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Improved empirical models of cattle growth, reproduction and mortality from native pastures in northern Australia

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Abstract

Simulation models of native pastures in northern Australia have seen wide and increasing use for environmental and ecological reviews (including climate impacts) and the evaluation of grazing management options. Current models of cattle performance (including liveweight gain) are based mainly on research conducted some 20 years ago. This project reviewed these models, and collated a range of existing and new data sets, to estimate improved predictions for rates of growth, reproduction and mortality. The performance of existing and adapted models across a wide range of locations was evaluated, with somewhat mixed results. When applied to different pasture communities and land types, the models generally need to be re-parameterised. It is recommended that these investigations continue, so that the available models can be used with good confidence across the rangelands of northern Australia.

Executive summary

A range of government and semi-government organisations, along with agribusinesses and producers across northern Australia, actively use models of native pastures and rangelands grazing systems. Environmental and ecological reviews, the evaluation of grazing management options, drought alerts and reports, investment analyses, and investigations of climate impacts have primarily used models from the GRASP suite of products. Outputs from GRASP can be coupled with other models such as ENTERPRISE to model herd dynamics and whole-property operations and economics.

The ‘grass production’ components of models such as GRASP are based on a sound understanding of the mechanisms involved. When accurate rainfall data sets are available, and the model is correctly parameterised (in terms of soil type and depth, initial conditions, pasture communities, tree cover, etc.), observed pasture characteristics such as standing dry matter are generally in good agreement with the simulated output. However, for the key biological variable of liveweight gain, the empirical models being used are less certain. The components relating to grazing and animal production (i.e. diet selection, intake, trampling and liveweight gain) were developed in the 1980s and mid 1990s, specifically for black speargrass pastures. The animal production relationships used in available models have remained largely unchanged since that time. These models predict annual liveweight gain from estimates of pasture utilisation and ‘green-days’, while mortality and weaning rates in ENTERPRISE are predicted using simple empirical relationships with annual liveweight gain imported from GRASP. Anecdotal evidence exists that these relationships do not apply to some pasture communities, and hence alternative model parameters were required for these locations.

This project report describes how more recent knowledge and data sources (including historical data now available) can be used to update and improve the existing models. The project was initiated in 2010, to review and develop improved empirical relationships for predicting liveweight gain, mortality and reproduction performance of beef cattle on native pastures in northern Australia.

Firstly, a detailed critique of the empirical relationships in existing rangelands models was conducted. Considerable data collection and scientific understanding has been gained since these models were developed, including: newly completed grazing trials such as Galloway Plains, Wambiana, Mt Sanford, and Pigeon Hole (as well as historical trials that had not previously been analysed from a modelling perspective, such as Swans Lagoon); the availability of remotely-sensed data such as the measurement of green cover (NDVI) which provides a complementary data source on the important ‘green-days’ variable; and the development of intake and energy balance models, some using faecal NIRS data, for estimating diet quality and animal intake.

One limitation of the current annual liveweight gain relationship in GRASP is that it does not support simulation of multi-paddock or intra-annual options such as pasture spelling or seasonal forage systems. As a ‘proof-of-concept’, a daily liveweight gain model was developed for use in GRASP (see Appendix 2). The model was based on the existing GRASP relationships with modifications to represent these processes on a daily basis. Research extending this approach to include improved pastures is on-going. It is recommended that further development of the daily liveweight gain model in GRASP should occur, using the liveweight data assembled and tested in this project.

Regarding the reproduction and mortality rates of breeding cows, the models currently in use were reviewed. These were generally found to be not satisfactory – whilst they accounted for some of the key variables, other important effects were ignored. An extensive data set from

across northern Australia was collated, covering over 24,000 cow-years. The reproduction and mortality rate models were then re-parameterised and adapted to achieve an acceptable degree of fit. These are now proposed as superior models for these key biological rates, and a paper on this research is shortly to appear in *Animal Production Science* (see Appendix 4).

For models of liveweight gain, a number of case studies were conducted. Firstly, broad-scale comparisons were performed for over 40 sites across Queensland, using AussieGRASS (a broad-scale spatial implementation of GRASP). These showed a generally good degree of agreement, with no discernable bias, however further analyses of the outliers is on-going. Secondly, weight gains from a short-term grazing trial were compared with the current models in APSIM. In this system, where the animals could largely achieve their specified potential weight gains, these values also compared well.

In the main study, GRASP was parameterised specifically to sites (and paddocks within sites), to test the liveweight gain model against observed data. The first independent validation of the existing coefficients, using data from Mt Sanford (VRD, NT), was successful. Subsequent investigations of a range of other locations across northern Australia, however, gave mixed results. The general lack of agreement here is still the subject of ongoing research, as many factors such as inaccurate rainfall records and incorrect model calibration of pasture yields can contribute to poor simulation of liveweight gain. Further interpretations of these data sets, and extension to more locations, are required.

The annual liveweight gain model was also tested for pastures and locations substantially different to the relatively infertile native grasslands of northern Australia. The approach was tested for stocking rate trials at: (a) Brigalow Research Station on fertile Buffel grass, Green Panic, and Rhodes grass pastures; (b) legume-based pastures at Galloway Plains; and (c) Buffel grass pastures at Alice Springs. The results highlighted the importance of 'green-days' where the nutritional quality of standing senescent material was low. Hence different coefficients are needed in the annual liveweight gain relationship to cover a range of geographical (e.g. rainfall variation) and nutritional (e.g. legume-based and sown pasture) situations. It is concluded that the current empirical models do work well for a range of locations and pasture communities, however there are other locations where this is not the case. Here, further research is needed to re-parameterise or adapt the models. Targeted future developments include moving to a mechanistic model of liveweight dynamics; however this approach has problems to overcome, including the estimation of intake.

Government organisations, agribusinesses and producers throughout Australia rely on a suite of models, many of which are based on GRASP and its extensions. This report recommends a number of tasks that are necessary so that future users of these models can have good confidence in the simulation results.

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1 Background

Since the early 1980s, the GRASP (GRASs Production) model has contributed to a wide range of industry and government agency applications with regard to the management of the grazed resource of northern Australia. More recently, the combination of the GRASP and ENTERPRISE models has allowed the bio-economic aspects, including the herd dynamics and economic components of the grazing system, to be simulated and grazing management recommendations to be informed. Current and future applications of GRASP (and in some cases ENTERPRISE) are:

- the evaluation of grazing management options (e.g. the MLA Northern Grazing Systems (NGS) project), including pasture spelling, stocking rate management, and other multi-paddock options (e.g. seasonal forage systems);
- the calculation of grazing pressure on different land types in Great Barrier Reef (GBR) catchments;
- calculation of likely climate change impacts on animal production and risks of resource degradation (e.g. DAFF projects); and
- monitoring of risks of drought and degradation across Australia’s rangelands in near-real time (AussieGRASS, a spatial implementation of the point model).

The GRASP model components relating to grazing and animal production (i.e. diet selection, intake, trampling and liveweight gain) were developed in the 1980s and mid 1990s. Similarly the herd dynamics (steer growth to age of turnoff, reproduction and mortality) and supplementation components of ENTERPRISE could be updated with currently available information from past and current projects. This project report describes how more recent knowledge and data sources (including historical data now available) could update GRASP and ENTERPRISE to better address current and future applications.

This project was initiated in 2010, to review and develop improved empirical relationships for predicting liveweight gain, mortality and reproduction performance of beef cattle on native pastures in northern Australia. To be most useful, pasture, herd and enterprise modelling applications require simple but realistic and repeatable predictions of key animal production responses. GRASP is the most commonly applied simulation model for pasture-based cattle production in northern Australia, and with the ENTERPRISE model, underpins much of the work within the NGS initiative. While GRASP is well developed and tested with respect to simulation of pasture growth across Australia’s rangelands, its capacity and reliability for estimating cattle production is somewhat limited, having been based primarily on data collected in the black speargrass zone of Queensland.

The animal production relationships used in available models have remained largely unchanged since the 1980s and mid 1990s. These models predict annual liveweight gain from estimates of pasture utilisation and ‘green-days’, while mortality and weaning rates in ENTERPRISE are predicted using simple empirical relationships with annual liveweight gain.

A limitation of the annual liveweight gain relationship is that it does not yet support simulation of multi-paddock applications such as pasture spelling or seasonal forage systems, particularly when there is high year-to-year variability in seasonal potential liveweight gain. As a ‘proof of concept’, a daily liveweight gain model was developed for use in GRASP. The model was based on the existing GRASP relationships, with modifications to represent processes on a daily basis. The results indicate that a daily liveweight gain model can be calibrated to monthly/seasonal liveweight data. It is recommended that further development of the daily liveweight gain model in GRASP should occur, using the liveweight data sets assembled and tested in this project.

The main aim of this project was to target data from grazing trials, particularly those which have collected animal growth, reproduction and mortality data, and to develop improved empirical relationships or alternative approaches for predicting key animal production measures.

2 Project objectives

1. Review and evaluate existing empirical models for predicting animal production currently within the GRASP, HerdEcon and ENTERPRISE models.

2. Review and document alternative or complementary approaches to prediction of key animal production measures and identify input variables which improve prediction accuracy by better explaining influences of pasture (quality, quantity and utilisation), climate, soil fertility and animal genotype.

3. Use a short list of these approaches to develop and/or refine predictive relationships, using data from selected grazing trials (including Wambiana, Mt Sanford and Pigeon Hole).

4. Test the predictive relationships against an independent data set.

5. Recommend the most pragmatic approach for improving the capacity of GRASP and ENTERPRISE to realistically and reliably predict animal production.

Project progress against each of these objectives, in turn, is outlined as follows. The methodologies used, and results obtained, are outlined separately for each of the studies that contributed data to this overall project, and these individual studies are grouped within the respective sections for each of the nominated objectives.

3 Review of existing empirical models for animal production

3.1 Liveweight gain models

There are a number of models in use in Australia that consider LWG. These are discussed as follows.

3.1.1 GRASP

The current (2012) versions of GRASP include two models (and their parameter sets) relevant to the simulation of liveweight gain. We describe below the evaluation of these existing models and parameters. Research on LWG models in GRASP effectively ceased in 1996, as priority had been given to the development of pasture growth models.

It is important at the outset to distinguish between models (i.e. structure & form of equations) and parameters / coefficients. As an example of this distinction, we can consider simulating a most important component of the pasture model, namely nitrogen limitation on pasture growth. The 'model' in this case is the direct relationship between pasture transpiration and nitrogen uptake, with growth stopping when the ratio of N uptake to pasture growth is less than a minimum %N concentration. The key parameters are N uptake and minimum %N concentration, and the values for these will vary for different land types and pasture species. The parameter values thus need to be specified for individual combinations of location, land type and pasture condition.

The pasture growth studies over the last 40 years and other field measurements have allowed the initial development of a library of land type parameter sets that can be applied across northern Australia. A set of average pasture parameters for northern Australia was developed in 1998 (McKeon et al. 1998). In contrast to pasture studies, the development of models and parameter sets for simulating liveweight gain are not as well advanced. The following descriptions of evaluation/refinement (Objective 3) and testing (Objective 4) are the basis for developing a more comprehensive capability in LWG modelling in GRASP.

Procedure

We have adopted the following procedure to achieve Objectives 3 and 4 of this project.

1. We describe two existing GRASP LWG models, referred to as **Utilisation Model 1** and **Annual Liveweight Gain Model 2** (ALWG Model 2). We describe how they are mutually supporting (i.e. ALWG Model 2 depends on components in Utilisation Model 1).
2. We evaluate the performance of Utilisation Model 1 using broad-based LWG data sets compiled across Queensland, indicating possible refinements to the model and parameter sets to support further application.
3. We evaluate ALWG Model 2 (as was applied in the NGS project), including development of new supporting parameter sets and independent testing (Objective 4), with specific grazing trials and survey information.
4. We developed a new daily LWG model for a subset of available data sets (Gayndah, Galloway Plains, Kangaroo Hills and Mt. Sanford), and report on a preliminary independent test (Wambiana grazing trial).
5. From the findings of steps 1 to 4, we report recommendations for further systematic development of LWG models.

LWG data availability

It is important to recognise that comprehensive datasets of liveweight gain are required to support the above procedure. The lack of collated data sets documenting the many factors affecting liveweight gain has been a major limitation to the development of LWG models, and in particular, the development of supporting comprehensive parameter sets. To address this limitation, new and existing data sets (e.g. Wambiana) were collated to allow model testing and to provide new parameter sets with wider application than just existing information. However, it was apparent in carrying out the project that much useful information still remains to be collated for use in model development and testing.

Data sets are only useful if they are available, accessible and fit for purpose. While a number of data sets were initially considered to be useful for this project, it became apparent that many were less valuable than initially considered. In the recommendations, we set out a series of steps to address the issue of data collation and model testing.

UTILISATION MODEL 1

The main purpose of Model 1 is to calculate dry matter intake, so that pasture utilisation can be calculated. The model structure is as follows:

Step 1: Daily potential LWG is calculated from seasonal potential LWG (4 parameters for DJF, MAM, JJA, SON).

Step 2: Potential intake for a weaner steer (200 kg liveweight) is calculated from an equation derived in McKeon and Rickert (1984) from data reported by Siebert and Hunter (1977).

Step3: Restrictions (0-1) on potential intake are calculated to include the effects of standing dry matter availability (e.g. <300 kg/ha) and utilisation calculated from the start of the growing season (e.g. 1st December).

Step 4: Actual dry matter intake per head and per hectare are calculated from specified stocking rate and conversions of animal type to weaner steer equivalents.

Step 5: Actual daily LWG is calculated from the inverse of the equation used in Step 2.

Step 6: Actual intake (per ha) is accumulated to calculate pasture utilisation (ratio of accumulated intake / accumulated pasture growth) for a specified time periods such as 12 months, as used in ALWG Model 2 (described below):

Utilisation Model 1 is used as the only LWG model in the AussieGRASS application of GRASP and in forage systems (e.g. APSIM) simulations, where there is a need for daily LWG calculations. The limitations of Utilisation Model 1 are:

a) No year-to-year variation in potential LWG.
b) Lack of parameter sets of seasonal distribution of liveweight.
c) Relationship between intake and liveweight needs to be updated to include new data sources and knowledge, including energy losses, with grazing activity.
d) Restrictions on potential intake are likely to vary with pasture species (e.g. prostrate, erect), type (forage, extensive tussocks), grazing management and restriction on grazing time.

Parameter sets relevant to utilisation Model 1 are yet to be developed for different pasture communities and land types.

ANNUAL LIVEWEIGHT GAIN MODEL 2 (ALWG MODEL 2)

ALWG Model 2 was designed to calculate annual liveweight gain accounting for year-to-year variability in nutrition and pasture utilisation. ALWG Model 2 was developed in 1994 for use in scenario testing where impacts of grazing management options are assessed considering year-to-year variation in climate (most importantly variation rainfall amount and distribution). ALWG Model 2 (described below) allows simulation of annual LWG using historical daily climate records (>100 years). ALWG Model 2 has 2 main components:

a. Impact of utilisation of 12 month pasture growth (%util) on LWG; and
b. Potential LWG calculated as a function of number of days (%GIdays) in the 12-month period that a pasture growth index (0-1) exceeds a specific threshold (0.05).

$$LWG = a + b^{*}\ \%utilisation + c^{*}\ \%GIdays,$$

where coefficients ‘a’, ‘b’ and ‘c’ are referred to as ‘parameters’. We describe in some detail the underlying components of the ALWG Model 2, to provide a basis for understanding the results reported later.

Model 2 subcomponent: %Utilisation

The utilisation term is calculated as the ratio of animal intake (kg DM/ha/year) to pasture growth (kg DM/ha/year). The size of the coefficient (‘b’) represents the extent to which LWG/hd declines with increasing utilisation (i.e. more negative values (‘b’) indicating larger negative stocking rate effects on LWG. McKeon and Rickert (1984) found similar coefficients for native and sown pastures. However, Ash and Stafford Smith (1996) in their review of rangeland grazing trials indicate smaller coefficients than those obtained in smaller scale research station trials. The factors that are likely to influence the impact of utilisation include:

a. Temporal (and spatial variation in preferred landscape (floodplain, alluvial) and plant (e.g. dicots, browse) components;
b. Variation between species in growth habit (e.g. leaf/stem ratio, pasture height/yield relationship) and impact of trampling;
c. Expenditure of energy as part of grazing activity; and
d. Nutritional value of 'carry over' feed from previous years (e.g. in arid environments carry over feed has been included in the 'pasture growth' component of the utilisation equation to calculate wool growth).

Model 2 sub-component: %GIdays

Early work in the 1980s (e.g. Gillard 1979; McCown et al. 1980; McKeon et al. 1980) indicated that a simulated weekly or daily pasture growth index explained a reasonable (i.e. 30-70%) proportion of spatial and temporal variability in the seasonal and animal liveweight gain in northern Australia. Further studies at Brian Pastures Research Station in southeast Queensland (McKeon et al. 1980; Rickert et al. 1981), demonstrated that a pasture growth index could be combined with stocking rate to explain a reasonable proportion of seasonal variation in liveweight gain across a range of pasture systems and grazing management. Similarly, M. McCaskill and J. McIvor demonstrated that comparable approaches in north eastern Australia.

The above studies were carried out in regions of northern Australia where there is usually sufficient warmth and rainfall (or length of growing season) for C_4 grasslands to maximise dry matter production by diluting available nitrogen to a low concentration (referred to as 'minimum %N'). The nutritional value (low %N and digestibility) in standing dry matter as a result of summer growth is too low for animal growth and therefore animal production (i.e. cattle and sheep) is dependent on the availability of old green pasture material and/or new pasture growth. The simulated pasture growth index represents the daily availability of these important nutritional pasture components and has allowed the development of useful equations for simulation of impacts of long term climate variability on LWG.

