuously from weaning until sale as feed-on steers to increase growth rates (by 10%), sale weight (by 6%) and feed conversion efficiency (by 4.5%) with either no price penalty or $0.10/kg price penalty
	(4) Market alternatives
Increasing age of steer turnoff from weaners to the optimal of 31 months (ND-Q)	Restructuring the herd to move from sale of 6-month (weaner) steers to the optimal of age of turnoff for this region (31 months) while maintaining equivalent grazing pressure
Organic beef (C-Q)	Selling all steers and cull heifers into the certified organic beef market by removing chemical control of parasites and supplementation, but reducing grazing pressure by 20% so that overall herd-productivity parameters remained unchanged
Wagyu beef, price premium reduces from Year 10 (C-Q)	Converting a *Bos indicus* crossbred, breeding herd to Wagyu genetics over time by replacing the current herd bulls with full-blood Wagyu bulls so that 100% price premiums were received in Year 7 of the transition, but reduced back to 0% price premium over 6 years from Year 10
	(5) Enterprise expansion
Purchasing a breeder property in Northern Gulf with transfer of weaners to Northern Downs property (ND-Q)	All weaners produced from the Northern Gulf property transferred to Northern Downs property which reduced breeder numbers to accommodate the extra steers
Purchasing a breeder property in Northern Gulf and managing it independently of Northern Downs property (ND-Q)	Northern Gulf property and Northern Downs property run as separate entities, each with the age of steer turnoff considered representative for their region (Table 1)

Table 3. Profitability and financial risk of implementing alternative management strategies for representative beef cattle enterprises in (1) Central Queensland, (2) Northern Downs of Queensland, (3) Northern Gulf of Queensland, and (4) Katherine region of the Northern Territory

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. 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, that is, the rate of return on the additional capital invested. It is a discounted measure of project worth. n/c, not calculable; P, phosphorus

Strategy	NPV of change (AU$)	Annualised NPV (AU$)	Peak deficit (with interest) (AU$)	Years to peak deficit	Payback period (years)	IRR (%)
Central Queensland (*base property net profit: AU$110 000*)						
Leucaena for all steers	$709 200	$46 100	–$190 500	4	7	37
Organic beef	$37 400	$2400	n/c	n/c	n/c	–0.28
Genetic improvement of weaning rate	$10 500	$700	–$900	6	9	n/c
Supplementing first-calf heifers	–$148 900	–$9700	–$416 300	Never	Never	n/c
Forage oats for all steers	–$530 700	–$34 500	–$1 544 300	Never	Never	n/c
Wagyu beef, price premium reduces from Year 10	–$646 700	–$42 100	–$1 927 500	Never	Never	n/c
Northern Downs, *Queensland* (*base property net profit: AU$184 000*)						
Managing prickly acacia, property level	$1 987 300	$129 300	–$1 328 300	4	13	13
Increasing age of turnoff from weaners to 31 months (the optimal)	$1 100 900	$71 100	–$122 100	2	2	n/c
Converting from breeding to steer turnover	$961 500	$62 500	–$576 700	2	9	18
Hormonal growth promotant for steers						
Same price, heavier weight	$145 400	$9500	–$12 700	2	3	67
10 c/kg penalty, heavier weight	–$80 000	–$5200	–$223 300	Never	Never	n/c
Purchasing a breeder property in Northern Gulf and running it separately to Northern Downs property	–$3 911 200	–$254 400	–$13 716 600	Never	Never	–0.06
Purchasing a breeder property in Northern Gulf with transfer of weaners to Northern Downs property	–$4 238 800	–$275 700	–$14 658 000	Never	Never	–0.40
Northern Gulf, *Queensland* (*base property net profit*: *–AU$23 500*)						
Stylo for steers, 500-ha paddock	$266 000	$17 300	–$92 700	6	9	20
Home-bred bulls	$255 400	$16 600	–$25 000	2	3	59
Genetic improvement of weaning rate	$103 900	$6800	n/c	Never	Never	n/c
Supplementing first-calf heifers	–$53 500	–$3500	–$147 000	Never	Never	n/c
Molasses production mix for steer tail	–$90 500	–$5900	–$252 500	Never	Never	n/c
Silage for all steers	–$282 300	–$18 400	–$784 000	Never	Never	n/c
Katherine region, *Northern Territory* (*base property net profit: AU$673 000*)						
P supplementation, entire herd	$5 106 300	$332 200	–$328 300	1	2	152
Herd segregation, AU$100 000 capital	$2 843 400	$185 000	–$100 000	1	1	235
Stylo for all steers	$2 282 500	$148 500	–$506 100	8	11	n/c
Home-bred bulls	$424 600	$27 600	–$78 400	2	3	40
Concentrate feeding the steer tail	–$479 100	–$31 200	–$1 344 300	Never	Never	n/c
Supplementing first-calf heifers	–$1 075 700	–$70 000	–$3 001 500	Never	Never	n/c

