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Down scaling to regional assessment of greenhouse gas emissions to enable consistency in accounting for emissions reduction projects and national inventory accounts for northern beef production in Australia

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Abstract. This paper explores the effect of using regional data for livestock attributes on estimation of greenhouse gas (GHG) emissions for the northern beef industry in Australia, compared with using state/territory-wide values, as currently used in Australia's national GHG inventory report. Regional GHG emissions associated with beef production are reported for 21 defined agricultural statistical regions within state/territory jurisdictions. A management scenario for reduced emissions that could qualify as an Emissions Reduction Fund (ERF) project was used to illustrate the effect of regional level model parameters on estimated abatement levels. Using regional parameters, instead of state level parameters, for liveweight (LW), LW gain and proportion of cows lactating and an expanded number of livestock classes, gives a 5.2% reduction in estimated emissions (range +12% to –34% across regions). Estimated GHG emissions intensity (emissions per kilogram of LW sold) varied across the regions by up to 2.5-fold, ranging from 10.5 kg CO_2-e kg^{-1} LW sold for Darling Downs, Queensland, through to 25.8 kg CO_2-e kg^{-1} LW sold for the Pindan and North Kimberley, Western Australia. This range was driven by differences in production efficiency, reproduction rate, growth rate and survival. This suggests that some regions in northern Australia are likely to have substantial opportunities for GHG abatement and higher livestock income. However, this must be coupled with the availability of management activities that can be implemented to improve production efficiency; wet season phosphorus (P) supplementation being one such practice. An ERF case study comparison showed that P supplementation of a typical-sized herd produced an estimated reduction of 622 t CO_2-e $year^{-1}$, or 7%, compared with a non-P supplemented herd. However, the different model parameters used by the National Inventory Report and ERF project means that there was an anomaly between the herd emissions for project cattle excised from the national accounts (13 479 t CO_2-e $year^{-1}$) and the baseline herd emissions estimated for the ERF project (8 896 t CO_2-e $year^{-1}$) before P supplementation was implemented. Regionalising livestock model parameters in both ERF projects and the national accounts offers the attraction of being able to more easily and accurately reflect emissions savings from this type of emissions reduction project in Australia's national GHG accounts.

Additional keywords: carbon farming, phosphorus supplementation.

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Introduction

The beef herd in northern Australia contributes a significant proportion of agricultural greenhouse gas (GHG) emissions, accounting for 4% of national emissions for 2013, and 25% of agricultural emissions, as estimated by Australian Greenhouse Emissions Information System (AGEIS) (Department of the Environment 2015*a*). AGEIS shows that total emissions for northern beef have grown by ~30% between 1990 and 2013. The overall beef industry in Australia is predicted to continue on this trajectory of increasing emissions (Centre for International Economics 2013) despite short-term impacts such as drought, with emissions in 2050 predicted to be 50% higher than 2012 levels. This is premised on meat remaining a major export, driven by both population growth and a shift to higher meat consumption in the Asian region (Centre for International Economics 2013).

Given the contribution that the northern beef industry makes to Australia's GHG emissions, the need to consider abatement options is strong. Recognising this, the Australian Government introduced the Emissions Reduction Fund (ERF), an incentive scheme to reduce emissions (Department of the Environment 2015*b*). There are two approved methodologies (as at January 2016) designed for northern beef production. These are feeding nitrate supplements to reduce enteric methane (CH_4), and improved beef cattle herd management to lift production efficiency (Department of the Environment 2015*b*). Other methodologies for building soil carbon, increasing sequestration in woody vegetation and reducing emissions from savanna burning are also approved and have relevance to the northern beef industry (Department of the Environment 2015*b*).

The GHG emissions for beef cattle in the National Inventory Report (NIR) are estimated from the number of animals in each class and feed intake which is a function of liveweight (LW), LW gain, proportion of cows lactating and pasture quality (Department of the Environment 2014; Charmley *et al*. 2016). To reflect differences throughout Australia these model parameters are described for each state/territory in the NIR. However, within each jurisdiction there are significant regional differences in these values brought about through different rainfall, soil fertility and pasture type, and market dynamics (Bray *et al*. 2015).

In order to more accurately estimate emissions for national inventory, a possible next step would be to move to regional model parameters, which would be a closer reflection of herd structure and performance than the state level values. An understanding of how different the GHG estimates might be from these two approaches is a useful step, in the first instance. Moving to a more regionally refined model would also facilitate the integration of GHG offsets from livestock ERF projects into the national accounts for GHG emissions. Through consistency in estimation approaches, changes in emissions brought about through improvements in herd productivity could be accurately and transparently reflected in the national accounts. As an example, the recently released ERF methodology for Beef Cattle Herd Management expands the number of classes of cattle to enable a more detailed representation of herd structure to be used to estimate emissions (Department of the Environment 2015*b*). This is in contrast to the earlier released ERF methodology for reducing GHG emissions in beef cattle through feeding nitrates, which is based on the smaller number of classes of cattle as defined in the NIR. Using the smaller number of classes was a workable arrangement for the nitrate methodology, as the abatement from feeding nitrate was not premised on any change to herd structure, but this approach does not work well for the herd management methodology.

This paper reports some of the background research that was done to support the technical assessments that underpinned the development of the Beef Herd Management Methodology (Emissions Reduction Assurance Committee 2015). The paper explores the effect of using regional values for livestock model parameters on the estimation of GHG emissions for the northern beef industry in Australia, reports the GHG emissions associated with beef production for individual regions, and demonstrates the importance of regionalised modelling parameters for allowing GHG emissions abatement from productivity-based ERF projects to be accurately reflected in the national GHG accounts.

Material and methods

Estimating beef production, herd structure and profitability

For northern cattle production, the data representing herd structure, reproduction rate, growth rate, turn-off weights and profitability were drawn from the Beef Co-operative Research Centre (CRC) Gross Margin Templates in the herd modelling program Breedcow and Dynama (Holmes *et al*. 2011). Breedcow and Dynama (Department of Agriculture and Fisheries 2011) is a steady-state herd model that generates a herd structure, for a given herd size, based on a starting number of weaner heifers retained for mating each year and premised on weaning and death rates, and sales from each class of stock. Breedcow and Dynama provides outputs of herd structure, herd value and gross margin (returns after accounting for variable costs) for the enterprise.

Breedcow and Dynama templates developed by the Beef CRC describe the major beef-producing regions in northern Australia. These templates are subsequently described in the paper as Beef CRC BandD templates. These regions were based on Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES) survey regions of northern Australia (Fig. 1). Templates cover all of Queensland and the Northern Territory, and Western Australia Region 511 and that part of Region 512 north of 26° latitude (level with the Northern Territory/South Australian border). In some instances the ABARES region was split into subregions based on within-region variation in production and predominant vegetation and soil type.

