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The effect of earlier mating and improving fertility on greenhouse gas emissions intensity of beef production in northern Australian herds

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Abstract. Approximately 5% of Australian national greenhouse gas (GHG) emissions are derived from the northern beef industry. Improving the reproductive performance of cows has been identified as a key target for increasing profitability, and this higher efficiency is also likely to reduce the GHG emissions intensity of beef production. The effects of strategies to increase the fertility of breeding herds and earlier joining of heifers as yearlings were studied on two properties at Longreach and Boulia in western Queensland. The beef production, GHG emissions, emissions intensity and profitability were investigated and compared with typical management in the two regions. Overall weaning rates achieved on the two properties were 79% and 74% compared with typical herd weaning rates of 58% in both regions. Herds with high reproductive performance had GHG emissions intensities (t CO_2-e t^{-1} liveweight sold) 28% and 22% lower than the typical herds at Longreach and Boulia, with most of the benefit from higher weaning rates. Farm gross margin analysis showed that it was more profitable, by \$62 000 at Longreach and \$38 000 at Boulia, to utilise higher reproductive performance to increase the amount of liveweight sold with the same number of adult equivalents compared with reducing the number of adult equivalents to maintain the same level of liveweight sold and claiming a carbon credit for lower farm emissions. These gains achieved at two case study properties which had different rainfall, country types, and property sizes suggest similar improvements can be made on-farm across the Mitchell Grass Downs bioregion of northern Australia.

Additional keywords: carbon farming, grazing systems, rangelands, tropical pastures.

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Introduction

The northern Australian beef industry has ~16 million head of cattle (Australian Bureau of Statistics 2014) with an estimated farm-gate value of \$3.7 billion AUD (Gleeson *et al*. 2012). The industry covers Queensland, the Northern Territory and the northern half of Western Australia, and is based predominantly on tropical native pastures. Rainfall across northern Australia is summer dominant, higher along the coastal margins and declining towards the interior, with the bulk of pasture growth occurring from December to March (Fitzpatrick and Nix 1970). Soils range from low-fertility, fragile sands through to high-fertility, stable clays. As a consequence, stocking rates range from 10 ha through to over 40 ha per adult equivalent (AE, a 450-kg dry beast at maintenance) between regions. Forage digestibility is generally low outside the growing season i.e. for the majority of the year, with digestibility, crude protein content and metabolisable energy declining as the non-growing season progresses (Dixon and Coates 2010).

Globally, enteric methane (CH_4) generated from livestock production systems accounts for 39% of anthropogenic CH_4 emissions (Lassey 2007). In Australia enteric CH_4 from livestock accounts for ~10% of national greenhouse gas (GHG) emissions (DCCEE 2012) and with ~60% of the beef cattle herd located in the north (Gleeson *et al*. 2012), this region is a major source of CH_4 in Australia.

The management of the northern beef industry grazing systems is highly variable across the region (McLean *et al*. 2014). In beef production systems, several management options have been identified that have the potential to increase the efficiency of production and reduce GHG emissions from the herd, including improving weaning rates, earlier mating of heifers, and increasing daily weight gain (Bentley *et al*. 2008; Eckard *et al*. 2010). The reductions in total emissions, or emissions intensity of production (t CO_2-e t^{-1} liveweight sold), that may be achieved by adopting these strategies are related to having fewer unproductive livestock on the property (i.e. cows and heifers that do not have a calf) and reducing the time to achieve market weight. For example, Bentley *et al*. (2008) reported a 31% reduction in the emissions intensity of beef weaner production by genetic improvement resulting in both higher weaning rates and calf liveweight at weaning.

Industry statistics suggest that weaning rates across the northern beef industry averaged 71% in 2010–2011 (Thompson and Martin 2012) whereas a survey by Bortolussi *et al*. (2005*a*) in central-western Queensland suggested that 30% of properties had 5-year average branding rates of <65%. In a recent study on commercial herds in the Northern Downs region, weaning rates on the lowest quartile of properties were <57% whereas the upper quartile of properties recorded weaning rates >78% (Fordyce *et al*. 2013). In the study by Bortolussi *et al*. (2005*a*) higher weaning rates were generally associated with cross-bred and composite breeds, and more intensively managed herds.