It is apparent from the above discussion that this approach may not be applicable to situations where: a) pasture growth is not large enough to dilute available nutrients (e.g. dry/arid regions) and hence the nutritional quality of senesced material remains high; and b) extensive grazing systems where animals have access to a wider range of landscape components (e.g. floodplains, browse) enabling diet selection for high quality material. For example, comparison of regional estimates of animal liveweight gain and average %GIdays indicated relatively high LWG in drier environments for low values of %GIdays.

3.1.2 Using expert opinion to extrapolate GRASP

For many of the targeted and important land types in northern Australia, few real-world data on LWG exist. Here, estimates of the coefficients for GRASP's LWG equation may be derived from estimated liveweight changes, as provided by the combined opinions of local 'experts'. For most land types, experienced extension officers and land managers will usually have a good knowledge of the typical age of turnoff and weight of steers. These values provide one estimate of annual LWG for near-normal conditions: in this case, average utilisation which would be near to safe utilisation at near-average 'green-days'. These persons also have an estimate of the range of turnoff weights during a dry period and a wet period. These estimates respectively reflect higher than safe utilisation rates with lower 'green-days', and lower utilisations than safe with higher 'green-days'. In addition, most practitioners will have reasonable estimates of what the maximum LWG in a particularly good year is - such years usually have high pasture production (therefore utilisation is low), and also good rainfall distribution during the year leading to high values for 'green-days'.

However, estimates of potential production during dry years with low/safe utilisation rates are often difficult to obtain, as the years of poor pasture productivity are usually those in which pasture utilisation rates are very high. Low pasture biomass on offer means that liveweight losses are common, especially during the dry (winter) period, making it difficult to estimate LWG during years with low 'green-days'. For all these cases, it is possible to estimate the utilisation rates and 'green-days' from GRASP runs. These results can then be used to provide estimates for the parameters of the liveweight change regression model. Yet with few degrees of freedom in the regression, small differences in estimates of 'green-days' or utilisation rates can lead to substantial differences in estimates of the coefficients.

Another related method using GRASP is to estimate the differences expected for a particular land type or pasture community, compared with the 'average native pasture' which was used for the liveweight relationship in the model. If a land type was similar to an average pasture but was perhaps lower in fertility, then it may be appropriate to approximately adjust the intercept to a lower value. If the pasture was known to be leafier, with a larger proportion of the above ground forage composed of leaf and/or material with higher feed value, then a less-negative coefficient for utilisation may be used. In all cases, the regression appears to be very sensitive to 'green-days'.

When estimated from modelling activities, 'green-days' can also be sensitive to how well runoff is represented, as well as to the accurate estimation of tree water use. Currently, the GRASP model uses an approach to runoff that was developed in particular land types located in north-eastern Queensland. Improvements to this approach have been suggested by Owens *et al.* (2003), while Silburn *et al.* (2011) has published parameter values for an alternative approach for simulating runoff in grazing lands in Queensland.

Overall, this 'expert-opinion' approach appears worthwhile. As part of the NGS initiative and other workshops, weight changes were estimated for 22 different land-types. The fitted parameters are summarised in Table 3.1.2.1, and show some definite trends, along with good agreement with the original data-based GRASP coefficients. Overall, the equivalent of the GRASP LWG equation fitted to these expert-estimated liveweight changes resulted in an R^2 of only 28%. However, adding in 'estimated safe utilisation rate' for each land-type (as estimated by local experts) as a third predictor for this multiple regression lifted the R^2 to 85%.

Table 3.1.2.1. Regression parameters for models based on liveweight gains estimated via expert opinion.

Fertility group	**High**	**Mod.-high**	**Moderate**	**Low-mod.**	**Low**	**All**	**GRASP**
Number of sites	6	8	2	3	3	22	3
%Utilisation slope	–0.0018	–0.0025	–0.0030	–0.0031	–0.0034	–0.0028	–0.0021
Green-days slope	0.0064	0.0050	0.0053	0.0053	0.0050	0.0054	0.0048

This approach, of using experts' opinions, appears to have merit. Currently, it is the only feasible approach for obtaining realistic simulations in systems where few or no data sets exist.

3.1.3 ENTERPRISE

This spreadsheet model, as outlined in MacLeod *et al.* (2004), uses annual LWG relationships of similar form, namely –

LWG = 0.0239 – 0.002117 * utilisation + 0.005 * GD% (land condition 1)

LWG = 0.23 – 0.005 * utilisation + 0.005 * GD% (land condition 2 and 3)

The same key variables are used here. Note that GD% (green-days) is a similar variable (but defined differently) to GRASP's %GIdays. The effects of supplementation on weight changes are also simulated in ENTERPRISE. In the NGS evaluation of grazing options, the predicted liveweight gains from GRASP have been imported into ENTERPRISE.

3.1.4 GRAZPLAN

The GRAZPLAN™ suite of models and tools (http://www.csiro.au/products/ps36a), including MetAccess™, GrazFeed™, GrassGro™, and AusFarm™, use complex and intensive LWG models based on feeding standards and energy partitioning. Anecdotal evidence exists that these models do not translate easily to rangeland and extensive grazing systems. A number of researchers have attempted to calibrate and tune some of these models to northern systems, with little success. This task was viewed as beyond the resources of this project, and as such was not pursued. However, informal collaboration between Drs Stu McLennan (DEEDI) and Mike Freer (CSIRO) on this challenge is on-going, and a tropical version of GrazFeed, using the outputs of faecal NIRS in terms of DMD and CP of the diet, is being developed and evaluated.

3.2 Reproduction rate and mortality models

The other key biological rates driving herd dynamics are fertility and mortality rates. These fall outside the scope of GRASP. In BREEDCOW and DYNAMA (Holmes 1995), these rates need to be input by the model user, i.e., they are not simulated within these packages. ENTERPRISE is a suitable economics / herd dynamics model which can be run in conjunction with GRASP, and simulates reproduction rates and mortality. ENTERPRISE takes predicted LWG from GRASP (or other models), and uses the following empirical equations –

Mortality (breeders) % = 6 + 94 * exp(–0.027 * (ALWG + 50))

Mortality (dry stock) % = 2 + 88 * exp(–0.034 * (ALWG + 50))

Branding % : 0 < 15.6 + 0.488* ALWG < 80

where ALWG is annual liveweight gain (kg/head). Hence branding % changes linearly from 0% at ALWG of –32, to 80% at ALWG of +132.

Here, weight gain is the only driving variable, and (importantly) actual weight or body condition score are not factored in. The same relationships are assumed for all breeds, ages and parity status.

These relationships, along with those in GRAZPLAN, were tested against seven fertility and mortality data sets across northern Australia (three sites in NT, and two each in northern and central Qld). These cohort-level data covered over 24,000 cow-years. Consequently, improved relationships were developed and validated, as outlined in 'Prediction of mortality and conception rates of beef breeding cattle in northern Australia', which is shortly to appear in *Animal Production Science* (see Appendix 4). The final relationships here are proposed as being appropriate for simulation models in northern Australia.

4 Review of alternative and complementary approaches to the prediction of animal production

In situations and systems where the empirical models do not work well, there are two possible avenues to investigate – adapt the empirical model, or move to a mechanistic model.

4.1 Adapt the empirical model

The simplest way of adapting the empirical model to alternate land types and systems is to re-estimate the parameters for the LWG model equations. This approach reflects the different importance and weighting of the key terms in different systems. This process can also lead to the identification and inclusion of addition key predicting terms and factors, for the different environments or pasture communities. However, it relies on the existence (and extraction) of appropriate data sets exist for each targeted system. Where adequate data sets do not exist, the existing models can be adapted using 'expert opinion' estimates, as outlined in section 3.1.2.

A more comprehensive, but also more useful, adaptation is the development of these base concepts into a daily model. Appendix 2 outlines the development of this model, and reports on the degree of fit to both the original data sets and for an independent validation data set (Wambiana). Whilst this daily LWG model is more complex, it offers users the scope to test within-year options, and as such should prove very useful. The underlying driving mechanisms have already been developed. The parameters of this daily LWG model still need to be tested against alternate land types, and tuned if necessary, and this research is ongoing.

4.2 Move to a mechanistic model

This approach appears to be a far more complex and difficult task. However, if completed successfully, it would give good confidence in the simulations of almost any pasture or even tree-based (e.g. Leucaena) grazing system in northern Australia. The logical method would be to use the feeding standards approach – either within the GRAZPLAN framework, or using some alternative system such as the Cornell Net Carbohydrate and Protein System (CNCPS; Fox *et al.* 2004). Past and current research has demonstrated that feeding standards give good predictions of cattle weight gains *when actual intake is known* (McLennan 2005; Dove *et al.* 2010). The major problems with this approach, however, appear to be in the estimation of animal intake in rangeland conditions, and the estimation of the quality of this diet.

Application of the feeding standards or their associated software systems under field conditions is a two-phase process involving both the estimation of the intake and quality of the selected diet (and thus nutrient intake), and the application of the equations from the feeding standards to estimate some measure of productive performance (such as liveweight gain from this predicted nutrient intake). In the field situation, intake estimation is usually based on separate equations relating it to aspects of diet quality, such as dry matter digestibility (DMD) and crude protein (CP) content. In northern Australia these can be derived using faecal NIRS, and/or animal characteristics. However, there are potential errors in both phases, and thus the prediction of grazing animal performance may be associated with large errors multiplied across sources.

Using experimental data from confined (hand-fed) animals fed a wide range of diets, McLennan (2005) showed that both the SCA (1990) and the CNCPS (Fox *et al.* 2004) models provided reasonably accurate and similar predictions of growth rate of cattle across the wide range of supplement intakes used. This similarity and accuracy in predictions across systems reinforced that the underlying principles for energy use and partitioning by the animal were appropriate and robust, but that there were differences between systems in the underlying equations used to calculate requirements and supply. This study further provided support for their general application in tropical feeding systems.

The major issue though lies in predicting the intake of herbage by grazing animals. Many of the nutrient requirement systems available across countries do not attempt to estimate intake and instead are generally designed for use with confined animals. GrazFeed, based on the SCA (1990) and its successor CSIRO (2007), has incorporated a function for estimating the potential intake of grazing animals - being that achievable for an all-grass diet when neither quality nor quantity are limiting, and where the relative intake is expressed as a proportion of the potential intake which an animal can acquire from the herbage supply. In essence, the relative intake is the extent to which the chemical composition of the herbage restricts its intake by the animal, and also the physical features of the sward which limit the animal's ability to harvest that herbage in a given time. In determining herbage intake the user of GrazFeed is required to enter data on attributes such as herbage mass and height, digestibility, legume content and N content which are incorporated in the algorithms for determining relative intake. In general the GrazFeed software has been successfully applied in southern Australia in temperate pasture systems, but not in tropical pasture or rangeland situations where the relationships established for temperate pastures do not appear to apply (Freer *et al.* 2009).

One approach being investigated to overcome this problem for northern grazing systems is to use a dry matter digestibility (DMD) value estimated from faecal NIRS analysis as a direct input into a 'tropical' version of GrazFeed (M Freer, *pers. comm*.), rather than allow the model to estimate digestibility from a description of the pasture. This version of the GrazFeed package is currently under development and is being evaluated in conjunction with S. McLennan using data from previous (NBP.331; McLennan 2005) and current (B.NBP.0391; S McLennan, unpub. data) projects. Several possible modifications are being investigated, including:

(i) changing the relationships between DMD and intake for C_4 vs. C_3 grasses;
(ii) increasing estimates of protein degradability for tropical grasses;
(iii) increasing the estimate of N-recycling for tropical cattle on low-protein diets;
(iv) re-evaluation of the N-requirements for optimal microbial protein production from tropical diets;
(v) re-evaluation of the maintenance requirements for *Bos indicus* cattle; and
(vi) changing the energy value of gain for *B. indicus* cattle. It is still strongly believed that the best prospects of developing a mechanistic model for predicting performance of grazing animals in northern Australia lie in modifying existing packages like GrazFeed rather than developing new ones.

Where the main purpose of intake estimation is for fodder budgeting and/or to set appropriate stocking rates, it should be possible to achieve a sufficiently accurate prediction of intake from calculations based on the observed growth rate of the animals. If the equations describing energy utilisation are sound for predicting animal performance from known nutrient intake, as demonstrated above, it should be possible to use the feeding standards in reverse and predict intake from liveweight change and some estimate of the energy density of the diet. In practice, the latter can be estimated from DMD derived from faecal NIRS and the liveweight change used could be one based on regular weighings of the animals or based on previous experience in the same area and for similar climatic conditions (historical values). S McLennan and D Poppi have developed such a program, called QuikIntake, based on the equations from SCA (1990). It is currently under evaluation (Project B.NBP.0391).

Appendix 3 presents two analyses where: a) intake estimates from QuikIntake were compared with three other intake estimates, to calculate overall pasture utilisation estimates for the Wambiana grazing trial; and b) intake estimates from QuikIntake were used to calculate estimates of pasture utilisation (paddock/treatment x drafts) for the Wambiana grazing trial.

4.3 Recent developments in research technologies to measure pasture, diet selection and cattle production

Advances during the last two decades in a number of technologies applicable to cattle grazing systems provide, or have the potential to provide, opportunities to obtain input and output data to develop improved models of cattle production from tropical pastures, and to do so at lower research costs than technologies used in the past. The following section is a précis of recent reviews (Dixon and Coates 2009; Boval and Dixon 2012) which also provide the supporting information and bibliography.

4.3.1 Developments in measurement of the attributes of pastures

Laboratory analysis of pasture samples has been facilitated by developments in near infrared spectroscopy (NIRS) to analyse a wide array of chemical, physical and morphological attributes of forages. This includes capacity to measure the proportions of major plant groupings, and to some extent specific plant species. Since most tropical grasses are C_4 and most dicot plants are C_3, the $^{12}C/^{13}C$ ratio estimates these proportions; NIRS can be used to measure this latter ratio and thus these classes of forage in mixed plant material. Differences in NIR spectra between herbaceous dicots and browses, and between green and dead forage material, suggests that it should be possible to develop NIR to measure these fractions. However, research is lacking. Also NIRS has been developed to measure the morphological attributes of forages such as the leaf / stem proportions, including in tropical grasses.

Improved spectrometers measuring in the visible and NIR ranges provide opportunities for improved measurement systems. Forage composition, attributes, biomass and plant species and cultivars can be measured using field-portable instruments located immediately above the canopy or in planes or satellites, and this has been applied to pastures and rangelands. In temperate Australia, 50-70% of the variance in growth rate of annual pastures could be predicted from satellite imagery and accumulated pasture growth usefully estimated from sequential measurements. In extensive rangelands, spectral information measured from satellites appears most useful to estimate plant community distribution, pasture cover and 'greenness' (Karfs *et al*. 2009). Ground-based instruments have been used with moderate success to measure composition of swards of tropical grasses, but application to botanically complex and variable pastures appears difficult.

4.3.2 Evaluation of the utilisation of pastures by animals

The liveweight change of animals is a useful criterion of nutrient supply, and with knowledge of the class of animal can be used to estimate the intake of dry matter and metabolisable energy from pasture. It has often been used as a measure of the magnitude and efficiency of production. However, for measurements of liveweight change to be reliable they must be measured in the longer term (e.g. over intervals of at least a month), and with standardisation of the weighing procedures to reduce errors associated with variations in digesta load. Substantial error may occur even when the measurement procedure is carefully standardized due to changes in digesta load of ruminants associated with diet and thermal environment (McLean *et al.* 1983; Schlecht *et al.* 2003). The concentration and intake of metabolisable energy can be calculated from DM intake and diet DM digestibility with only minor error.

4.3.3 Plant wax constituents as diet markers

There has been substantial development of plant wax components as markers to measure forage intake, diet composition and digestibility (Dove 2010). These plant wax constituents vary greatly among plant species or plant morphological components, and are largely excreted in faeces, but the long-chain alcohols and fatty acids have comparable variation and characteristics, should allow discrimination of a greater number of species in the diet including of plant species or components containing low concentrations of alkanes. Numerous studies have examined constraints and potential errors associated with use of these plant waxes, particularly n-alkanes, as markers (e.g. sampling of herbage, diurnal variation, faecal recovery of individual constituents, animal species) and there is consensus that in temperate pasture systems reliable results can be obtained.

Knowledge of the use and constraints of the plant waxes as markers in tropical pasture systems is limited. The concentrations of a variety of n-alkanes are sufficient, and vary sufficiently, in many tropical grasses for alkane marker procedures to be applied. Validation studies with cattle fed tropical grass forages reported that voluntary intake and diet digestibility could be satisfactorily measured with alkane markers. However, in some tropical grasses the concentrations of important alkanes may decrease markedly with increasing age of leaves (Laredo *et al.* 1991); this is of concern since the method depends on estimation of alkane concentration in the leaf ingested. A further difficulty is that some tropical forages and edible browses contain very low concentrations of alkanes (Laredo *et al.* 1991; Ali *et al.* 2005) so that the presence of these plant species could not be measured in the diet from faecal alkane concentrations. Even if these constraints associated with the markers can be overcome, a further consideration is that tropical native pasture grassland systems usually contain too large and diverse a range of edible plant species for all species to be measured satisfactorily.