re-conception rates resulted in decreases in profitability (AU$42 100, AU$34 500 and AU$9700 less profit/annum respectively) and the investments were not paid back within the 30-year analysis period. The strategies of (1) genetic improvement of weaning rate and (2) targeting the organic beef market were unlikely to make a measurable difference to whole-farm profitability, being less than ±AU$5000/annum.

(2) Northern Downs of Qld

In the Northern Downs region of Qld, the most profitable management strategy for the base property with very low prickly acacia infestation, and with the optimal age of steer turnoff, was to convert from a breeding and growing property to a steer turnover property, resulting in AU$62 500 extra profit/annum and 18% IRR. However, the peak deficit for investment in this strategy was –AU$576 700, and it took 9 years until the investment was paid back. Utilising hormonal growth promotants to increase growth rates of steers resulted in either a small increase (AU$9500/annum) or decrease (–AU$5200/annum) in profit, depending on whether a price penalty was applied. Purchasing a breeder property in the Northern Gulf region of Qld had a substantial negative effect on profit regardless of whether it was integrated with the Northern Downs property or run separately, resulting in at least AU$250 000 less profit/annum.

Property-level control of prickly acacia where 80% of the modified base property had various levels of infestation ranging from low to high, and assuming 5 years before the onset of wet years capable of causing rapid increase in prickly acacia, resulted in a very substantial increase in profit (AU$129 300 extra profit/annum and 13% IRR), but required >AU$1.3 million to be invested over the first 4 years of treatment. When the base property was assumed to have an existing weaner turnoff (sale) target and then converted to the optimal age of turnoff of 31 months, profit was increased by AU$71 100/annum.

(3) Northern Gulf, Qld

In this region, the management strategies showing the best return were (1) establishing a 500-ha paddock of stylo to increase steer growth rates and (2) converting to use of home-bred bulls, resulting in AU$17 300 and AU$16 600 extra profit/annum respectively. While both of these strategies resulted in a similar increase in profit per annum, the stylo strategy added a greater financial risk than did converting to home-bred bulls, with 3.7 times the peak deficit and 3 times the payback period (9 cf. 3 years). Producing forage sorghum silage for on-farm feeding to increase steer growth rates resulted in a substantial decrease in profit of AU$18 400/annum. The strategy of (1) genetic improvement of weaning rate resulted in a small positive increase in profit (AU$6800/annum), while (2) feeding a molasses production mix on an annual basis to the lower-liveweight group of the steer cohort (the steer tail) resulted in a small reduction in profit (–AU$5900/annum). Supplementing first-calf heifers to improve re-conception rates made no measurable difference to the whole-farm profitability, being less than ±AU$5000/annum.

(4) Katherine region, NT

Effective P supplementation of the acutely P-deficient base cattle herd that was being fed no P supplement resulted in the greatest potential benefit of all strategies examined for the Katherine region, namely, AU$332 200 extra profit/annum, 152% IRR (for comparable results, see Bowen *et al*. 2020*b*). This strategy had a short payback period of 2 years, but resulted in a substantial peak deficit (–AU$328 300). The strategies of (1) segregation and targeted management of breeders on the basis of lactation and pregnancy status requiring investment of AU$100 000 capital, and (2) establishing sufficient stylo pastures to increase growth rates of all steers, also had very substantial positive effects of AU$185 000 and AU$148 500 extra profit/annum respectively, but with stylo pastures resulting in a longer payback period (11 cf. 1 year). Converting to the use of home-bred bulls had a lesser, but positive, effect of AU$27 600 extra profit/annum. Profit was reduced as a result of supplementing first-calf heifers or an annual strategy of feeding concentrates to increase the sale weight of the lower-liveweight group of steers (the steer tail), resulting in AU$70 000 and AU$31 200 less profit/annum respectively.

