final report

Project code: B.GBP.0036

Prepared by: Stuart McLennan 1, Ian McLean 2 and Col Paton 3

1 Department of Agriculture & Fisheries Queensland, Brisbane; 2 Bush AgriBusiness, Toowoomba; 3 EcoRich Grazing, Goombungee

Date published: January 2020

PUBLISHED BY
Meat and Livestock Australia Limited
Locked Bag 1961
NORTH SYDNEY NSW 2059

Re-defining the animal unit equivalence (AE) for grazing ruminants and its application for determining forage intake, with particular relevance to the northern Australian grazing industries

Meat & Livestock Australia acknowledges the matching funds provided by the Australian Government to support the research and development detailed in this publication.

Abstract

The adult equivalent (AE) system describes and quantifies, in commonly recognised units, the grazing pressure imposed on the pasture by foraging ruminants. The AE rank assigned to an animal is determined as the ratio of its (metabolisable) energy (ME) requirements relative to that of a ‘standard animal’, where ME requirements are usually determined using the feeding standards. Previous research has indicated that the Australian feeding standards (NRDR 2007) considerably over-estimated the energy requirements of cattle consuming tropical forages in northern Australia. In the current project, modifications were made to the equations of the feeding standards which improved predictions of ME, and so also forage dry matter (DM) intake by cattle. However, these changes were not tested with cattle in temperate regions, or sheep in any region meaning that two systems, one using modified and the other unmodified equations, were required to accommodate this regional demarcation. Simulations carried out using cattle growth data from northern Australia showed that the estimate of AE score was similar using either system providing they were used systematically. Furthermore, it was found that the forage intake predicted by direct calculation using the modified system could be closely matched by calculating an AE rank using the unmodified system and then multiplying this rank by an intake constant. The optimum intake constant fluctuated with regional variations in animal productivity. This agreement between predictions suggested that, for most circumstances, the existing (unmodified) feeding standards could be used across regional boundaries. Recommendations are made for application of the revised animal unit systems to practical grazing scenarios and forms the basis of revising current EDGE (NutritionEDGE) material.

Executive summary

- The current project reviewed the animal unit systems primarily for potential revision in application in northern Australia, for instance through incorporation into the EDGE training networks, but with cognisance of a more widespread (national) usage.
- The animal unit equivalence of an animal of interest is now defined as the ratio of its energy requirement for a particular production rate to that of a 'standard animal' (cattle (AE) or sheep (DSE)).
- Within Australia, the Australian feeding standards for ruminants (NRDR 2007) are recommended for determining energy requirements.
- For this project, the definition adopted for the standard (bovine) animal (representing 1 AE) was that described recently by McLean and Blakeley (2014), a 450 kg, 2.25-year-old *Bos taurus* steer with zero weight (W) change and walking 7 km/day on level ground.
- A desktop study was undertaken in the current project to address previous findings (McLennan 2013) that NRDR (2007) over-predicted the metabolisable energy (ME) requirements, and thus also dry matter (DM) intake, of cattle consuming tropical and sub-tropical forages in northern Australia.
- Modifications to equations within NRDR (2007), particularly those pertaining to the maintenance energy requirements of cattle and the estimation of the energy density (M/D) of the diet, improved predictions of DM intake of forages by cattle in pen-feeding studies relative to those predicted without modifications. These findings only apply to northern cattle; similar evaluations of the feeding standards were not undertaken with cattle in temperate regions or sheep in any region.
- The ME requirements of the standard bovine animal (1 AE) was calculated to be 73 MJ/day using NRDR (2007) without modification (hereafter NRDR_unmod) or 64 MJ/day after changes to the equations (hereafter NRDR_mod), where a standard diet of 55% dry matter digestibility (DMD) was assumed for both.
- Simulations carried out using regional cattle growth path data from northern Australia indicated that the AE ranking of animals was similar using either version of equations of the feeding standards providing they were used consistently. This finding suggests that animal unit rankings are unlikely to be affected by any future changes to the feeding standards.
- Further simulations with the same data set were used to compare intakes calculated (i) directly applying NRDR_mod equations and (ii) indirectly applying NRDR_unmod equations in a two-stage process of first estimating the AE rank and then multiplying this rank by an intake constant. The appropriate intake constant, which minimised discrepancy between the two methods, varied with regional animal productivity, from 7.5 to 8.0 to 8.5 kg DM/AE.day as annual steer growth rates changed from high (>150 kg) to moderate (110-150 kg) to low (<110 kg) productivity, respectively. This exercise demonstrated: (i) a method of converting from an AE score to a forage intake, which is the aspect of most interest in a grazing scenario; (ii) that, by applying the intake constant multipliers, the more universally applied NRDR_unmod equations could be used universally to estimate intake without jeopardising the greater precision of estimates achieved with NRDR_mod equations in northern Australia.
- The definition of the standard (ovine) animal, representing 1 DSE, recommended for general use from this study is a 45 kg Merino wether with zero W change, walking 7 km/day on level ground and with no wool growth above that included in maintenance.
- The ratio of DSE: AE, based on NRDR_unmod equations, is 8.4: 1 (73/8.7). This substitution ratio can be used in grazing scenarios to express the herd population in either AE or DSE units.
- By applying this substitution ratio, intake constants to convert DSE to forage DM intake of 0.89, 0.95 and 1.01 kg DM/DSE.day were derived for high, moderate and low productivity regions, respectively, despite there being no simulations with sheep comparable to those carried out with cattle.
- The largest errors in the estimation of forage DM intake using the intake constant approach will be at the extremes of forage quality, where DMD varies most widely from the 55% DMD used in simulations, for instance in dry season feeding or with high-quality forage crop grazing scenarios.

- The practical applications of the animal unit systems, can vary in complexity the baseline information available and the purpose of the application. Some recommendations for application:
    - Use the NRDR_unmod system (AE or DSE x intake constant) for:
        - long-term carrying capacity determinations [cattle and sheep; temperate and tropical regions]
        - medium-term fodder budgets (6 months or more) [cattle and sheep; temperate and tropical regions]
    - Use the NRDR_mod system (direct calculation using multi-variate animal demand models) for:
        - short-term fodder budgets (<6 months) [cattle only; northern (tropical) Australia only; very low or very high diet quality]
- Where intake is the primary consideration, and DMD is either known or can be reasonably estimated, the direct approach of using a multi-variate animal demand model, based on either set of equations according to region and animal species, may provide a simple solution for determining grazing pressure.
- The incorporation of the equations from the feeding standard into simple spreadsheet calculators such as *GrazFeed*, *ME_required* and *QuikIntake* easily facilitates this calculation.

Table of contents

1 Background

1.1 Background to the animal unit methodology

The adult equivalent (AE) concept evolved from a need to assess the overall effect of different classes of animals, separately or in combination, on the pasture they were grazing, with an overriding aim of achieving responsible land management. Multiple uses for the AE concept have been proposed (Scarnecchia 2004);

1. describing and summing, in equivalent units (AE), the feed requirements of mixed herds within, and between (cattle, sheep, goats, feral animals), species to determine total grazing density;
2. summing the intakes of mixed herds of animals and defining their impacts on the pasture;
3. calculating stocking variables such as stocking density (AE/ha) and grazing pressure (AE/tonne pasture) in common units;
4. describing forage supply and demand in common terms for the purpose of supply/demand analysis for fodder budgeting;
5. quantifying the long-term carrying capacity (LTCC) of properties for management and valuations;
6. undertaking business analysis and decision-making using broadly accepted units. Describing the number of stock an enterprise is running in “common currency” terms

Using a common terminology such as AE allows meaningful comparisons of grazing dynamics within and across properties. In addition, as Scarnecchia and Gaskins (1987) contend, standardising the method of defining the AE is required to improve communication among researchers and grazing land managers.

The equivalent terms for AE in the USA are animal units (AUs) and animal unit equivalents (AUEs). The evolution of the concept of an AU, or cow unit as it was earlier known, from the early 20th century (Jardine and Anderson 1919) to more recent times has been documented by Scarnecchia (1985) and follows a natural progression from a unit of weight (W) to one of energy demand. Originally the AU was defined as being equivalent to a 1000 lb (454 kg) of liveweight, which was roughly the W of a mature cow and calf (Stoddart and Smith 1955, cited by Scarnecchia 1985). No distinction was initially made for the productive or physiological status of the animal, for instance whether it was losing, maintaining or gaining W or was pregnant and/or lactating, despite the obvious effect of this production and physiological status on the energy requirements and pasture DM intake of the animal. Basing AUs on W alone thus assumed a direct relationship between animal W and feed intake, (that a 250 kg steer would consume half as much pasture as a 500 kg steer, or a 50 kg sheep 10% of that of the heavier steer, with no cognisance of effects of herbage or environmental variables). Later modifications involved calculations based on the metabolic size of the animal, i.e., $W^{0.75}$ (Edwards 1981), and whilst this change provided a better relationship between animal W and forage intake it still made no allowance for the productivity of the animal. Around the same time, the AU was starting to be defined more in terms of animal demand than metabolic size.

The Society for Range Management Rangeland Assessment and Monitoring (SRM 2017) recently addressed the question of whether the W of the standard animal (AU) should be increased in keeping with the increased W of range cows in present times but could see no advantage, and considerable confusion, in changing the W from 1000 lb.

Scarnecchia and Gaskins (1987) strongly contended that animal requirements be defined in terms of energy, not DM, demand or intake. Intake is a product of not only demand in terms of animal factors such as W gain, gestation and lactation but also of animal-pasture and animal-environment interactions which will vary widely. Intake was a function of both animal demand and forage supply, and that whilst intake could be expressed in units of DM or energy, and forage supply in units of DM, animal demand could only be expressed with any precision in units of energy. The calculation of AUEs required an estimate of energy requirements, in terms of metabolisable energy (ME), digestible energy (DE) or total digestible nutrients (TDN), which could be subsequently converted to DM requirements where some estimate of diet quality was available. Scarnecchia and Gaskins (1987) defined an AU as an energy demand of 7.2 kg TDN/day, which was equivalent to 12 kg DM/day if assumed that 1 kg DM = 0.6 kg TDN. Obviously, this conversion is not a constant but varies with pasture and thus diet quality. In agreement, the American Society for Range Management (SRM 1998), in their glossary of terms used in range management, adopted the definition of an AU as a mature 454 kg cow or equivalent with an average pasture consumption of 12 kg DM/day. It was further stated that 'this allowed for forage trampled or used by other animals'. This figure of 12 kg DM/day was derived from Maddox (1964) as the mean daily DM demand for a cow/calf pair averaged over a year and included a feed requirement for travel during grazing, this being 0.92 kg DM/day for 2 miles walking/day while grazing on 'average' pasture. Thus, this definition was a function of animal factors such as metabolic size, W change and physiological state and also included some aspects of herbage and environmental characteristics by assuming herbage quality over a defined period.

Meyer (2010) determined that there were many different definitions of the AU in peer-reviewed and extension material in the USA, even from recent times, but that they were all generally based on the amount of feed required to sustain the 'standard animal' for a particular duration; daily, monthly or annually. The definition of the standard animal varies; it is usually a ~ 450 kg cow, sometimes with calf at foot, but the emphasis seems to be on the amount of feed required and this is often expressed in kg DM/day with no reference to the quality of that feed material. Meyer (2010) suggested that the consensus of literature indicated this standard animal consumed approximately 2.6% W, on a DM basis, although this was presumably averaged over an annual production cycle. The AU rating is then calculated as multiples of the feed intake of the 'standard animal'.

Within Australia, most states have adopted the concept of a dry sheep equivalent (DSE) and assign a DSE rating to an animal based on various criteria. There is no single national approach to defining this term (see Turner and Alcock 2000), with the definition varying across, and sometimes within, state boundaries. What appears common though is that the DSE is calculated in relation to the energy requirements of the 'standard animal' to maintain W, although this definition is often implied rather than clearly stated in some state department of agriculture advisory notes. The DSE, or other unit like AE, rating of a particular animal is then determined as multiples of its energy requirements relative to that of the standard animal. Thus, all factors which influence energy requirements of the animal, including breed, age, W, W change, pregnancy, lactation will in turn affect its animal unit rating. Many of the department of agriculture and other information bulletins assign DSE or AE values to different classes of cattle and sheep, as a fixed value based on their energy requirements relative to that of the standard animal.

Much of the inconsistency between reports centres on the definition of the 'standard animal' and the calculation of its energy requirements for maintenance. In separate advisory notes from Victoria (McLaren 1997; Anon. A 2017) and South Australia (Anon. B) a DSE is defined as the 'feed' required by a 45 kg, twoyear-old Merino non-pregnant, non-lactating sheep (wether) for maintaining W and translates to an energy requirement of 7.6 MJ ME/day. In another reference of Victorian workers (Sargeant and Saul 2013) a DSE is defined as a 50 kg dry ewe, with no level of performance indicated, but assumed to be maintenance, and the energy requirement is stipulated as 8.3 MJ ME/day. Corresponding farm notes for NSW (Anon. C) refer to a DSE as the 'feed' required for a 50 kg wether or dry ewe for maintaining W, and is variously defined as 9 MJ ME/day (Davies 2005) or 1 kg DM/day of 'average quality' feed (AIMS 2009). In a farm-note from Tasmania, Griffiths (1998; cited by Turner and Alcock 2000) refer to the standard animal being a 48 kg dry sheep. It is difficult to find a published definition of a DSE from Queensland. One reference suggests it is the 'nutritional' requirement of a 50 kg dry (non-lactating) sheep, but no level of production is stated, and maintenance is assumed (Millear *et al*. 2003). This lack of precision in definition of the animal unit leads to confusion for users.

In recognising this inconsistency in definitions Turner and Adcock (2000), using a survey of available data on Merino wethers, defined the standard sheep (1 DSE) as a three year-old, 50 kg Merino wether at maintenance and, utilizing the '*GrazFeed*' decision support model (Freer *et al*. 1997), determined its daily ME requirement to be 9.7 MJ/day. Other classes of sheep were then given a DSE rating by dividing their calculated ME requirements by that of this standard animal. This approach was supported by Hyder (2006) from the WA Department of Agriculture although the ME requirement of the standard animal used was 8.6 MJ/day.