4.3.4 F.NIRS for measurement of diet constituents

Near infrared spectroscopy of faeces (F.NIRS) can be used to estimate many diet constituents and digestibility (Dixon and Coates 2009). Diet constituents include the concentrations of N, fibre fractions, tannins, lignin and the proportions of grasses to non-grass (forbs, legumes and browses). Proportions of *Stylosanthes* spp. legume and *Acacia aneura* browse in the diet can be measured, but that of the numerous other pasture species which occur in northern Australia is difficult and may only be possible in some circumstances. Some research indicates that leaf/stem proportions of tropical grasses can be measured. The precision in measurement of diet digestibility is generally high with a standard error of generally <2.5 percentage units.

4.3.5 F.NIRS for measurement of voluntary intake and LW change of the animal

F.NIRS calibrations to measure voluntary DM intake (VDMI) have been developed for cattle grazing tropical pastures in northern Australia. Calibration statistics were R^2 0.85, SECV 1.9 g/kg LW (equivalent to about 8 g/kg $W^{0.75}$). These prediction errors for VDMI of forages are generally comparable with, or smaller than, the errors associated with prediction of VDMI from the NIR spectra of forages, or from conventional laboratory analyses of forage such as for the *in vitro* digestibility, neutral detergent fibre or acid detergent fibre. Thus, F.NIRS calibrations can be developed to predict VDMI of forage diets by ruminants in at least some circumstances. F.NIRS predictions of VDMI are expected to estimate the potential intake, as limited by forage characteristics, rather than necessarily the actual intake which will be influenced by numerous aspects of the physiological state of the animal and availability of the forage.

F.NIRS calibrations have also been developed for animal LW change, and when the data were restricted to young healthy growing tropically-adapted cattle the calibration had a similar R^2 to that for the digestible DM intake (DDMI) (i.e. metabolisable energy intake) and the SECV was 0.16 kg/day. Since there is a broad curvilinear relationship between metabolisable energy intake and LW change of an animal, such calibrations for LW change are comparable with calibrations for VDMI. Because both VDMI and LW change are influenced by many animal factors (e.g. maturity, lactation, compensatory growth, parasites and disease), thermal environment and forage availability, it will be difficult to develop calibrations for either VDMI or LW change applicable to a wide range of animal and pasture circumstances. For example, although the current northern Australian LW change calibrations predicted satisfactorily where cattle grazed pastures comparable with those in the calibration data set, large errors sometimes occurred for cattle grazing different pasture systems which were not represented in the calibration data set, or for animals in different physiological states such as lactation or compensatory growth. Nevertheless, as has often been observed during development of NIR calibrations, inclusion of some data representing a new pasture system (e.g. Leucaena-grass) has often radically improved the calibrations.

In conclusion, while a number of studies have shown that F.NIRS can be used to predict voluntary intake and LW change by cattle in some circumstances, it is likely to be difficult to apply these calibrations generally. Certainly caution is required to apply such calibrations except in the pasture systems and for the animal class in which they were developed. In addition, possible constraints on voluntary intake due to low pasture availability and other animal and environmental influences on VDMI need to be considered.

4.3.6 Concurrent use of various new technologies with old technologies and some other promising new approaches

Faecal NIRS has been combined with field measurements of microbial protein synthesis, animal liveweight and reproduction to provide comprehensive information on the nutrient intake and responses of the grazing cattle (Dixon *et al.* 2011). The validity of the use of excretion of purine derivatives in urine as a measurement of microbial protein synthesis is well established. However, development of more satisfactory urinary markers would be very valuable to reliably measure microbial protein synthesis in grazing cattle. Limited information suggests that laser-induced fluorescence (LIF) spectroscopy of faeces is likely to be a valuable technique to identify the plant species and plant species groups in the diet of grazing ruminants from measurements of faeces. Plant DNA in faeces has been examined to identify the plant species present in the diet of herbivores. However, much more research is needed to evaluate and develop both of these techniques before they can be applied routinely to grazing livestock.

5 Testing and refinement of liveweight relationships against data sets

Three approaches were used, namely 1). Broad-scale comparisons across locations using approximate GRASP parameters in AussieGRASS, using utilisation model 1; 2). More detailed comparisons for the targeted grazing trials using GRASP's annual liveweight gain model 2; and 3). A test of GRASP's utilisation model 1 (as implemented in APSIM) on short-term grazing of improved pastures; as follows.

5.1 Broad-scale comparisons across locations, using AussieGRASS

(study conducted by John Carter)

AussieGRASS is a variant of GRASP used for broad scale modelling of pasture production and other aspects of the environment. Typically we expect that AussieGRASS is accurate at a quarter to half a local government area (LGA; roughly equivalent to a shire). Given the model scale, AussieGRASS is useful to test the generalities of simple LWG models when used to simulate a large number of trials (30+), and hopefully reproduce the statistics of the LWG data ***without specific site calibration***. It is likely to be a reasonable assessment of how well LWG models might perform outside the individually calibrated grazing trial locations. This study focuses on the seasonal distribution of LWG. The role of year-to-year variability is expanded in section 5.2 which uses the annual LWG Model 2. The limitations of the relationship between intake and liveweight gain, and variation in restrictions on intake, were not investigated in this scoping study.

This study was conducted in two parts: (A) evaluation and modification of the existing AussieGRASS parameterisation, and (B) assessment of alternative daily live weight gain functions using variables output from the AussieGRASS model. AussieGRASS has the GRASP daily LWG model implemented (estimated as a function of achieved intake) - where seasonal potential LWG regulates intake, and with further intake constraints based on feed availability and pasture utilization.

(A) Evaluation and modification of existing AussieGRASS parameterisation

Methods - AussieGRASS in this study was:
(a) Run with best estimates of stock numbers as derived from ABS data (redistributed), rather than using the actual stocking rates in these trials.
(b) Run at the pixel defined by the estimated latitude and longitude for the trial site. This pixel will often NOT represent the actual paddocks used for the experiments, especially in regard to tree density and soil fertility.
(c) For a number of sites the documentation indicated cleared paddocks whereas the AussieGRASS tree basal layer indicated high tree densities. The model tree basal area input layer was modified at a number of pixels to reflect cleared paddocks.
(d) Run with 200 kg ‘weaner equivalents’ as the standard animal type. In some cases multiple animal types will be grazing on the same pixels (e.g. sheep in the Mitchell grass, kangaroos in the mulga zone).
(e) Parameter tuning of seasonal LWG estimates took place for some pasture communities to better approximate the measured seasonal average LWGs.
(f) Modified to change length of the seasons on which potential LWG is assessed. Prior to this study the seasons were summer (Dec-Feb), autumn (Mar-May), winter (Jun-Aug) and spring (Sep-Nov); for this study the seasons were taken as summer (Dec-Mar), autumn (Apr-May), winter (Jun-Jul) and spring (Aug-Nov). This change improved the adjusted R^2 for observed vs. predicted monthly LWGs from 75.6% to 84.4%.

Two data sets were prepared for use in AussieGRASS which requires data formatted into daily format with files named by date and including latitude, longitude, date and observations for each location for each record. These two data sets were:

- The Hasker Liveweight gain data set (formatted by Jill Heywood) with 32 data sets (1960–1980; see Figure 5.1.1).
- Sinclair & Loxton (1995), 'Task 3' (Producer Properties) with 19 data sets (1990-1994; see Figure 5.1.1).

Modifications to these data sets included:
(a) Use of control animals only.
(b) Updated co-ordinates to reflect property homestead / centroid rather than nearby town where possible.
(c) Conversion to daily data (daily LWG) for utility.
(d) Some sites have more than one cohort at the one time - so the data were split into “experiments” within the one location.

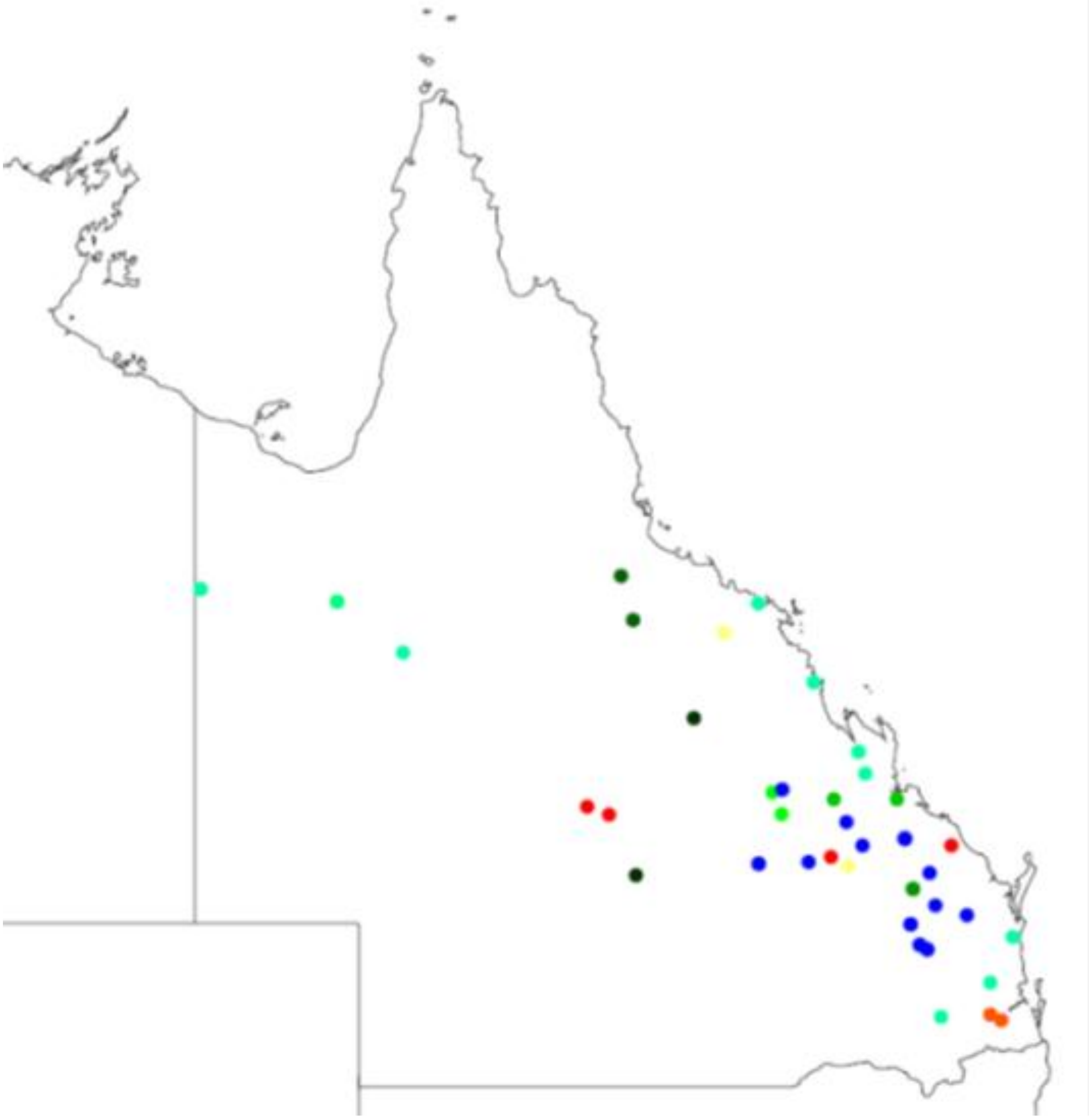


Figure 5.1.1. Locations of Hasker data set (various colours) and Task 3 data set (dark blue).

For every pixel with a ‘measured/inferred daily LWG’, AussieGRASS produced a corresponding modelled estimate of LWG as well as other relevant variables e.g. mass of green leaf and growth index. Figure 5.1.2 shows the distributions for the observed and simulated data, indicating reasonable agreement except that the AussieGRASS predictions do not cover the ‘more extreme’ values (both positive and negative). Figure 5.1.3 graphs the monthly averages for the measured and simulated data, showing good overall agreement (R^2 = 91.3%). It should be noted here that by using monthly means the year-to-year variability is suppressed. Figure 5.1.3 also suggests that further improvement might be achieved by increasing the number of seasons defined by parameters (i.e., 6 seasons of 2 months).

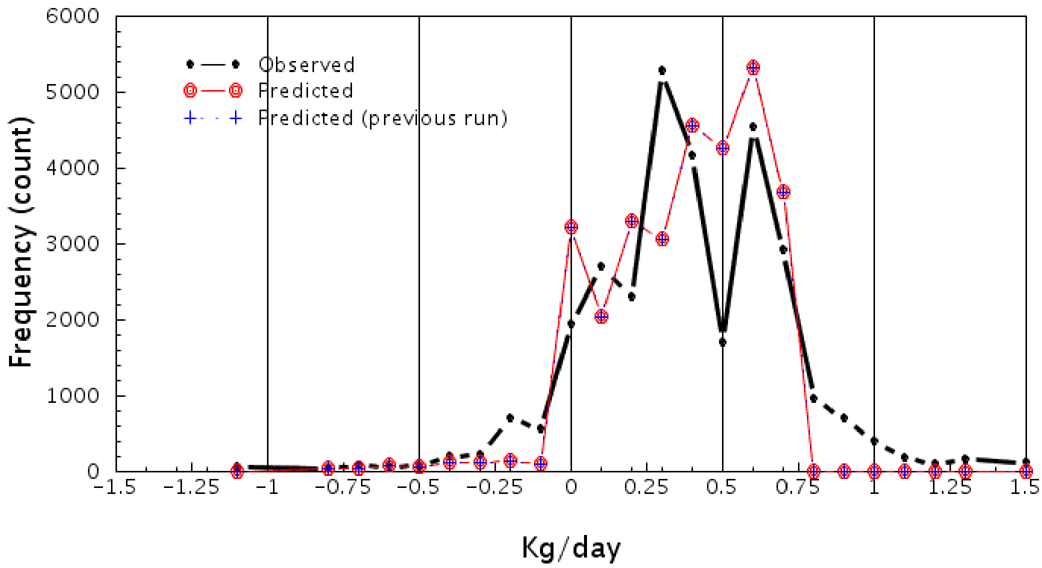


Figure 5.1.2. Frequency distribution of daily LWG - observed and simulated.

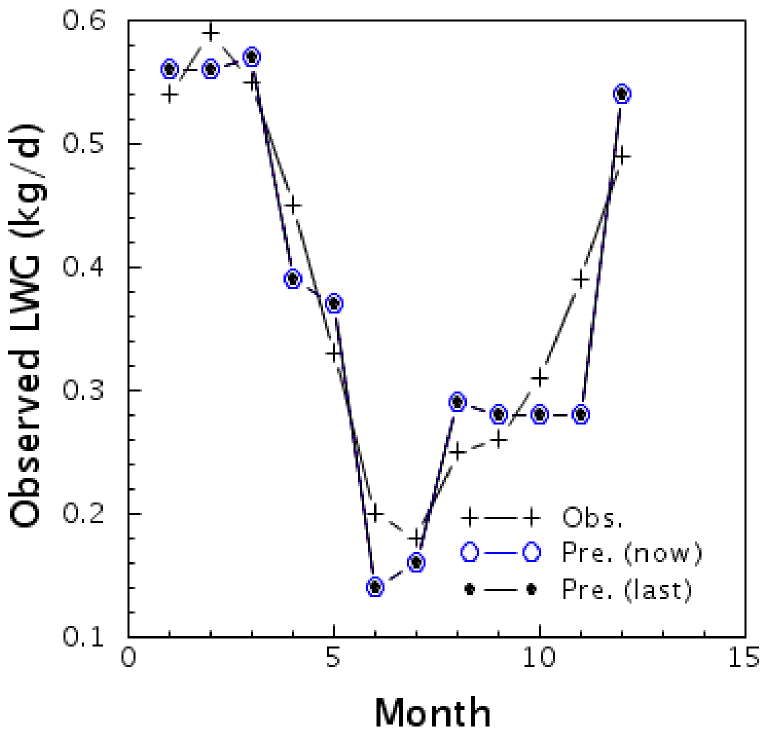


Figure 5.1.3. Observed and simulated mean monthly LWG for combined data sets.

A comparison of the observed and simulated weight gains for each cohort is given in Figure 5.1.4, which shows a considerable degree of variation due to site, season, and modelling deficiencies. An analysis of outliers, and extraction of the sites where GRASP is not expected to work well, is yet to be done. For example, point 52 indicates these animals gained far more weight that was simulated. However, the pasture here was 'sown pastures', namely Green Panic, Rhodes & Purple Pigeon grass, which are nutritionally superior to the simulated 'native pastures', so this result is explainable. One encouraging aspect here is the overall lack of apparent bias – the points approximately cluster about the 1:1 line.