Discussion

The present study has demonstrated the application of the farm-management economics framework to assess alternative management strategies (as outlined in Table 2) applicable to beef enterprises in northern Australia. This framework applies a marginal, whole-farm perspective and incorporates the additional capital required, the effect on herd structure, the implementation phase, the timing of costs and benefits, the economic life of the investment and an initial assessment of the financial risks associated with each change in management. Our study demonstrated that a variety of alternative management strategies can be satisfactorily compared and ranked for efficiency and risk as a first step in considering a change in management strategy. Whereas others have applied the same framework to consider questions generally for individual representative farms or closely related farms (e.g. Foran *et al*. 1990; Lewis *et al*. 2012; Malcolm *et al*. 2012; Sinnett *et al*. 2019), our study applied the framework and process to a wide range of representative beef properties across disparate regions of northern Australia, which enabled identification of key strategies that consistently improved or reduced profitability across the north.

The farm-management economics framework efficiently identified substantial differences in net benefits among strategies and allowed ranking of the alternatives at the property level (Table 3). Several strategies had an effect on annual enterprise profit that was considered unmeasurable (less than ±AU$5000), that is, less than the error of the prediction, while several previously favoured strategies were likely to cause substantial decreases in annual enterprise profit. However, within each region, strategies were identified that could substantially improve profit compared with the base property net profit per annum (undiscounted), which ranged from –AU$23 500 for the Northern Gulf to AU$673 000 for the Katherine region property. However, strategies that substantially improved profit also generally increased management complexity and risk. For example, property-level control of the exotic woody weed, prickly acacia, in the Northern Downs resulted in positive returns of 13% IRR, but required >AU$1.3 million to be invested over the first 4 years of treatment. This would be beyond the capacity of the constructed property to fund, given the base property net profit of AU$184 000/annum (undiscounted), indicating that a staged implementation of control would be more appropriate.

In the three low-productivity environments of the Northern Downs, Northern Gulf and Katherine region, several well established strategies were examined to improve the overall herd performance (Table 2). These included effective P supplementation where appropriate, herd segregation, use of home-bred bulls and converting from a breeding to a steer turnover operation, all of which improved profit (IRR 18–235%). These results are in agreement with previous analyses of development strategies to improve overall herd performance for extensive, low-productivity beef properties in northern Australia (Foran *et al*. 1990; Stockwell *et al*. 1991; Walsh and Cowley 2016). The present study also considered purchase of an additional breeder property as a strategy to increase the overall enterprise profitability for the Northern Downs region. This strategy had a negative effect on the total enterprise profit, regardless of whether the purchased property was managed separately or integrated with the Northern Downs property (IRR –0.06% and –0.40% respectively). The negative result was caused by the recent, and apparently ongoing, escalation in grazing property capital values, combined with decoupling of asset values and rates of return on investment (McCosker *et al*. 2010; McLean *et al*. 2014). This suggests that building business resilience in the future through an increase in the size of the grazing property holdings in northern Australia is likely to be more risky than it has been in the past.

The present study showed that the strategy to improve reproductive efficiency of breeders through genetic gain (Table 2) resulted in either no measurable change (less than ±AU$5000 profit/annum) in the high-productivity Central Qld region or only a small positive change (AU$6800 extra profit/annum) in the low-productivity Northern Gulf environment. This is in contrast to the results of Ash *et al*. (2015) who reported substantial increases in enterprise profit from strategies to improve reproductive efficiency of breeders through genetic gain. However, the analysis of Ash *et al*. (2015) did not incorporate the implementation phase required for each of the scenarios. The poor economic performance of the improved breeder genetics strategy in our study was partly due to the extended interval of time before the improved genes predominated in the herd and also due to herd structural changes caused by the implementation of the strategy, leading to diminishing returns (see Chudleigh *et al*. 2019*a*).

The importance of incorporating the implementation phase in any analysis of change in the management of beef properties in northern Australia has been clearly demonstrated in the studies of Chudleigh *et al*. (2017, 2019*a*). These studies highlighted the importance of appropriately modelling the steps in moving from an existing herd structure and target to a new target and, consequently, a different herd structure, when implementing alternative management strategies. Additionally, the studies of Chudleigh *et al*. (2017, 2019*a*) identified the critical importance of correctly incorporating any change in the timing and/or amount of benefits and costs when implementing strategies to improve the economic performance of breeding herds run under extensive grazing conditions in northern Australia.