It is quite common for state government advisory notes to refer to DSEs in terms of the amount of 'feed' or 'nutrients', rather than energy, to sustain the standard animal at maintenance. This leads to confusion in that it follows that some authors suggest an animal with a DSE rating of six would consume x6 more feed (DM) than the standard animal whereas in fact it is probably based on the animal requiring x6 more energy, the relativity differing considerably between DM and energy intake depending on feed quality. Blackwood *et al*. (2006) define the DSE as 'the average amount of pasture feed consumed by a 50 kg wether (an adult but non-lactating sheep) on a monthly basis'. At the same time, they ascribe a DSE rating of six to a 450 kg dry beef animal based on its energy requirements (at maintenance) of 54 MJ ME/day compared to that of the 'standard' 50 kg dry wether (1 DSE) of 9 MJ/day. The Nutrition EDGE manual (MLA 2017) states that a steer with an AE rating of 0.81 indicates that "its energy and feed requirements are 81% of" that of another with a rating of 1. This interchangeability between energy and feed requirements in these publications adds to the confusion. The need for a clear and precise definition of the standard units, either AE or DSE, is required.

Allocation of a standard unit such as AE or DSE allows the aggregation, in common units, of livestock from different species and classes in terms of their nutritional or feed requirements. In order for these terms to be meaningful, the herd should be described in terms of either one or the other (AE or DSE), not as both. Thus, cattle can be given a DSE rating just as sheep or other species can be given an AE rating. The important thing is that both units are a function of the energy requirement of the respective standard animals and the ratio of DSE to AE is thus constant once the standard animals have been defined.

The relationship between the two units cited in the extension literature varies widely. Mature 450 kg dry cattle at maintenance have been variously allocated DSE ratings of 6 (Davies 2005; Blackwood *et al*. 2006), 6.8 (Millear *et al*. 2003), 7.5 (McLaren 1997; Anon. A 2017), 9 (MLA 2001, 2017) and 10 (Anon. B) but these obviously depend on the definition used for a DSE. Holistic Results Pty Ltd Australia (2010) published tables of DSEs, one DSE being equivalent to a 50 kg adult Merino sheep at maintenance and determined a 450 kg feeder steer with zero W gain was equivalent to 7.3 DSE. Similarly, Resource Consulting Services in conjunction with Bell (1992; cited by Turner and Alcock 2000), have developed a spreadsheet calculator to determine livestock unit (LSU) and DSE ratings of both growing and breeding cattle and Merino and crossbred sheep at different weights, W changes and pregnancy and lactation status. No definition of an LSU is given in the spreadsheet, but a feeder steer of 425 kg W and zero W change had a rating of 1.01. A fixed conversion rate of 6.9 DSE to 1 LSU across all species, breeds and production levels is used. In another publication (McCosker *et al*. 2009) relating to northern Australia, the same abbreviation of LSU was used for a 'large stock unit' which was equivalent to a 400 kg steer with zero W gain. In the UK and Europe, a LSU (livestock unit) is the grazing equivalent of an adult dairy cow producing 3000 kg of milk annually.

There is a distinction, however, and one which is often mis-understood by users, between the ratio of DSE to AE and that expressing the number of one species that would equivalently replace another species of animal, e.g., sheep for cattle, in a grazing situation. The former is a ratio of the energy requirements attributed to the standard animals defining one DSE and one AE. The latter refers to what is termed in the literature a substitution ratio and relates to the number of one species, or class of animals (yearling steers, mature, pregnant cows), that will have the same grazing outcome as another species or class of animal.

1.2 Reasons for undertaking study

In keeping with the approach estimating animal unit equivalents based on energy requirements, various attempts have been made in recent years to define the standard animal and its energy demands, as it relates to northern Australia. The spreadsheet calculator '*QuikIntake*'(McLennan 2004; Dove *et al*. 2010), which encapsulates the equations from the Australian feeding standards SCA (1990) and its successor NRDR (2007), has included this approach , allowing individual users to define the weight of the standard animal.

McLean and Blakeley (2014), used the same approach of applying the NRDR (2007) equations to estimate AEs, but they fixed the definition of the standard animal as a 2.25-year-old, 450 kg *B. taurus* steer maintaining W and walking 7 km/day. This meant that the resulting AE ratings were comparable across users and applications. The ME requirement of this standard animal was 72.6 MJ/day (rounded to 73), this value thus constituting one AE. Thus, the AE rating for an animal of interest was determined by estimating its ME requirements for its current or expected production level and dividing this value by 73 MJ/day. These workers applied this system on an annualised basis by setting a constant feed quality; an energy density (M/D) of 7.75 MJ/kg DM (equivalent to 55% DM digestibility; DMD). Using a fixed value like this for M/D on an annualised basis reduces errors associated with the variations in feed quality, including differences between regions, and provides a relatively useful and simplified approach for comparing carrying capacities of different beef enterprises. The main variable between enterprises is the level of production, or ME requirements of the animal population.

Although outside the scope of their task, the work of Mclean and Blakeley (2014) was later used by others to predict the forage intake of an AE which came to 9.4 kg/day (72.6 MJ ME/day divided by 7.75 MJ/kg DM), or *ca*. 2.1%W/day for a 450 kg steer at maintenance. This intake seemed very high especially in comparison with observed intakes of cattle of this size on low-quality maintenance diets. In their studies (McLennan 2013), steers of this W in pens were maintaining W when consuming *ca*. 1.3%W DM/day of a low-quality *Heteropogon contortus* (black speargrass) hay, albeit these were *B. indicus* crossbreds and were confined to pens (zero walking assumed). Nevertheless, this estimate coupled with the findings of other workers (Bowen *et al*. 2015) suggested that the Australian feeding standards (NRDR 2007) may not be providing accurate predictions of the energy requirements of cattle consuming tropical forages. In previous projects, McLennan and Poppi (McLennan 2005; Dove *et al*. 2010), using growth response data derived from pen-feeding studies with confined animals fed tropical forages with and without supplement, showed that these feeding standards tended to under-predict W change from known feed intake and diet quality. It would follow that they would over-predict intake from known W change when the feeding standards were used ‘in reverse’. This was demonstrated in a more recent project (McLennan 2013) in which a range of mainly tropical forages were fed to steers in pens and intakes predicted from W change using the NRDR (2007) equations. Others have also recently questioned the accuracy of NRDR (2007) in predicting the performance of tropical cattle (*B. indicus*), even those grazing temperate forages (Bowen *et al*. 2015). These observations, in support of other anecdotal evidence, suggested the need for further investigation of the reliability of the current feeding standards for predicting nutrient requirements of northern ruminants grazing mainly tropical forages. The implications for the animal unit definitions, AE, were also investigated. The need to review information provided in the MLA Nutrition EDGE manual was also examined.

1.3 Conclusions

It is relatively difficult to find authoritative definitions of the standard units especially now that some state departments of agriculture have largely discontinued providing farm-notes for distribution. Where descriptions are available, they often lack precision, interchanging ‘feed’ or ‘nutrient’ for (we suspect) ‘energy’ requirements or they fail to adequately describe the standard animal and its baseline productivity. There is considerable diversity within Australia, (and in the USA), in the definition of the standard unit, whether it be DSE, AE, AU, LSU or some other equivalent term. There is not even agreement on what constitutes the standard animal for the various units. It is also apparent that most current equivalence units are now based on the energy requirements of the animal, mostly it seems for zero W change. However, the method of calculating these energy requirements is often not stated or clear. Where the energy needs approach has been applied recently in northern Australia (McLean and Blakeley 2014), and where this energy requirement is converted to feed DM intake using an assumed feed quality, the computed DM intakes seem unrealistically high for the standard animal at maintenance (2.1% W/day). This suggests that the Australian feeding standards are over-predicting energy and thus DM requirements, as has been suggested by McLennan (2005, 2013).

The most precise and logical way of quantifying animal units is to base them on the energy requirements of a standard animal. We suggest these definitions for both an AE and DSE could be used nationally, thereby simplifying the comparison of different grazing enterprises, for business reasons in particular. Because energy requirements are not easily conceptualised by animal producers, and perhaps by some of their advisors, the practical application of the animal unit will be to convert energy requirements to pasture DM intake as it is a knowledge of the intake of forage or its removal from the landscape that is important for fodder budgeting, for setting appropriate stocking rates and also for calculating LTCC. An estimate of feed (diet) quality is required for this translation from energy to forage intake requirements.

2 Project objectives

The objectives of this study are as outlined below:

1. With respect to the AE terminology, better estimate the standard animal's energy requirements and intake, for use in northern Australia.
2. Demonstrate how this revised AE definition can be applied to practical grazing situations including for fodder budgeting, for LTCC determinations and for establishing intra-species substitution ratios.
3. Assess whether the revised AE system can be used on a national scale that allows for the contributions of multiple species.

3 Methodology and results

3.1 Standard animal definition (one AE)

The standard (bovine) animal is defined as a 2.25-year-old, 450 kg *B. taurus* steer maintaining W and walking 7 km/day (McLean and Blakeley 2014). Using the existing NRDR (2007) equations, the energy requirement of this standard animal at zero W change is 73 MJ ME/day. A diet energy density of 7.75 MJ/kg DM (equivalent to 55% DMD) is assumed.

3.2 Determining animal unit scores and intake on tropical pastures

3.2.1 Adjusting the NRDR formulae to better match predicted and observed DM intake on tropical pastures

Animal unit equivalence is best determined on the basis of the estimated energy requirements of an animal relative to that of the defined standard animal. The accuracy with which this animal unit score is determined affects the accuracy of prediction of forage intake (Section 3.3) and thus of the grazing pressure applied by the resident animals. In this section a small data set is used to examine the accuracy of prediction of intakes by cattle using the feeding standards relative to those observed experimentally. Equations from the feeding standards relevant to energy intake are examined and in some cases modified to improve intake predictions.

It is logical to calculate energy requirements using the Australian feeding standards (NRDR 2007). However, previous research by McLennan and Poppi (McLennan 2005, 2013) using pen feeding data collected under controlled conditions (zero walking assumed), indicated that the NRDR (2007) model, as encapsulated in the derived spreadsheet calculator *QuikIntake* (McLennan and Poppi, unpublished data) which incorporates the key equations from NRDR (2007), over-estimated the ME requirements of cattle consuming tropical forages which led to an over-prediction of their DM intake from known W gain. Forage DM intake was calculated by dividing total ME requirements of the animal for maintenance and production by the energy density of the diet selected (M/D). Details of the cattle, forages, experimental protocols and the data derived in the above studies are provided in McLennan (2013). The relationship (Fig. 1 between the intakes predicted (excluding a lucerne treatment) using *QuikIntake* (PredIntk; kg DM/day) and those observed (ObsIntk; kg DM/day) was:

ObsIntk = 0.467 PredIntk + 1.454; R^2 = 0.29, sum of squared errors (SSE) = 45.2 (Eqn A)

The agreement between observed and predicted values was assessed by determining the modelling efficiency, as described by (Mayer and Butler 1993). This test effectively determines the bias of the derived relationship from the Y=X line. With the original data represented by Eqn A, the modelling efficiency was -1.46, this negative value suggesting significant bias and that the model be rejected. Predicted intakes poorly reflected the observed values.

In the study described by McLennan (2013), of which the current project could be considered an extension, several modifications were subsequently made to some equations in *QuikIntake* related to the calculations of the maintenance energy requirements (ME_m), the energy value of gain (EVG) of *Bos indicus* cattle, and to the efficiency of use of ME for maintenance (k_m). The relevant equations from NRDR (2007) are:

$$ME_m = \frac{KSM\,(0.28W^{0.75}\exp(-0.03A))}{k_m} + 0.1MEgain + \frac{Egraze}{k_m} + Ecold \quad \text{(MJ/day) (Eqn 1)}$$

where:
K = 1.2 for *B. indicus*, 1.4 for *B. taurus* and 1.3 for *B. indicus*/*B. taurus* crossbreds;
S = 1.0 for females and steers (castrates) and 1.15 for bulls;
M = 1 + (0.23 x proportion of DE from milk);
W = liveweight (kg), unfasted;
A = age in years, with a maximum value of 6.0;
k_m = net efficiency of use of ME for maintenance;
MEgain = the amount of dietary ME (MJ) used directly for production;
Egraze = additional energy expenditure in grazing relative to a similar housed animal;
Ecold = additional energy expended in cold stress by animals when below critical temperature.

$$EVG = (6.7+R) + \frac{b-R}{1+\exp(-6(P-0.4))} \quad \text{(MJ/kg)} \qquad \text{(Eqn 2)}$$

$$P = \frac{CurrentW}{SRW} \qquad \text{(Eqn 3)}$$

$$R = \frac{EBC}{4\,x\,SRW^{0.75}} - 1 \qquad \text{(Eqn 4)}$$

where:
EVG = energy content of the empty W gain (MJ/kg);
b = parameter used for predicting EVG; b = 16.5, 18.4 or 20.3 according to animal type;
SRW = standard reference W (kg);
CurrentW = current liveweight of the animal (kg);
P = current W as a proportion of the SRW;
R = adjustment for rate of gain or loss;
EBC = empty body change (g/day), or liveweight gain x 0.92.

$k_m = 0.02\, M/D + 0.5$ (Eqn 5)

where:
M/D is the energy density of the diet (MJ ME/kg DM).

Specifically, modifications (**Modifications 1, 2 and 3**) were:

1. a value of 1.2 used for the "k" term in the calculation of ME_m for both *B. Indicus* and *B. indicus* crossbreds, not 1.3 for *B. indicus* crossbred cattle as suggested in NRDR (2007);
2. a value of 16.5 used for the "b" term in the estimation of EBG of *B. indicus* x B. *taurus* crossbred cattle, not 18.4, as the latter was suggested for Euro x British crossbred in NRDR (2007);
3. a fixed k_m value of 0.72 used for cattle that were gaining W, rather than using Eqn 5 to calculate k_m from M/D.

Justification for these changes is provided in McLennan (2013) but derived largely from discussions with, and recommendations of, Dr Mike Freer (CSIRO), one of the key architects of the SCA (1990), its successor NRDR (2007) and the *GrazFeed* decision-making software package incorporating their equations (Freer *et al*. 2012). The changes are partly based on acknowledging the lower maintenance requirements, and leaner composition, of *B. indicus* compared with *B. taurus* cattle. However, some changes; that to k_m, were also applied to *B. taurus* cattle and McLennan (2013) can be read in conjunction with the current document.

Amongst these changes the factor having the greatest effect was the efficiency of use of energy for maintenance (k_m) and this impacts directly on the ME required for maintenance (ME_m). This aspect has been discussed in some detail in McLennan (2013). Increasing k_m, a divisor in the equation to calculate ME_m (Eqn 1), reduces the maintenance energy requirements and thus total energy needs of the animal and also the predicted DM intake. In NRDR (2007) k_m increases with increasing M/D of the diet in accordance with the Eqn 5. Using a fixed value for k_m of 0.72 is in keeping with MAFF (1984) and consistent with the value used in the "*ME_required*" spreadsheet calculator designed by Mike Freer, although NRDR (2007) suggests caution in using such a fixed value for low-quality roughages used as maintenance feeds. The NRDR (2007) recommends using a k_m of 0.80 for the efficiency of use of energy from liveweight loss.