The reproductive efficiency of a beef herd is influenced by the age at which heifers reach puberty and have their first calf. Earlier calving heifers will produce more calves over their lifetime (Burns *et al*. 2010). In the northern beef industry the majority of heifers are joined at ~2 years of age and have their first calf at 2–3 years of age, with the remainder joined at ~3 years (Bortolussi *et al*. 2005*a*). However, attainment of puberty can occur from 13 to 40 months for Brahman and 11 to 31 months for tropical composite breeds in northern Australia (Johnston *et al*. 2009). Schatz *et al*. (2010) demonstrated that yearling-mated Brahman heifers could achieve pregnancy rates of 50–79% under more controlled management. Reduced age at first joining has been shown to decrease the GHG emissions intensity of production in self-replacing sheep systems (Alcock and Hegarty 2011), and similar findings could be expected for beef breeding herds.

Increasing the daily liveweight gain of steers will allow target sale weights to be achieved earlier. On commercial properties, significant variation exists in annual liveweight gain, with Bortolussi *et al*. (2005*b*) reporting mean liveweight gain of 153 kg year^{-1} but a range of 112–203 kg year^{-1} on Mitchell grass landtypes in central-western Queensland. There is evidence that increases in liveweight gain can be achieved by adopting cross-bred and composite breeds, which have reported average liveweight gain advantages of 10% (range 0–21%) compared with purebreds in the northern industry (Bortolussi *et al*. 2005*b*).

Liveweight gains from Mitchell grass landtypes depend on the availability of higher quality plant species and digestible plant components (Lorimer 1981; Orr *et al*. 1988). The biomass within these land types is dominated by perennial tussock grasses, with annual grasses and broad-leaf herbages growing between tussocks contributing high quality but low biomass forage (Orr and Holmes 1984). Both pasture biomass and composition are important factors in annual liveweight gain and interact with stocking rate (Holechek *et al*. 1982; Hunt *et al*. 2014). Biomass declines gradually as the dry winter period progresses through detachment (Pakiding and Hirata 2001) with consumption through grazing the main determinant of this rate (Orr and Phelps 2013). Mitchell grass pasture quality declines only gradually over the dry season from weathering, due to unfavourable conditions for decomposition of standing material (Orr and Holmes 1984). Resting pastures over the wet season and forage budgeting into the dry season can help to retain higher quality components such as dry Mitchell grass leaf and herbages that provide cattle with a higher quality diet during the dry season, thus minimising liveweight losses before the flush of new pasture growth once summer rains begin (Phelps 2012). Pastures can thus be managed to maximise the liveweight gains of heifers or to hold the condition of pregnant and lactating breeders, and contribute to earlier joining and higher weaning rates.

As evidenced by the range of reported weaning rates, heifer age at first joining and animal liveweight gain across the northern beef industry, large potential exists for improvements in the efficiency of these production systems through more intensive grazing management, breeding and genetic selection. With these improvements the GHG emissions intensity of production may also be significantly lowered. The aim of this study was to investigate the changes in production, GHG emissions, emissions intensity and profitability from beef herds managed to achieve high reproductive performance and growth rates, and compare it to herds more typical of the region, using two case studies in western Queensland. The herds were compared under two scenarios, first with equal number of AE and second, with equal liveweight sold.

Materials and method

Property and herd characteristics

Two case study properties were modelled in the Mitchell Grass Downs bioregion of western Queensland, with different land types, average rainfalls and property size. The properties were selected because the farm managers had made significant changes to herd reproductive management compared with what would be considered typical for their regions. At both properties this involved selection of animals for higher weaning rates and early joining of heifers as yearlings. On each property three herd structures were modelled covering a range of herd reproductive management outcomes from what is considered typical of the region to the improved management carried out on the case study properties.

The Longreach property was 23 000 ha and located within the Mitchell Grasslands (Orr and Holmes 1984), 65 km south of Longreach (23.44°S, 142.25°E), in central-western Queensland, Australia. The region has a summer-dominant rainfall pattern. Mean annual rainfall (1970–2012) was 435 mm and is highly variable, ranging from 107 to 886 mm over the same period (Bureau of Meteorology 2013). The property can carry ~1750 AE. Farm records from the property were used to document the current herd structure, including number of animals mated, weight and age of breeders, weaning percentages, and beef turn-off times and sale weight.