Another strategy for improving breeder reproductive performance, by supplementing first-calf heifers, also resulted in either unmeasurable (Northern Gulf; less than ±AU$5000/annum), small-negative (Central Qld; –AU$9700 profit/annum) or large-negative (Katherine region; –AU$70 000 profit/annum) effects on enterprise profit. The poor economic outcome of the two strategies examined in the present study to improve breeder herd efficiency highlighted the critical importance of implementing low-cost strategies, such as optimising herd structure, as approaches to improve profitability. Selecting the appropriate age for heifer and breeder-cow culling, and steer sale, can improve the profitability of a beef property, as well as mitigating drought risk. Optimising herd structure reduces drought risk through (1) a lower number of breeders requiring supplementation, (2) a reduced proportion of breeders at risk of mortality during drought, and (3) improved flexibility if forced sale of part of the herd is required. This has been shown to be universally important across northern Australia's grazing regions (Chudleigh *et al*. 2017, 2019*b*; Bowen and Chudleigh 2018; Bowen *et al*. 2019, 2020*a*).

Introducing perennial legumes (leucaena and stylos) to established grass pastures so as to improve steer growth rates was a consistently profitable strategy (IRR up to 37%) across relevant regions (Central Qld, Northern Gulf and Katherine region). Although Ash *et al*. (2015) did not include the implementation phase in their analysis, their results are in accord with our conclusion that establishing perennial legumes into pastures systems is one of the more profitable strategies for beef enterprises in northern Australia. The agreement of the two reports is not unexpected, given that the implementation phase for the legume scenarios examined in our work was short in the context of a 30-year analysis (2–3 years). However, in ignoring the implementation phase, the study of Ash *et al*. (2015) did not identify the financial deficit and risks associated with establishment failure when establishing perennial legumes into beef productions systems. Consideration of these aspects in our study highlighted the importance of staggering legume plantings over time and across the property to minimise the inherent risks of this strategy.

In the present study, other strategies that improved steer growth rates (annual forage crops, silage or production feeding; Table 2) caused substantial decreases in annual profit (up to AU$35 000 less profit/annum). These conclusions are in contrast with those of Bell *et al*. (2014) and Hunt *et al*. (2014), which indicated potentially large economic benefits from utilising small areas of irrigated annual forages as part of beef production systems in northern Australia; however, again, the latter studies did not consider the implementation phase for these forage strategies, the additional capital required or its opportunity cost. These are all essential and established aspects of appropriate farm-management economic analysis (Malcolm *et al*. 2005).

The present study clearly showed that increased cattle production in response to a management strategy does not always lead to a profitable outcome for the beef enterprise. This finding is in accord with the principle that the most profitable level of output is achieved when marginal cost almost equals marginal revenue, but never when production is maximised (Malcolm *et al*. 2005). Farm-management economic principles indicate that profit is the true measure of economic performance and that appropriate decision-making frameworks are about considering the future, not the past. Despite these established principles, there has been a recent tendency for agencies funding and/or providing industry research and extension activities to look for more simple 'indicators', produced via analysis of historical data, to rank strategies. These indicators include technical efficiency measures and benchmarks of production and financial parameters, including cost-of-production calculations. This issue has been identified and discussed in detail by others, including Campbell (1944), Mauldon and Schapper (1970) and Malcolm (2004*a*, 2004*b*). These authors (and numerous others cited therein) have demonstrated that such efficiency ratios or benchmarking activities are of little use in indicating the effect of alternative management options on the whole-farm profitability, or in planning, budgeting or diagnosing strengths and weaknesses. They also give inaccurate and misleading ranking of strategies for their effect on farm profitability. We repeat the assertion made previously in our reports (e.g. Chudleigh *et al*. 2017, 2019*a*) and by others (e.g. Stafford Smith and Foran 1988; Ferris and Malcolm 1999) that good-quality science must be paired with equally sound economic methods to ensure that appropriate conclusions are reached about the value of technology and management strategies to beef producers and the industry. For new or developing technologies, appropriate economic modelling incorporating sensitivity analysis can indicate the required change in biological performance, or cost of implementation, at which the technology would become economically viable and hence indicate whether further research to develop the technology is worthwhile. A proposed agricultural research activity can establish criteria for success prior to funding that can be tested for sensibility and expected benefits using the farm management economics framework. Such economic analyses should be re-visited regularly as more or better research data becomes available for a technology.