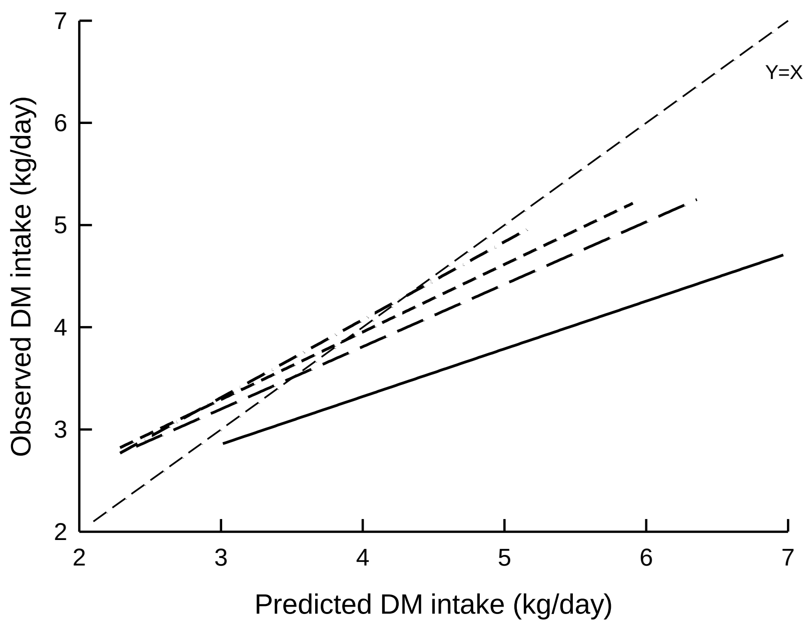


Fig. 1. Relationships between the intakes predicted using *QuikIntake* and those observed for cattle fed forage diets in pens. Relationships include that for intakes predicted before changes to various coordinates in QuikIntake (Eqn A; solid line), that predicted after changes to equations in QuikIntake calculating the maintenance requirements (MEm), the efficiency of use of energy for maintenance (km) and the energy value of gain (EVG) (Eqn B; long dash), that predicted after the changes made in Eqn B plus modification to the energy density of the diet (M/D; Eqn C; short dash) and that predicted after the above changes plus modification to the efficiency of use of energy for gain (kg; Eqn D; dash-dot).

When the three modifications to the NRDR (2007) equations are adopted, including with k_m equal to 0.8 at W maintenance, the estimated ME requirement for the standard animal at zero W change (see above) was 59.5 MJ/day, compared with 73 MJ/day calculated previously without modifications (McLean and Blakeley 2014).

The calculation of the k_m has a marked effect on estimated ME_m. The ME_m (MJ/day) estimates for the standard animal described earlier, consuming a diet with M/D 6.9 MJ/kg DM (50% DMD), with W changes of -0.2, 0 and 0.2 kg/day are as follows: (i) using the formula for k_m shown in Eqn 5 above: 74.2, 74.8 and 76.3; (ii) using a fixed value for k_m of 0.72 throughout: 65.7, 66.2 and 67.8; and (iii) using a fixed value for k_m of 0.72 for W change greater than maintenance and 0.80 for maintenance or W loss: 59.0, 59.6 and 67.6, respectively. The decision on what k_m value to use for zero W change is critical as the AE is defined as the energy requirements of the standard animal at maintenance. If a k_m of 0.72 is used, ME_m is 66.2 MJ/day translating to a DM intake of 2.14%W/day (when M/D = 6.9 MJ/kg DM) whereas if the k_m is 0.80, the ME_m is 59.6 MJ/day and the corresponding DM intake is 1.92%W/day. This change in the k_m value at zero W change is undesirable. It means that, with a change in W gain from zero to 0.01 kg/day, the ME_m changes from 59.6 to 66.3 MJ/day and the predicted DM intake changes from 1.92 to 2.06%W/day, a substantial change in ME requirements and predicted DM intake for negligible W change.

Alternatively, we propose that a more gradual transition in the k_m value is required when animals change from losing to gaining W. An asymmetric sigmoidal function has been arbitrarily applied (Fig. 2) whereby k_m changes from 0.8 when cattle are losing 0.4 kg/day or more to 0.72 when they are gaining 0.2 kg/day or more. According to this function, the k_m value is ~0.74 at zero W change.

The sigmoidal function is as follows:

$$k_m = 0.7219 + \frac{0.08586}{(1+0.026\exp(7.25(ADG+0.0618)))\hat{}(\frac{1}{0.026})} \qquad \text{(Eqn 6)}$$

where ADG is average daily gain (kg).

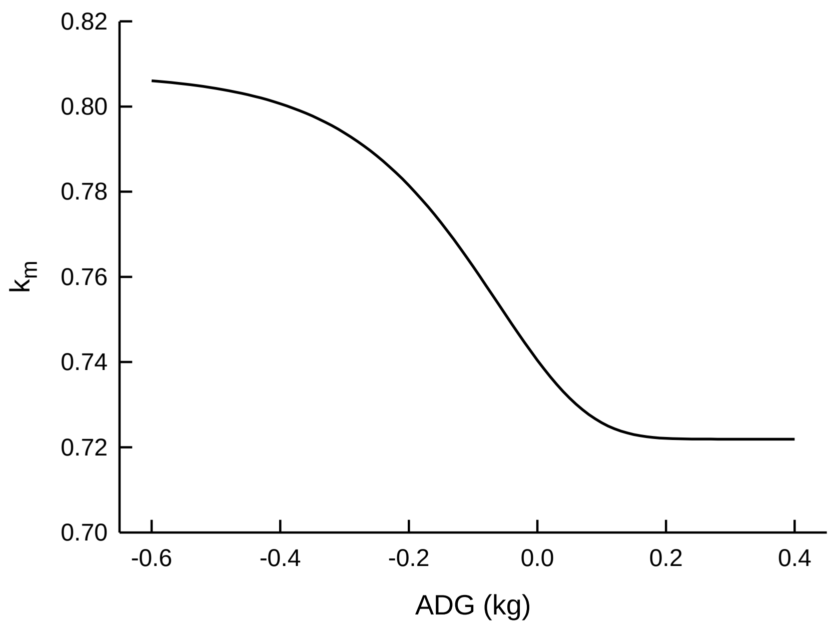


Fig. 2. The asymmetric sigmoidal function describing changes in the efficiency of use of energy for maintenance (k_m) against the average daily gain (ADG) of steers between -0.4 and 0.2 kg, as applied in QuikIntake. When ADG is less than 0.4, and more than 0.2 kg, k_m is 0.8 and 0.72, respectively.

Thus, Modification 3 above has been changed to **Modification 4**:

4. A variable k_m value following an asymmetric sigmoidal function so that k_m changes from 0.80 when cattle are losing 0.4 kg/day or more W to 0.72 when they are gaining 0.2 kg/day or more W.

Applying Modification 4 to *QuikIntake*, and thus to the equations of NRDR (2007), together with Modifications 1 and 2, resulted in a predicted ME requirement of 64.3 MJ/day and predicted DM intake of 1.84% W/day at zero W change (at M/D = 7.75 MJ/kg DM) for the standard animal. By comparison, when Modifications 1, 2 and 3 were applied such that k_m was 0.80 at zero W change, the predicted ME requirement was 59.5 MJ/day and predicted DM intake was 1.71% W/day.

The modified equation describing the relationship between predicted and observed intakes when Modifications 1, 2 and 4 were applied to *QuikIntake* is as follows:

ObsIntk = 0.611 PredIntk + 1.367; R^2 = 0.49, SSE = 13.5 (Eqn B)

Collectively, these modifications improved the prediction of intake, as shown by Eqn B in Fig. 1, with increased slope, reduced intercept and a markedly lower error sum of squares compared with Eqn A. The modelling efficiency associated with this relationship was 0.28, this positive value indicating that the model need not be rejected. Nevertheless, the intake was still over-predicted, especially at higher growth rates, and the regression line had a slope different to one and an intercept different to zero ($P < 0.05$). There was closer agreement between predicted and observed values when intakes were low (maintenance or below) than when higher quality diets supporting higher W gains and intakes were fed. There was scope for further improvement.

The approach taken in this current project was to build further on the above changes to equations in *QuikIntake* and NRDR (2007), as used in deriving Eqn B, by using the Solver function within Microsoft Excel to minimise the SSEs associated with the regression between the observed and predicted intakes. The same data set was used as in McLennan (2013). Although this is a small data set, it is difficult to find experiments with comparable data reporting all of intake, W change and diet quality (DMD). The aim was to investigate changes which were biologically valid, and which would provide better agreement between predicted and observed intakes, (move the regression line representing this relationship closer to Y=X than was represented by Eqn B). In this exercise, modifications to various equation coordinates within *QuikIntake* were investigated, either singly or in combination, in an effort to minimise the SSE, but also achieve an intercept approaching zero and slope approaching unity. The main equations investigated were those associated with the calculation of ME_m (Eqn 1), M/D of the diet (Eqn 7) and the efficiency of use of energy for growth, k_g (Eqn 8).

$$M/D = 17.2\,DMD - 1.71 \quad \text{(MJ/kg DM)} \qquad \text{(Eqn 7)}$$

$$k_g = 0.043\,M/D \qquad \text{(Eqn 8)}$$

In relation to the equation calculating ME_m (Eqn 1), it was specifically the 0.28 coordinate that was targeted. Modifications to this coordinate did not reduce the SSE but tended to reduce rather than increase the slope of the regression line and thus resulted in greater over-prediction of intake across the range examined. Thus, this avenue of change was rejected.

Using the Solver function to examine changes to the M/D calculation (Eqn 7), the SSE was minimised when the M/D coordinate of 0.043 was multiplied by 1.05 in conjunction with the previous modifications used to derive Eqn B. The effect of this small change is shown in Fig. 1. The revised relationship between predicted and observed intakes is:

ObsIntk = 0.661 PredIntk + 1.309; R^2 = 0.49, SSE = 12.2 (Eqn C)

With this change, the modelling efficiency for the regression was 0.35, this positive value suggesting the model need not be discarded. There was still considerable variation about this regression relationship and departure from the Y=X line (Fig. 1), but the slope and intercept were not different from one and zero (P =

0.08), respectively. Further increases in the multiplier of M/D, although increasing the slope of the regression line (closer to slope of 1), resulted in increases in the SSE. Increases beyond a multiplier of 1.05 were not seen as appropriate.

Consequently, in addition to the modifications (Modifications 1, 2 and 4) to the NRDR (2007) equations previously suggested, a further minor change (Modification 5), reflected in Eqn C, was adopted:

5. The M/D value calculated from the DMD of the diet increased by a factor of 1.05.

Further applying the Solver function in Excel, changes to the calculation of k_g, specifically using a multiplier for the 0.043 coordinate in Eqn 8, were also explored. In conjunction with previous modifications used to derive Eqn C, increasing this coordinate had the effect of tilting the regression line upwards,(increasing slope of the regression line closer to unity and thus reducing the extent of over-prediction of intake). The optimal solution provided by applying Solver was to multiply the 0.043 coordinate by 1.32, which minimised the associated SSE. Using an even higher multiplier, [2.3, provided closer agreement between predicted and observed intakes (greater slope)] but this represents an extreme change such that k_g values formerly calculated as 0.44 or above would translate to efficiencies greater than 1.0, which is not tenable.

The derived equation (Fig. 1) using the 1.32 multiplication detailed above was:

ObsIntk = 0.762 PredIntk + 1.024; R^2 = 0.56, SSE = 11.3 (Eqn D)

With this change the regression line, relative to that of Eqn C, had a reduced SSE, increased slope and reduced intercept. The modelling efficiency was 0.40 so the model need not be discarded. Furthermore, there was a non-significant ($P > 0.05$) departure of both the slope and intercept from the Y = X line. It appears that modifying the k_g values by applying a multiplier, in this case 1.32, provided the best option to align more closely with the Y = X line. However, whilst this change was seen to improve the prediction of intake, multiplying k_g by 1.32 increased efficiencies of gain to what would be considered unrealistically high values which would not be biologically defensible. The change to k_g was not adopted.

3.2.2 Summary of changes to the energy requirement predictions

Changes to the equations in *QuikIntake*, and thus NRDR (2007) equations, are proposed to improve the predictions of intake. These changes are represented by Eqn C (Fig. **1**) and are summarised as Modifications 1, 2, 4 and 5. Four observations can be made around this modified predictive equation. First, the adopted solution (Eqn C), although an 'improvement' on the predictive precision of the original relationship (Eqn A), still demonstrates some over-prediction of intake when values are high but a slight under-prediction when values are low, i.e., at the W maintenance level of production. Nevertheless, using the modified prediction equation results in intakes which are more in keeping with values observed in practice. Second, whilst improving predictions, there is still considerable variability around the prediction relationship, as suggested by the low correlation coefficient and high SSE value. This could be considered typical of the normal biological variability encountered in practice. To counter this, it would be desirable to work with a much larger data set but the difficulty of finding such data sets cannot be overstressed. Third, we can offer no biological basis for the changes made to the equations of NRDR (2007). To do so would require massive data sets which are already encompassed in the existing equations of the feeding standards, albeit probably with a high bias towards temperate diets fed to British-bred and European cattle in confinement. What is offered in the absence of a biological justification is an empirical solution to improving predictions of ruminant requirements, based largely on energy demand. Fourth, the suggested changes are only proposed for cattle given tropical and sub-tropical forage diets as are encountered in northern Australia. We suggest that the existing equations, without modification, may apply well for ruminants on temperate diets, as evidenced by the widespread use of programs such as *GrazFeed* which incorporates the NRDR (2007) equations. Whilst the same scrutiny has not been applied to sheep given tropical diets, we would expect similar changes to the equations of the feeding standards to apply with sheep given these diets.

The possible reasons for the differences between the tropical and temperate grazing production systems are not addressed here.

3.2.3 The energy demand of the standard animal

By applying the above-mentioned Modifications 1, 2, 4 and 5 to the equations in NRDR (2007), the revised energy requirement of the standard animal is 64.3 MJ ME/day. It is proposed that this ME requirement be rounded to 64 MJ ME/day. For stall-fed animals (zero walking) the equivalent revised ME requirement is 48.4 (rounded to 48) MJ/day.