The Boulia property was 81 760 ha located within the northern end of the channel country (White 2001), 10 km east of Boulia (22.57°S, 139.55°E). The region has an arid environment with a summer-dominant rainfall pattern. Mean annual rainfall (1970–2012) was 278 mm and is highly variable, ranging from 81 to 774 mm over the same period (Bureau of Meteorology 2013). The property can carry ~1842 AE.

On both case study properties herd reproductive management was atypical for that region. In each case, management changes had been adopted over the previous decade that allowed joining heifers as yearlings rather than at 2 years of age, and selection for improved reproductive performance as measured by weaning rate. Farm records from the case study property before management changes, together with expert opinion, were used to develop herd structures that reflected typical management in the region. In addition, a herd structure was simulated that had intermediate reproductive performance by introducing early joining at Longreach and increased weaning rates (high fertility) at Boulia. This approach was taken to determine whether earlier joining or increased weaning provided most of the gains.

The basis for the three herd structures modelled on each farm were as follows:

(1) 'Typical herd' (TH) – a Brahman breeder herd with average management for the region, where heifers were first mated at 2 years.

(2) 'Early joining' (EJ, Longreach only) or 'High fertility' (HF, Boulia only) – on the Longreach property, EJ was modelled with a Brahman breeder herd where heifers were first mated at 1 year of age, compared with average management for the region, where heifers were first mated at 2 years. At the Boulia property, HF was modelled with a Brahman breeder herd selected for improved reproductive performance, where heifers were first mated at 2 years of age.

(3) 'Early joining and high fertility' (EJ-HF) – on both properties a combination of joining at 1 year of age and selection for increased weaning rate was modelled, based on farm records. At Longreach this was achieved with a composite breeder herd (Brahman, Charolais, Angus) with heifers first mated at 1 year of age and improved management to enhance reproduction rates and liveweight gain. The key animal management differences were the use of cross-breeding with low birthweight Angus bulls to increase weaning rates from heifers, and selection for cows with higher reproductive performance by culling based on pregnancy testing. Hybrid vigour, although not F_1 hybrids in all cases, further contributed to higher steer growth rates and consequent liveweight at sale. Pasture management incorporating forage budgeting to match stocking rates with available feed, annual land condition assessments and wet-season rest were incorporated to improve forage availability and the pasture-based nutrition.

At Boulia, EJ-HF was achieved with a Brahman breeder herd by culling cows that were not pregnant and did not have a calf at foot. The same improved pasture management practices as the Longreach property were implemented, with wet-season rest specifically used to provide the best possible forage quality for breeders with calves at foot during the non-growing season. Over the growing season, the best available forage based on response to rainfall was reserved for the weaner heifers to achieve early joining.

On each property similar patterns of seasonal management were applied in all three herd structures. At Longreach the peak calving was in December. Mortality rates were assumed to be 1.5% and 2% per year for male and female animals, respectively. The key assumptions about liveweight at joining and weaning percentage for each of the livestock classes in each of the herds are listed in Table 1. In the TH and EJ herds, liveweight and weaning percentages were similar except that yearling heifers in the EJ herd had lower weaning percentages. In the EJ-HF herd the management changes outlined above resulted in higher weaning percentages across all livestock classes. The hybrid vigour associated with cross-breeding further contributed to higher liveweight of yearling heifers at joining and high weaning percentages. The selling policies for livestock are outlined in Table 2. In each of the herd structures, 89% of steers were sold at 18 months of age with 11% carried over to the following year. Liveweight at sale for steers sold at 18 months in the TH and EJ herds were lower than the EJ-HF herd reflecting the contribution of cross-breeding to higher rates of liveweight gain. Heifers that were not required to maintain breeder herd numbers were sold after the first joining in TH and EJ-HF herds, with some sold after the first and second joining in the EJ herd. Mature cows were sold as 'not in calf' or 'cast for age' at 12 years.

At Boulia, peak calving occurred in February. Mortality rates were assumed to be the same as at Longreach. Liveweight at joining and weaning percentage for each of the livestock classes in each of the herds are listed in Table 1. Selection of cows based on pregnancy testing was the basis of the improved weaning rates compared with TH. Steers were sold either at 14 months (30% steers) or 38 months (70% steers), with liveweight at sale shown in Table 2. Surplus heifers were sold at 20 months, with mature cows sold as 'not in calf' or 'cast for age' at 10 years.