In Breedcow and Dynama the user specifies a start and end weight for each class of cattle over a 12-month period, but the model does not account for the seasonal pattern of growth within the year. To establish the seasonal growth pattern, a function was set up in a Microsoft Excel tool (Breedcow-FarmGAS Macro) to allow the user to choose a particular growth trajectory based on local information. The growth curves to accommodate seasonal variation were created by taking the linear trend (as reflected by the start and end weight) and super-imposing a seasonal deviation. For this study, a consistent trajectory was chosen for all regions resulting in a pattern for mature animals

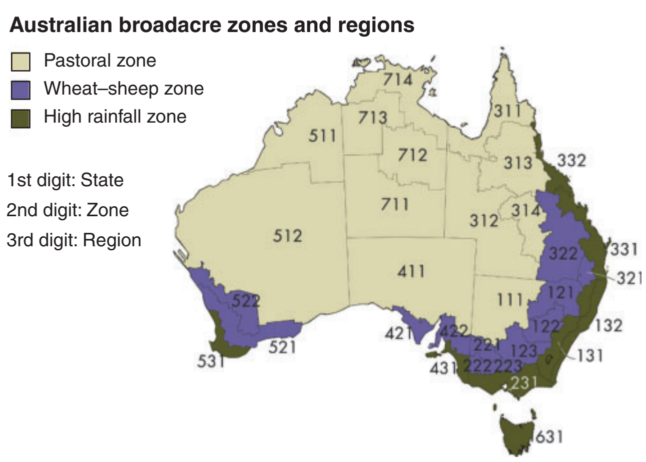

Fig. 1. ABARES survey regions across Australia for agricultural commodities (Department of Agriculture and Water Resources 2016).

where LW is steady at the beginning of the wet season in December, increases over late summer and autumn and peaks in winter, with a subsequent period of loss over spring. This growth trajectory was well matched to Beef CRC data collected from cattle on field stations and other projects in the northern beef region (Bray *et al*. 2015; Heather Burrow, UNE, pers. comm.).

Livestock numbers (total number expressed as adult equivalents; AE = 450-kg dry beast for 12 months) (McLean and Blakeley 2014) were drawn from the Beef CRC BandD templates, whereas grazing area in each region was sourced from Australian Bureau of Statistics Census for 2010–2011 (Australian Bureau of Statistics 2013).

Estimating GHG emissions

The methodology for identifying and quantifying GHG emissions followed the methods used by the NIR (Department of the Environment 2014) for agriculture up until June 2015. Some of the emission factors have since been revised. Therefore, the GHG emissions values generated by this study should be viewed as comparative rather than absolute estimates of emissions. Likewise, financial returns should also be used in a comparative rather than definitive manner.

GHG emissions that occur from livestock are:

- CH_4 from enteric fermentation (digestion) of pasture,
- CH_4 from manure,
- direct nitrous oxide (N_2O) emissions from dung and urine, and
- indirect N_2O emissions as the N_2O moves through the land system and N from ammonia emissions deposited in soils and re-emitted as N_2O.

Methane GHG emissions for northern Australian beef cattle are estimated from feed intake, which is a function of LW, LW gain, and proportion of cows lactating. N_2O emissions are estimated as a function of feed intake and pasture quality. The equations describing these relationships are defined in the NIR (Department of the Environment 2014) and are based on Australian research for cattle, for southern regions with *Bos taurus* cattle and northern Australia with *Bos indicus* cattle. The emissions factors used in this study for northern beef are those used until June 2015.

A Microsoft Excel version of the FarmGAS software (Australian Farm Institute 2010) was used to estimate cattle GHG emissions. FarmGAS applies the NIR equations to calculate livestock emissions for a given herd structure, animal growth rate, and reproduction rate. Monthly data on livestock numbers, LW, LW gain and proportion of cows lactating were extracted from the Beef CRC BandD templates and converted into the appropriate format for FarmGAS by the use of a Breedcow-FarmGAS Microsoft Excel Macro, allowing a complex and time-consuming activity to be automated.

Comparison of NIR state/territory level estimates and regional estimates of GHG emissions

Several model parameters were modified to allow the comparison of 'NIR' state level estimates and 'Regional' estimates of GHG emissions. The modified parameters included the number of classes of cattle (see Table 1 for matching of classes for each approach), the LW and LW gain of cattle (Appendix 1), and the season of lactation and proportion of lactating cows (Table 2). These parameters determine feed intake and subsequent CH_4 production. Parameters for quality of feed consumed, (which determine N_2O emissions) were not varied from the NIR State values, as data are scarce and the N_2O contribution to total emissions is small. The total number of cattle in each region (drawn from the Beef CRC BandD templates) was the same for the comparison of NIR and Regional parameters. The weight of livestock sold was extracted from the Beef CRC BandD templates to allow an estimation of GHG emissions intensity (emissions per kg LW sold).

Table 1. Correspondence between National Inventory Report (NIR) classes and Regional classes

NIR classes	Regional classes	Reason for varying classes
Steer calves	Steer calves	No change in classes required
Heifer claves	Heifer calves	
Bull calves	Bull calves	
Heifers 1–2 years old	Heifers 1–2 years old	
Bulls >1 year old	Bulls >1 year old	
Cows >2 years old	Heifers 2–3 years old Cows 3–4 years old Cows >4 years old	Significant decrease in fertility at second mating in northern systems. Mature weight not reached until 4 years
Steers >1 year old	Steers 1–2 years old Steers 2–3 years old Steers 3–4 years old Steers >4 years old	Range in sale ages (2–4 years of age) gives different weight profiles for each age class retained on the property

Validation of FarmGAS modelling

As overall emissions are determined by both the set of model parameters (for LW and lactation) and the total animal numbers, a check was made to ensure that the FarmGAS modelling for the NIR parameter set was consistent with estimates of GHG emissions from AGEIS. To do this the numbers of cattle in each NIR class for each state/territory for 2011 were obtained from the National Inventory team at the Department of the Environment, Canberra. These livestock numbers were used in FarmGAS with the NIR state/territory parameters and compared with the published AGEIS GHG emissions estimates for 2011.

It was not possible to compare AGEIS outputs with the Regional parameter set estimates, as data were not available at the regional level within AGEIS. Nor was it possible to include Western Australia in this comparison as AGEIS reports only the state average for beef cattle emissions, which includes both northern (Kimberley and Pilbara) and south-western beef regions in WA.

Case study of wet-season phosphorus (P) supplementation in northern cattle

Wet-season P supplementation was chosen to demonstrate the effect of using NIR or Regional model parameters on estimation of GHG emissions at the property scale. Wet season-P

Table 2. Number of cows lactating and period of lactation assumed for estimation of feed intake at the regional level and state/territory level

Region definitions based on Beef CRC BandD template name	Proportion lactating	Months lactating
R311A – Cape York	47%	Jan.–May
R311B – Burke and Carpentaria	70%	Jan.–May
R312 – W and SW Qld	82%	Nov.–Mar.
R313A – Croydon	47%	Jan.–May
R313B – East Mareeba, Herberton, Etheridge	60%	Feb.–June
R313C – Goldfields – east Dalrymple Shire	75%	Jan.–May
R313D – Desert (Dalrymple and Gulf forest)	70%	Jan.–May
R313E – Basalt and Downs (Dalrymple, Flinders, Richmond, McKinlay)	92%	Feb.–June
R314 – Mitchell Downs, Mulga, Desert	85%	Jan.–May
R321 – Darling Downs	91%	Nov.–Mar.
R322 – Brigalow	93%	Nov.–Mar.
R331 – Coastal speargrass	75%	Nov.–Mar.
R332A – Wet Coast and Tableland	87%	Oct.–Feb.
R332B – Lower Burdekin and Bowen	76%	Dec.–Apr.
R511A – Pindan and North Kimberley	47%	Dec.–Apr.
R511B – Fitzroy Valley	63%	Dec.–Apr.
R512 – Pilbara and Gascoyne	74%	Jan.–May
R711 – Alice Springs	62%	Dec.–Apr.
R 712 – Barkly Tableland	64%	Jan.–May
R713 – Katherine and VRD	62%	Dec.–Apr.
R714 – NT Top End and Western Gulf	59%	Nov.–Mar.
NIR State/Territory		
Queensland	75%	Sept.–Jan.
Northern Territory	70%	Dec.–Apr.
Western Australia – Pilbara	80%	Sept.–Jan.
Western Australia – Kimberley	80%	Dec.–Apr.

supplementation on P-deficient country (e.g. much of Region R311A and R313A) increases the efficiency of nutrient utilisation and voluntary feed intake, removing the limitation placed on growth and metabolism by the P deficiency (Winter *et al*. 1990; Jackson *et al*. 2012). This results in faster growth rates and higher survival of young cattle, heavier LW of heifers at first mating, more body reserves for mature cows leading to better lactation performance, lower cow death rates, higher rates of conception for the following pregnancy and more LW sold (Winter *et al*. 1990).