The above energy requirement compares with that for the standard animal of 73 MJ/day proposed by McLean and Blakeley (2014) before modifications to the equations of NRDR (2007) were applied. Some workers may prefer using the nil-activity option and adding a variable percentage increase to the maintenance requirement to account for walking. In the spreadsheet calculator *ME_required* it is suggested that the maintenance requirements be increased from between 0 and 20% to cater for the walking energy expenditure. However, based on the current calculations for cattle walking 7 km a day, this increment should be about 30% at the upper extreme.

To differentiate between the different versions of the feeding standards, they will be referred to from this point on as NRDR_unmod (NRDR (2007) without modifications) and NRDR_mod (including the modifications described).

3.2.4 Determining the AE rank of an animal

It is logical, objective and defensible to base the AE rating for any animal on its energy requirements relative to that of the standard animal where both calculations of ME requirements use the same formulae and assumptions. This general approach for determining the animal unit ranking was suggested by Scarnecchia and Gaskins (1987). The energy requirements of animals can be estimated using the various feeding standards, especially when they are translated into some form of multi-variate animal demand software such as *GrazFeed* or *QuikIntake*. Within Australia, it is recommended that the Australian feeding standards (NRDR 2007) are the basis for calculating energy requirements.

According to the two different estimates of the ME requirements of the standard animal the AE rating would be determined by dividing the ME requirement of a particular animal by either 73 (NRDR_unmod) or by 64 (NRDR_mod) MJ/day. In both instances, the ME requirement of the animal of interest must be determined using the same equations as are used to determine that of the standard animal. As an example, for a 400 kg *B. indicus* crossbred steer walking 7 km/day and gaining 0.5 kg/day, the ME requirements are 89.8 and 83.0 MJ/day, and the AE ratings are 1.24 (89.8/72.6) and 1.29 (83/64.3), using the NRDR_unmod and NRDR_mod equations, respectively.

The question is: what equations should be used for a particular set of circumstances. The NRDR_mod version only applies to cattle in northern Australia whereas the NRDR_unmod version, at this stage, applies to cattle grazing in other regions of Australia and to sheep in all regions, as the effects of modifying the equations have not been tested more widely. The default situation is to use the NRDR_unmod equations universally. The effects of using either set of equations on the eventual AE ranking, and on the associated predicted DM intakes, are assessed.

The Americans have probably better defined the terminology around animal units. They use the standard animal to define an AU according to its intake of energy or DM and then relate other animals to this in terms of animal unit equivalence (AUE). Our terminology uses the intake of the standard animal to define one AE, rather than an AU, and uses the same terminology of AE for other animals under consideration. However, the current terminology is well established, and changes would only cause confusion. Despite the potentially better conceptual approach to animal units, it was not obvious that the Americans have practical tools to assist users in the application of the approach, for instance the generic tables or multi-variate modelling tools suggested here.

3.2.5 Revised definition of a DSE

There is a wide range of definitions for a DSE on the national scene (section 1.1) , particularly in terms of the W of the standard animal and its energy requirements. The standard animal is usually considered to be a wether with zero weight change, but the defined W varies between 45 and 50 kg. It is unlikely that national consensus will be reached on the preferred weight.

It is proposed here that the standard animal is a 45 kg wether, as suggested by McLaren (1997) and used in previous national studies (Holmes *et al*. 2017), with zero weight change, no wool growth additional to that included in maintenance, and walking 7 km/day. Using the same standard diet of 55% DMD as used in the definition of an AE, the standard animal which represents 1 DSE has an energy requirement based on NRDR (2007) of 8.68 MJ ME/day (rounded to 8.7 MJ ME/day). This is based on NRDR_unmod equations as the exercise undertaken with cattle in tropical northern Australia, has not been repeated with sheep. It makes sense to use the common value for diet quality of 55% DMD for defining both the AE and DSE.

3.2.6 Ratio of AE to DSE

As proposed earlier, any plan to manage grazing pressure needs to consider the contributions of all species. Sheep are the other major grazing ruminant species and the importance of defining their contribution relative to cattle is underlined where the two species are grazed conjointly on a property or where, in a business sense, they are grazing alternatives. However, to a large extent this section is about expressing the contributions of all grazing species, including goats, macropods in terms of a single ‘currency type’, for instance, as AEs or DSEs. It is useful to have an easy conversion between the two units for accounting purposes.

Using the NRDR_unmod equations, 1 AE represents an energy intake of 73 MJ ME/day (McLean and Blakeley 2014) compared with 8.7 MJ ME/day for 1 DSE. Thus, the ratio of DSE to AE is 8.36:1 (72.6/8.7).

This ratio can be considered a constant being the relative energy requirements of the two standard animals. As established above, the AE ranking for any animal of any species and class is determined by its energy requirements for a stated level of production relative to that of the standard animal, i.e., to 72.6 MJ ME/day (NRDR_unmod). Similarly, the DSE ranking is determined by the ME requirements of the animal relative to that of the DSE standard of 8.7 MJ ME/day. Whether the grazing population is expressed as AEs or DSEs will not matter; it will depend on which divisor (72.6 or 8.7 MJ/day) is used in relation to computed energy requirements for each animal or animal class. The ratio between the two will remain the same (8.4 DSE:1 AE).

The contribution of any animal species/class - cattle, sheep, kangaroo, can be expressed either in AE terms or DSE terms with interconversion between the two by applying the 8.4 multiplier (8.4 DSE: 1 AE). As an example, a 500 kg *B. taurus* steer gaining 0.3 kg/day has an ME requirement of 102 MJ/day (using NRDR_unmod equations) and thus an AE ranking of 1.4, i.e., 102/72.6. Similarly, its DSE ranking would be 11.8, i.e., 102/8.7, or its AE rank of 1.4 multiplied by 8.4 = 11.8. The same exercise can be done with a sheep which can also be described in AE or DSE terms by using the same divisors of 72.6 or 8.7 MJ/day, respectively. The carrying capacity of a herd comprising multiple species and classes of animals might be expressed as 1,000 AE or 8,400 DSE. It is of course important that where different grazing situations are being compared the animal unit rankings are determined uniformly for each situation; the same standard animals are used to define the animal unit ranking and the same models and assumptions are used to estimate the energy requirements of the resident animals.

This ratio (DSE:AE) is useful for accounting or modelling purposes and because of the easy conversion between AE and DSE the unit of choice is less important. In southern Australia grazing pressure is usually expressed in terms of DSE for both cattle and sheep. In northern Australia both terminologies are used with more emphasis on AE for cattle and DSE for sheep. It is important, however, to point out that it does not follow that 1 DSE of a particular species/class of animal will apply the same grazing pressure (same forage intake) as 1 DSE of another species/class of animal. This will depend on whether the diet selected by the two is the same (according to Eqn 9). This potential difference in diet selection is implicit in what is described as the substitution ratio between different animals, usually between different species such as sheep and cattle. The substitution ratio relates to the relative grazing pressure applied by different animals, classes or species of animal. Thus, one DSE of sheep may apply the same grazing pressure on a particular weed in the pasture as three DSE of steers. However, in the absence of better information about the diet selected by the different animal types under practical grazing situations, an assumption of uniformity of diet quality is made so that forage intake is proportional to energy requirements and thus animal unit equivalence.

3.3 Applications of the animal unit methodology

There are three main applications (**Applications 1, 2 and 3**) of the animal unit technology:

1. Determining the long-term carrying capacity (LTCC) of paddocks/properties.
2. Carrying out whole business and enterprise analysis, on a regional or national scale.
3. Developing fodder budgets for shorter-term grazing periods.

Applications 1 and 3 can be done on a regional basis. Application 2 requires methodology that is a common currency across regions and states.

The basis of all three applications will be that the animal unit ranking (AE or DSE) is calculated on the ME requirements of the animal relative to that of the standard animal. However, the prime consideration under practical grazing situations is knowing how much forage (DM) the animal is removing from the pasture and it is important that the conversion from energy requirement to forage DM intake is made at some point during application. The rate of removal of forage DM from the pasture, alternatively described as management of total grazing pressure, is the prime consideration for determining stocking rates and carrying capacities. Most advisors and livestock producers will not easily make the connection between the energy requirements of an animal and its forage consumption under field conditions. Scarnecchia and Gaskins (1987) contended that fodder availability is best described in units of DM whereas animal requirements can be expressed in energy units or, where some measure of diet quality is available, as a DM intake.

3.3.1 Forage intake and its relationship with animal unit equivalence

For practical purposes the conversion from energy requirements to DM intake is achieved using the equation:

$$\text{DM intake (kg/day)} = \frac{ME\ requirement\ \ (\mathrm{MJ/day})}{diet\ M/D\ \ (\mathrm{MJ/kg\ DM})} \qquad \text{(Eqn 9)}$$

From Eqn 9, in order to convert an energy requirement into a forage DM intake an estimate of the energy density of the diet (M/D) is required. A major practical issue though is that diet quality is often not known in the field especially when the period of assessment is longer-term and includes seasonal changes, for instance over the course of a year or more. In the absence of a direct measure of diet quality (faecal NIRS) estimates can be made over the shorter-term using animal performance, seasonal and pasture conditions and operator experience which will provide a reasonable approximation for the applications described above. For instance, in developing a table of forage intakes relative to the W and growth rates of cattle, Minson and McDonald (1987) assumed a linear relationship between growth rate and DMD of the diet whereby growth rates of 0 and 1 kg/day corresponded to DMDs of 50 and 70%, respectively.

The various applications of the animal unit technology and suggestions for the conversion from ME requirement to DM intake based on AE (or DSE) ratings, are discussed. Different approaches are suggested for the different applications. The methods described necessarily require compromises where information on diet quality is not available.

The other key issue is that, under practical grazing conditions, production increases by the animal (and thus its ME requirement) usually accompany increases in diet quality (M/D). Both the numerator and denominator (Eqn 9) will usually increase as animal production increases so that the relationship between DM intake and ME requirement is not constant; DM intake does not increase in direct proportion to ME intake. A 500 kg *B. indicus* crossbred steer just maintaining W on a diet of 6.8 MJ/kg DM (47.5 % DMD) will have a DM intake of 8.4 kg/day, the same intake as a similar steer, with restricted pasture access, gaining 0.23 kg/day on a diet of 9.0 MJ/kg DM (60% DMD). The calculated ME intakes are 57.1 and 76.2 MJ/day, respectively. This demonstrates that the same DM intake can be achieved when ME intakes are different due to the variability in diet quality (M/D). Conversely, the same ME intake could be associated with quite different DM intakes.

There are several options that can be applied for estimating forage intake by grazing animals, which vary in complexity and in the skills required in their implementation;

Forage intake calculation options (**Options 1, 2 and 3**):

1. Calculate the ME requirements of the animal for its current or projected level of production using a multi-variate animal requirement model and then, with an estimate of diet quality, apply Eqn 9 to directly convert this ME requirement to forage DM intake.
2. Calculate the animal unit equivalence (AE or DSE score) of an animal, using the multi variate model, and multiply this score by an intake constant (kg DM/AE.day or /DSE.day).
3. Look up the animal unit equivalence score for an animal from a set of generic tables and multiply this score by an intake constant, as in 2 above.

The approach taken will vary with the experience of the operator and the degree of precision required. More precision will be demanded by field workers involved in animal and pasture research than is usually required by producers or their advisors. Nevertheless, the same general principles will apply. The estimation of ME requirements of the animal, as included in Options 1 and 2 above, can be determined using a multi-variate animal requirement model like *GrazFeed* or spreadsheet calculators such as *ME_required*, *QuikIntake* or that of McLean and Blakeley (2014), which all incorporate the NRDR (2007) equations in some form. Most workers in agriculture are conversant with the use of spreadsheets and this is the most direct and accurate way of estimating ME requirements for conversion to forage intake, for all applications. Furthermore, where an estimate of diet quality is derived directly or indirectly, a sufficiently accurate estimate of intake for determining grazing pressure can be achieved by applying Option 1 . This would be especially relevant for devising forage budgets for shorter-term grazing periods. This is the preferred option.

Options 2 and 3 above include a preliminary step in the estimation of forage intake, namely the determination of an animal unit ranking (AE or DSE) for each animal or class of animals. In the case of Option 2, this involves using the same multi-variate animal demand models as used in Option 1 as an initial step. Options 2 and 3 also express stocking rates and carrying capacities in animal unit terms, e.g., AE/sq. km, which is a common, convenient and widely recognised language for use across grazing situations. For Option 3, a typical generalised table with designated AE ranks for different classes of animals is shown below (Table 1). Regardless of which method is used to estimate the animal unit rankings for Options 2 and 3, an intake constant is required in order to calculate forage intake, by applying Eqn 10:

Forage intake (kg DM/day) = animal unit score (AE) x intake constant (kg DM/AE.day) (Eqn 10)

A relationship (Eqn 10) can be applied with DSEs instead of AEs. The determination of this intake constant is a critical step in the application of the technology and its derivation is discussed.

Table 1. Typical generic AE ranks for cattle of different classes and ages

Class of cattle (age in years)	**AE rank**
Females <1	0.68
Females 1-2	0.91
Females 2-3*	1.12
Females 3-4*	1.49
Females 4+*	1.28
Steers <1	0.72
Steers 1-2	1.03
Steers 2-3	1.27
Steers 3-4	1.39
Bulls	1.52

* includes calf to weaning and accounts for reproductive rate (i.e. average of all females)

3.3.2 The intake constant

The intake constant for use in Eqn 10 can be derived by applying Eqn 9 where the ME required is that for one animal unit, for instance 1 AE. This ME requirement for cattle across Australia, derived using the NRDR_unmod equations, is 73 MJ/day. This ME requirement is a constant which does not vary with application. In applying Eqn 9, it is divided by an appropriate estimate of diet quality (M/D). The question is: what diet quality should be used to arrive at an appropriate intake constant. We contend that this diet quality will not be constant across all applications and thus the intake constant would also vary with application, and perhaps region.

In practice, the diet quality for a class of animals, averaged over a year, will vary and is almost always unknown. McLean and Blakeley (2014) addressed this issue by assuming a constant annualised diet M/D across grazing enterprises in northern Australia based on empirical surveys of faecal NIRS data. They assumed a fixed annual average diet quality (M/D) of 7.75 MJ/kg DM, which roughly equated to 55% DMD. In practice, the range in annual growth rates of growing cattle will mostly fall within the range of ~0.3-0.5 kg/day (110-180 kg/year), and a fairly narrow range in annual average diet quality would also be expected. This supports, in general principle, the compromise approach taken by McLean and Blakeley (2014).