Modelling tools and approaches

The herd structures on each case study property were simulated in Breedcow version 6.0 (Holmes 2012). This spreadsheet was used to ensure the herd dynamics were captured and for calculation of total stocking rate. The case study approach was based on average performance of each of the herds across years

Table 1. Liveweight at joining (kg) and weaning rate for heifers joined at 1 and 2 years and mature cows in the three herd structures at Longreach and Boulia

TH = typical herd; EJ = early joining; HF = high fertility; EJ-HF = early joining and high fertility

Herd	Heifers – 1 year		Heifers – 2 years		Mature cows	
	Liveweight at joining (kg)	Weaning rate (%)	Liveweight at joining (kg)	Weaning rate (%)	Liveweight at joining (kg)	Weaning rate (%)
			Longreach			
TH	–	–	360	68	475	54
EJ	240	29	360	65	475	51
EJ-HF	290	70	420	86	460	83
			Boulia			
TH	–	–	400	58	480	58
HF	–	–	400	73	480	74
EJ-HF	290	63	400	72	480	78

(Tables 1 and 2), however it is acknowledged that breeding success and liveweight gain are closely related to seasonal conditions and that these are highly variable from year to year.

Farm GHG emissions (t CO_2 equivalents (CO_2-e)) were estimated based on the Australian National Greenhouse Gas Inventory method based on the animal numbers, liveweight and growth using the Greenhouse Accounting Framework for beef (Browne *et al*. 2011). Farm emissions were comprised of CH_4 (enteric and manure), and nitrous oxide (dung, urine and other indirect sources).

Breedcow was also used to calculate farm gross margin based on regional average prices received and husbandry and selling costs (Tables 3 and 4). The same prices were used across all structures, except for weaner and 1-year-old steers in the EJ-HF herd at Longreach, which had higher prices reflecting the higher prices actually received on the case study farm for cross-bred steers. The same selling and animal husbandry costs per animal were used across all three herds. An interest payment of 10% of the capital value of the herd was included in the gross margin analysis of each herd. Potential gross income from a scheme like the Australian Emissions Reduction Fund (ERF) (ComLaw 2014) was included in the calculation of gross margin. In this instance emission reductions in the EJ and EJ-HF herds were calculated as the difference in emissions from TH, which was used as the baseline. Each tonne of CO_2-e was valued at \$10 net income, and no costs for participation or compliance with the scheme were included for all three herds at each location.

Scenarios examined

The productivity, profitability and GHG emissions for the three herds on the case study farms were examined under two scenarios:

(1) Maintain number of AE – where the total number of stock in AE on the property was maintained at the current level on each case study property for each of the herds (1750 and 1842 AE at Longreach and Boulia, respectively). In this scenario total beef production changed according to reproductive performance and liveweight gain achieved by the herds, and
(2) Maintain liveweight sold– where the amount of liveweight sold was maintained at the same level as TH on each case study property. In this scenario the herd size of the EJ, HF

Table 2. Steer and heifer age (months) and liveweight (kg) at sale in the three herd structures at Longreach and Boulia

TH = typical herd, EJ = early joining, HF = high fertility, EJ-HF = early joining and high fertility

Herd	Steers		Heifers	
	Age (months)	Liveweight (kg)	Age (months)	Liveweight (kg)
		Longreach		
TH	18, 27	370, 500	27	430
EJ	18, 27	370, 500	19, 27	380, 430
EJ-HF	18, 27	400, 500	19	380
		Boulia		
All herd structures	14, 38	292, 613	20	371

Table 3. Prices[A] received (\$ kg^{-1} liveweight) for each livestock class in the herd structures at both Longreach and Boulia

TH = typical herd; EJ = early joining; HF = high fertility; EJ-HF = early joining and high fertility

Livestock class	Herd		
	Longreach		Boulia
	TH and EJ (\$ kg^{-1})	EJ-HF (\$ kg^{-1})	All herds (\$ kg^{-1})
Heifers – weaners	1.70	1.70	1.70
Heifers – 1 year	1.60	1.60	1.60
Heifers – 2 years	1.55	1.55	1.55
Cows – 3+ years	1.40	1.40	1.40
Steers – weaners	1.74	1.90[A]	–
Steers – 1 year	1.74	1.89[A]	1.60
Steers – 2 years	1.60	1.60	–
Steers – 3 years	–	–	1.70
Bulls	1.25	1.25	1.25

[A]Prices used from actual farm case study, where these deviated from the district average.