In the modelled scenario, the utilisation of feed grown on the property was kept the same, that is, AE were reduced so that the same amount of available pasture was consumed. The scenario was modelled for a herd size of 4000 AE, reducing to 3600 AE when wet-season P-supplementation was provided at the rate of 15 kg AE^{-1} $year^{-1}$ (Jackson *et al*. 2012).

Although effective wet-season P supplementation is not common, some individual cattle producers have been able to implement this practice with infrastructure and time management planning designed to overcome the logistical challenges of supplementation in the wet season, when access to feed stations is difficult and supplements can deteriorate from getting wet (Bernie English and Bill Holmes, QDAF, pers. comm.).

Results

Comparison of NIR state/territory level estimates and regional estimates of GHG emissions

The effect of using Regional parameters, rather than NIR, is a decrease of 5.2% in estimated total GHG emissions (range +12% to –34%; Fig. 2), across the northern beef industry, with the average for Queensland being –6.7%, Western Australia –6.9% and the Northern Territory +4.2%. Across the regions, enteric CH_4 contributed the majority of emissions (92–95%), whereas N_2O made a small contribution (5–8%) and CH_4 from manure was very low (<0.1%).

The same overall number of cattle was assumed for the NIR and Regional comparison and, in general, there was good agreement ($\leq$10%) variation) between NIR and Regional estimates for 12 of 21 regions. Where the variation was in excess of 20%, the trend was for Regional estimates to be lower than NIR (R311A, R311B, R313A and R332B).

Given the number of animals was kept equivalent for the comparisons, the main contributing factor for the differences appears to be LW (Table 3), which is lower for the Regional values compared with the NIR values, although in two of the regions (R311A and R313A) the proportion of cows lactating was also substantially lower for Regional values compared with NIR (47% vs 75% weaning rate, respectively).

Validation of FarmGAS modelling

The validation of FarmGAS estimates for the NIR parameter set against AGEIS for 2011 (at the state/territory level and using the same cattle numbers for the calculations) show that the two estimates varied by 2.5%, when in theory they should be the same. The equations in FarmGAS have been checked against the NIR methodology and found to be consistent (Patrick Madden, NSW DPI, pers. comm.). The cattle numbers were provided by the Department of the Environment as being the same numbers used for the AGEIS estimates for 2011 but they may have been slightly different, as our request was subsequent to the Department's own calculation for the 2011 accounts. The 2.5% difference may be due to differences in rounding of numbers between the two models, as a difference of this magnitude is within the bounds of possible error (O'Leary 2009). However, the closeness of the results gave confidence that the models were working as expected.

Regional differences in northern beef GHG emissions

Estimated GHG emissions per kilogram of LW sold across the regions ranged from 10.5 kg CO_2-e kg^{-1} LW sold for Darling Downs (R321), Queensland, through to 25.8 kg CO_2-e kg^{-1} LW sold for the Pindan and North Kimberley (R511A), Western Australia (Table 4). Regions with the highest financial returns tended to have the lowest emission intensity (Fig. 3). The GHG emissions per ha of land ranged from 13 to 1009 kg CO_2-e ha^{-1}. Low emissions per ha were associated with less profitable regions with lower livestock carrying capacity.

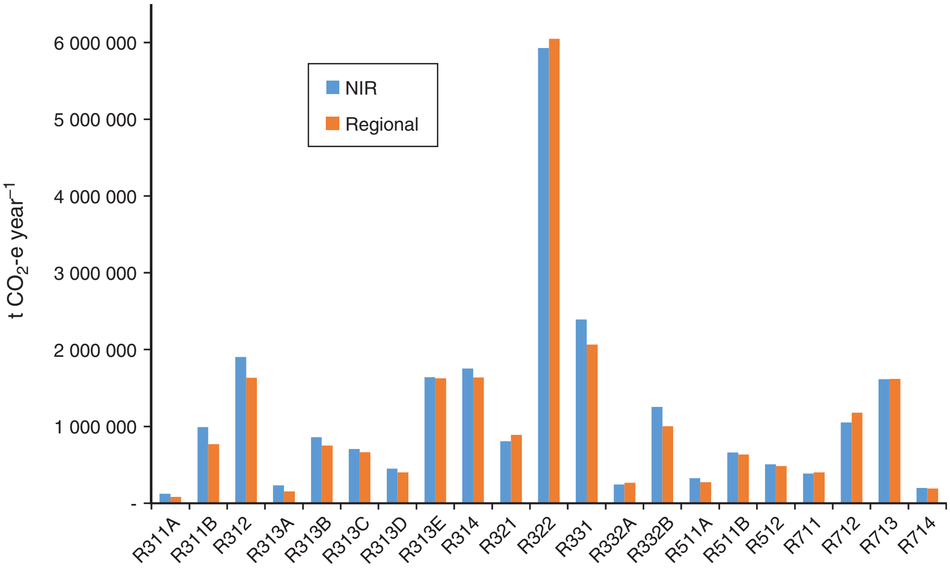

Fig. 2. Total greenhouse gas emissions from beef cattle in each ABARES region estimated using regional specific parameters (Regional) or National Inventory Report (NIR) state/territory default values.

Table 3. Mean liveweight for the three main classes of cattle in regions where the Regional estimates of greenhouse gas emissions were lower than the National Inventory Report (NIR) estimates by >20%

Region definitions	Mature cows (kg)	Steers <1 (kg)	Steers 1–2 (kg)
R311A	386	110	181
R311B	407	142	251
R313A	386	110	181
R332B	407	147	268
Queensland NIR	475	365	430

Case study of wet-season P supplementation in northern cattle

Key performance indicators for the baseline production system and the production system with wet-season P supplementation are described in Table 5; they represent the steady-state under the baseline and the new management scenario. The improved reproductive rate of the cow-herd allows cow numbers to be significantly reduced (from 2944 to 2211 cows retained after mating; a 25% decrease in cow herd size) while maintaining weaner output (1277 versus 1288 weaners for non-P supplemented and supplemented scenarios, respectively). Phosphorus supplementation allows steers to be sold 12 months earlier and at a slightly higher LW (360 kg vs 350 kg). Mortality rates are also reduced by 1–3%, depending on the age class.

Total livestock turnoff is increased under P supplementation even though the retained cow herd size was reduced by 25%. Although numbers of weaners are similar, lower death rates resulted in more steers being sold from the P-supplemented herd (605 vs 529). Overall, wet-season P supplementation increased turnoff by 111 620 kg LW year^{-1}, an increase of 36%. By providing wet-season P supplementation, total gross margin for the case study herd was improved from \$228 299 to \$369 558 year^{-1}. With P supplementation, net husbandry costs increased by \$43 450 year^{-1} as a result of additional expenses for wet-season supplement, although there are less variable expenses for other inputs per head such as vaccinations, dry-season supplements and pregnancy testing due to lower cow numbers.