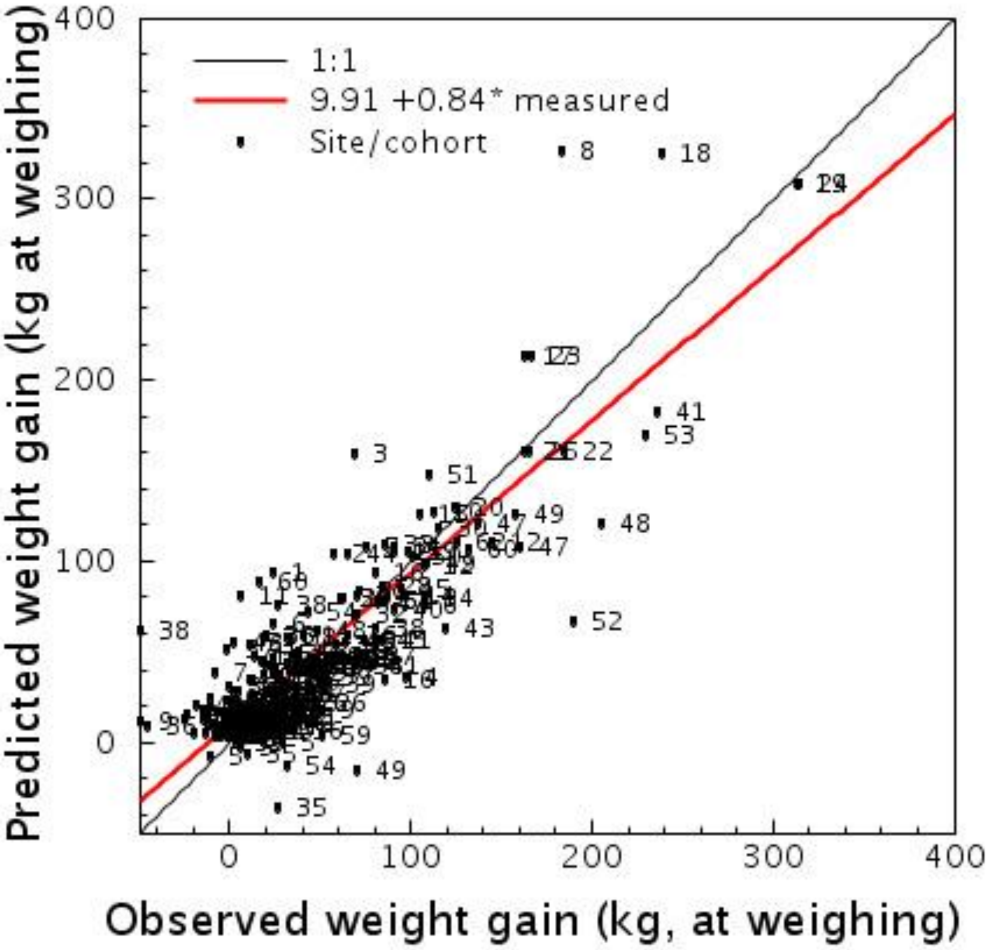


Figure 5.1.4. Observed and predicted LWG for each weighing period for each cohort at each site.

(B) Assessing the potential for a new daily LWG model using model outputs from AussieGRASS

Daily data on pasture variables for each site and location were produced by AussieGRASS, and alternative daily models were parameterised and evaluated using a genetic algorithm. Here daily live weight gains were accumulated for each weighing period and compared to the measured data, across all weighings and trials in the Hasker data set (as the task 3 data set was considered to have too long an interval between weighings for use in model development). The objective function was to minimise the absolute error (observed – predicted) and minimise the bias of mean LWG across all observations. Once an optimum solution had been reached the fit was evaluated in terms of correlation, slope and intercept, error score, and correlation at monthly and annual time scales.

The following candidate variables were tested: growth index (= temperature index * soil water index * radiation index), proportion of days with a growth index > 0.05, green in diet, %N in growth, %N in sward, total standing dry matter, pasture growth, green cover, rainfall and temperature. While % utilisation is used in seasonal to annual LWG models, it is less appropriate for short time frames e.g. around the season start when the utilisation variables (growth and eaten) are reset, and high utilisation can occur at the same time as the highest quality growth.

The best candidate variable was proportion of days with a growth index > 0.05. This variable explains 86.2% of the variation amongst average monthly LWG across the data sets (Figure 5.1.5), suggesting it is a good candidate predictor variable for LWG at the sub-annual time frame.

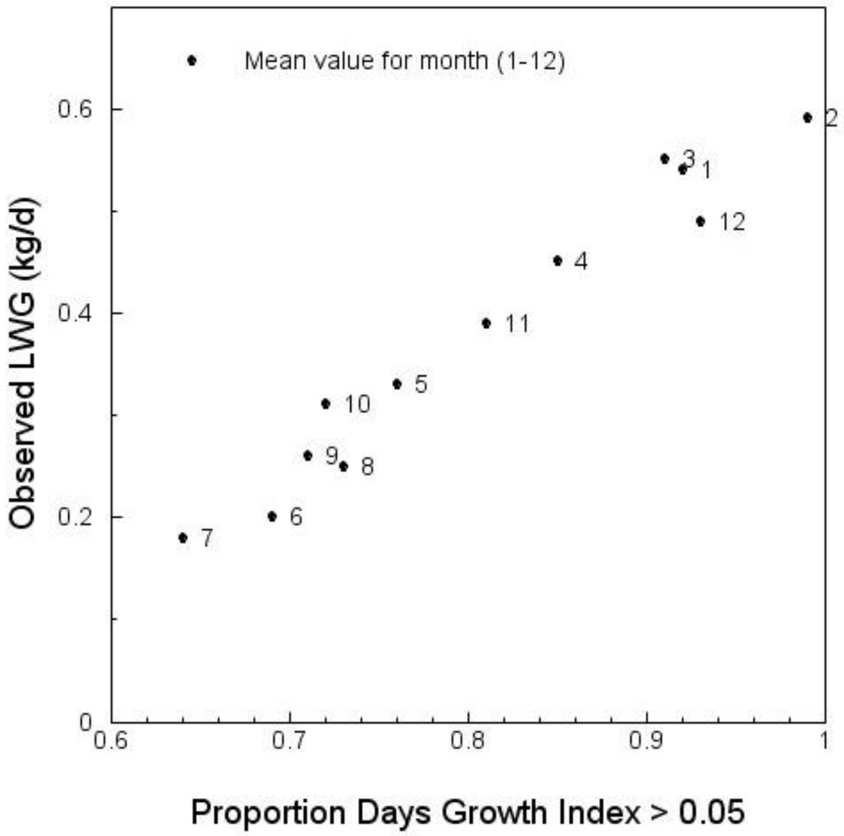


Figure 5.1.5. Observed mean monthly LWG and proportion of the month's days that the AussieGRASS growth index is > 0.05, for months 1 to 12.

Analysis of each experiment shows variation due to site, season and modelling deficiencies. Maximising the correlation and reducing bias in this dataset was the objective function against which new variants of a daily LWG model were compared. The best candidate model (of the 29 models tested) indicated that a linear function of growth index added to an exponential function of sward N (Figure 5.1.6) improved the calibrated daily seasonal potential live weight gain model. Given that sward N can be simulated with some skill in AussieGRASS, this feature could be added to the point version of GRASP. The new model is likely to have similar features to the simple parameterisation of declining quality with time used in the CSIRO Enterprise model.

Performance of the new daily model was generally better than the original AussieGRASS version, lifting R^2 for annual weight changes from 35.3% to 53.3%, and reducing the mean absolute error (kg) from 26.5 to 24.4.

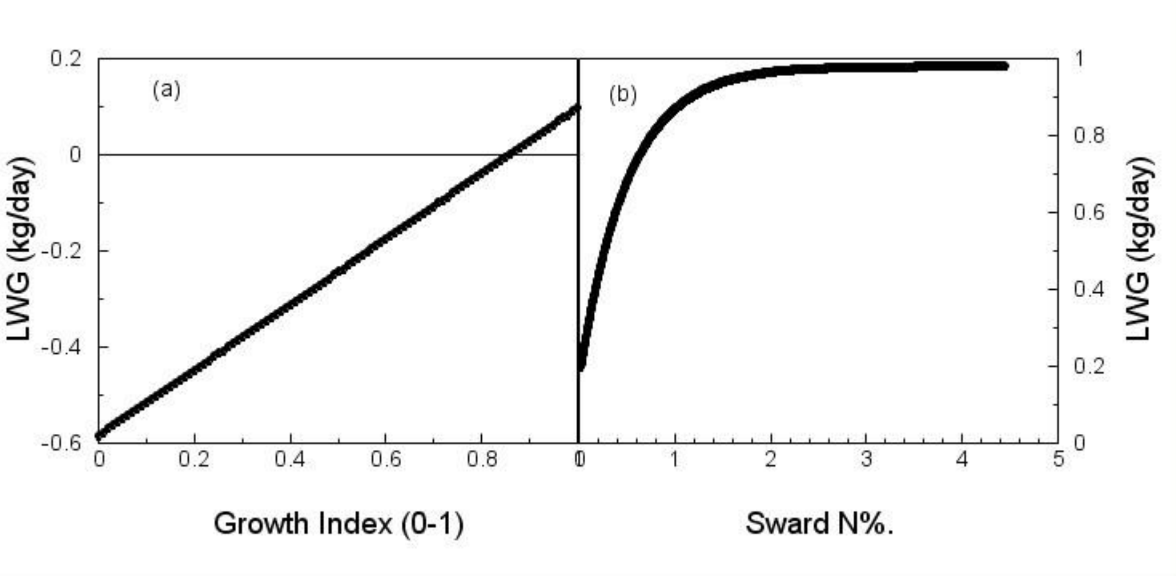


Figure 5.1.6. Overall daily LWG is the sum of (a) the linear function of growth index, and (b) the nonlinear function of sward N. LWG(kg/h/day) = -1.499 + 0.761*GIX + 1.719 - 0.927* exp(-3.841* Sward_N%).

Overall, this scoping study using AussieGRASS has revealed:

(1) The seasons (to which parameters describing potential live weight gain are related) were not well aligned to the observed data. Changing the months assigned to each season improves LWG estimates.

(2) The daily model based on growth index days benefited from an additional variable describing sward quality.

(3) Changing the daily model in GRASP to predict daily intake and related LWG is potentially worthwhile. In the GRASP model daily intake and live weight gain is controlled by 9 parameters per pasture community:

4 parameters describe potential seasonal LWG,
1 parameter describes TSDM threshold where intake restriction occurs,
2 parameters describe slope & intercept of the utilization effect on intake,
2 parameters describe slope and intercept relating intake to LWG.

In reality many these parameters can be held constant across pasture communities. It appears that LWG predictions based on a daily model could be improved beyond the base model by moving to a simpler (but potentially less intuitive) parameterisation for daily LWG. The best model to emerge from testing was one where daily LWG was a linear function of growth index (negative below a growth index of about 0.85) summed to an exponential function N in pasture sward with a maximum value of 1 kg/hd/day (Figure 5.1.6).

(4) Various data quality issues with the Hasker data set need to be investigated further, as much of the error & bias appears to originate from a few locations.

Future developments

(1) On the basis of LWG from 229 cohorts of animals from 32 trials, the seasons for the potential live weight gain parameters should be modified from DJF MAM JJA SON to DJFM AM JJ ASON. Consideration should also be given to using six two-month periods for setting potential LWG.

(2) The values for parameters of seasonal LWG should be adjusted, as potential live weight gain in some seasons may be low relative to measurements.

(3) Implementing a simple accounting for Nitrogen in the sward (TSDM), and not just current growth as in the current versions, appears worthwhile. A minimal approach involves creating one new state variable and 3 parameters to describe the rate of loss of N from dead material. The parameters describe a loss rate of N for heavy dew/rain days, a loss rate for dry days and dew point temperature for prescribing heavy dew. Enrichment in N intake due to selection of better quality material by livestock may also need to be estimated.

(4) Test possible new daily model formulations & parameterisations against major grazing trials in point GRASP, and against State and national estimates of LWG (as derived from sales, exports, imports, deaths, and slaughter numbers). Note that in the current study, the most recent LWG data used is 18 years old, and more recent data sets should be included in the analysis.

(5) Frost and rain effects on sward N content need to be parameterised (perhaps from targeted measurements), and added to the GRASP model. Using growth index based LWG models could conceptually fail, as during the days after frost there could be a moderate growth index for a ‘dead’ sward.

(6) Data sets where sward nitrogen and digestibility, and quality and quantity of intake at the same time need to be established, as this is the critical link between pasture modelling and animal production modelling.

Conclusions

The main findings from this broad-scale AussieGRASS study across locations are:

a) The AussieGRASS formulation of GRASP allowed rapid development of new relationships (e.g. %N in standing dry matter) and parameters from spatially diverse data sets.

b) The four seasonal potential LWG parameters could be replaced by 12 monthly values allowing greater flexibility in use of Utilisation Model 1 in spelling / rotational and forage system simulation studies.

c) Monthly potential LWG was, on average closely related to the pasture growth index simulated by GRASP. This result provided independent support to the approaches used in the existing ALWG Model 2 and new daily LWG Model 3 (as described in Appendix 2).

5.2 Comparisons for targeted grazing trials, with GRASP data parameters specific to each site

(studies conducted by Grant Stone, Robyn Cowley, Joe Scanlan, John Carter, Grant Fraser and Greg McKeon)

The preparation of 'mrx' data files for GRASP modelling of grazing trials is a time-consuming but worthwhile process. Experience is needed for both timely and accurate preparation of data files, and for assessing sources of variability. The resulting master data sets are of high value, both for current and future use.

Generally, with the necessary data parameters specified for each site, the 'grass production' part of the simulation works well. For example, for Pigeon Hole (NT), Figure 5.2.1 shows the simulated and observed standing dry matter values over time. These graphs are for the three utilisation rate treatments, and have R^2 values (percentage of the variation explained) of 66%, 92% and 88% respectively.

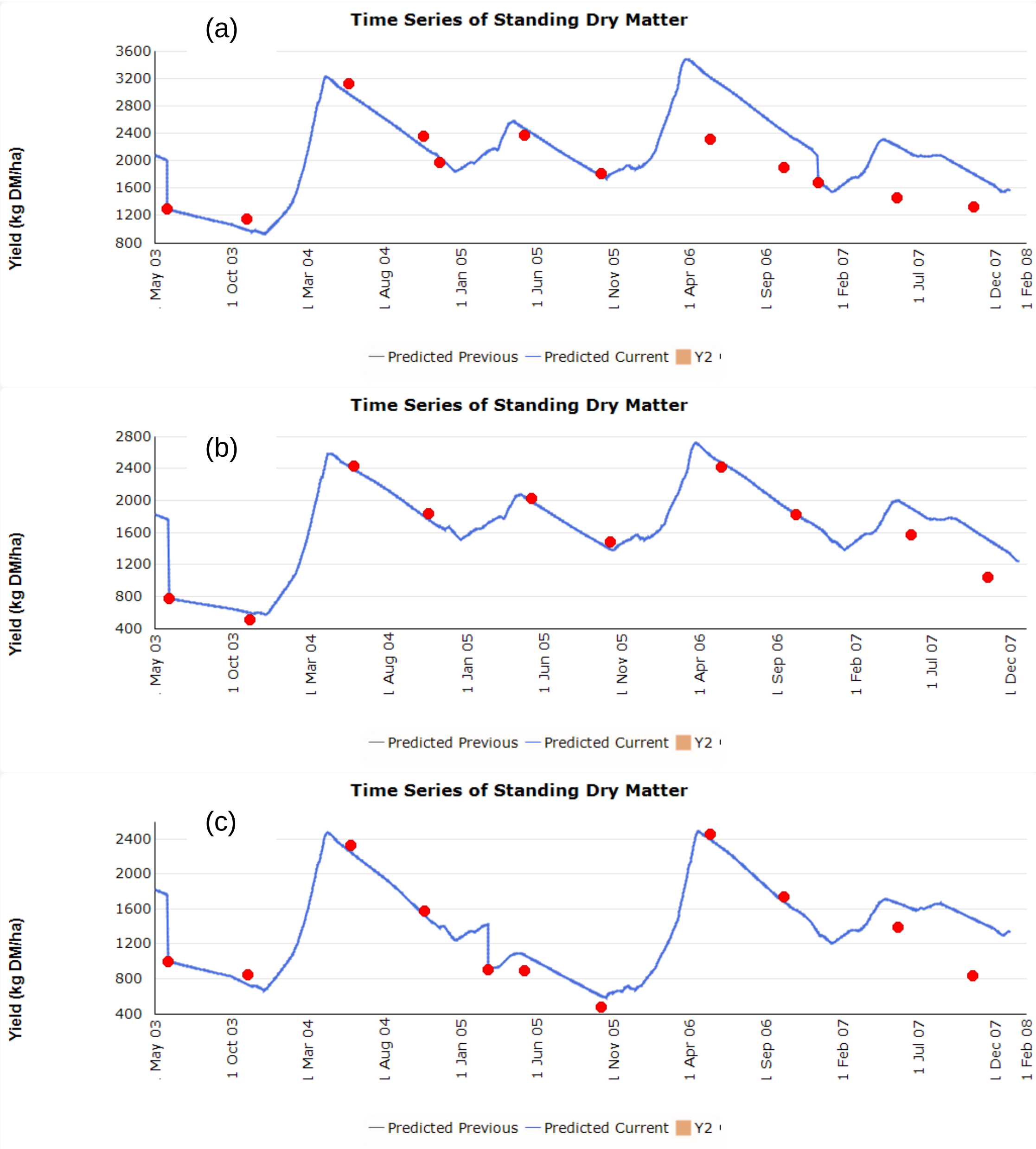


Figure 5.2.1. Simulated (blue lines) and observed (red points) standing dry matter values, for the (a) 20%, (b) 25% and (c) 40% utilisation rates.

To address project objectives 3 and 4, the far more important test is how well the predicted liveweight gains agree with the observed values. The structure of the ALWG Model 2 and the black speargrass parameters (developed in 1996) were tested on available LWG data sets covering a range of locations across northern Australian pasture species (including native sown legumes) and grazing management (e.g. varying stocking rates). The testing of the LWG model component of GRASP requires time-consuming collation of climate, pasture, animal and management data. Given the scoping nature of the project, we concentrated on testing the LWG model on as many data sets as possible, with only simplistic parameterisation of the pasture component. However, we note that where there were several iterations of careful parameterisation of the pasture component of the grazing trials (R. Cowley, Mt Sanford; J. Scanlan, Wambiana), there was an increase in the percentage of variation in liveweight gain explained.