Table 4. Selling and animal husbandry costs applied in the three herd structures at Longreach and Boulia

'Kept' are cattle kept for the full year. 'Sold' are cattle sold during the year

Item	Cost (\$ head^{-1})	
	Longreach	Boulia
	Annual husbandry costs (variable costs only)	
Heifers <1 year	\$29.00 kept and sold	\$11.64 kept and sold
Heifers 1–2 years	\$22.75 kept; \$2.75 sold	\$14.97 kept; \$1.14 sold
Cows >2 years	\$20.00 kept and sold	\$14.97 kept; \$5.24 sold
Steers <1 year	\$29.00 kept and sold	\$11.64 kept
Steers >1 year	\$10.00 kept; \$5.00 sold	\$2.63 kept and sold
Bulls	\$22.37 kept; \$0.00 sold	\$49.17 kept; \$20.90 sold
	Selling costs	
Freight	\$4.50 for weaner and 1 year heifers, \$8.30 for 2 year heifers, \$60.00 for all other livestock	\$80.00 for heifers and cull cows, \$120 for steers
Commission	1.58% of value	5.0% of value
Other selling costs	\$3.50	\$5.00

and EJ-HF herds was adjusted to achieve the same level of liveweight sold, resulting in different total herd size (in AE).

The key results presented for the three herds in each scenario were total stock number (AE), breeder number, liveweight sold (t liveweight sold), property gross margin (\$ property^{-1}), total GHG emissions (t CO_2-e), and GHG emissions intensity (t CO_2-e t^{-1} liveweight sold).

Results

Scenario 1. Maintain number of AE

For both properties the number of breeders joined, mean breeder weight, weaning percentage and number of livestock sold from each of the three herds is shown in Table 5. At Longreach, the breeder herd size was lowest and mean breeder weight was highest in TH, which also had the lowest number of livestock sold. The weaning rate was lowest in the EJ herd and highest in the EJ-HF herd. At Boulia, TH had the lowest weaning rate and number of cattle sold whereas the EJ-HF herd had the lowest mean breeder weight, highest weaning rate and number of cattle sold.

At Longreach, liveweight sold from the EJ and EJ-HF herds was 8% and 39% higher than TH (Table 6). In TH and EJ herds 45% of liveweight sold was from steers, compared with 49% in the EJ-HF herd. Total GHG emissions were similar across the herds, with 95% of CO_2-e derived from enteric CH_4 (data not shown). Emissions intensity was reduced by 7% and 28% for the EJ and EJ-HF herd, respectively, compared with TH. The gross margin for the EJ-HF herd was more than double that of the TH (Fig. 1).

At Boulia, the HF and EJ-HF herds had 12% and 29% more liveweight sold compared with TH (Table 6). Total GHG emissions were similar between the three herds but emissions intensity was reduced by 10% and 22% for the HF and EJ-HF herds, respectively. The property gross margin for the HF and EJ-HF herds were 28% and 48% higher than TH (Fig. 1).

Scenario 2. Maintain liveweight sold

At Longreach, to maintain the amount of liveweight sold the number of AE in the EJ and EJ-HF herds were 7% and 28% lower than in TH, with similar percentage reductions in total GHG emissions (Table 6). Gross margins (including ERF income) were lowest in TH and highest in the EJ-HF herd (Fig. 1). The gross margin advantage for the EJ compared with TH was 10%, with the ERF income contributing 15% (~\$2600) of the

Table 5. Number of cows joined, mean breeder weight, weaning rate and number of steers, heifers and weaners sold in the herds at Longreach and Boulia

Stocking rate was 1750 AE at Longreach and 1842 AE at Boulia. TH = typical herd, EJ = early joining, HF = high fertility, EJ-HF = early joining and high fertility

Herd	Number joined				Mean breeder weight (kg)	Weaning rate (%)	Number sold		
	Heifers –1 year	Heifers –2 years	Mature cows	Total			Steers	Heifers	Mature cows
					Longreach				
TH	–	273	711	984	481	58	280	16	238
EJ	302	285	670	1 256	436	49	303	49	267
EJ-HF	343	249	415	1 007	435	79	393	89	285
					Boulia				
TH	–	137	766	903	473	58	252	117	119
HF	–	123	658	811	473	74	287	166	107
EJ-HF	201	146	577	924	426	74	327	187	111