Targeting alternative markets (organic beef or Wagyu genetics), or strategies that affected market access (e.g. hormonal growth promotant; Table 2), had variable effects in the present study depending on price assumptions. An important general consideration is that production systems that reduce management flexibility over the longer term are inherently less responsive and are, therefore, likely to expose the property to greater variation in returns, which was also an aspect highlighted by Stockwell *et al*. (1991). Nevertheless, the benefit in targeting the optimal age of steer turnoff for each property was clearly demonstrated for the Northern Downs property, where increasing the age of turnoff from weaners (6 months) to 31 months (the optimal) improved profit by AU$71 100/annum. This strategy can also improve drought resilience due to a reduction in the size of the breeder herd relative to growing cattle at the same grazing pressure. However, an important consideration is that the implementation of this strategy will cause a substantial peak deficit (–AU$122 100 in Year 2), which would create a barrier to management change that would be difficult for some enterprises to overcome.

The present study indicated that capital constraints and perceived risks are likely to play a critical role in the level and rate at which a change in management strategy is likely to be adopted and implemented. Applying a method that appropriately highlights the financial risks associated with the implementation of a management strategy, as well as the potential economic benefits, is necessary to assist understanding of the nature of the alternative investments. This assertion was also made by Foran *et al*. (1990) who concluded that the whole-of-property approach incorporating farm-management economic principles is essential for both comparing management options and for setting priorities for research and development in the northern beef industry.

An extended range of management strategies for these same beef producing regions, beyond those discussed herein, have been analysed and documented in a series of reports (Bowen and Chudleigh 2018; Bowen *et al*. 2019, 2020*a*; Chudleigh *et al*. 2019*b*). These reports, as well as the current study, have indicated that a wide range of management strategies is available for consideration by northern beef producers and that examining one possible strategy in isolation does not identify the relative benefits compared with other alternatives. Furthermore, many of the strategies can be implemented simultaneously and are complementary. For example, in the Katherine region, the combination of appropriate P supplementation, herd segregation, objective selection of home-bred bulls, and establishing stylo pastures for steers could make a substantial difference to the economic performance of the base property. The farm-management economics framework demonstrated in the present study can be readily applied to assess the combined benefits of such complementary strategies for a particular property.

In the present study, the biological parameters required as inputs for the analysis were derived from empirical data and expert opinion of experienced beef producers, scientists and extension officers. The assumptions for the scenarios, including the scale of the strategies and how they were implemented, varied for each region, with consideration of local factors as being relevant and appropriate. This is considered a strength of the present study as comparison and ranking of relevant strategies for a representative property within localised regions provides a better guide for decision making for an individual enterprise than does comparison across regions. Our focus in the present study was on identifying alternative strategies to improve efficiency and resilience. This requires that the farm-management economics framework be applied at the property level to identify the extra costs and extra returns of change for beef enterprises. Such analyses should consider the goals of the producer and, wherever possible, incorporate assumptions of potential productivity responses from relevant research and the experience of local producers and advisors. We argue that, for this purpose, it is not necessary to describe the full range of potential outcomes or variability of the production system in detail in the model; it is necessary to identify only a 'best-bet' range of parameters on the basis of the local knowledge of experienced property managers, beef extension officers and scientists. This same assertion has been made by others, including Malcolm (2000). Our experience was that the conversation with industry participants, to describe what the 'best-bet' parameters might be that adequately capture the variability likely to be experienced by the representative property, is a key component of model development. We concluded that the learning and shared understanding of all industry participants, which resulted from the discussion to set appropriate values for the key parameters, was much more valuable than focussing on the minutiae of the modelling process and capturing the expected full range of variability of outcomes. The beef property manager considering change can then apply the insights from the models, and with consideration of their goals, can determine whether a more detailed investigation of strategies for their circumstance is needed.

In conclusion, the present study (1) demonstrated an appropriate economics framework to compare management options and support decision making, (2) efficiently indicated the potential range of outcomes, and (3) provided insight into the risks associated with development processes and technology adoption. The freely available BCD software can be used to assess alternative strategies for individual beef enterprises and to guide investment decisions.

Conflicts of interest

The authors declare no conflicts of interest.

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