The above approach provides a possible compromise for deriving forage intakes to use in calculating LTCC. AE rank increases in direct proportion to ME requirements and, with the assumption of constant diet quality (M/D), so too does predicted forage intake. Differences in LTCC between grazing units will reflect differences in animal productivity (and thus ME requirements) alone.

It could be argued that under practical grazing conditions, diet quality will vary from the constant of 55% DMD used here, changing in line with animal productivity. Averaged over a year, the variations will be relatively small especially within the range in annual growth rates (0.3-0.5 kg/day). The corresponding range in DMD would probably be in the order of ~53-57% (7.4-8.1 MJ/kg DM). Nevertheless, the more diet quality varies from the 55% DMD constant used, the greater will be the errors in prediction of intake when an intake constant is applied. In accordance with Eqn 9, as diet quality increases above 55% DMD, intake predictions will be increasingly over-estimated, and *vice versa* when average diet quality is lower than 55% DMD.

Much larger errors would be expected if the same approach was used for shorter-term grazing situations where diet quality and animal production was much lower; with dry season feeding where cattle are just maintaining or even losing weight on a diet of less than 50% DMD. Using the same intake constant would substantially under-estimate forage intake. This has implications for forage budgeting. The opposite result would occur if cattle were consuming a very high-quality forage with DMD>60%.

This approach broadly mirrors that taken in the USA by the Society for Range Management (SRM 1974, 2017) for defining an AU. They defined an AU as a 1000 lb (455 kg) cow or equivalent with a forage consumption of ~26 lb (12 kg) DM/day (~2.6% W/day). In deriving this value, the estimated energy requirement of the standard animal was calculated to be 7.2 kg TDN/day with a diet quality of 0.6 kg TDN/kg DM, roughly 60% DMD. These values were calculated on an annualised basis. The approach was similar in assuming a fixed diet quality, but the energy requirements were based on an animal with moderate to high (annual) performance, not one at zero weight change as used in the definition of the standard animal (AE) here. Hence, the comparison is of an intake constant of 12 kg/day for a standard animal in the USA (~60% DMD diet average) compared with 7.9 kg DM/day (~55% DMD diet average) for the standard animal. The USA approach when intake is not known is to adjust intake according to the metabolic weight (MW) of the animal in question relative to that of 1 AU ($450^{0.75}$ = 97.7 kg). For example, the estimated intake for a 600 kg cow (121 kg MW) would be 12 x 121/97.7 = 14.9 kg/day. A similar approach seems to have been adopted in Canada (AAF 2017) where the AU is similarly defined as an intake of 12 kg DM/day and adjusted according to MW in the absence of a better estimate of DM intake.

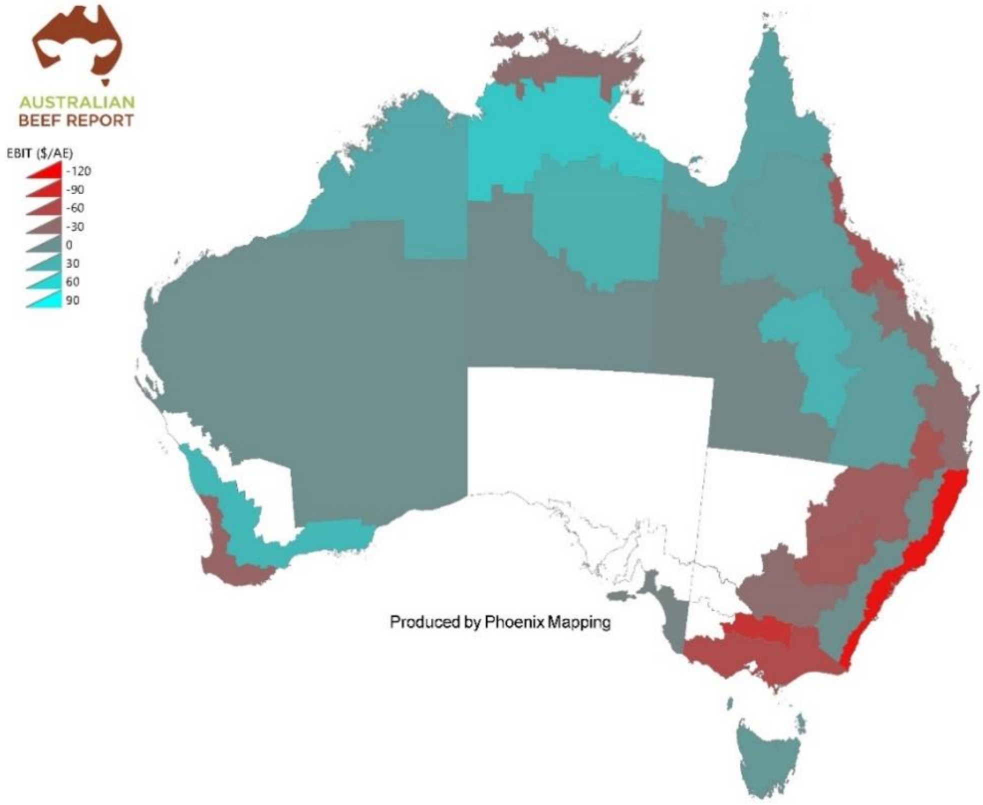
Applying an intake constant provides a useful means of converting from an AE (or DSE) score to a DM intake; for quantifying overall grazing pressure, when applied to longer-term grazing scenarios. However, it is less likely to be accurate at the extremes of diet quality and animal performance, particularly for dry season grazing scenarios. For an intake constant to be practical it should be a constant value or vary within a narrow range. It is not practical to apply a different intake constant for every situation. The application of this process (applying an intake constant, section 3.3.3)) is tested using representative regional animal performance and diet quality data (Bray *et al*. 2015).

The other key issue is the need to reconcile any differences encountered between using the NRDR_unmod or the NRDR_mod equations. The intake constant should minimise differences in predictions using the different sets of equations, allowing the more universal application from applying NRDR_unmod without sacrificing the accuracy of intake predictions for northern cattle provided by NRDR_mod.

3.3.3 Derivation of the intake constant

The foregoing discussion and calculations have direct application to cattle in northern Australia, based as they are on using the modifications to the NRDR (2007) equations (NRDR_mod). Problems arise when the main use is for Application 2, that of carrying out whole business and enterprise analysis. This is an extension of the LTCC of Application 1, but may require comparisons on a national scale. There are examples of where a national approach to business analysis is required. These include comparison of grazing enterprises across state boundaries, for instance on gross margin per AE or DSE, or for conducting national surveys of business performance. An example of the latter is the Australian Beef Report (Holmes *et al*. 2017) which analysed beef business performance across all of Australia on both an AE and DSE basis (Map 1). The emphasis in these cases is on annualised, not shorter-term, performance.

For business and enterprise analysis, grazing livestock are converted to animal units and an annualised average calculated. Forage consumed, whilst a critical aspect of grazing management, is not directly used in business or enterprise analysis. For comparisons between grazing enterprises to be valid the calculations need to be carried out using a consistent methodology. An animal unit needs to have the same meaning irrespective of where it is applied; northern or southern Australia. The other requirement is that the analysis includes, and is consistently applied to, all grazing species.

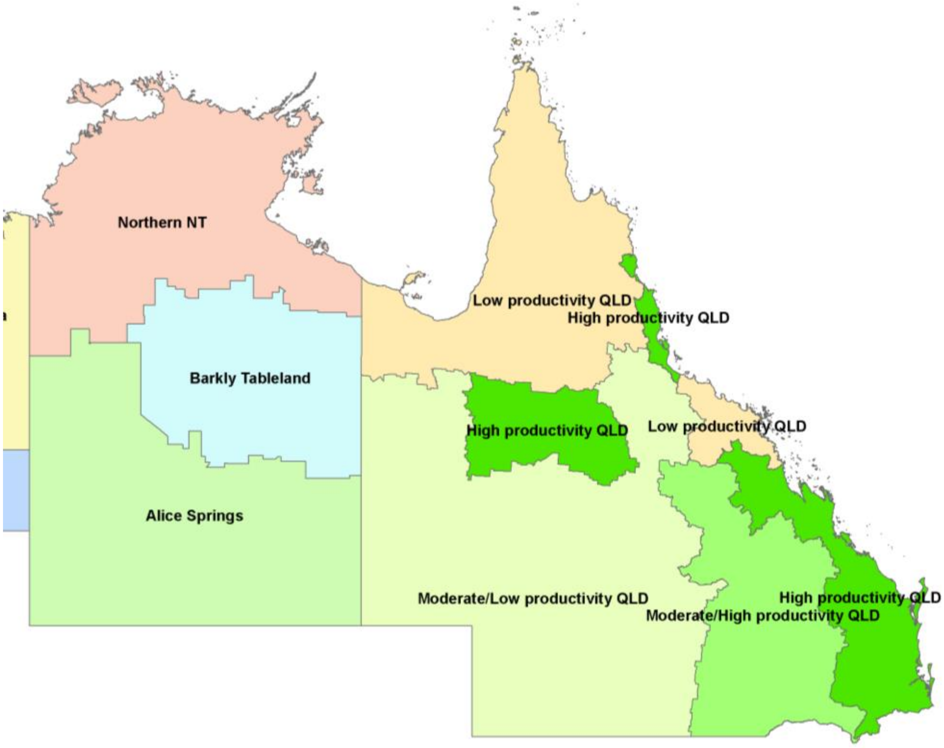


Map 1. Earnings Before Interest and Tax (EBIT) per AE for specialist beef producers on a regional basis across Australia (from Holmes *et al*. 2017).

The requirement for consistency of approach creates a problem where business comparisons are made between northern and southern grazing enterprises. The early sections of this document described a process undertaken to improve prediction of the energy requirements of cattle grazing predominantly tropical pastures in northern Australia and in so doing provide seemingly improved prediction of animal unit equivalence and of forage intake for that region. Equations within NRDR (2007) were modified (NRDR_mod) to achieve these changes. No similar process has been carried out for cattle in southern Australia, or for sheep in any region. It is not suggested that the predictions currently provided using the NRDR_unmod equations for southern grazing ruminants are flawed. Workers in this region widely apply, with apparent success, the *GrazFeed* model which incorporates the NRDR_unmod equations.

A uniform approach is required to realise valid business comparisons between northern and southern enterprises. This raises two important questions:1) which set of NRDR equations should be uniformly applied in the predictions and comparisons and 2) what diet quality to use in Eqn 9 to estimate forage intake. Because the NRDR_mod equations have only been developed for northern Australia, it seems obligatory to apply the NRDR_unmod equations to cater for all regions. The effect of this use of NRDR_unmod equations on predictions for northern businesses, where the foregoing discussion has suggested over-prediction of forage intake, needs some resolution.

A comparison of the effects of using either the NRDR_unmod or NRDR_mod equations on the AE ranks of cattle are illustrated in Fig. 3 and Fig. 4. Data collated by Bray *et al*. (2015) on the seasonal LW performance of ten different classes of male and female cattle (growth paths) in the various regions of Queensland and the NT, with corresponding information on estimated diet quality values (from F-NIRS analyses), were used. Bray *et al*. (2015) divided Queensland into four regions based on productivity; high, moderately-high, moderately-low and low productivity, and the NT into the northern NT (Top End), Barkly Tablelands and Alice Springs (Map 2). The two sets of equations were applied in these figures to data collated from the high-productivity region of Queensland. The respective ME requirements for the standard animal (1 AE) using the NRDR_unmod and NRDR_mod equations were 73 (McLean and Blakeley 2014) and 64 MJ/day. Included in these figures for comparison are the AE ranks of the animals calculated on a MW basis, the approach previously used in the EDGE material; MW relative to that of 1 AE (1 AE = $450^{0.75}$ = 97.7 kg) and AE's derived on a percentage of body weight; W divided by 450 kg.



Map 2. The different regions of northern Australia defined by Bray *et al*. (2015). Map courtesy of S. Bray (pers. comm.).

These figures show that when the same equations were used to calculate the ME requirements of the animal of interest as were used to define the AE standard, the differences between AE rankings determined using the NRDR_mod and NRDR_unmod equations for northern Australian cattle were relatively small. The figures also illustrate that basing the AE rank on the LW and MW of the animal markedly under predicts the AE ranking of the animals at some stages of their growth path as it does not take into consideration the changes in productivity (weight change and reproduction).

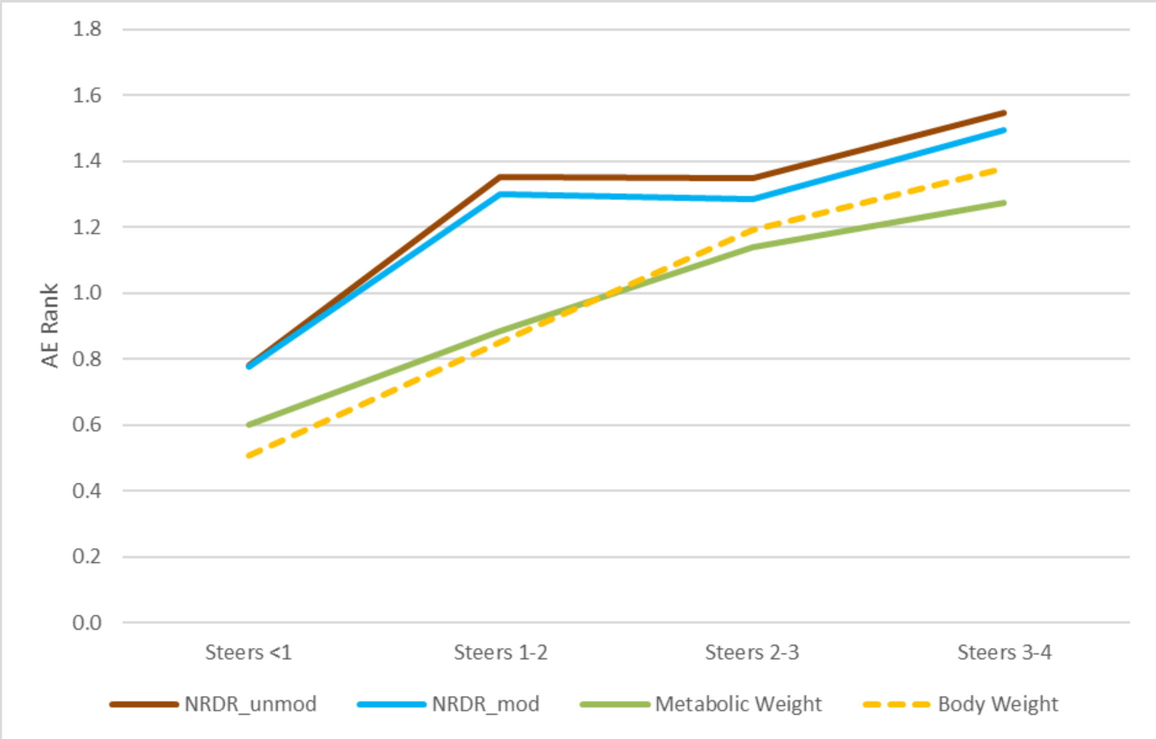


Fig. 3. Changes with age in the AE ranks for steers in the high-production regions of Queensland, calculated using different methods (see text).