Table 6. Herd size (AE), liveweight sold, greenhouse gas (GHG) emissions, and GHG emissions intensity for the three herd structures in the 'maintain number of AE' and 'maintain liveweight sold' scenarios at Longreach and Boulia

TH = typical herd, EJ = early joining, HF = high fertility, EJ-HF = early joining and high fertility

Herd	Scenario	Herd size (AE)	Liveweight sold (t)	GHG emissions (t CO_2-e)	Emissions intensity (t CO_2-e t^{-1} liveweight sold)
			Longreach		
TH	–	1750	236.3	3521	14.9
EJ	Maintain number of AE	1750	255.4	3523	13.8
EJ-HF		1750	328.8	3520	10.7
EJ	Maintain liveweight sold	1621	236.3	3260	13.8
EJ-HF		1259	236.3	2530	10.7
			Boulia		
TH	–	1842	238.0	3627	15.3
HF	Maintain number of AE	1842	266.1	3635	13.7
EJ-HF		1842	305.8	3624	11.9
HF	Maintain liveweight sold	1650	238.0	3244	13.7
EJ-HF		1429	238.0	2808	11.9

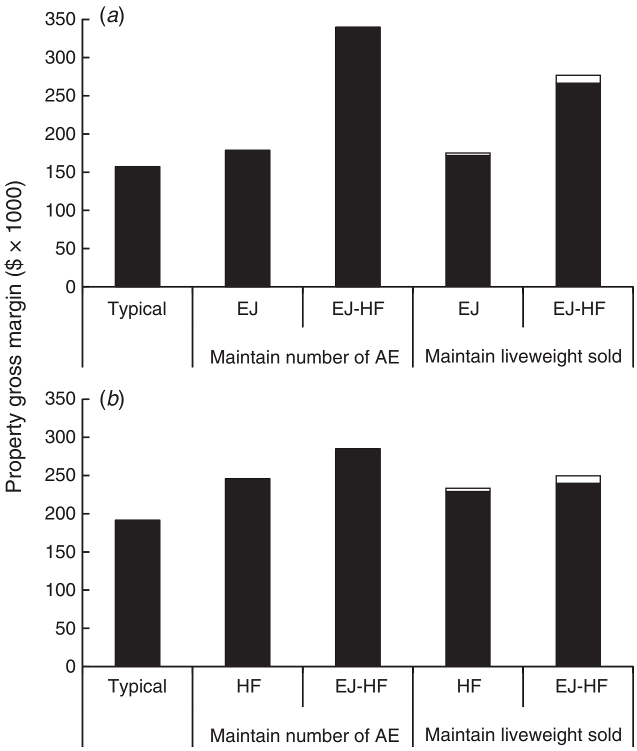

Fig. 1. Property gross margin ($) for beef production (black) and additional ERF income (white, where appropriate) for the herd structures and scenarios at (*a*) Longreach and (*b*) Boulia. Abbreviations for herd structures are: 'EJ' early joining, 'HF' high fertility and 'EJ-HF' early joining and high fertility.

gross margin advantage. For the EJ-HF herd the total gross margin was 76% higher than TH with ERF income making up 8% (~$9900) of the gross margin advantage.

At Boulia, the amount of liveweight sold was maintained in the HF and EJ-HF herds with the number of AE 10% and 22% lower than TH, and corresponding reductions in total GHG emissions (Table 6). The gross margin advantage for the HF compared with TH was 21%, with the ERF income contributing 9% (~$3800) of the gross margin advantage. For the EJ-HF herd the total gross margin was 29% higher than TH with ERF income making up 15% (~$8200) of the gross margin advantage.

Discussion

Early joining and increasing weaning rates have potential to improve the productivity, profitability and GHG emissions intensity of production in the northern Australian beef industry. In the scenario where the number of AE was maintained on the two case study farms, the EJ-HF herd sold 29–39% more liveweight with a 22–28% decrease in GHG emissions intensity (Table 6), and the property gross margin more than doubled at Longreach and increased by 48% at Boulia (Fig. 1). In the scenario where the amount of liveweight sold was maintained at the same level as the TH, the number of AE and GHG emissions were both reduced by 22–28% in the EJ-HF herd (Table 6). Comparing between the two scenarios, maintaining the amount of liveweight sold and reducing emissions was less profitable (by ~$62 000 at Longreach and ~$38 000 at Boulia) than maintaining the number of AE and increasing beef production on both properties.