Model parameters for ALWG Model 2 were developed in 1996 from three grazing trials in the black speargrass zone of Queensland including a range of treatments and locations. In the following analyses we will refer to the Black speargrass parameters as “BSG parameters”. These parameters were used in subsequent scenario testing in the black speargrass zone (e.g. Hall et al. 1998b, Ash et al. 2000, Stafford Smith at al. 2000, McIntosh et al. 2001). However, for wider geographical application to include a drier environment, it was recognised that black speargrass parameters particularly needed to be changed to reflect regional estimates of LWG (e.g. the LUCNA project; Stafford Smith at al. 1996).

We report our findings (see Table 5.2.1) under the following headings:

1. Data sets from the black speargrass in Queensland (Galloway Plains, Swans Lagoon and Wambiana);
2. Data sets from C_4 perennial grasslands from the VRD, N.T. (Mt Sanford and Pigeon Hole);
3. Data sets from sown perennial pastures in central Queensland including buffel, green panic and Rhodes grass;
4. Data sets from buffel grass pastures in central Australia;
5. Producer survey data from across northern Australia (e.g. Bortolussi et al. 2005); and
6. Examples of model parameters for a range of locations as used in the NGS project.

At the start of this project, an independent data set from Mt Sanford in the N.T. was used to test the model with black speargrass parameters. This location was well outside the Queensland black speargrass zone, thus testing the concept of %GIdays in a dry monsoonal environment. The trial also included 5 levels of pasture utilisation, thus testing the utilisation component of the model.

As documented in the interim report to MLA, and in Mayer et al. (2011), the annual liveweight gains simulated by the black speargrass parameters were in reasonable agreement in observed liveweight gains – the fitted equation was close to the desired 1:1 line, with R^2 = 72%. As a result, we have used the black speargrass parameters as the default prediction for all trials and LWG data tested below. The results are summarised in Table 5.2.1, followed by details of the pasture parameterisations and results for the individual sites. The reported slope and intercept for the direct comparison indicated the degree of difference from the 1:1 line. The coefficients for the intercept, %utilisation and GIdays allow comparison with the original black speargrass parameters, and provide parameters that could be used for different pasture systems.

Table 5.2.1 Overview of the comparative studies *(italics = not significant; P > 0.05).*

Location	n	Direct comparison (obs. *vs.* predicted)			Coefficients for re-fitted models (sep. for each site)			
		R^2	Int.	Slope	Int.	%util.	GIdays	R^2
BSG Parameters					0.06	-0.0021	0.0048	71
Independ. BSG Trials								
Wambiana (2005 & 2007 excluded)	108	64	0.05	0.96	0.11	-0.0020	0.0036	65
Galloway Pl. (west) -								
Independent validation	22	66	-0.27	1.72	-0.19	*-0.0033*	0.0085	66
All native pasture SRs	42	37	-0.13	1.38	-0.04	-0.0029	0.0066	37
Supplement	9	45	0.23	0.53	0.34	-0.0012	0.0016	53
Burnt	22	79	-0.30	1.86	-0.32	-0.0030	0.0103	80
Galloway Pl. (east) -								
All native pasture SRs	43	25	-0.06	1.06	0.08	-0.0030	0.0044	26
Supplement	9	53	0.26	0.44	0.33	*-0.0013*	*0.0016*	57
Burnt	15	71	-0.38	1.88	-0.36	-0.0028	0.0100	72
Swans Lagoon	32	17	0.17	0.35	-0.01	*0.0000*	0.0040	34
Northern Territory								
Mt Sanford	26	72	0.01	1.00	0.05	-0.0019	0.0050	72
Pigeon Hole	15	*4*	0.28	0.31	0.54	-0.0030	-0.001	*13*
Central Australia								
Alice Springs - Buffel	5	*53*	0.49	0.21	0.58	-0.0012	*0.0000*	*74*
Sown Pastures (CQ)								
Brigalow - Buffel	12	42	0.15	0.78	0.39	-0.0024	*0.0016*	52
Brigalow - green panic and Rhodes grass	24	54	0.14	0.85	0.25	-0.0020	0.0034	55

Data comparisons for the GRASP simulations for each individual site follow, with the model predictions (which contain no variation) on the X-axis and the observed data (containing error) on the Y-axis, for obvious statistical reasons (Mayer and Butler 1993). For each comparison, the overall degree of agreement is illustrated in the graph, followed by some key notes and interpretations.

Wambiana

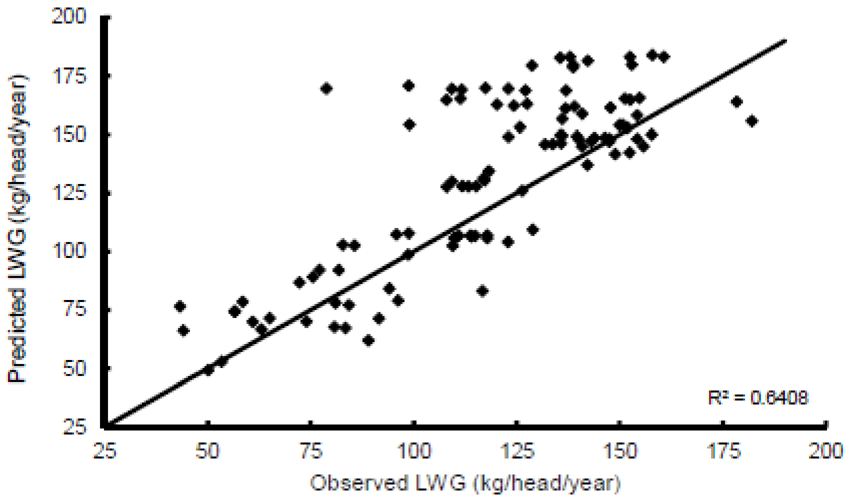


Figure 5.2.2. Annual observed *vs.* predicted liveweight gains (kg/head/day, from GRASP) for Mt Sanford, reproduced from Scanlan et al. (in press).

The Wambiana grazing trial provided an independent test of the annual liveweight gain model and parameters. The 10 years of data from the trial covered a wide range of rainfall variability. There was a well-above rainfall period (1998 to 2001), followed by a severe drought (2002 to 2007), with a return then to average/above average rainfall conditions. The 10 paddocks represented a number of grazing managerial strategies, resulting in a wide range of pasture utilisation. The up-to-date (October 2012) modelling analysis of the Wambiana grazing trial is described in a separate MLA report (B.NBP.0635; April 2012) and resulting publication (Scanlan et al.; in press). The variation of annual liveweight gain was improved in several modelling stages with improved parameterisation of the variation in pasture standing dry matter. A key feature leading to better pasture standing dry matter was the inclusion of the model and parameter modification of GRASP to better represent the negative effects of heavy utilisation on pasture condition (Pahl et al. 2011; Scanlan et al. 2011).

The Wambiana grazing trial provides a most important independent test of ALWG Model 2 and BSG parameters for the following reasons:

1. paddocks were carefully selected to represent each of the 3 main land types reducing potential for between-paddock variability.
2. large paddocks with reasonably large number of animals (e.g. 17?) per paddock.
3. frequent measurement of pasture standing dry matter (2 per year), allowing parameterisation of the pasture component of GRASP particularly the impacts of long (3-5 years) sequences of above and below-average rainfall years (Scanlan et al. in press).
4. evaluation of ALWG Model 2 and parameters in the context of scenario testing (Scanlan et al. in press).

At Wambiana, there was reasonable agreement in most years. However, 2004/05 and 2006/07 were large outliers. These 2 years had substantial liveweight loss during the dry season. Scanlan (pers. comm.) indicated that without these outlier years included in his analysis, the black speargrass parameters explained 64% of the variability (n=108). The overall intercept (a) was slightly higher (0.11 cf. 0.06 kg/hd/day). The coefficient on utilisation was about the same as for the black speargrass parameter, but the coefficient for %GIdays was less than the BSG value (0.0036 cf. 0.0048), indicating less sensitivity to climatic variation.

Mt Sanford

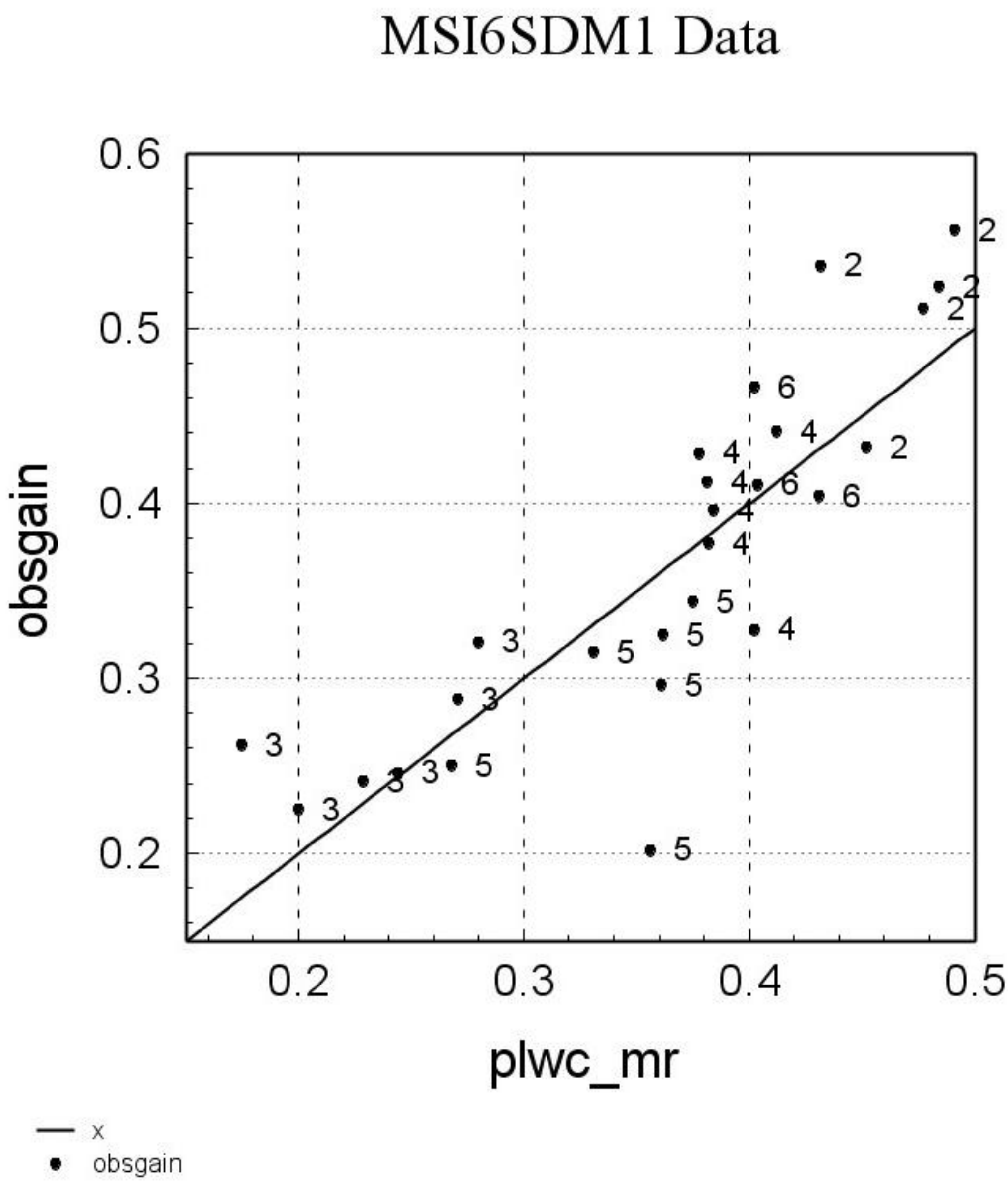


Figure 5.2.3 Annual observed (obsgain) *vs.* predicted (plwc_mr) ADG (kg/head/day, from GRASP) for Mt Sanford (VRD; open *Dichanthium* - *Astrebla* grassland). Point labels indicate the year.

Results for this study at Mt Sanford are more fully outlined in Mayer *et al.* (2011), with this conference paper being freely available at www.mssanz.org.au/modsim2011/B1/mayer.pdf Agreement is quite good for this site, with no apparent biases. This is an encouraging result, given the distance between the sites which contributed the original GRASP model data and Mt Sanford.

Pigeon Hole

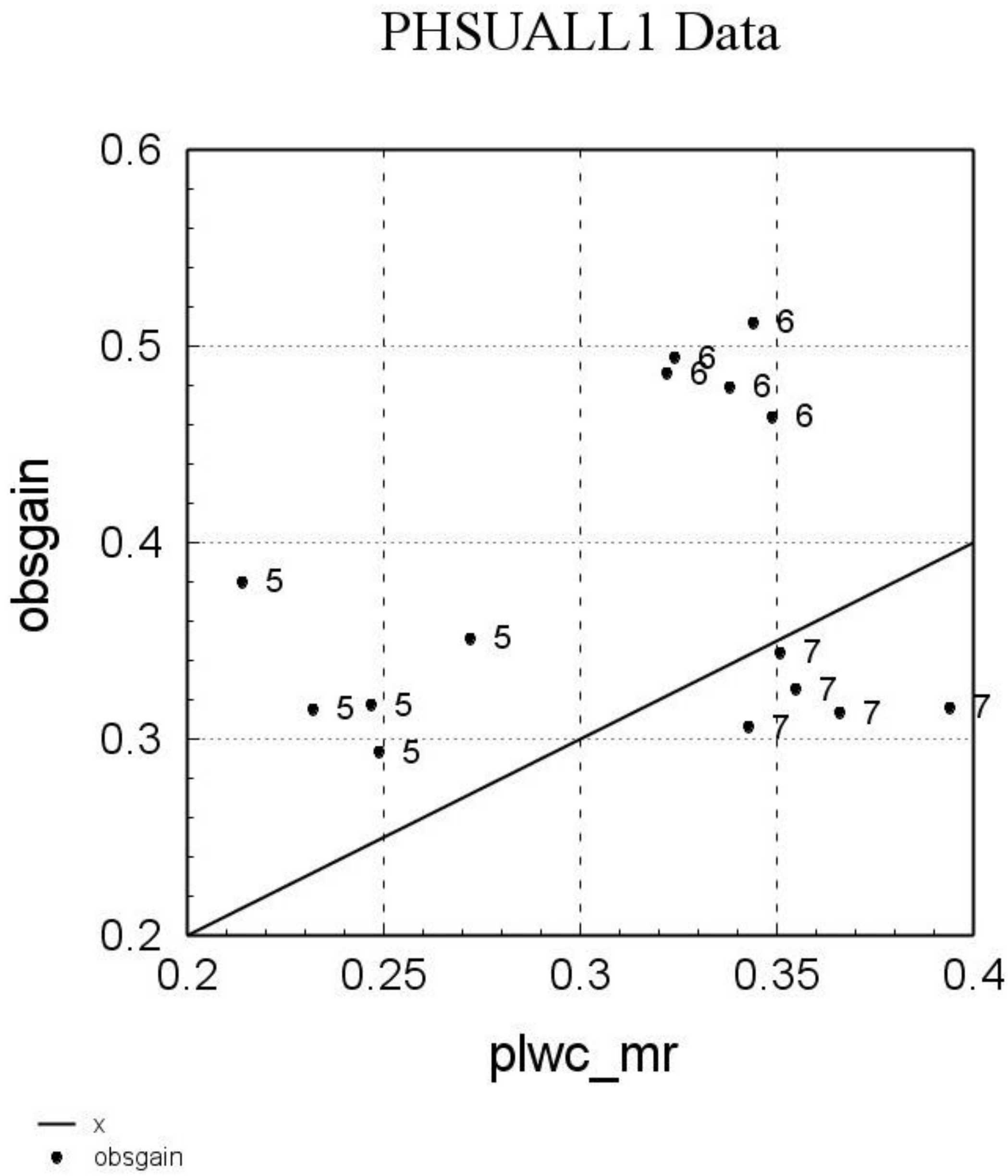


Figure 5.2.4 Annual observed (obsgain) *vs.* predicted (plwc_mr) ADG (kg/head/day, from GRASP) for Pigeon Hole (VRD). Point labels indicate the year.

For Pigeon Hole there is little agreement. This trial used commercial-size paddocks, which had 50-65% annuals, 13-22% forbs and legumes, and 35-45% annual sorghum. Liveweight data were collected in only 2 types of growth years - median (2005 and 2007), and high (2006). Out of season rainfall caused the model to see more growth-index days in 2007 (*vs.* 2005), but no more actual growth and liveweight gain.