The change in herd structure and improved performance brought about by wet-season P supplementation is not immediate and takes 2–3 years to achieve, as the benefits take time to build up in terms of improved fertility. In this intervening period the impact of the additional expenditure on P supplement reduces cash flow, and an estimated capital expenditure of \$22 000 would be needed to set up wet-season feeding stations for a herd of this size (Jackson *et al.* 2012).

When regional level parameters were used, the estimate of GHG emissions for the non-P-supplemented herd was 8896 t CO_2-e year^{-1} compared with 8273 t CO_2-e year^{-1} for the P-supplemented herd, giving an abatement of 623 t CO_2-e year^{-1}. If the emissions for an equivalent number of cattle are estimated using NIR model parameters, the non-P supplemented herd emissions are estimated to be much higher, 13 479 t CO_2-e year^{-1}, because the state level values used by NIR overestimate emissions for the R311A/R313A regions by 34%.

The GHG emission intensity of the non-P supplemented and P-supplemented herds was 28.5 kg CO_2-e kg^{-1} and 19.5 kg CO_2-e kg^{-1} LW sold, respectively. The large reduction in the size of the cow herd and significantly higher number of stock available for sale at heavier LW resulted in total herd emissions being reduced by 7%, and emission intensity declining by 32%.

Discussion

Based on our analysis, a shift from state/territory to regional level parameters would only make a small difference of –5.2%

Table 4. Livestock numbers, grazing area and greenhouse gas (GHG) emissions for different regions of the northern beef industry

Region definitions based on Beef CRC BandD template name	Livestock numbers[A] (Adult equivalents – AE)	Area grazed[B] (ha)	GHG emission intensity (kg CO_2-e kg^{-1} LW sold)	GHG emissions per ha (kg CO_2-e ha^{-1})	Gross margin[A] (\$ AE^{-1})
R311A – Cape York	43 000	3 729 160	24.6	22	\$52
R311B – Burke and Carpentaria	396 000	8 081 524	13.7	95	\$153
R312 – W and SW Qld	827 000	46 407 347	13.9	35	\$143
R313A – Croydon	80 000	NA[C]	24.6	NA	\$60
R313B – East Mareeba, Herberton, Etheridge	384 000	NA	17.8	NA	\$106
R313C – Goldfields – east Dalrymple Shire	336 000	NA	15.8	NA	\$152
R313D – Desert (Dalrymple and Gulf forest)	206 000	NA	18.2	NA	\$113
R313E – Basalt and Downs (Dalrymple, Flinders, Richmond, McKinlay)	823 600	NA	13.6	NA	\$186
R314 – Mitchell Downs, Mulga, Desert	806 000	14 741 173	13.7	111	\$170
R321 – Darling Downs	448 000	1 285 269	10.5	693	\$285
R322 – Brigalow	3 043 000	20 720 261	11.6	292	\$243
R331 – Coastal speargrass	1 065 000	9 169 633	14.0	225	\$132
R332A – Wet Coast and Tableland	132 000	262 932	11.1	1009	\$227
R332B – Lower Burdekin and Bowen	504 000	2 573 949	14.8	390	\$148
R511A – Pindan and North Kimberley	140 000	11 581 159	25.8	24	\$73
R511B – Fitzroy Valley	325 000	6 710 396	19.1	95	\$99
R512 – Pilbara and Gascoyne	330 000	37 620 557	13.7	13	\$125
R711 – Alice Springs	208 000	17 283 742	15.4	23	\$90
R 712 – Barkly Tableland	645 000	18 913 822	17.8	62	\$98
R713 – Katherine and VRD	848 000	1 336 447	18.1	122	\$95
R714 – NT Top End and Western Gulf	101 500	4 967 652	21.1	38	\$83

[A]From Beef CRC BandD Templates.
[B]From Australian Bureau of Statistics Census for 2010–2011 (Australian Bureau of Statistics 2013).
[C]NA = not available; the complexity of R313 subregions made estimation of grazing area highly uncertain.

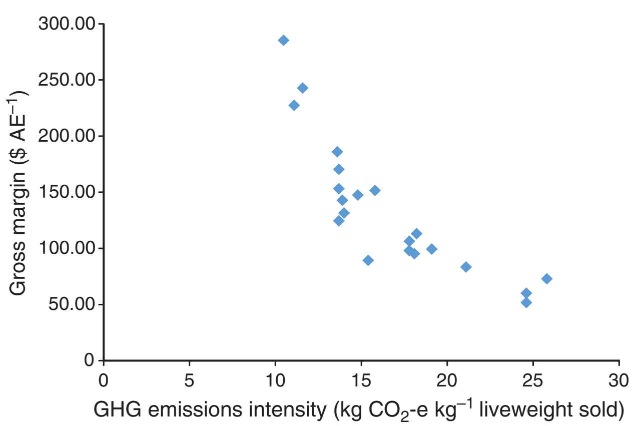

Fig. 3. Relationship between gross margin per adult equivalent (AE) and greenhouse gas (GHG) emissions per unit of product sold.

in estimation of total northern beef cattle emissions for the national accounts. However, at the regional scale, the difference in emissions ranged from +12% to a substantial –34%. Therefore, to allow abatement from productivity-based ERF projects to be accurately estimated and factored into the national accounts, a shift to regional model parameters is required.

Once ERF projects come into existence, to construct the national GHG accounts for beef cattle there will be two pools of animals to consider – a small number of cattle in ERF projects that have reduced emissions and the rest of the cattle population. The cattle covered by ERF projects will have their emissions estimated from individual project level data whereas the bulk of the cattle will have their emissions estimated by the NIR methods. The ERF cattle will be 'excised' from the total cattle population and treated differently. There is an anomaly introduced by having individual project level data drive the baseline emission's estimation in ERF projects for a certain subpopulation of cattle, while these animals are excised from the national accounts based on emissions estimated with mismatched state/territory level values. As demonstrated in the case study presented, the herd emissions excised from the national accounts would be 13 479 t CO_2-e $year^{-1}$ (rather than the more accurate estimate of 8896 t CO_2-e $year^{-1}$), whereas

Table 5. Summary of key herd performance indicators for scenario with and without wet season phosphorus (P) supplementation for a herd in Region 311A/313A in northern Queensland

Key Performance Indicator	Without P supplementation	With P supplementation
Number of adult equivalents	4000	3600
Number of cows mated	2944	2211
Number of weaners produced	1277	1288
Number of steers sold	529	605
Turn-off of cattle (kg liveweight)	312 170	423 790
Gross margin (\$ per year)	228 300	369 600

8273 t CO_2-e year^{-1} would be added back into the national accounts for the project herd after P supplementation was implemented.

To achieve consistency with ERF projects based on improvements in productivity, the national accounts would need to disaggregate to using an increased number of classes of cattle so that improvements in productivity within an individual ERF project can be articulated as a change in herd structure. Currently, any strategy to reduce herd GHG emissions by reducing age of turnoff of steers from 2.5 to 1.5 years of age, through improved growth rates, could not be quantified and factored into the national accounts because of the resolution at which the NIR modelling operates. The NIR currently specifies only one class of steer – those greater than one year of age with a single seasonal value for LW and LW gain. Equally, more appropriate regional values for LW and LW gain are also needed to estimate the emissions of the ERF project cattle that should be excised from the national accounts.