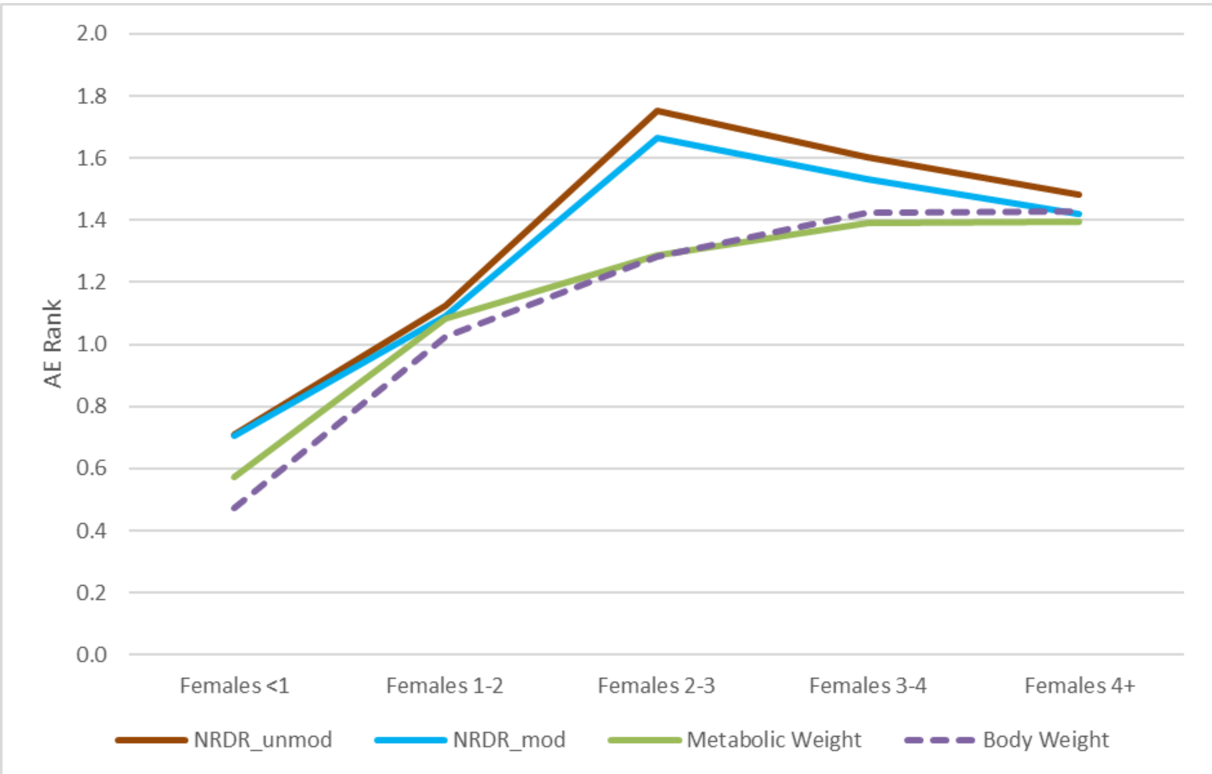


Fig. 4. Changes with age and physiological state in the AE ranks for female cattle in the high-production regions of Queensland, calculated using different methods (see text).

Forage intake calculations for use in determining carry capacity involve another variable namely diet quality. The standard diet quality used in predictions for tropical and sub-tropical regions of northern Australia was 55% DMD but with the rider that variations from this standard, which would accompany variations in animal performance, could result in under- or over-predictions of forage intake. The extremes in animal performance, and in accompanying diet quality, between extensive northern regions of Australia and the intensive pastoral regions in the south may represent such variability.

The effects of using either the NRDR_mod or NRDR_unmod equations to estimate the AE rank of cattle, and subsequently their DM intake, were examined using the data collated by Bray *et al*. (2015). This data included extremes in animal performance from the four regions in Queensland and the northern NT. Data from the Alice Springs and Barkly regions of the NT were excluded from the analyses as diet information was limiting. For each of these regions the growth paths of females, steers and bulls was reported on a seasonal basis until maturity or sale together with long-term diet DMD averages. This data, encompassing the various classes and physiological states of animals (breed, sex, average weight, liveweight gain, pregnancy and lactation status) for different seasons, provided 250 data points comprising 18 season-regions for bulls and females and 14 for steers, or 50 data points/region across five regions. Intake was calculated by two methods:

Method 1. DM intake calculated directly by applying the NRDR_mod equations to the cattle production and seasonal average DMD data from Bray *et al*. (2015).

Method 2. DM intake calculated by (i) estimating the AE rating for the various animal classes for each season, based on their ME requirements, using the NRDR_unmod equations and assuming a constant DMD of 55%; and (ii) multiplying this AE rating by an intake constant.

Intakes estimated using the two methods were compared by regression analysis. An iterative process was used to determine the intake constant to apply with Method 2, this being the value which produced the least sum of squares in the regression of intakes estimated by Method 2 against Method 1. When the data were analysed across seasons, the intake constant producing the best fit was 8.03 kg DM/AE.day, rounded to 8.0 kg DM/AE.day for practical application (see Figure 5a; R^2 = 0.92, RSD = 0.90). It is apparent that when this intake constant of 8.0 kg/AE.day was applied universally, much of the data pertaining to the higher productivity regions lay below the regression line, suggesting an over-estimate of intake by Method 2 relative to Method 1, and *vice versa* for the low productivity regions. Consequently, data for each of the five regions was analysed separately and separate intake constants were derived in the manner described above. The intake constants derived, and those applied after rounding off, are shown in Table 2. An intake constant of ~7.5 kg DM/AE.day seemed most appropriate for high productivity regions whilst ~8.5 kg DM/AE.day appeared to fit best for low productivity regions. The results of applying these separate intake constants to the seasonal data for the different regions on the regression of intakes for Method 2 relative to Method 1 are illustrated in Figure 5b (R^2 = 0.95, RSD = 0.65) which shows closer agreement between the two estimates of intake and no apparent dispersion of the data on a regional (productivity) basis.

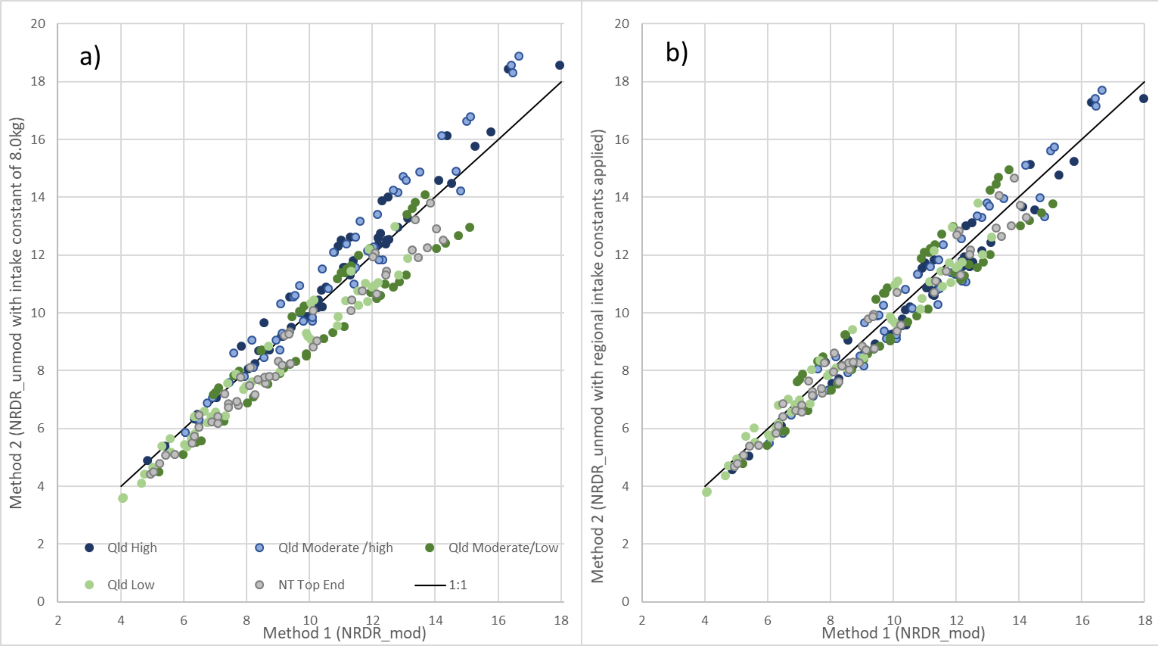


Fig. 5. Regression of average annual intakes (kg DM /day) predicted using Method 2 (see text), with an intake constant of (a) 8.0 kg/AE.day and (b) varied by region, against intakes predicted using Method 1 (see text) for cattle of all classes across five regions in northern Australia. Data derived from Bray *et al*. (2015).

Table 2. Calculated intake constants (kg DM/AE.day) for each region in northern Australia, derived using the seasonal production data of Bray *et al*. (2015; see Fig 5b), which provided the best-fit in the regressions of intakes estimated using either Method 1 or Method 2 (see text for description).

Region	Intake constant for least sum of squares	Applied intake constant
ALL regions combined	8.03	8.0
QLD high	7.65	7.5
Qld moderate-high	7.49	7.5
Qld moderate-low	8.47	8.5
Qld low	8.53	8.5
NT Top End	8.63	8.5

The data was then analysed as annualised data for each animal class by region, which reduced the number of data points to 70. This annualised approach is arguably more representative of the longer-term application of the animal unit technology to LTCC than using seasonal data. The separate intake constants that were used in the analysis illustrated in Figure 5b were applied to the different regions and the resulting regression is illustrated in Figure 6 (R^2 = 0.995, RSD = 0.25), showing a very close agreement between the two estimates of intake.

Thus variable intake constants, changing with annual productivity of the region, seem appropriate for determining intake from an estimate of the AE rank. These results suggest the best-fit intake constant for use in Method 2 would be around 7.5 kg DM/AE.day for the more-productive regions (annual steer liveweight gain of >150 kg) and 8.5 kg DM/AE.day for the less-productive regions (annual steer gains of <110 kg). A default value of 8.0 kg/AE.day seems appropriate. Data for the Barkly and Alice Springs regions were not included in these analyses but, likely mid-way between the intake constant extremes.

These results tend to reflect the effects of changes in diet quality in relation to the constant of 55% DMD suggested by McLean and Blakeley (2014). As diet DMD increases above this constant of 55%, intake calculated (Eqn 9) will be increasingly over-estimated, and *vice versa* for diets of lower DMD. Using a lower and higher intake constant, respectively, effectively corrects for these effects.

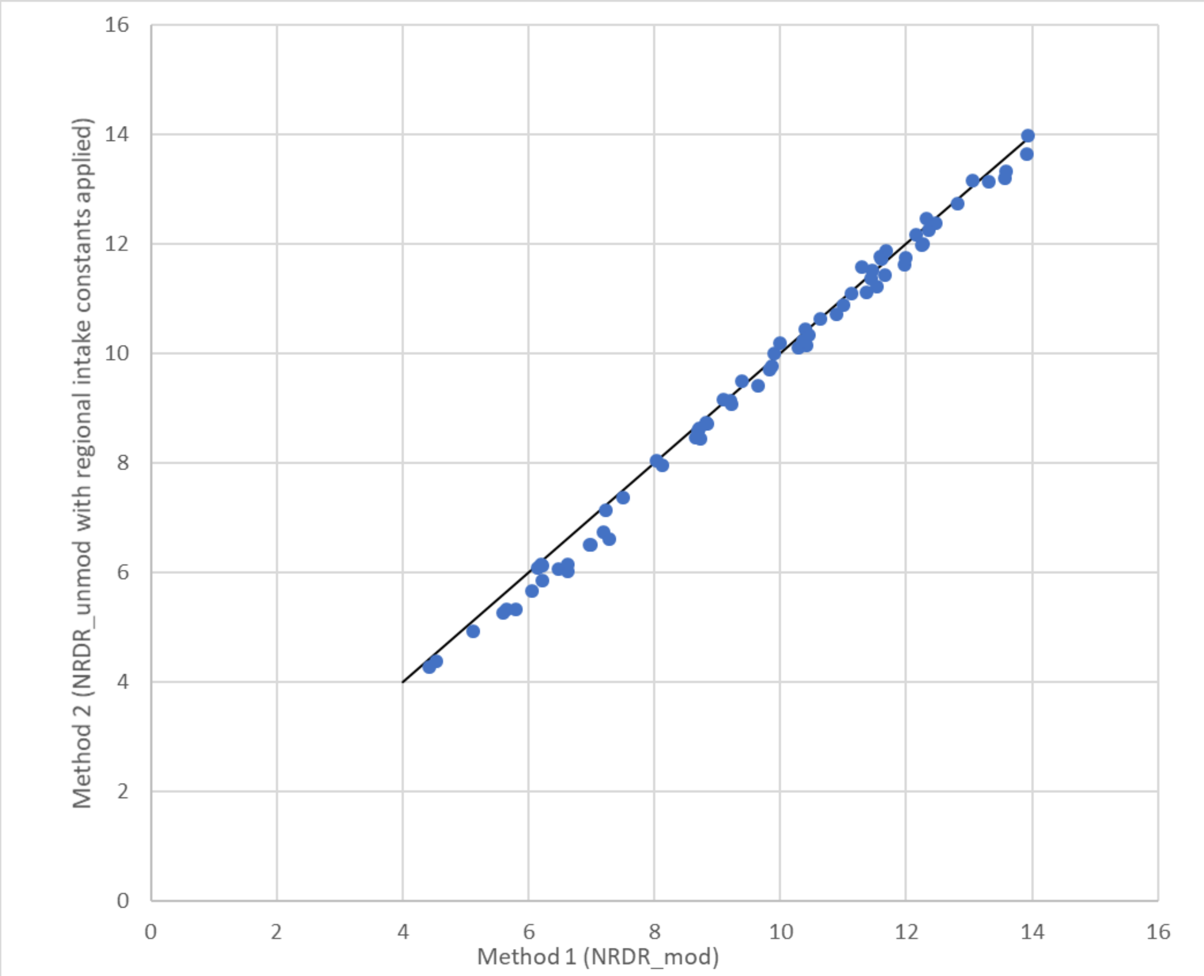


Fig. 6. Regression of average annual intakes (kg DM /day) predicted using Method 2 (see text), with an intake constant varying with region (Table 2), against intakes predicted using Method 1 (see text) for cattle of all classes across five regions in northern Australia. Data derived from Bray *et al*. (2015).