Swan's Lagoon

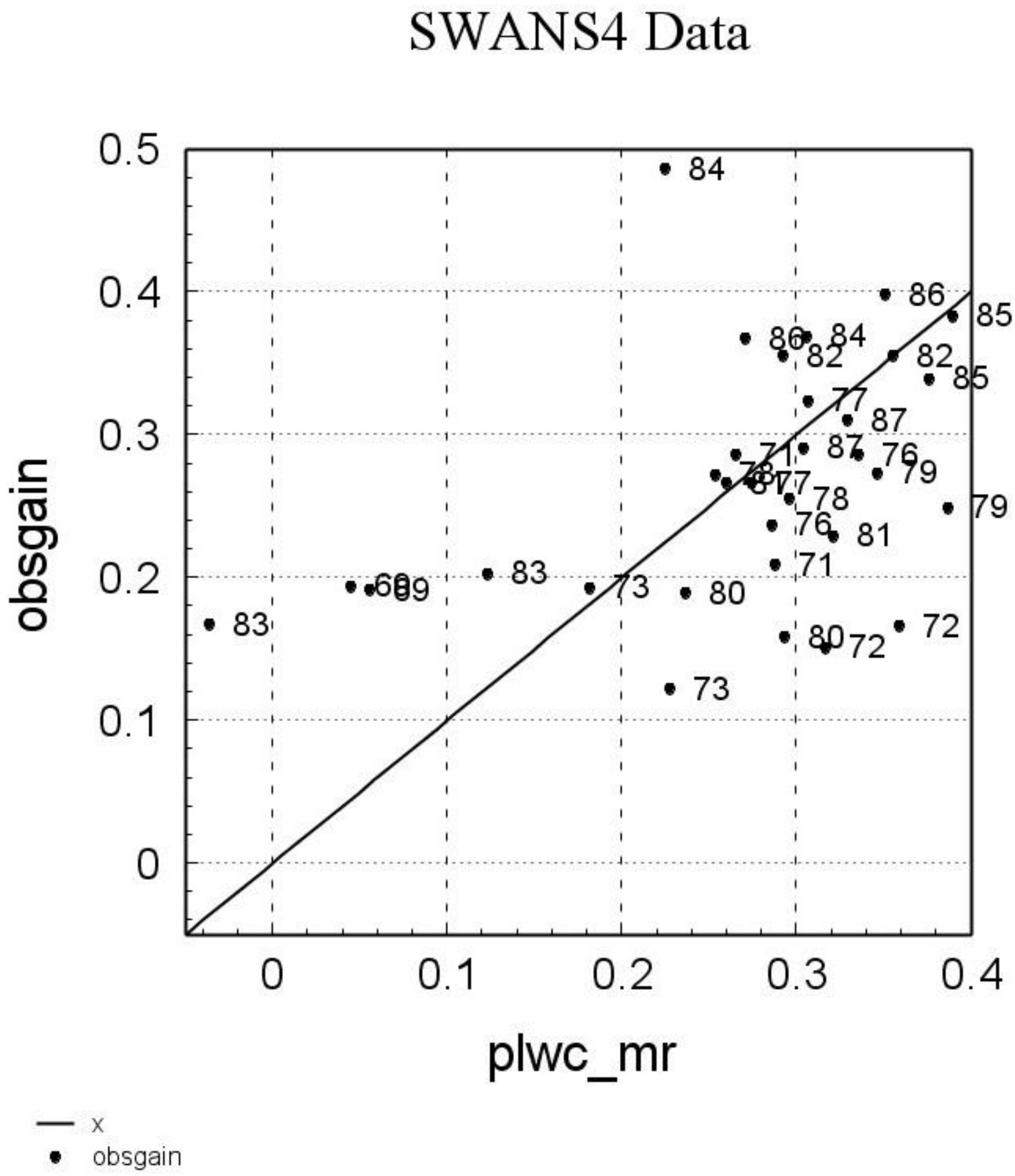


Figure 5.2.5. Annual observed (obsgain) *vs.* predicted (plwc_mr) ADG (kg/head/day, from GRASP) for Swans Lagoon (north eastern Queensland); native pastures (long-term control treatment). Point labels indicate the year.

At Swans Lagoon, annual liveweight gain was measured in native pasture paddocks grazed at two stocking rates from the late 1960s until 1987 (S. McLennan pers. comm.). An initial simulation was conducted using pasture parameters derived from a pasture growth study at the Swans Lagoon Research Station by A. Pressland. These parameters were modified, based on expert opinion (A. Pressland), to reduce soil depth and increase tree density. A daily rainfall file that can be used in GRASP has now been developed by G. Stone from monthly research station data.

For now, analyses of the Swans Lagoon remain at a preliminary stage, however we report the results here as an example of a trial where there was little effect due to variation in utilisation. The general northern Australian liveweight gain model accounted for only a small proportion (17%) of the measured variation. Whilst the long term average liveweight gains were in general agreement, the observed data showed little impact of differences in stocking rate compared to that expected from the general liveweight gain model. The observed data includes the impact of important extreme climatic years such as 1982/83 and 1983/84 which can contribute to further model development. In the case of 1982/83, a severe spring/ summer drought was followed by a warm autumn/winter period in 1983 with high quality pasture nutrition. Such years provide important insights for the development of annual and daily liveweight gain models.

Brigalow

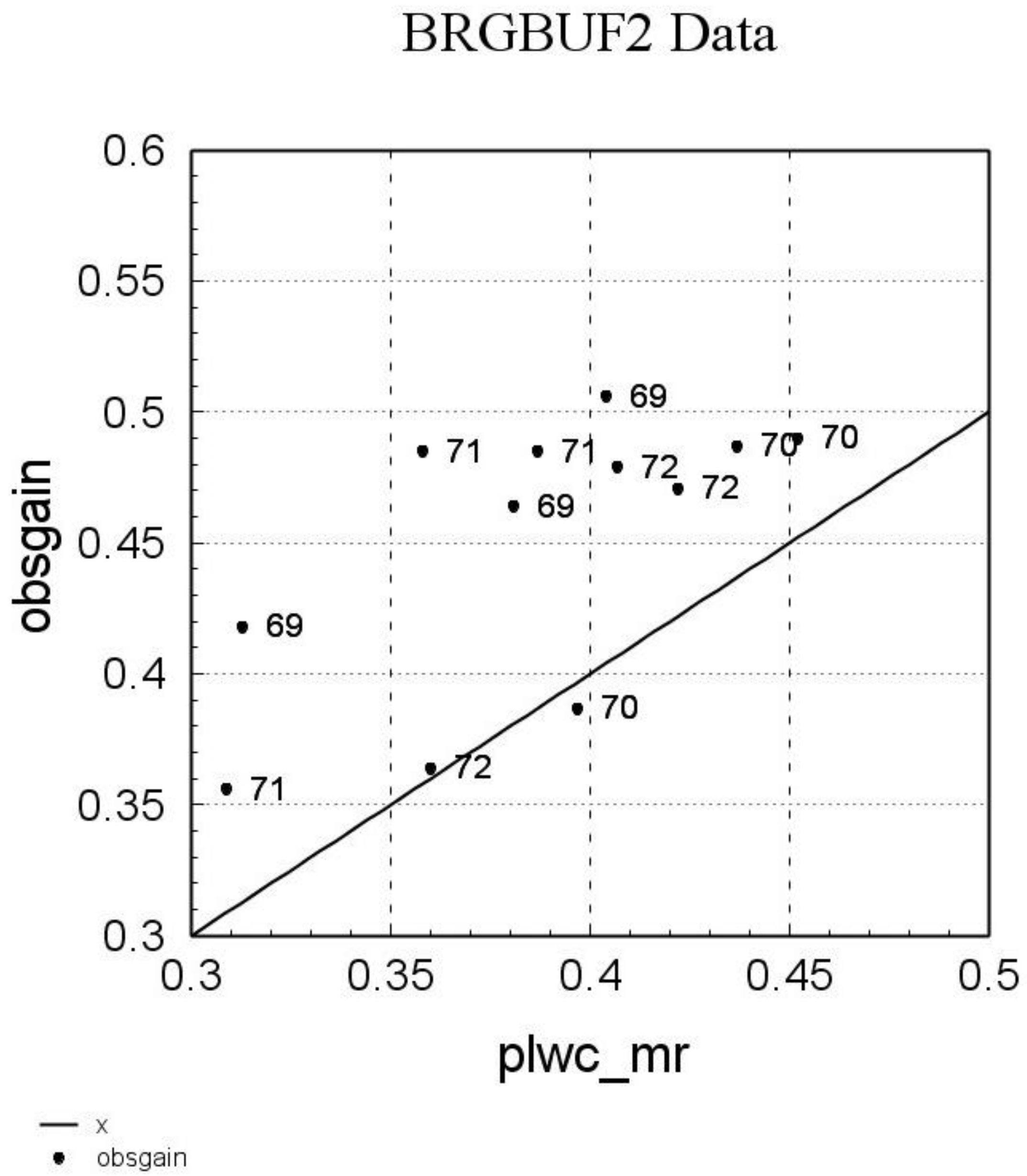


Figure 5.2.6. Annual observed (obsgain) *vs.* predicted (plwc_mr) ADG (kg/head/day, from GRASP) for Brigalow; Buffel grass. Point labels indicate the year.

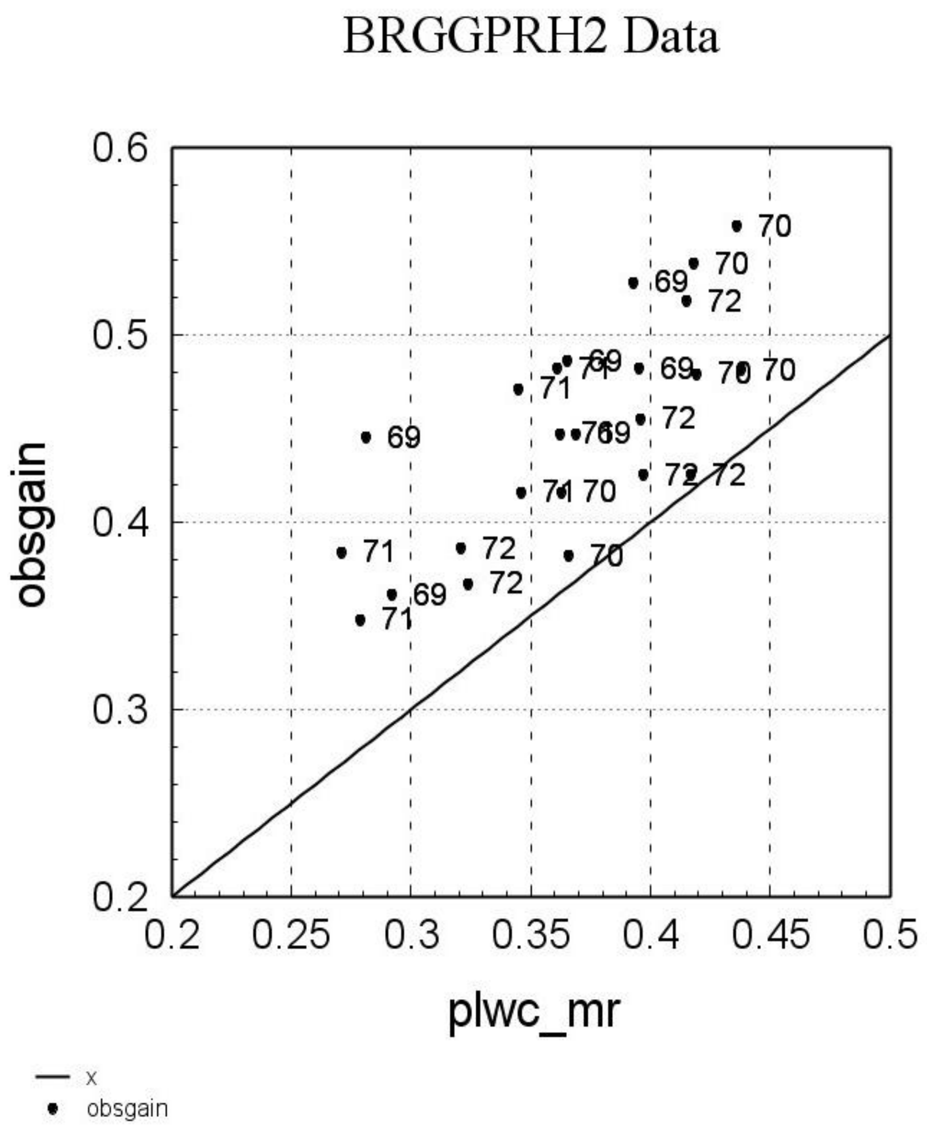


Figure 5.2.7 Annual observed (obsgain) *vs.* predicted (plwc_mr) ADG (kg/head/day, from GRASP) for Brigalow; Green Panic and Rhodes pastures. Point labels indicate the year.

In the early 1970s, a stocking rate trial was conducted on newly established sown grass pastures on fertile Brigalow soils of Brigalow Research Station (central Queensland). Three pasture species (Buffel grass, Green Panic, Rhodes grass) were grazed at three stocking rates (Walker *et al.* 1987). Thus the trial provides important information on liveweight gain under fertile soil conditions, where standing dead material is likely to be of high nutritional quality. For the purposes of this report, an initial model calibration was conducted to match the average observed pasture standing dry matter in each paddock. Soil and pasture parameters from a pasture growth study at Brigalow Research Station in the early 1990s were used as a base for model calibration.

For Buffel grass, observed annual liveweight gains were mostly greater than the general northern Australian liveweight gain model. The re-fitted model indicated a reasonable proportion of variation explained (52%), with the coefficient on the utilisation term similar to the general northern Australian value. Importantly, the coefficient on 'green-days' was small and not significant, indicating that standing dead pasture was likely to be of similar nutritional quality to green material. Overall, the coefficient of the utilisation term was similar to the general model. However, there was little impact of climate variability as expressed by coefficient of the 'green-days' term.

For the Green Panic and Rhodes grass pastures both coefficients were similar to the black speargrass and Mt Sanford parameters. The legume-based treatments at the Galloway Plains western replicate had a high correlation with the general northern Australian model but substantially higher coefficients, suggesting greater impacts of utilisation and climate variability on liveweight gains.

The Green Panic and Rhodes grass pastures did not remain as productive as the Buffel grass pastures of the period of the trial. Observed liveweight gains were in closer agreement with the general northern Australian liveweight gain model, which explained a reasonable proportion of the variation (54%). The re-fitted multiple regression explained 55% of the variation, with coefficients on utilisation and 'green-days' similar to the general northern Australian liveweight gain model. The main difference was that the intercept (0.25 kg/day) was substantially higher than GRASP model 2, suggesting better pasture quality over a wide range of climatic conditions.

Alice Springs

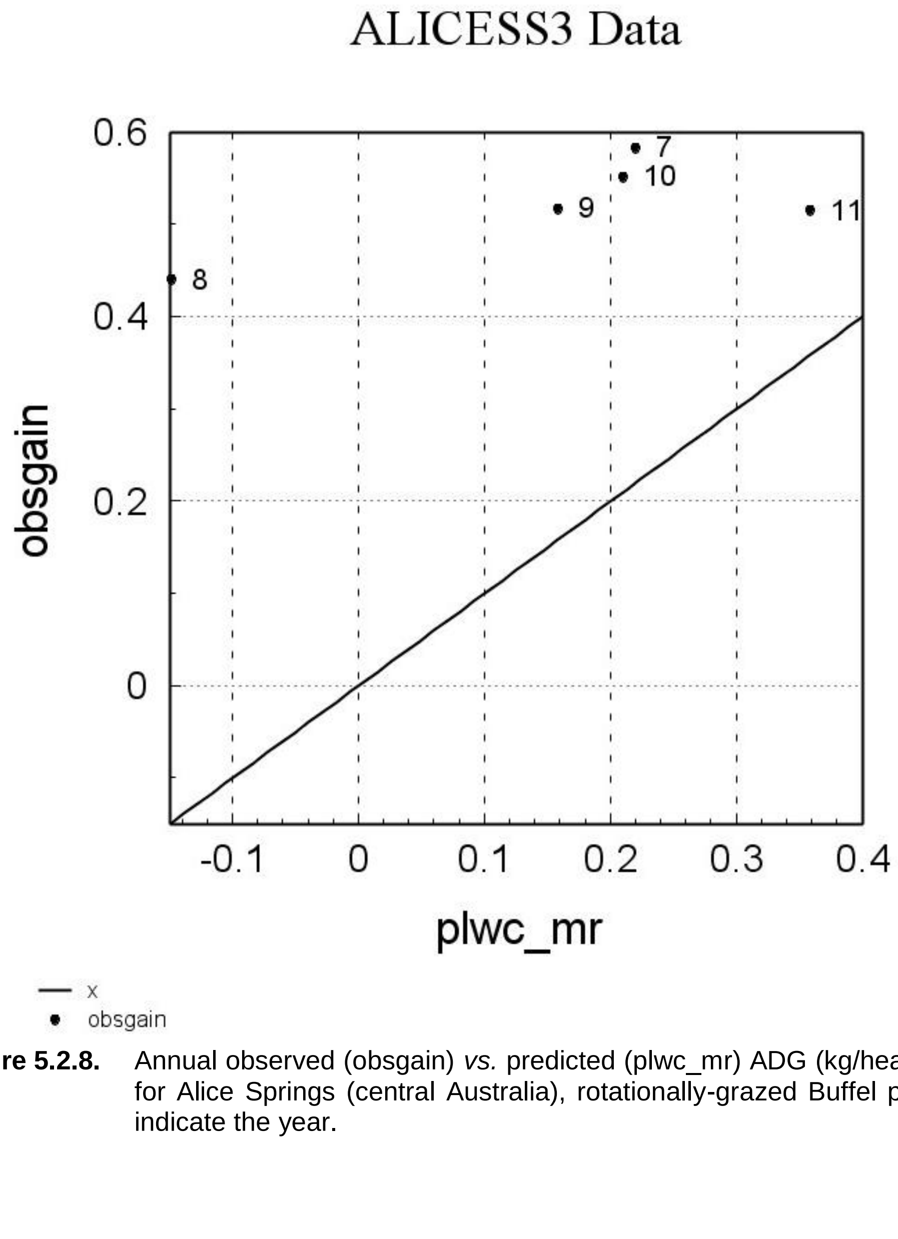


Figure 5.2.8. Annual observed (obsgain) *vs.* predicted (plwc_mr) ADG (kg/head/day, from GRASP) for Alice Springs (central Australia), rotationally-grazed Buffel pastures. Point labels indicate the year.