A comprehensive assessment of regional GHG emissions across the northern Australian beef herd provides a useful benchmark and gives some insights into the relationship between emissions intensity and profit. Estimated gross margins across the regions ranged from \$52 AE^{-1} for Cook Shire (R311A) through to \$285 AE^{-1} for the prime beef regions on the Darling Downs in Queensland (R321). The strong relationship between gross margin and emissions intensity (Fig. 3) indicates efforts to improve profitability will also result in an improvement in GHG emissions intensity. However, it is acknowledged that there are limitations due to land type and climate, restricting the gross margin and emissions intensity that can be achieved. Emissions intensity across the regions ranges from 10.5 kg CO_2-e kg^{-1} LW sold for Darling Downs, Queensland, through to 25.8 kg CO_2-e kg^{-1} LW sold for the Pindan and North Kimberley, Western Australia.

Although comprehensive regional estimates of GHG emissions have not been published previously for the northern beef industry, the emissions intensity results are comparable with similar (although methodologically not identical) studies where the regions are well matched. Wiedemann *et al.* (2016) reported emissions of 10.6–12.4 kg CO_2-e kg^{-1} LW sold for cattle from prime grass-fed production systems in eastern Australia, similar to the Darling Downs (R321; 10.5 kg CO_2-e kg^{-1} LW sold) and Brigalow (R322; 11.6 kg CO_2-e kg^{-1} LW sold). Cullen *et al.* (2016) calculated emissions intensity values between 10.7 and 15.3 kg CO_2-e kg^{-1} LW sold in Western Queensland, which is comparable to the western Queensland regions in this study (R312 and R 314; 13.7–13.9 kg CO_2-e kg^{-1} LW sold). Although ranking the same as the regional estimates reported here, results from Ash *et al.* (2015) were higher than found in this study, with emissions intensity of 18.7 kg CO_2-e kg^{-1} LW sold for northern Queensland (equivalent to region R313C; 15.8 kg CO_2-e kg^{-1} LW sold), 21.9 kg CO_2-e kg^{-1} LW sold for Victoria River District (R713; 18.1 kg CO_2-e kg^{-1} LW sold) and 15.5 kg CO_2-e kg^{-1} LW sold for south-east Queensland (R331; 14.0 kg CO_2-e kg^{-1} LW sold). The herd structure and productivity used by Ash *et al.* (2015) was well aligned with the Beef CRC BandD templates used for this study and the method of CH_4 estimation (based on feed intake) was also consistent. However, the approach used to estimate feed intake was different and this is the most likely variable to have influenced the consistent variance in results.

Across the northern beef regions, differences in production efficiency (driven by reproduction rate, growth rate and survival) resulted in up to a 2.5-fold difference in GHG emissions intensity, suggesting that some regions in the north are likely to offer opportunity for GHG abatement, confirmed by the results of the P supplementation case study. However, this must be coupled with the availability of management activities that can be implemented to improve production efficiency, and an adequate financial return on investment. Without considering potential income from emissions abatement, we found a clear relationship between improved emissions intensity and higher herd gross margin (Fig. 3). The existence of this relationship has been supported by other studies (Broad *et al.* 2011; Cullen *et al.* 2016; Walsh and Cowley 2016) and potentially provides a win–win opportunity for the northern Australian beef industry to improve both profitability and emissions intensity.

The productivity-based ERF methodology requires that the agricultural practice implemented to achieve the productivity improvement is additional to 'business as usual'. Although there are demonstrated benefits, the practice of wet-season P supplementation chosen for the case study is not widely adopted due to several constraints. These include difficulties with regular distribution of the supplement during the wet season and the need to construct paddock depots for storing feed and roofed troughs to keep the supplement dry. There is also an upfront 'cost' of annual supplementation that is not rewarded with improved productivity for the first 2–3 years, resulting in an initial deterioration of cash flow. Lack of accuracy in being able to predict the level of P deficiency of stock, and hence the likely response to supplementation, also creates uncertainty in returns.

However, individual beef producers have been able to overcome these barriers with their enterprises yielding considerable gain in both animal performance and financial returns (Bernie English and Bill Holmes, QDAF, pers. comm.). Hence, the possibility of designing ERF projects around improved productivity over and above business as usual is feasible, but, in the instance of this case study, a substantially higher price for carbon than that achieved to date in ERF auctions (Carbon Market Institute 2015) would need to be realised to cover estimated compliance costs (Australian Farm Institute 2014) and overcome the initial negative impact on cash flow.

Building on the work reported in this paper, the Department of Environment subsequently commissioned a review of regional LW and LW gain data (Bray *et al.* 2015). This study combined subregions with similar productivity capacity and rationalised livestock classes based on growth trajectory and livestock numbers in each class. The report concluded that the Queensland and the Northern Territory jurisdictions should be divided into four and three regions, respectively, and that the number of livestock classes should be increased from 7 to 10, to enable integration of emissions abatement from ERF projects with the national GHG accounts. This recommended number of regions and livestock classes was lower than that used in this study, as it sought to balance the complexity of national data collation against a substantially improved ability to estimate the GHG emissions differences due to alternate northern beef livestock management practices.

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Appendix 1. Regional parameters for liveweight and liveweight gain for expanded classes of cattle