An example of the application of these intake constants is provided in Table 3. Generic AE ranks are given to different classes of animal and intake constants of 7.5, 8.0 and 8.5 kg DM/AE.day are used for high-, medium- and low-production regions, respectively, for calculating the forage intake by the cattle. These broad productivity classifications were derived from Bray *et al*. (2015). The AE ranks were determined by the production rate of the various classes of animals (and thus their ME requirements) in the different regions. The intake constant of 8.0 kg/AE.day could be considered a default value for moderate-production levels, and thereby correspond with systems for which the average annual diet quality of 55% DMD applies. This constant is essentially the same as that calculated above (7.9 kg/AE.day) in the LTCC example and is recommended for use in both applications (Applications 1 and 2; Section 3.3).

Table 3. Generic AE ratings for different classes of livestock based on productivity (annual steer growth rates: high, moderate or low), and the intake constants applying to those production rates

Class (age)	**High** (>150 kg/year)	**Moderate** (110-150 kg/year)	**Low** (<110 kg/year)
Females <1	0.77	0.68	0.57
Females 1-2	1.10*	0.91	0.72
Females 2-3*	1.74	1.12	0.96
Females 3-4*	1.61	1.49	1.18
Females 4+*	1.53	1.28	1.08
Steers <1	0.80	0.72	0.60
Steers 1-2	1.31	1.03	0.78
Steers 2-3	1.35	1.27	1.02
Steers 3-4	1.52	1.39	1.15
Bulls	1.55	1.52	1.29
Intake constant (kg DM/AE.day) **	7.5	8.0	8.5

*includes calf to weaning and accounts for reproductive rate (i.e. average of all females)

** Forage intake is calculated as the product of the AE rating and the intake constant

Several conclusions can be drawn from the above: 1) the agreement between estimates of intake made using either NRDR_unmod or NRDR_mod equations does not infer veracity in the predictions made with either method. There is no practical way of testing this under grazing conditions. However, acceptance in the early part of this document that changes to the NRDR (2007) equations (NRDR_mod) improved predictions of ME requirements and intakes of cattle in northern Australia gives confidence that the predictions are sufficiently accurate for practical use. 2) the exercise indicates that the NRDR_unmod equations can be used on a national scale without jeopardising the intake predictions for northern Australia. 3) the high variability in annual productivity and in the accompanying diet quality encountered on a national scale can be accommodated by applying correction factors (intake constants) for adjusting forage intake predictions. These adjustments will apply when estimating LTCC for an individual grazing unit within a region. The advantage of the approach taken with Method 2 is that stocking variables can still be described and summed in equivalent units; as AEs or DSEs/unit area, but these can also be converted to forage DM intakes using the intake constant approach.

3.3.4 Substitution ratio - sheep to cattle

The term 'substitution ratio' is often used to compare the grazing pressure effects of one species relative to another; sheep to cattle, or even one class of animals relative to another of the same species (steers vs cows). This is quite distinct from the ratio of DSE to AE which is a constant describing the energy requirements of the standard animals defining an AE and DSE, and is used in an accounting sense to convert between units (8.4 DSE: 1AE; section 3.2.6). In terms of substitution, the question might be – how any AEs (or DSEs) of sheep will have the same grazing outcome for some purpose as an AE (or DSE) of steers? There is evidence that under some circumstances sheep will select a higher quality diet than cattle grazing the same pasture. Squires (1982) reported that when grazing on the same pasture, the diet selected by sheep had an *in vitro* digestibility of 5-6 percentage points higher than for cattle. However, in another study, Wilson (1976) found the differences in diet quality for the two species were generally small. These differences between species will, however, vary in magnitude according to factors such as the stage of maturity of the animals, the pasture type and availability, the presence of forbs and browse and general dietary preference, and cannot be predicted with any certainty under field conditions.

Scarnecchia (1990) contended that the term substitution ratio is meaningless unless it is related to an objective and to specific management options. He states that the substitution ratio can be defined as "the optimum ratio of the number of individual animals or animal-units of one species or class of livestock to the number of animals or animal-units of another species or class to achieve specific objectives, given specified management options". The objective may be to harvest a particular grass species or to harvest foliage from tree seedlings, where the substitution ratio between sheep and cattle might be quite different for the different objectives. Five sheep may harvest as much foliage from shrubs as 10 steers, so that the substitution ratio of sheep to cattle for harvesting shrub foliage is 1 to 2 but, based on productivity (and thus ME requirements), each sheep may have a DSE rank of 1.2 and each steer a DSE rank of 12.0. Thus, the substitution ratio could be expressed as 1 sheep DSE to 20 steer DSEs. The substitution ratio is quite different to the ratio of DSE to AE; one is defined by grazing objectives and management, the other by energy requirements. Livestock substitution ratios are not animal unit equivalents but may be expressed using animal unit equivalents' (AE or DSE) (Scarnecchia, 1990).

For practical purposes, the units of either AE or DSE could be used with reference to any species or class of animal and are defined by their ME requirements, with a constant conversion of 8.4 DSE: 1 AE, but the substitution ratio between species or classes of animal will vary according to the stated objectives of the grazing exercise and the management systems applied.

3.3.5 DSE and forage intake

An intake constant has been determined to apply to the AE rank, the latter derived using the NRDR_unmod equations. Forage intake was determined as the AE rank multiplied by the intake constant (Eqn 10). Simulations carried out using the data of Bray *et al*. (2015) indicated that, in applying the intake constant in this way, estimated intakes were similar to those calculated directly using an animal-requirement model incorporating the NRDR_mod equations. For medium-production regions (110-150 kg average daily gain/year) and medium-quality diets, the calculated intake constant was 8.0 kg DM/AE.day and this was adjusted up (to 8.5 kg DM/AE.day) for lower-production regions (<110 kg ADG/year) and down (7.5 kg DM/AE.day) for higher-production regions (>150 kg ADG/year) to account for changes in diet quality relative to the median value of 55% DMD.

The DSE rank of cattle, sheep and other grazing animals is based on their ME requirements relative to that of the standard sheep (1 DSE = 8.68 MJ ME/day) and the DSE: AE ratio was determined, using the NRDR_unmod equations, to be 8.4:1. Modifications to the feeding standards similar to those described above for cattle have not been carried out with sheep so this ratio was calculated using NRDR_unmod equations to determine the energy requirements of both the standard cattle and sheep units. Similarly, it seems appropriate to apply the same intake constants, appropriately reduced, to the DSE rank of animals. Accordingly, the corresponding intake constants for DSE ranks would be 0.95 (8.0/8.4), 1.01 (8.5/8.4) and 0.89 (7.5/8.4) kg/DSE.day for medium-, lower- and higher-production regions, respectively. The default value of 0.95 kg/DSE.day is proposed where information on annual productivity is unknown. These intake constants will cater for most production systems but in the more intensive regions of southern Australia, where diet quality is relatively high, some further adjustment may be needed.

The most accurate way of estimating forage intake will be by direct calculation using a multi-variate animal-requirement models such as *GrazFeed*, *QuikIntake* and *ME_required*, if the user has an accurate estimate of diet quality over the period analysed. The calculated intake will only be as accurate as the diet quality estimate. These models are required to predict the energy requirements of the animal, so it requires just one more step of including a predicted diet quality in order to calculate forage intake. Nevertheless, the intake constants calculated above will be useful for incorporation in generic tables, allowing for subtle changes with productivity differences between regions.

3.3.6 Determining long-term carrying capacity (LTCC) – practical application

The LTCCdescribes the average number of animal units (AE) the land area (property usually, or paddock) can support over the longer term, say 10 years or more, within a sustainable, productive grazing system. The LTCC can target various objectives and Scarnecchia (1990) stressed the importance of clearly defining to what the carrying capacity referred. In northern Australia it will be maximising grazing pressure on the area without deterioration in the land or pasture; land condition, or perhaps with improvements to either or both. The LTCC will usually be expressed as animal unit equivalents per unit area; AE or DSE per ha, km^2, or ha per animal unit. Converting stock numbers into common animal unit terms is useful for valid comparisons and is a language widely understood by the grazing community. Usually this LTCC will span a range of annual climatic conditions and include variability in between-year pasture growth conditions but these variables are accounted for in deriving the LTCC. Notwithstanding, these variations in climatic conditions across years will usually be accompanied by short-term changes in the annual stocking rates. For convenience, the ensuing reference will be to AE but the principles apply equally to the use of DSE as the standard animal unit.

LTCCs are calculated on a land type basis within the property structure. Carrying capacity is determined by matching forage supply and utilisation. Average annual pasture production (growth) for each land type on the property, expressed in units such as kg DM/ha.year, can be estimated using the *GRASP* pasture growth model which is encapsulated in output tables and software such as *Stocktake Plus*, which in turn takes into account climatic variables, soil types and pasture communities. A desired safe utilisation rate (30%) is then applied to this figure to determine the total amount of pasture available for consumption by herbivores on each land type, the remainder representing a reserve to ensure long-term stability of the system. The annual intake of an AE is then divided by the amount of available forage per ha to derive the number of ha required per AE. LTCCs of each land type within a paddock or property are then summed. The resulting number of AE can then be converted to stock numbers of desired class and weight for stocking the paddock or property to its LTCC or for comparison with current stocking rates.

In northern Australia the default annual intake of an AE will be 8 kg DM/AE.day x 365 days = 2920 kg DM/AE.year. This figure can be adjusted to 7.5 kg DM/AE.day in high production regions and 8.5 kg DM/AE.day in low production regions. An example of this application, consistent with the grazing land management (GLM) approach is:

LTCC = annual intake of an AE (Intake Constant (kg DM/AE.day) x 365 kg DM / (average annual pasture growth for land type and climate centre (kg DM/ha) x safe utilisation rate (%) for the land type).

3.3.7 Devising forage (fodder) budgets – practical application

Forage budgeting can take on several forms, including (i) dry season forage budgets which can extend from 3 to 12 months; (ii) short-term forage budgets for rotational-grazing over the dry season where stock weight gains might be expected to be equal to or less than 0.6 kg/day and a grazing period of less than three months; and (iii) rotational grazing during phases 1 and 2 of pasture growth with high-quality pastures or forages such as oats. Thus, forage budgets are determined over a shorter period than for LTCC, often over only several months of the year, and can involve short-term changes in diet quality. They can be developed for any phase of the annual grazing cycle, including when pasture is actively growing. However, they most commonly fit category (i) above and are employed for the dry season grazing phase when pasture growth is negligible, diet quality is low and the duration of grazing of the limited pasture reserve needs to be determined.

In preparing a forage budget the operator needs to forecast the duration of the grazing period and requires information on forage supply and demand to determine whether there is sufficient pasture to last the number of stock in a paddock or property for the duration. On the supply side, inputs required include total pasture yield on offer (kg DM/ha) at the start, the estimated pasture growth rate (kg DM/ha.day) for the budgeting period (if any), the proportions of unpalatable pasture species and 3P species in the pasture and the desired minimum residual yield of pasture at the end of grazing. On the demand side, the main inputs are the number and class of stock and their productivity, which are converted to an AE or DSE number for the paddock from which demand in kg DM/ha for the period is calculated and compared with the supply of pasture.

An estimate of intake by the grazing animal is required for forage budgeting. A similar approach to that described above for LTCC can be used but, due to their shorter-term duration, the effects of short-term changes in diet quality and the need for greater precision to avoid depleting the pasture resource, some differences apply. It is stressed here that the most accurate way of estimating intake is by direct means, i.e., applying a multi-variable animal demand model based on the feeding standards with a description of the animals (breed, sex, age, W, W change, pregnancy and lactation status) and an estimate of the quality of the diet selected. This method should be used for options (ii) and (iii) above. The growth rate of the grazing animals is often unknown. This can be provided by regular weighing of the animals, albeit that this growth rate is always in arrears, or a historical value can be derived from past experience on seasonal conditions and production rates. In the case of preparing a budget for (ii) above, past experience coupled with an appraisal of the proportion of green in pasture (if any) and present-day climatic information will provide an estimate of likely growth rate which might be W maintenance, small losses or small gains. Estimates can be adjusted regularly according to observed changes in body condition score of the animals and seasonal conditions. A similar approach can be used with breeding animals where pregnancy and lactation status are known or deduced. The DMD of the selected diet can be estimated by NIRS screening of faeces of the grazing animals through a commercial laboratory service or, could be estimated according to the pasture and seasonal conditions, the apparent W change and condition of the cattle, and operator past experience. Using the animal demand modelling approach, a direct estimate of intake is provided without the intermediary step of calculating the animal unit equivalence. Nevertheless, estimation and expression of the stocking rate in AE or DSE units provides a convenient, common descriptor with relevance to the grazing community.

The approach for option (i) is similar to calculating LTCC, where the operator first allocates an AE or DSE rank to each animal or animal class based on animal performance and consequent energy requirements relative to that of the standard animal. This animal unit ranking is then multiplied by an intake constant which corresponds to a long-term average diet quality. The default intake constant suggested is 8.0 kg DM/AE.day or 0.95 kg DM/DSE.day based on an average annual diet quality of ~55% DMD (7.75 MJ ME/kg DM). Adjustments are made to the intake constant where both animal performance and diet quality are higher (higher-production regions; 7.5 kg DM/AE.day) or lower (lower-production regions; 8.5 kg DM/AE.day) than the average used to derive the default value. The range in annual diet quality to which these corrections apply is probably between about 53 and 57% DMD, which is quite a large range when averaged over a year.

This system is suitable for dry season forage budgets of 3 to 12 months duration, and is well supported in section 3.3.3 with the use of Bray *et al*. (2015) data to derive intake constants for regions of medium/unknown, high and low productivity .

3.3.8 Summary on application of the animal unit system

There are several practical applications of the animal unit system, but these can generally be categorised according to the duration of application, *viz*., into long-term use (>1 year) described by LTCC, shorter-term use in forage budgets of > 3 to 6 months duration, or short-term forage budgets of < 3 to 6 months. All rely on an estimate of forage intake so that the stocking rate or carrying capacity can be determined. The simplest method for the first two applications is to use an intake constant to calculate annual (LTCC) or daily (forage budget) consumption. For the third application, forage intake can be directly estimated using a multi-variate animal demand model together with an estimate of diet quality. Appropriate intake constants have been calculated, these changing over a narrow range according to annual liveweight productivity. The carrying capacity can be expressed in terms of animal units per unit area, either as AE or DSE with an inter-conversion of 8.4 DSE: 1 AE.