The approach was also tested for a Buffel grass trial at Alice Springs (Central Australia), in a much drier environment than where the parameters were developed. The observed data indicated high liveweight gains despite the very low rainfall compared to northern Australia. This site had generally low utilisation (<15%). Observed liveweight gains were much higher than model predictions, due to high quality pasture of standing dead material, and possibly also the use of very small paddocks. This demonstrates that the LWG intercept (GRASP parameter p228) should vary with land type (higher on more productive pastures). Also, browse might reduce the impact of higher utilisation (reduce GRASP parameter p229). The lack of agreement with the general northern Australian model further highlights the importance of the nutritional quality of standing dead pasture for animal production, and the need for further model and parameter developments.

The coefficient of utilisation was lower than the BSG value (-0.0012 cf. -0.0021 for BSG). As indicated above, in previous applications of the ALWG approach used in dry environments (e.g. wool growth in western Queensland), carryover pasture standing dry matter from the previous year was included in the utilisation calculation (i.e. %utilisation = intake/(carryover SDM + growth). However, in this case there were insufficient pasture data to investigate this additional approach.

Galloway Plains

A preliminary investigation (results not graphed here) was also conducted for Galloway Plains, which lies in the black speargrass zone of coastal central Queensland, from 1989 to 2001. Because of differences in soil type, the trial was analysed as two separate datasets, namely the western and eastern replicates (see this case study in Appendix 3). The trial involved a range of treatments including six levels of stocking rate on native pasture, supplementation and pasture burning, and oversowing with pasture legumes. Thus the trial provided a range of stocking rate and nutritional treatments. Liveweight gain data on the western replicate for the period 1989 to 1993 was used in the development of the initial regression, which formed the general northern Australian liveweight gain model.

For the purposes of this project, a preliminary calibration of pasture parameters was conducted to provide an initial simulation of the trial, so as to assess likely issues in the data set (see Appendix 3). The preliminary calibration provided a reasonable simulation of average standing dry matter for each paddock. However, only a small proportion of year-to-year variation in standing dry matter was explained by this preliminary calibration. Issues include: year-to-year variation in available nitrogen, minimum nitrogen concentration, detachment and trampling rates. These issues are particularly important at Galloway Plains because of the perennial grass species and high rainfall in this environment. Other issues include: accuracy of daily rainfall data, variation in soil type within the western replicate, and systematic variation in botanical composition (forest bluegrass and black speargrass) across the trial (see Appendix 3). Because of variation in the time of changes in animal drafts, annual liveweight gains were not available for every year of the trial. These missing years still contain valuable liveweight measurements for the construction of daily liveweight gain models in the future. At the time of reporting (April 2012) these calibration issues are yet to be resolved, and suggest that a paddock-by-paddock calibration is required. Nevertheless, a summary these of preliminary findings follows.

The first four years of the Galloway Plains western replicate had been used in developing the BSG parameters for model 2. For the years which form the independent data set, simulated LWG explained 66% of the variation in liveweight gains. However, the coefficients for utilisation (-0.0033) and %GIdays (0.0085) indicated stronger effects of these variables than by the BSG parameters (-0.0021 and 0.0048 respectively). As indicated above, the parameterisation of the pasture component needs to be re-evaluated to account for paddock differences in soil type, topography and species composition.

None of the Galloway Plains east replicate data were used in developing the BSG parameters. The simulated LWG with BSG parameters explained only 25% (n=43) of the variability in observed LWG. The intercept (0.08) and %GIdays coefficient (0.0044) were similar to BSG parameters. The coefficient for utilisation (-0.0030) indicated a greater effect of utilisation than in the BSG parameters (cf. -0.0021). For the burnt native pasture paddocks, results were similar to the Galloway Plains west replicate burnt paddocks with a high correlation (R^2=72%), but with coefficients indicating greater effects of utilisation and %GIdays. As with the Galloway Plains west replicate, detailed analysis indicated differences in species composition across the paddocks of the replicate that are yet to be fully included in the parameterisation.

Northern Australia Producer Survey

Bortolussi et al. (2005) surveyed over 800 properties across northern Australia in the mid 1990s. They estimated annual LWG from turnoff liveweight, carcass weight and age in conjunction with weaning weight. They collated data to calculate average LWG for pasture communities within regions, as listed in Table 5.2.2. In most regions, there were wide ranges in annual LWG across pasture communities, reflecting the impact of variation in both climate and landscape attributes (e.g. soil fertility, flood plains).

Table 5.2.2 Comparison of simulated LWG with Black speargrass parameters and reported regional LWG from producer surveys averaged for pasture communities (after Bortolussi et al. 2005).

Survey Region	Survey data – average LWG	GRASP LWG	Observed range across pasture communities	Number of communities
Central Coast (CCQ)	137	142	130 - 144	2
Central Highlands (CHQ)	159	128	128 - 219	5
Central West (CWQ)	149	93	145 - 153	2
Maranoa (MSW)	150	109	122 - 164	6
North West (NWQ)	126	103	93 - 145	5
North (NQ)	110	118	100 - 121	7
Northern Territory (NNT)	106	108	87 - 110	6
Northern WA (NWA)	125	89	91 - 146	7

As part of this study, we conducted preliminary simulation of LWG for 6 representative locations in each region to estimate the likely climatic component of LWG. We used average native pasture parameters for pasture and soil parameters and BSG parameters for the calculation of LWG. A more comprehensive analysis will require simulation with the AussieGRASS model parameters which allows better estimates of soil and pasture parameters (including tree density) for each pasture community. This preliminary analysis is nevertheless instructive in terms of the general effect of geographical variation in climate across northern Australia.

For regions where the BSG parameters were developed (and tested e.g. central coastal and northern Queensland and northern N.T.), there was general agreement between average observed and simulated values (Table 5.2.2). However, the BSG parameters underestimated LWG for the drier regions and particularly those regions which included very fertile pasture communities such as gidgee, Mitchell and bluegrass grasslands (CHQ, CWQ, MSW and NWQ). In these land types, reported LWG was well above that simulated by the BSG parameters.

This analysis supports the findings of Bortolussi et al. (unpublished; J. McIvor pers. comm.) who found little relationship between climatic indices (e.g. green weeks per year) and LWGs reported in the survey. For extensive grazing properties in drier regions, they commented on the importance of animals having access to a wide range of landscape features such as floodplains allowing for high levels of nutrition. The survey results also highlight that relatively high LWG can be obtained in drier environments.

Conclusions – a). Black speargrass studies

For grazing trials in the Queensland black speargrass zone, the agreement between observed and simulated liveweight gains using the BSG parameters was less than desirable. The agreement at Wambiana in most years supported the use of the model and parameters in scenario testing (e.g. Scanlan et al. in press). The lack of agreement with independent data described above at Galloway Plains and Swans Lagoon is as yet not understood. We recommend that these trials be further investigated with particular attention to:

1. quality of rainfall records;
2. pasture parameterisation to account for soil type and topographical differences between paddocks (e.g. Galloway Plains);
3. effects of varying changeover time of drafts, animal age and genotype through the course of the experiment;
4. the possible causes of liveweight loss at Wambiana in severe dry seasons. and
5. comparison of model performance simulating different grazing strategies (e.g. SOI and responsive strategy) at Wambiana.

b). Grasslands in the VRD, N.T.

Simulated LWG using the BSG parameters was in close agreement with independent data at Mt Sanford (R^2=72; n=26), with the intercept and coefficients being very close to the BSG parameters. However, at an adjacent site (i.e. Pigeon Hole), there was little agreement over the 3 years of the trial (R^2=13; n=15). Two years (2004/05 and 2006/07) at Pigeon Hole had similar LWGs but large differences in %GIdays. The year 2006/07 had rare high rainfall in the dry season contributing to a high value of %GIdays. Thus the results from Pigeon Hole for 2006/07 suggest that the %GIdays approach may overestimate the value of infrequent out-of-season rainfall in this dry monsoonal environment, and should be the subject of further research. Overall, the results from the Mt Sanford trial support the extrapolation of ALWG Model 2 and the wider use of BSG parameters to a similar grassland type with a reliable dry season. However, the lack of agreement at the adjacent Pigeon Hole trial is yet to be adequately explained.

c). Sown pastures in Queensland

Relatively young sown grass pastures on fertile Brigalow soils allow the modelling approach and BSG parameters to be tested well outside the range of soil fertility where the model and parameters were developed. Compared to native pastures, young sown grass pastures are likely to have greater availability of soil nitrogen resulting in high pasture productivity and higher quality (e.g. protein) pasture available for diet selection. Comparison of simulated LWG using the BSG parameters indicated, as expected, that observed LWG was underestimated for buffel and green panic/Rhodes grass treatments (intercept 0.39 and 0.25 respectively cf. 0.06 for BSG). The coefficients in the utilisation term were similar to BSG values. The coefficients on the %GIdays term were lower than the BSG value (-0.0016 for buffel grass, -0.0034 for green panic/Rhodes grass cf. 0.0048 for BSG). The lower coefficients for %GIdays indicate less impact of climatic variation through the production of new pasture growth, suggesting that senesced sown pasture material is of higher value than senesced native pasture.

d). Overall

In this scoping study, we evaluated GRASP's ALWG model 2 with the BSG parameters across a wide range of climatic zones and soil fertility:

1. for grazing trials within the Queensland black speargrass zone.
2. for grazing trials in the VRD, N.T. with similar vegetation characteristics of low quality senesced pasture.
3. for highly productive sown grass pastures on a fertile soil in central Queensland.
4. for low rainfall buffel grass pastures in central Australia.
5. estimates of property LWG for different climatic regions in northern Australia.

The independent evaluation of BSG parameters was inconsistent. Observed and simulated LWGs for Mt Sanford (northern N.T.) were in excellent agreement with coefficients of utilisation and %GIdays similar to BSG parameters. Similarly for Wambiana (Scanlan et al. 2012) there was general agreement in most years, but there were major outliers in two years with severe dry seasons. In contrast to Mt Sanford and Wambiana, for the other grazing trials where agreement would have been expected (such as Galloway Plains, Swans Lagoon and Pigeon Hole), there was a general lack of good agreement in the effects of utilisation and/or %GIdays. It should be noted that the agreements in simulating LWG at Mt Sanford and Wambiana trials were achieved only when uncertainties regarding rainfall and pasture parameters were resolved. In the case of Galloway Plains and Swans Lagoon, we are yet to reach the same degree of certainty

5.3 Short-term grazing of improved pastures in central Queensland - Evaluating GRASP and GRAZPLAN coupled with APSIM

(study conducted by Dhananjay Singh, Maurice Conway, Jyoteshna Owens, Peter DeVoil, Jason Brider and Joe Scanlan)

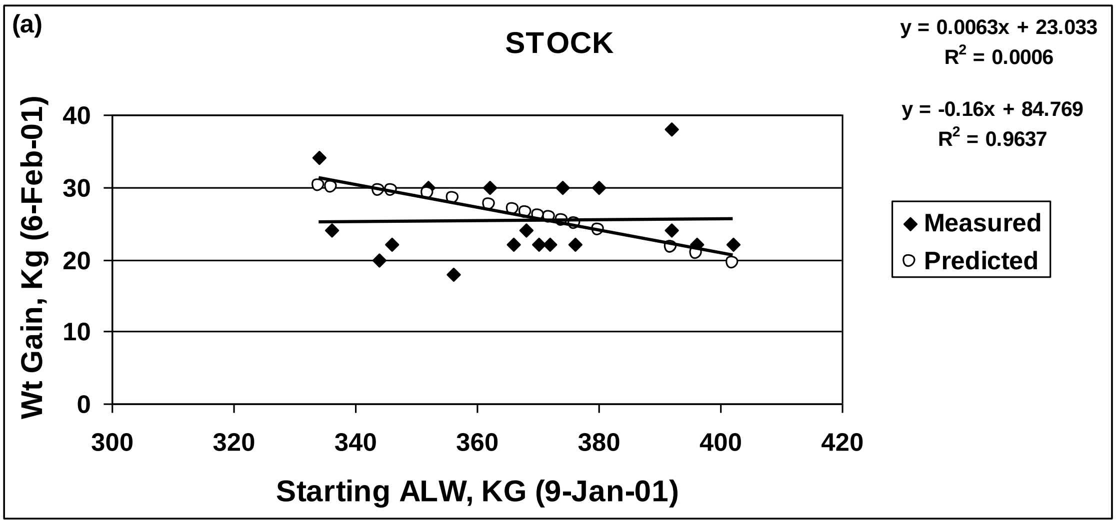
Introduction - Models provide information on forage production and animal liveweight gain by extrapolating results from grazing experiments. This gives simulated responses beyond the limited climate and soil conditions of the original experiment, applicable to other parts of northern Australia. The user-friendly and widely used crop/pasture/livestock simulation model APSIM has been coupled with the dynamic animal production models GRAZPLAN and GRASP. This study evaluates these models (within APSIM) against measured animal production data from a grazing system in central Queensland.

Materials and methods - A full description of the GRAZPLAN model and simulation equations are described in Freer *et al.* (1997), similarly see Day *et al*. (1997) for GRASP. The GRASP model incorporated in APSIM, referred to as GRAZ, is 'model 1', where the potential liveweight gains are input as four parameters (one for each season of the year). The effects on intake restriction due to pasture availability and utilisation are calculated. It is important to note that when abundant feed is available, the simulated liveweight change per day is equal to the input parameter for the seasonal liveweight change divided by the number of days in the season.

The field experimental site was located 15 km south of Baralaba, Central Queensland, Australia, on self-mulching black and grey cracking clay soils. Treatments included butterfly pea (*Clitoria ternatea*) (100% of the paddock), and Buffel grass (*Cenchrus ciliaris*) (100% of the paddock). Brahman (*Bos indicus*) cattle were used for grazing. Data used in this study are from the second round of grazing, commencing from 9/1/2001 to 11/4/2001 with a resting period of paddock from 6/2/2001 to 20/3/2001. Daily climate data for Baralaba was downloaded from SILO, LongPaddock. Soil profile characteristics of most represented soil in the trial area (12 ha) at Bindaree, Black vertosol (Jambin No 056) from ApSoil was used for simulations. The models were run for each grazing period and for a range of starting weights to accommodate individual starting weight of the animals or herd on a daily basis. Models were statistically evaluated by calculating mean bias error (MBE), root mean error square (RMSE) and index of agreement (d) (Andales *et al.* 2005).

Results and Discussion - GRAZPLAN (termed STOCK within APSIM) is a complex and dynamic model compared with the simpler 'utilisation model 1' of GRASP, which is described as GRAZ in APSIM. The GRAZ model is generally used within the older versions of GRASP model to predict animal intake on tropical native pastures in northern Australia. In GRAZ users define the potential weight gains for each particular forage and season.

Evaluation of these two models against the observed set of data for herd or individual animals suggests that both models can be reliably used as the index of agreement (d, indicating the proportion of the observed variance that is explained by the model), was between 85% and 97% for both models. However, when predicted weight gains were plotted against the actual starting weight of the animals on butterfly pea, then the complex STOCK model showed significant bias. It overestimated the weight gains for the lighter and underestimated the weight gains for the heavier animals (Figure 5.3.1a). This was more apparent during the second grazing period (Figure 5.3.2a), when absolute weight gains for heavier animals were predicted at more than 10-15 kg lower than the observed values over a 22 day grazing period. On the other hand, the simpler GRAZ model showed no relationship with initial weight, and also little bias, indicating a satisfactory model for the first period (Figure 5.3.1b). For the second period (Figure 5.3.2b), GRAZ predicted about 10 kg lower absolute weight gains than the observed values. Since the prediction of weight gain is independent of animal liveweight at the start of grazing, the GRAZ model would be less biased than the STOCK model if there were heavier animals used in this study. Use of heavier animals (between 500Kg and 600kg) is quite common on improved pastures or forage crops for finishing the animals in the mixed farming zones of Queensland.