Liveweight table: Regional Approach, Queensland

State	region	season	Cows 4 + years	Cows 3–4 years	Heifers 2–3 years	Heifers 1–2 years	Heifer calves (0–1 year old)	Spayed cows	Other	Steers 4 + years	Steers 3–4 years	Steers 2–3 years	Steers 1–2 years	Steer calves 0–1 year old	Bulls 1 year & older	Bull calves 0–1 year old
Queensland	R311A - Cape York	Spring	387	367	265	192	126	0	0	0	0	275	202	133	488	0
		Summer	378	309	222	153	81	0	0	0	291	233	163	84	480	0
		Autumn	386	313	230	157	96	0	0	0	318	240	167	96	487	0
		Winter	393	347	259	183	125	0	0	0	339	269	193	128	496	0
Queensland	R311B - Burke & Carpentaria	Spring	407	400	364	280	160	400	0	0	0	0	290	167	663	0
		Summer	400	376	315	210	100	376	0	0	0	334	220	103	649	0
		Autumn	407	380	327	213	128	380	0	0	0	390	223	128	661	0
		Winter	414	398	359	259	165	398	0	0	0	0	269	168	673	0
Queensland	R312 - W&SW Qld	Spring	461	437	372	276	142	431	0	0	0	0	209	148	701	0
		Summer	463	415	350	225	103	409	0	0	0	0	238	103	705	0
		Autumn	472	436	393	279	162	423	0	0	0	0	281	163	722	0
		Winter	472	457	406	307	180	457	0	0	0	0	0	186	721	0
Queensland	R313A - Croydon	Spring	387	367	265	192	126	0	0	0	0	275	202	133	488	0
		Summer	378	309	222	153	81	0	0	0	291	233	163	84	480	0
		Autumn	386	313	230	157	96	0	0	0	318	240	167	96	487	0
		Winter	393	347	259	183	125	0	0	0	339	269	193	128	496	0
Queensland	R313B - E.Mareeba Herberton Etheridge	Spring	462	459	444	330	202	0	0	0	552	449	322	202	622	0
		Summer	451	447	396	297	159	0	0	577	513	371	286	159	601	0
		Autumn	453	445	363	249	112	0	0	590	482	366	246	112	606	0
		Winter	464	459	413	303	180	0	0	603	519	405	295	180	626	0
Queensland	R313C - Goldfields - eastern half of Dalrymple Shire	Spring	468	456	400	348	232	456	0	0	565	492	393	247	665	247
		Summer	460	415	365	291	131	408	0	585	518	436	323	138	649	137
		Autumn	468	417	380	298	128	409	0	605	534	447	328	128	662	128
		Winter	476	447	408	339	201	447	0	0	553	487	377	206	681	206
Queensland	R313D - Desert (Dalrymple and Gulf forest)	Spring	437	427	381	338	222	0	0	0	517	461	366	236	635	236
		Summer	430	392	351	280	125	0	0	533	484	406	305	132	619	132
		Autumn	437	396	365	288	120	0	0	553	487	416	311	120	633	120
		Winter	445	420	390	329	190	0	0	0	510	455	354	196	650	196
Queensland	R313E - Basalt (Dalrymple, Flinders) & Downs	Spring	493	481	440	347	251	481	0	0	533	551	427	263	693	263
		Summer	481	459	403	321	204	456	0	538	547	515	394	217	671	217
		Autumn	483	440	375	302	118	436	0	579	582	476	342	118	676	118
		Winter	496	473	423	338	202	473	0	0	546	531	398	205	698	205
Queensland	R314 - Mitchell Downs,Mulga,Desert	Spring	488	480	434	331	191	480	0	0	0	537	354	217	645	0
		Summer	474	450	374	257	112	439	0	0	580	431	288	117	632	0
		Autumn	483	455	386	261	120	432	0	0	630	444	294	120	652	0
		Winter	497	476	431	312	175	476	0	0	0	509	339	181	660	0
Queensland	R321 - Darling Downs	Spring	502	493	493	438	243	0	0	0	0	546	451	255	872	255
		Summer	510	482	509	389	124	0	0	0	0	598	407	124	878	124
		Autumn	520	502	530	455	223	0	0	0	0	0	468	226	903	226
		Winter	513	508	517	489	294	0	0	0	0	0	513	305	896	305
Queensland	R322 - Beef CRC Brigalow	Spring	521	520	473	343	209	0	0	0	524	475	391	209	801	0
		Summer	525	515	437	307	112	0	0	0	572	491	336	112	807	0
		Autumn	537	516	495	352	196	0	0	0	0	550	398	196	828	0
		Winter	534	534	524	399	253	0	0	0	0	519	429	253	826	0
Queensland	R331 - Coastal speargrass	Spring	462	454	401	273	152	0	0	0	0	0	215	152	701	0
		Summer	471	447	364	232	106	0	0	0	0	0	245	106	706	0
		Autumn	475	465	417	279	169	0	0	0	0	0	290	169	723	0
		Winter	472	467	442	319	192	0	0	0	0	0	0	192	722	0
Queensland	R332A -Wet Coast & Tableland	Spring	520	512	441	337	160	0	0	0	0	618	410	167	699	0
		Summer	527	516	457	373	176	0	0	0	0	625	411	176	714	0
		Autumn	535	523	505	430	262	0	0	0	0	696	484	268	729	0
		Winter	529	527	514	401	287	0	0	0	0	720	521	302	717	0
Queensland	R332B - Lower Burdekin & Bowen	Spring	403	403	399	286	171	403	0	0	563	447	314	179	656	0
		Summer	402	401	307	191	84	400	0	576	469	343	204	84	651	0
		Autumn	411	410	349	239	149	405	0	584	501	384	257	149	666	0
		Winter	413	413	396	274	173	413	0	0	543	440	297	177	674	0

Liveweight table: Regional Approach, North of Western Australia

State	region	season	Cows 4 + years	Cows 3–4 years	Heifers 2–3 years	Heifers 1–2 years	Heifer calves (0–1 year old)	Spayed cows	Other	Steers 4 + years	Steers 3–4 years	Steers 2–3 years	Steers 1–2 years	Steer calves 0–1 year old	Bulls 1 year & older	Bull calves 0–1 year old
Western Australia	R511A - Pindan & North Kimberley	Spring	353	348	291	227	143	348	0	0	0	0	246	143	555	0
		Summer	351	300	241	156	80	309	0	0	0	270	159	80	551	0
		Autumn	359	324	274	193	137	341	0	0	0	300	201	137	562	0
		Winter	362	342	294	219	152	353	0	0	0	320	232	152	567	0
Western Australia	R511B - Fitzroy Valley	Spring	403	402	380	285	163	402	0	0	0	0	0	163	606	0
		Summer	401	384	304	183	88	384	0	0	0	0	193	88	605	0
		Autumn	411	398	343	232	157	395	0	0	0	0	241	157	626	0
		Winter	413	406	376	270	173	403	0	0	0	0	274	173	632	0
Western Australia	R512 Pilbara and Gascoyne	Spring	407	407	402	307	195	407	0	0	0	0	325	202	613	0
		Summer	400	400	337	247	113	400	0	0	0	345	252	116	599	0
		Autumn	406	407	344	254	108	404	0	0	0	370	263	108	608	0
		Winter	413	414	379	292	168	409	0	0	0	395	298	171	621	0

Liveweight table: Regional Approach, Northern Territory

State	region	season	Cows 4 + years	Cows 3–4 years	Heifers 2–3 years	Heifers 1–2 years	Heifer calves (0–1 year old)	Spayed cows	Other	Steers 4 + years	Steers 3–4 years	Steers 2–3 years	Steers 1–2 years	Steer calves 0–1 year old	Bulls 1 year & older	Bull calves 0–1 year old
Northern Territory	R711 - Alice Springs	Spring	403	403	400	297	188	0	0	0	0	0	322	205	706	0
		Summer	403	401	319	209	84	0	0	0	0	352	230	84	703	0
		Autumn	414	410	365	256	150	0	0	0	0	392	278	151	721	0
		Winter	418	413	396	288	183	0	0	0	0	425	311	191	727	0
Northern Territory	Region 712 - Barkly Tableland	Spring	458	449	404	319	231	449	0	0	0	0	0	217	764	0
		Summer	450	420	349	266	118	412	0	0	0	0	240	101	749	0
		Autumn	458	424	362	274	168	415	0	0	0	0	281	168	762	0
		Winter	466	445	402	311	229	445	0	0	0	0	0	223	775	0
Northern Territory	Region 713 - Katherine & VRD	Spring	393	393	390	288	195	393	0	0	0	0	246	212	656	212
		Summer	391	391	305	208	104	392	0	0	0	268	231	104	651	104
		Autumn	401	400	344	249	194	398	0	0	0	307	266	195	666	195
		Winter	403	403	375	279	211	402	0	0	0	0	256	220	673	220
Northern Territory	R714 - NT Top End & Western Gulf	Spring	381	381	339	250	144	0	0	0	0	256	227	157	601	156
		Summer	384	383	307	218	100	0	0	0	0	279	240	100	605	100
		Autumn	393	393	349	258	158	0	0	0	0	313	272	161	620	161
		Winter	390	390	380	276	181	0	0	0	0	0	255	193	619	193

(*continued next page*)

Appendix 1. (*continued*)