In the scenario where the number of AE was kept constant there was only a small difference in total GHG emissions between the herds. This is not surprising given that the number of AE was constant with the herd merely shifting to a higher proportion of productive animals. The early mating and improved weaning rates both increased the amount of liveweight sold and reduced the GHG emissions intensity of beef production in both case studies. The larger improvement in liveweight sold and emissions intensity was achieved with HF only on the Boulia property compared with the smaller improvement with EJ only on the Longreach property. This suggests that increased weaning rates contributed most to the improvement in production efficiency. Reduced age at first joining has been shown to provide a small improvement in the GHG emissions intensity of production in self-replacing sheep systems (Alcock and Hegarty 2011). Overall, the reductions in emissions intensity in this study were of a similar magnitude to that reported by Bentley *et al*. (2008) for similar systems in the Australian rangelands.

The weaning rates across the three herds assumed in this study are similar to the range reported in commercial herds, with TH similar to the industry average and the EJ-HF to the top 25% of properties (Bortolussi *et al*. 2005*a*; Fordyce *et al*. 2013). This suggests that the weaning rates used in this study are realistic. Breeding and management are clearly important in this respect. At Longreach, a key difference in the weaning rate for the heifers joined as yearlings in the EJ and EJ-HF was in liveweight at the time of mating, with heifers reaching 240 and 290 kg in the EJ and EJ-HF herds, respectively. This is consistent with the finding of Schatz *et al*. (2010) who showed that lighter heifers joined as yearlings had lower pregnancy rates, and that with selection for fertility, weaning rates similar to those used in EJ-HF can be achieved.

On both case study farms, increasing weaning rates contributed the majority of the gains in liveweight sold and gross margin, as well as in reducing GHG emissions intensity (Table 6). This suggests that selection for fertility and increasing weaning rates should be the first focus for producers to achieve these multiple objectives. In the Boulia case study, pregnancy testing was used as a tool to select higher fertility cows, whereas at Longreach a cross-breeding strategy was also used. Importantly, the animal husbandry changes were predicated on best-practice grazing land management for the region (Phelps 2012), to maximise the expression of genetic gains through the best possible native pasture-based nutrition. Land was maintained in good to moderate condition by removing cattle at the start of the wet season, spelling the pastures for their first 6–8 weeks of growth until the majority of Mitchell grass had started to set seed (early wet-season spelling). At Longreach, spelling was achieved by fencing Mitchell grass pastures into smaller paddocks and spreading cattle across several paddocks whereas others were destocked. At Boulia, cattle were grazed on spinifex land types over the summer wet period to spell the Mitchell grass pastures for the full wet season. In both cases, forage budgeting was conducted after peak pasture growth was achieved and cattle numbers set for the ensuing dry season to retain at least 1000 kg DM ha^{-1} of standing biomass. Although not specifically tested, the success of the land-holders in achieving early joining and higher weaning rates through the case study years suggests these are practical strategies that link pasture and animal performance. One limitation of the present study was a lack of drought conditions during the case study period. There would be value in re-analysing the case studies based on drought data for breeder parameters.

In the scenario where liveweight sold was maintained at the same level as TH, the EJ-HF herd structure resulted in 22–28% lower total GHG emissions. Under the Australian ERF, if this system were eligible to generate carbon offsets, this could have generated an additional \$9900 per year at a carbon price of \$10 t CO_2-e^{-1} at Longreach, with a corresponding value of \$8200 at Boulia. Although not as profitable as the maintaining stock numbers scenario, the maintain liveweight sold scenario could lead to substantial reductions in GHG emissions from the industry. The northern beef industry is estimated to produce 5% of national GHG emissions (national GHG emissions 554.6 Mt CO_2-e in 2011–2012, DCCEE 2012), if 25% of farms achieved the 25% reduction in emissions intensity documented in this study, then the same liveweight turnoff could be achieved with 1.7 Mt CO_2-e less emissions per annum. In addition, the lower number of AE will ensure improved rangeland condition, conferring additional benefits and longer-term sustainability of the resource.

These results show that improving the efficiency of production through increasing weaning rates, early mating and cross breeding is a highly profitable strategy for northern beef producers. The gains achieved across the two case study properties with different rainfall, country types, and property size suggest similar improvements can be made on-farm across the Mitchell Grass Downs bioregion in northern Australia.

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