4 Summary and conclusions

The definitions of animal units in Australia have been inconsistent, confounding and often conflicting. This report has:

- surveyed the available literature to provide a comprehensive background on animal units and their applications, in Australia and northern America;
- addressed the issue of over-estimation of ME and DM intake by cattle on tropical pastures by changing equations within the Australian feeding standards, with implications for both the direct estimation of intake and for use within an animal unit methodology;
- suggested complementary definitions for standard animals for both sheep and cattle, thereby defining both the AE and DSE and allowing either to be calculated and used as a common currency for describing and quantifying grazing pressure;
- developed intake constants for converting from AEs and/or DSEs to DM intake, with national application.

The overestimation of DM intake by cattle on tropical/sub-tropical pastures using the existing Australian feeding standards (NRDR 2007), as described by McLennan (2013) and Bowen *et al*. (2015), limited the application of an animal unit methodology based on ME demand (McLean and Blakeley 2014). The current work has corrected for this overestimation of intake, using the best available pen trial data, by modifying key equations on energy utilisation. This presented the dilemma of having two different systems for determining the animal unit rating of animals and for estimating their forage intakes, one based on the modified version of the feeding standard equations (NRDR_mod) which had application only to cattle in northern Australia and the other based on the unmodified version (NRDR_unmod) applying to cattle in temperate regions and sheep in all regions, as the same experimental scrutiny had not been undertaken for these latter situations.

Simulations carried out in our study indicated, firstly, that the animal unit rating was similar using either system providing they were used in synchrony; the ME requirements of an animal under consideration and that of the standard animal were determined using the same system. An advantage of this approach is that the animal unit rating is unlikely to change significantly even if changes are later made to the feeding standard equations. Second, they showed that the more accurate intake for tropical cattle achieved with the NRDR_mod system could be matched with the NRDR_unmod system by applying a two-step calculation to it, namely determine the animal unit ranking and multiply this by an intake constant. Third, this intake constant was shown to vary according to the productivity of the region, being 8.0 kg DM/AE.day for a moderate-productivity (110-150 kg/year steer growth) region, increasing to 8.5 and reducing to 7.5 kg DM/AE.day for low- (<110 kg/year) and high-productivity (>150 kg/year) regions, respectively. The suggested default value was 8 kg DM/AE.day where information on regional productivity was unknown. This finding indicated that the NRDR_unmod system could be applied universally and nationally without jeopardising the increased accuracy of the NRDR_mod system for cattle in the tropics. The constraint on this approach occurs with diets of very low quality (≤50%DMD) or very high quality, for instance high-quality forage crops (>60% DMD).

Recommendations are:

- Use the **NRDR_unmod system** (AE or DSE x intake constant) for:
  - long-term carrying capacity determinations [cattle and sheep; temperate and tropical regions]
  - medium-term fodder budgets (6 months or more) [cattle and sheep; temperate and tropical regions]

Generic tables for different classes of animal, similar to that of Table 3, can be used to provide the AE ranks or they can be derived from multivariate animal demand models, as described earlier.

- Use the **NRDR_mod system** (direct calculation using multi-variate animal demand models) for:
  - short-term fodder budgets (<6 months) [cattle only; northern (tropical) Australia only; very low or very high diet quality]

In southern Australia, the approach suggested above could be used for short-term fodder budgets with direct calculation using an animal demand model but based on the NRDR_unmod equations. It is a matter of using the most appropriate system to fit the circumstances.

Where an estimate of intake is the primary requirement, and diet DMD is either known or can be estimated with some precision, the use of a multi-variate animal demand model like *QuikIntake* may be the easiest approach.An estimate of the animal unit ranking it will also usually be required in order to quantify grazing pressure. This has been incorporated into most such models.

Any grazing animal can be defined in either AE or DSE units with an interconversion of 8.4 DSE: 1 AE.

These results allow animal units to be applied consistently across uses (e.g. property valuations, LTCC assessments, business and enterprise analysis, forage budgeting) and species (initially sheep and cattle, but potentially other species as well), in a way that was not previously possible.

5 Recommendations

- The new standards around animal unit definitions be widely distributed and explained to animal industry advisors across northern Australia
- Generic AE tables be created for cattle, based on the NRDR_unmod equations, as done in McLean and Blakeley (2014). (DSE tables for sheep could be created later using the same equations and with a fixed conversion rate of 8.4 DSE: 1 AE)
- Simple tables be constructed and made available showing the energy, protein, phosphorus (P) and calcium (Ca) requirements of cattle of different classes and production rates for northern Australia, inclusive of the modifications to the feeding standards (NRDR_mod) arising from the current project.
- Modifications to the Australian feeding standards arising from the current project (NRDR_mod) be made to a multi-variate energy requirement model for cattle in northern Australia, and this model be made available to users via the MLA web site
- The revised protein, P and Ca requirements of cattle be included in the animal requirement model for the MLA web site
- Revisions to the animal unit methodology be included in revised editions of the EDGE network packages and in Stocktake Plus for the education of animal producers and their advisors.

6 Bibliography

AAF (2017) Using animal unit month (AUM) effectively. Agri-Facts (Practical Information for Alberta's Agriculture Industry), Agdex 420/16-1. At https://open.alberta.ca/publications/3989721. (Confirmed 2 July 2018)

AIMS (2009) Stocking rate, stock density and using DSE values to estimate pasture intake. Grazing Management Fact Sheet 4. Agricultural Information and Monitoring Services. At https://www.google.com/search?q=AIMS+%282009%29+Stocking+rate%2C+stock+density+and+using+DSE+values+to+estimate+pasture+intake&ie=utf-8&oe=utf-8&client=firefox-b-ab (Confirmed 8 May 2018)

Anon. A (2017) Monitoring tools. Victorian Agriculture. At http://agriculture.vic.gov.au/agriculture/farm-management/business-management/ems-in-victorian-agriculture/environmental-monitoring-tools/sustainable-carrying-capacity (Confirmed 8 May 2018)

Anon. B (Year unknown) 'Grazing livestock – a sustainable and productive approach'. Fact sheet. Adelaide and Mt Lofty Ranges Natural Resources Management Board, Government of South Australia. At http://www.naturalresources.sa.gov.au/files/sharedassets/kangaroo_island/land_and_water/land_management_support/managing_livestock/grazing_livestock_-a_sustainable_and_productive_approach_fact_sheet.pdf (Confirmed 8 May 2018)

Anon. C (Year unknown) Using DSEs and carrying capacity to compare sheep enterprises. NSW Dept Primary Industries. At https://www.dpi.nsw.gov.au/agriculture/budgets/livestock/sheep-gross-margins-october-2015/background/dse (Confirmed 8 May 2018)

Bell, A (1992) Dry sheep equivalents (DSE) tables. Hassall and Associates, Dubbo NSW

Blackwood I, Briggs G, Christie J, Davies L, Griffiths N (2006). Beef stocking rates and farm size – Hunter region. NSW Dept Primary Industries. At https://farmtable.com.au/build/beef-stocking-rates-farm-size-hunter-region/ (Confirmed 8 May 2018)

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

Bray S, Walsh D, Hoffmann M, Henry B, Eady S, Collier C, Navarro J, Corbet D, Pettit C (2015) Desktop research project to provide data on liveweight and liveweight gain in the beef cattle sector in Queensland and the Northern Territory: Final report, 2015, State of Queensland.

Davies L (2005) How to use dry sheep equivalents (DSEs) to compare beef enterprises. Fact sheet. NSW Dept Primary Industries.

Dove H, McLennan SR, Poppi DP (2010) Application of nutrient requirement schemes to grazing animals. In 'Proceedings of the 4th grazing livestock nutrition conference'. (Eds BW Hess, T DelCurto, JGP Bowman, RC Waterman) pp. 133-149. (Western Section of American Society of Animal Science: Champaign, Illinois)

Edwards PJ (1981) Terms describing aspects of vegetation and its management. In, 'Veld and pasture management in South Africa'. Chapter 14. (Ed. NM Tainton). Shuter and Stooter Pty Ltd, Pietermaritzburg, South Africa.

Freer M, Moore AD, Donnelly JR (1997) GRAZPLAN: Decision support systems for Australian grazing enterprises – II. The animal biology model for feed intake, production and reproduction and the GrazFeed DSS. *Agricultural Systems* **54**, 77-126.

Freer M, Moore AD, Donnelly JR (2012) The GRAZPLAN animal biology model for sheep and cattle and the GrazFeed decision support tool. CSIRO Plant Industry Technical Paper (revised December 2012). At www.csiro.au/en/Organisation-Structure/Divisions/Plant-Industry/GRAZPLAN-supporting-documents-and-programs (confirmed April 18, 2013).

Griffiths HD (1998) Dry sheep equivalents for assessing livestock enterprises. Farmnotes No. 300 7/1989. Dept of Agriculture, Tasmania.

Holistic Results Pty Ltd (2010) Australian DSE Tables – Cattle. At https://www.google.com/search?client=firefox-b-ab&ei=MjLxWrzpFcSM8wXTwJawAw&btnG=Search&q=Holistic+results+DSE (Confirmed 8 May 2018)

Holmes P, McLean I, Banks R (2017) 'The Australian Beef Report.' (Bush AgriBusiness)

Hyder MW (2006) Calculation of dry sheep equivalents. *Proc. Aust. Soc. Anim. Prod.* **26**, short communication number y.

Jardine JT, Anderson M (1919) Range management on the national forests. USDA Bulletin 790.

Maddox LA (1964) 'Nutrient requirements of the cow and calf'. Texas Agriculture Extension Service Bulletin B-1044.

MAFF (1984) 'Energy allowances and feeding systems for ruminants.' (Ministry of Agriculture, Fisheries and Food, Technical Bulletin Number 433, Her Majesty's Stationary Office: London)

Mayer DG, Butler DG (1993) Statistical validation. Ecological Modelling 68, 21-32.

McCosker T, McLean D, Holmes P (2009) Northern beef situation analysis. 2009 final report. Project B.NBP.0518. Meat and Livestock Australia.

McIvor, J, 2010, Enhancing adoption of improved grazing and fire management practices in northern Australia: Synthesis of research and identification of best bet management guidelines, Meat & Livestock Australia Final Report B.NBP.0579.

McLaren C (1997) Dry sheep equivalents for comparing different classes of livestock. Agriculture Note AG0590, Dept Primary Industries, Victoria. At http://www.academia.edu/30819193/Dry_Sheep_Equivalents_for_comparing_different_classes_of_livestock (Confirmed 8 May 2018)

McLean I, Blakeley S (2014) Adult equivalent methodology – A method to accurately and consistently calculate cattle grazing loads in northern Australia. Final Report to Meat and Livestock Australia - Project B. NBP.0779.

McLennan SR (2004) More effective supplements for the northern beef industry. Final Report to Meat and Livestock Australia - Project NAP3.122.

McLennan SR (2005) Improved prediction of the performance of cattle in the tropics. Final Report to Meat and Livestock Australia - Project NBP.331.

McLennan SR (2013) Optimising growth paths of beef cattle in northern Australia for increased profitability. Final Report to Meat and Livestock Australia - MLA project B.NBP.0391.

ME_required.xls spreadsheet calculator. CSIRO GrazPlan Supporting Programs. http://www.grazplan.csiro.au/?q=node/18

Meyer TL (2010) 'Estimating livestock forage demand: defining the animal unit'. MSc thesis. University of Nebraska.

Millear G, Conway A, Mills T (2003) Calculating a gross margin for sheep, goat and cattle enterprises. Farm Note. Queensland Dept Primary Industries and Fisheries. At https://web.archive.org/web/20060823081336/http://www2.dpi.qld.gov.au/sheep/5340.html (Confirmed 8 May 2018)

Minson DJ, McDonald CK (1987) Estimating forage intake from the growth of beef cattle. *Tropical Grasslands* **21**, 116-122.

MLA (2001) Northern nutrition. An education package for beef producers in northern Australia.

MLA (2017) Nutrition EDGE. An introduction to the essentials.

NRDR (2007) 'Nutrient requirements of domesticated ruminants.' (CSIRO Publishing: Melbourne, Australia)

Sargeant K, Saul G (2013) 'Understanding your stocking rate and feed supply demand profile'. EverGraze (More Livestock from Perennials). At http://www.evergraze.com.au/library-content/understanding-your-stocking-rate-and-feed-supply-demand-profile/ (Confirmed 8 May 2018)

SCA (1990) 'Feeding standards for Australian livestock. Ruminants'. (Standing Committee for Agriculture, CSIRO: Melbourne)

Scarnecchia DL, Gaskins CT (1987) Modelling animal-unit-equivalents for beef cattle. *Agricultural Systems* **23**, 19-26.

Scarnecchia DL (1985) The animal-unit and animal-unit-equivalence concepts in range science. *Journal of Range Management* **38**, 346-349.

Scarnecchia DL (1990) Concepts of carrying capacity and substitution ratios: a systems viewpoint. *Journal of Range Management* **43**, 553-555.

Scarnecchia DL (2004) Viewpoint: entropy, concept design, and animal-unit equivalence in range management science. *Journal of Range Management* **57**, 113-116.

Stoddart LA, Smith AD (1955) 'Range Management (2nd edition)'. McGraw-Hill Book Co. New York.

Squires V (1976) Walking, watering and grazing behaviour of Merino sheep on two semi-arid rangelands in south-west New South Wales. *The Rangeland Journal* **1**, 13-23.

Squires VR (1982) Dietary overlap between sheep, cattle, and goats when grazing in common. *Journal of Range Management* **35**, 116-119.

SRM (1998) Glossary of terms used in range management. A definition of terms commonly used in range management. 4th edition. Available at https://globalrangelands.org/glossary - check and give date

SRM (2017) Does size matter? Animal units and animal unit months. Society for range management rangeland assessment and monitoring committee. *Rangelands* **39**, 17-19.

Thomas DT, Wilmot MG, Alchin M, Masters DG (2008) Preliminary indications that Merino sheep graze different areas on cooler days in the southern rangelands of Western Australia. *Australian Journal of Experimental Agriculture* **48**, 889-892.

Turner BW, Alcock D (2000 C) The dry sheep equivalent – redefining a 'standard'. *Asian-Australian Journal of Animal Science* **13** (Supp.), 215.

Wilson A (1976) Comparison of sheep and cattle grazing on a semiarid grassland. *Australian Journal of Agricultural Research* **27**, 155-162.