Liveweight gain table: Regional Approach, Queensland

State	region	season	Cows 4 + years	Cows 3–4 years	Heifers 2–3 years	Heifers 1–2 years	Heifer calves (0–1 year old)	Spayed cows	Other	Steers 4 + years	Steers 3–4 years	Steers 2–3 years	Steers 1–2 years	Steer calves 0–1 year old	Bulls 1 year & older	Bull calves 0–1 year old
Queensland	R311A - Cape York	Spring	−0.11	0.20	−0.01	0.05	−0.02	0.00	0.00	0.00	0.00	−0.01	0.05	0.02	−0.15	0.00
		Summer	−0.01	0.32	0.16	0.16	0.33	0.00	0.00	0.00	0.36	0.15	0.16	0.34	−0.03	0.00
		Autumn	0.12	0.45	0.38	0.34	0.46	0.00	0.00	0.00	0.35	0.39	0.34	0.46	0.12	0.00
		Winter	0.04	0.31	0.25	0.23	0.19	0.00	0.00	0.00	0.36	0.24	0.23	0.24	0.07	0.00
Queensland	R311B - Burke & Carpentaria	Spring	−0.12	−0.01	−0.08	0.15	−0.09	−0.01	0.00	0.00	0.00	0.00	0.15	−0.05	−0.22	0.00
		Summer	−0.03	0.08	0.15	0.32	0.48	0.08	0.00	0.00	0.00	0.76	0.32	0.50	−0.05	0.00
		Autumn	0.12	0.23	0.41	0.58	0.72	0.23	0.00	0.00	0.00	0.73	0.58	0.72	0.18	0.00
		Winter	0.03	0.14	0.30	0.43	0.17	0.14	0.00	0.00	0.00	0.00	0.43	0.22	0.09	0.00
Queensland	R312 - W&SW Qld	Spring	−0.09	0.06	0.03	0.20	0.27	0.05	0.00	0.00	0.00	0.00	0.48	0.30	−0.16	0.00
		Summer	0.08	0.22	0.44	0.56	0.70	0.14	0.00	0.00	0.00	0.00	0.48	0.70	0.15	0.00
		Autumn	0.08	0.21	0.43	0.54	0.54	0.13	0.00	0.00	0.00	0.00	0.47	0.57	0.15	0.00
		Winter	−0.06	0.18	0.00	0.19	0.09	0.35	0.00	0.00	0.00	0.00	0.00	0.13	−0.12	0.00
Queensland	R313A - Croydon	Spring	−0.11	0.20	−0.01	0.05	−0.02	0.00	0.00	0.00	0.00	−0.01	0.05	0.02	−0.15	0.00
		Summer	−0.01	0.32	0.16	0.16	0.33	0.00	0.00	0.00	0.36	0.15	0.16	0.34	−0.03	0.00
		Autumn	0.12	0.45	0.38	0.34	0.46	0.00	0.00	0.00	0.35	0.39	0.34	0.46	0.12	0.00
		Winter	0.04	0.31	0.25	0.23	0.19	0.00	0.00	0.00	0.36	0.24	0.23	0.24	0.07	0.00
Queensland	R313B - E.Mareeba Herberton Etheridge	Spring	−0.10	−0.07	0.03	0.17	0.12	0.00	0.00	0.00	0.23	0.09	0.14	0.12	−0.19	0.00
		Summer	−0.09	−0.07	0.04	0.18	0.35	0.00	0.00	0.24	0.27	0.28	0.17	0.35	−0.17	0.00
		Autumn	0.08	0.11	0.34	0.54	0.78	0.00	0.00	0.22	0.38	0.42	0.47	0.78	0.15	0.00
		Winter	0.11	0.15	0.65	0.54	0.63	0.00	0.00	0.22	0.45	0.54	0.54	0.63	0.22	0.00
Queensland	R313C - Goldfields - eastern half of Dalrymple Shire	Spring	−0.14	0.05	−0.18	0.01	0.28	0.05	0.00	0.00	0.08	−0.05	0.09	0.38	−0.26	0.38
		Summer	−0.02	0.15	0.08	0.21	0.61	0.12	0.00	0.34	0.29	0.18	0.30	0.64	−0.05	0.64
		Autumn	0.12	0.28	0.37	0.53	0.72	0.19	0.00	0.33	0.39	0.53	0.61	0.72	0.21	0.72
		Winter	0.05	0.29	0.19	0.34	0.71	0.41	0.00	0.00	0.14	0.32	0.42	0.80	0.12	0.80
Queensland	R313D - Desert (Dalrymple and Gulf forest)	Spring	−0.13	0.04	−0.19	0.02	0.29	0.00	0.00	0.00	0.04	−0.03	0.05	0.39	−0.25	0.39
		Summer	−0.02	0.14	0.06	0.22	0.56	0.00	0.00	0.28	0.13	0.18	0.24	0.59	−0.05	0.59
		Autumn	0.11	0.27	0.33	0.52	0.65	0.00	0.00	0.27	0.29	0.52	0.55	0.65	0.22	0.65
		Winter	0.05	0.22	0.16	0.34	0.70	0.00	0.00	0.00	0.20	0.32	0.37	0.79	0.11	0.79
Queensland	R313E - Basalt (Dalrymple, Flinders) & Downs	Spring	−0.11	0.02	0.02	−0.02	0.36	0.02	0.00	0.00	−0.22	0.06	0.20	0.46	−0.19	0.46
		Summer	−0.09	−0.03	0.06	−0.02	0.52	−0.06	0.00	0.98	0.19	0.07	0.20	0.58	−0.17	0.58
		Autumn	0.09	0.20	0.47	0.35	0.85	0.16	0.00	0.90	0.36	0.54	0.57	0.85	0.17	0.85
		Winter	0.11	0.23	0.50	0.35	0.91	0.23	0.00	0.00	−0.55	0.54	0.57	0.97	0.19	0.97
Queensland	R314 - Mitchell Downs,Mulga,Desert	Spring	−0.14	−0.01	−0.07	0.13	0.13	−0.01	0.00	0.00	0.00	0.20	0.09	0.38	−0.25	0.00
		Summer	0.02	0.10	0.18	0.33	0.51	−0.01	0.00	0.00	0.68	0.50	0.27	0.59	0.01	0.00
		Autumn	0.17	0.28	0.53	0.63	0.65	0.06	0.00	0.00	0.65	0.82	0.57	0.65	0.28	0.00
		Winter	0.09	0.18	0.37	0.45	0.47	0.50	0.00	0.00	0.00	0.59	0.39	0.59	−0.02	0.00
Queensland	R321 - Darling Downs	Spring	−0.07	−0.08	−0.19	0.19	0.65	0.00	0.00	0.00	0.00	0.87	0.22	0.71	−0.22	0.71
		Summer	0.17	0.08	0.17	0.69	0.94	0.00	0.00	0.00	0.00	0.87	0.63	0.94	0.23	0.94
		Autumn	0.04	0.27	0.20	0.67	1.15	0.00	0.00	0.00	0.00	0.00	0.75	1.21	0.22	1.21
		Winter	−0.11	−0.05	−0.31	0.24	0.56	0.00	0.00	0.00	0.00	0.00	0.16	0.66	−0.22	0.66
Queensland	R322 - Beef CRC Brigalow	Spring	−0.09	−0.14	0.09	0.15	0.54	0.00	0.00	0.00	0.80	0.17	0.19	0.54	−0.20	0.00
		Summer	0.11	0.00	0.60	0.47	0.80	0.00	0.00	0.00	0.80	0.64	0.64	0.80	0.19	0.00
		Autumn	0.11	0.00	0.58	0.46	0.96	0.00	0.00	0.00	0.00	0.62	0.63	0.96	0.18	0.00
		Winter	−0.11	0.16	0.14	0.39	0.45	0.00	0.00	0.00	0.00	−0.61	0.19	0.45	−0.15	0.00
Queensland	R331 - Coastal speargrass	Spring	−0.06	−0.05	0.07	0.21	0.31	0.00	0.00	0.00	0.00	0.00	0.50	0.31	−0.17	0.00
		Summer	0.17	0.14	0.54	0.50	0.74	0.00	0.00	0.00	0.00	0.00	0.50	0.74	0.16	0.00
		Autumn	0.01	0.18	0.52	0.49	0.60	0.00	0.00	0.00	0.00	0.00	0.49	0.60	0.15	0.00
		Winter	−0.10	−0.04	0.11	0.33	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.13	−0.12	0.00
Queensland	R332A -Wet Coast & Tableland	Spring	−0.04	−0.04	0.22	0.45	0.83	0.00	0.00	0.00	0.00	0.42	0.52	0.86	−0.07	0.00
		Summer	0.13	0.13	0.65	0.68	1.14	0.00	0.00	0.00	0.00	0.92	0.92	1.14	0.25	0.00
		Autumn	0.03	0.02	0.40	0.57	0.70	0.00	0.00	0.00	0.00	0.62	0.68	0.79	0.06	0.00
		Winter	−0.12	0.01	−0.03	−0.53	0.20	0.00	0.00	0.00	0.00	0.14	0.30	0.29	−0.22	0.00
Queensland	R332B - Lower Burdekin & Bowen	Spring	−0.12	−0.12	0.00	0.11	−0.03	−0.12	0.00	0.00	0.21	0.06	0.17	0.01	−0.22	0.00
		Summer	0.05	0.03	0.33	0.40	0.74	0.02	0.00	0.10	0.33	0.40	0.45	0.74	0.05	0.00
		Autumn	0.11	0.11	0.47	0.54	0.67	0.06	0.00	0.09	0.35	0.46	0.60	0.69	0.17	0.00
		Winter	−0.04	−0.02	0.41	0.27	0.06	0.04	0.00	0.00	0.44	0.52	0.32	0.11	0.00	0.00

Liveweight gain table: Regional Approach, North of Western Australia

State	Region	Season	Cows 4 + years	Cows 3–4 years	Heifers 2–3 years	Heifers 1–2 years	Heifer calves (0–1 year old)	Spayed cows	Other	Steers 4 + years	Steers 3–4 years	Steers 2–3 years	Steers 1–2 years	Steer calves 0–1 year old	Bulls 1 year & older	Bull calves 0–1 year old
Western Australia	R511A - Pindan & North Kimberley	Spring	−0.11	0.06	−0.05	0.07	−0.11	0.06	0.00	0.00	0.00	0.00	0.13	−0.11	−0.17	0.00
		Summer	0.03	0.20	0.23	0.30	0.67	0.33	0.00	0.00	0.00	0.33	0.36	0.67	0.04	0.00
		Autumn	0.10	0.27	0.37	0.42	0.57	0.36	0.00	0.00	0.00	0.33	0.47	0.57	0.14	0.00
		Winter	−0.03	0.14	0.12	0.20	−0.03	0.02	0.00	0.00	0.00	0.33	0.25	−0.03	0.00	0.00
Western Australia	R511B - Fitzroy Valley	Spring	−0.12	−0.07	−0.04	0.14	−0.12	−0.07	0.00	0.00	0.00	0.00	0.00	−0.12	−0.22	0.00
		Summer	0.04	0.09	0.28	0.43	0.80	0.08	0.00	0.00	0.00	0.00	0.54	0.80	0.12	0.00
		Autumn	0.12	0.17	0.44	0.55	0.67	0.12	0.00	0.00	0.00	0.00	0.53	0.67	0.24	0.00
		Winter	−0.03	0.03	0.30	0.32	−0.03	0.07	0.00	0.00	0.00	0.00	0.54	−0.03	−0.11	0.00
Western Australia	R512 Pilbara and Gascoyne	Spring	−0.12	−0.12	−0.05	0.04	0.24	−0.12	0.00	0.00	0.00	0.00	0.07	0.29	−0.23	0.00
		Summer	−0.03	−0.03	0.15	0.22	0.48	−0.02	0.00	0.00	0.00	0.34	0.27	0.49	−0.07	0.00
		Autumn	0.10	0.11	0.39	0.46	0.55	0.06	0.00	0.00	0.00	0.33	0.41	0.55	0.17	0.00
		Winter	0.05	0.04	0.46	0.38	0.60	0.07	0.00	0.00	0.00	0.33	0.43	0.65	0.13	0.00

Liveweight gain table: Regional Approach, Northern Territory

State	Region	Season	Cows 4 + years	Cows 3–4 years	Heifers 2–3 years	Heifers 1–2 years	Heifer calves (0–1 year old)	Spayed cows	Other	Steers 4 + years	Steers 3–4 years	Steers 2–3 years	Steers 1–2 years	Steer calves 0–1 year old	Bulls 1 year & older	Bull calves 0–1 year old
Northern Territory	R711 - Alice Springs	Spring	−0.12	−0.12	−0.03	0.08	0.05	0.00	0.00	0.00	0.00	0.00	0.09	0.14	−0.23	0.00
		Summer	0.07	0.03	0.37	0.37	0.74	0.00	0.00	0.00	0.00	0.45	0.39	0.74	0.09	0.00
		Autumn	0.13	0.11	0.51	0.52	0.72	0.00	0.00	0.00	0.00	0.43	0.54	0.75	0.22	0.00
		Winter	−0.06	−0.02	0.26	0.24	0.15	0.00	0.00	0.00	0.00	0.44	0.25	0.24	−0.06	0.00
Northern Territory	Region 712 - Barkly Tableland	Spring	−0.13	0.00	−0.08	0.01	−0.03	0.00	0.00	0.00	0.00	0.00	0.00	−0.13	−0.24	0.00
		Summer	−0.03	0.11	0.17	0.19	0.86	0.06	0.00	0.00	0.00	0.00	0.69	0.96	−0.05	0.00
		Autumn	0.13	0.27	0.50	0.48	1.04	0.24	0.00	0.00	0.00	0.00	0.66	1.04	0.20	0.00
		Winter	0.04	0.17	0.30	0.31	0.37	0.17	0.00	0.00	0.00	0.00	0.00	0.27	0.10	0.00
Northern Territory	Region 713 - Katherine & VRD	Spring	−0.12	−0.12	−0.02	0.06	−0.19	−0.12	0.00	0.00	0.00	0.00	−0.13	−0.10	−0.22	−0.10
		Summer	0.04	0.03	0.30	0.34	1.07	0.04	0.00	0.00	0.00	0.42	0.36	1.07	0.05	1.07
		Autumn	0.12	0.12	0.44	0.46	0.86	0.08	0.00	0.00	0.00	0.41	0.38	0.89	0.18	0.89
		Winter	−0.04	−0.03	0.34	0.25	−0.08	0.01	0.00	0.00	0.00	0.00	−0.25	0.01	−0.01	0.01
Northern Territory	R714 - NT Top End & Western Gulf	Spring	−0.07	−0.08	0.07	0.09	0.29	0.00	0.00	0.00	0.00	0.38	0.20	0.35	−0.14	0.36
		Summer	0.09	0.09	0.39	0.41	0.67	0.00	0.00	0.00	0.00	0.38	0.35	0.67	0.14	0.67
		Autumn	0.07	0.08	0.55	0.40	0.57	0.00	0.00	0.00	0.00	0.37	0.34	0.63	0.13	0.63
		Winter	−0.08	−0.08	0.07	0.09	0.13	0.00	0.00	0.00	0.00	0.00	−0.35	0.22	−0.11	0.22