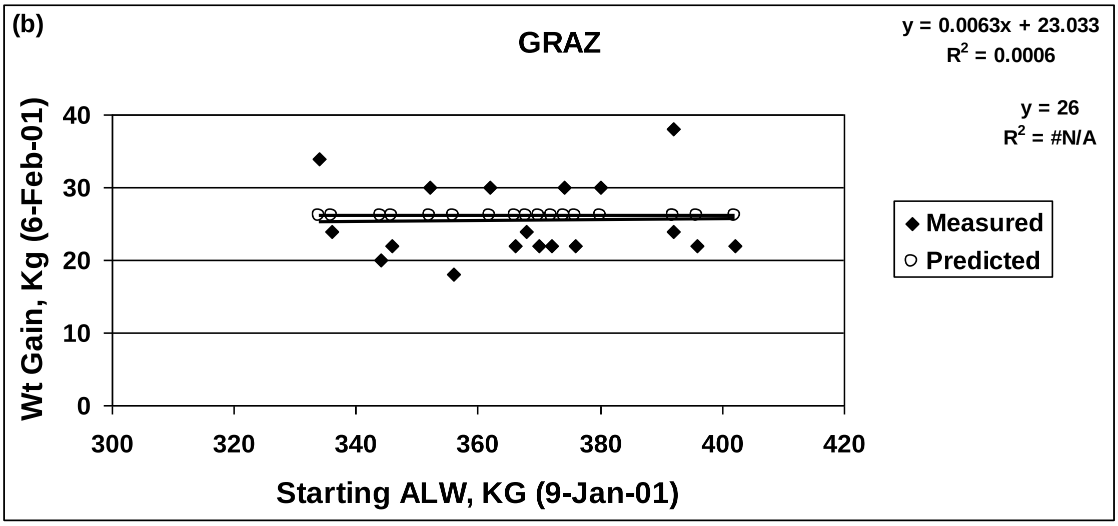
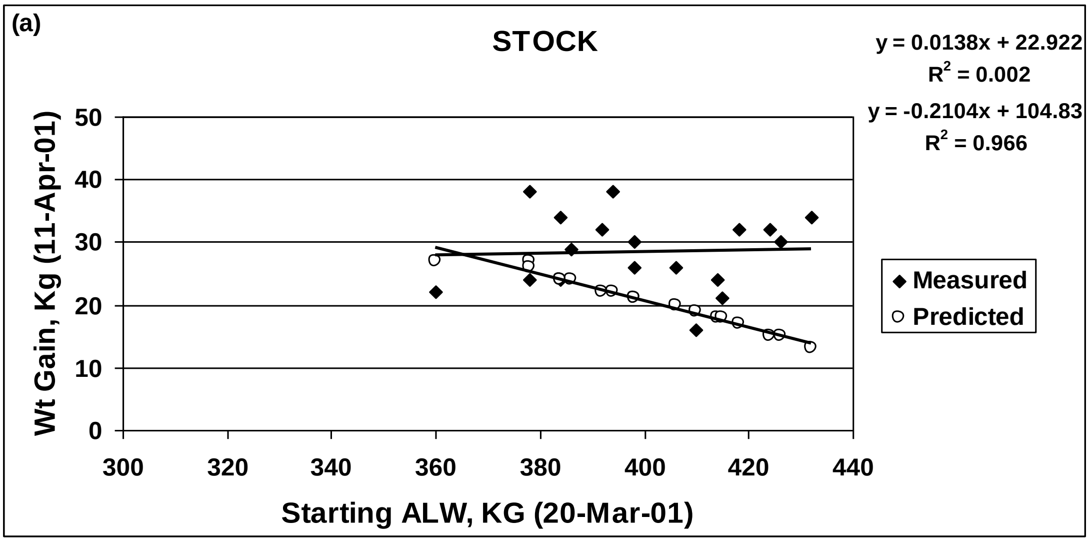


Figure 5.3.1. Relationship between weight gain and corresponding starting weight of animals for measured and predicted weight gains from (a) STOCK and (b) GRAZ, during the first grazing period with lighter animals. Measurements were taken on 18 individual animals.



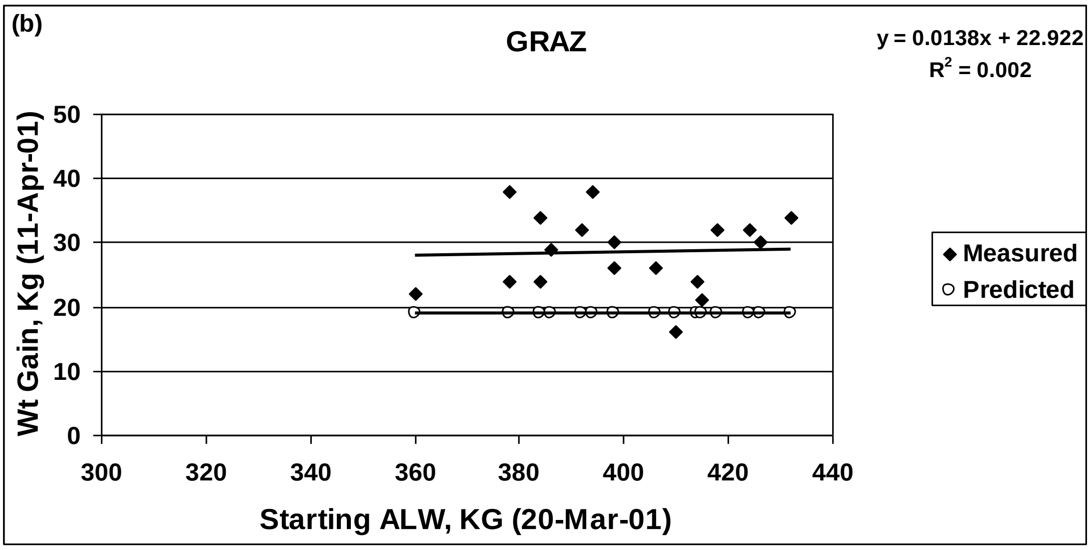


Figure 5.3.2. Relationship between weight gain and corresponding starting weight of animals for measured and predicted weight gains from (a) STOCK and (b) GRAZ, during the second grazing period with heavier animals. Measurements were taken on 18 individual animals.

Weight gains on the Buffel grass were predicted from GRAZ only (STOCK is not programmed yet to predict ALW from GRASP pasture simulation) (Figure 5.3.3). Heavier animals (>350kg) on Buffel pasture lose weight during the first grazing period (Figure 5.3.3a) and gain very little during the second grazing period (Figure 5.3.3b). The Buffel grass and butterfly pea pastures were severely affected due to the dry weather during the first grazing period. However, it is important to note that the trend of observed weight gains in animals was similar on the butterfly pea pasture, where the heavier animal did not lose weight with drier conditions (Figure 5.3.1a). This indicates the higher nutritive value of legume pasture (butterfly pea) when compared with the grass pasture, even when conditions got worse with extremely dry and hot condition during the end of the first grazing period.

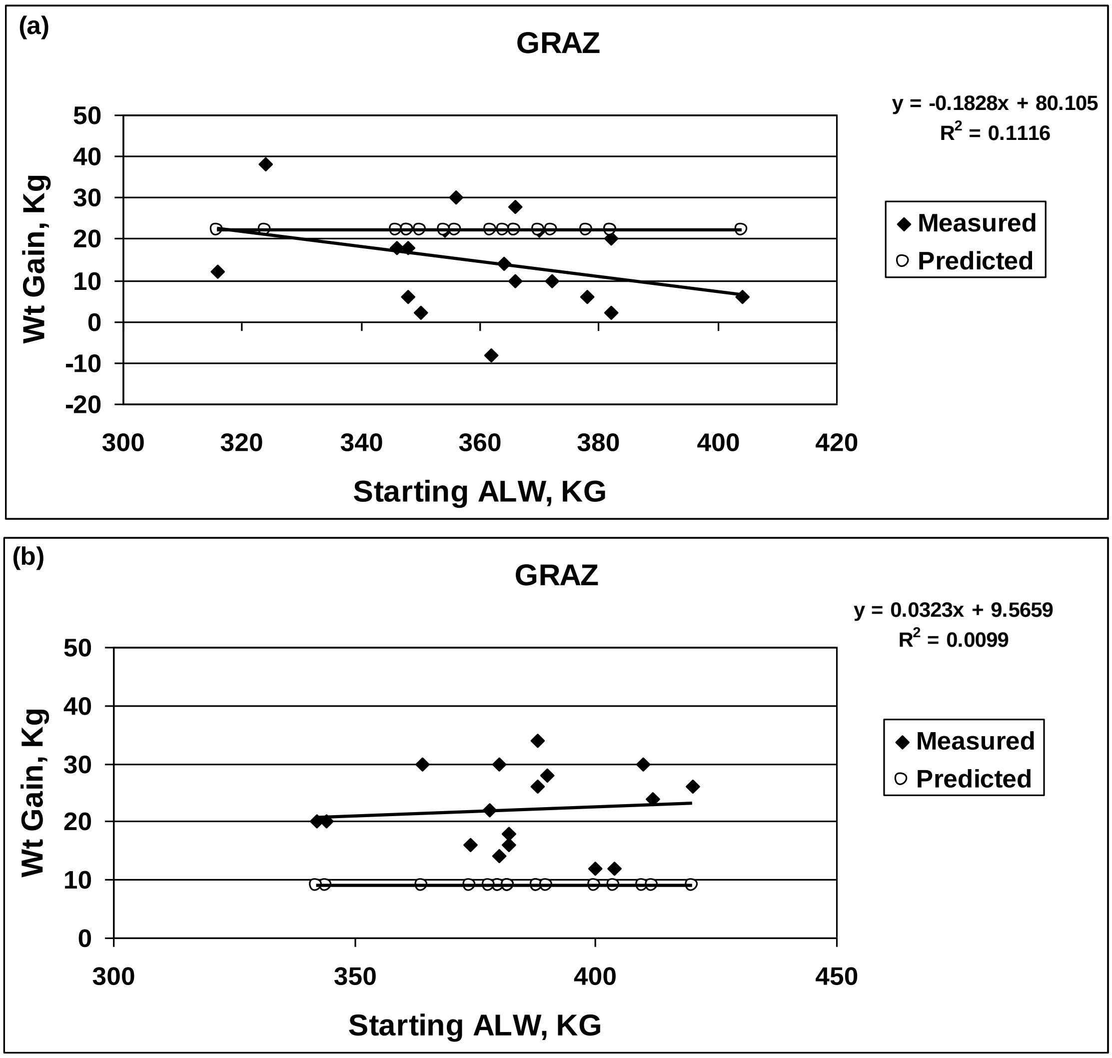


Figure 5.3.3. Relationship between absolute weight gain and corresponding starting weight of animals for measured and predicted weight gains on Buffel grass from GRAZ during (a) the first grazing period and (b) the second grazing period. Measurements were taken on 18 individual animals.

The prediction of lower weight gains than the observed values during the second grazing period for both butterfly pea (Figure 5.3.2) and Buffel pastures (Figure 5.3.3) may be due to a greater intake, compensatory animal growth, and/or better forage conditions and nutritive values. This indicates the likely need for retuned parameters for 'potential seasonal liveweight gain'. The second grazing period started with good rain and had some follow up rain, whereas the first grazing period ended with extremely dry weather and poor pasture conditions.

In conclusion, both the STOCK (GRAZPLAN) and GRAZ (GRASP) models predicted reasonably well under the given conditions, except that the complex STOCK model appeared to show bias with the different starting animal weights – overestimating the weight gains for lighter animals, and underestimating the weight gains for the heavier animals. Hence STOCK is predicting lower liveweight gains for the heavier animals, as may reasonably be expected. However, the observations do not support this hypothesis. This needs to be investigated further, in particular after the improved daily liveweight gain model for GRASP has been developed and tested.

5.4 Spatial coverage of key nominated grazing trials

For the grazing trials where sufficient records exist (allowing GRASP to be parameterised to the specific pastures), Table 5.4.1 lists the spatial coverage of our obtained and targeted data sets. It is intended (see recommendations) that, over time, the research team will complete the GRASP simulations for the sites marked ‘preliminary’, and then move on to the ‘targeted’ sites, in order of perceived importance. These locations are displayed in Figure 5.4.1.

Together with Figure 5.1.1 (the sites modelled at the broader-scale), these demonstrate quite good coverage across Queensland and the Northern Territory. It is, however, of some concern that we do not (yet) have any data sets from the northern part of Western Australia.

Table 5.4.1 Locations and modelling status of liveweight data sets.

Study site	Latitude	Longitude	Status
Kangaroo Hills	-18.93	145.67	Completed
Mt Bambling	-25.66	151.75	Completed
Mt Sanford	-16.98	130.57	Completed
Pigeon Hole	-16.98	130.57	Completed
Alice Springs	-23.81	133.90	Preliminary
Brigalow	-24.84	149.80	Preliminary
Galloway Plains	-24.13	150.97	Preliminary
Swans Lagoon	-20.12	147.25	Preliminary
Wambiana	-20.56	146.12	Preliminary
Alexandria Downs	-19.06	136.71	Targeted
Cardigan	-20.20	146.65	Targeted
Glentulloch	-25.80	148.40	Targeted
Glenwood	-25.69	150.87	Targeted
Hillgrove	-19.64	145.79	Targeted
Isis	-25.20	152.45	Targeted
Keilambete	-23.45	147.60	Targeted
Kidman Springs	-16.10	130.95	Targeted
Lansdown	-19.66	146.83	Targeted
Manbulloo	-14.52	132.20	Targeted
Narayen	-25.69	150.87	Targeted
Rosebank	-23.50	144.25	Targeted
Springmount	-17.12	145.33	Targeted
Toorak	-21.03	141.80	Targeted
The Springs	-22.87	150.27	Targeted

(a)

(b)

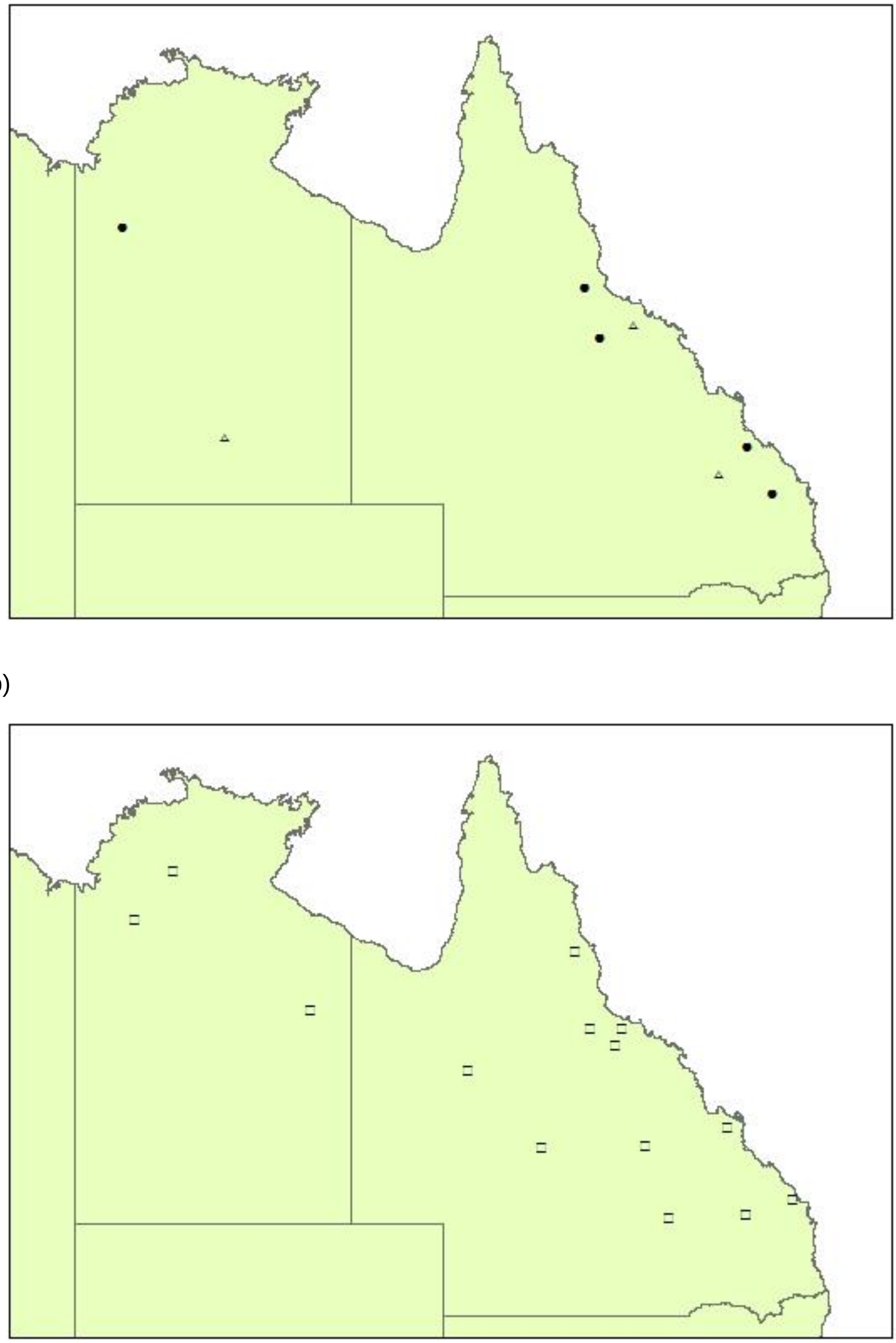


Figure 5.4.1. Locations of liveweight data sets. (a) Obtained – completed (dots) and preliminary (triangles) modelling; (b) Targeted (squares).

6 Discussion

Since the early 1980s, the GRASP model has contributed to a wide range of industry and government agency applications with regard to the management of the grazed resource of northern Australia. However, the GRASP model components relating to grazing and animal production (i.e. diet selection, intake, trampling and live weight gain) were developed in the 1980s and mid 1990s. With more recent knowledge and data sources now available, this project review has highlighted a wide range of areas where components of GRASP could be updated to better address current and future applications. We reviewed current and future applications, and indicate where further development could improve the use of GRASP. Current and future applications of GRASP, contributing to industry and government agency objectives, are:

- the evaluation of grazing management options (e.g. NGS project) including pasture spelling, rotational grazing, and other multi-paddock options (e.g. seasonal forage systems);
- the calculation of grazing pressure on different land types in Reef catchments;
- calculation of likely climate change impacts on animal production and risks of resource degradation (e.g. Commonwealth DAFF projects);
- monitoring of risks of drought and degradation across Australia's rangelands in near-real time (AussieGRASS, a spatial implementation of point GRASP); and
- optimisation of the use of animal supplements to improve animal production, including the impacts on risk of resource degradation.

The project workshop (21st March 2012) and other discussions indicated that there is a need to simulate the interaction of variable pasture nutrition and animal supplementation. For example, NGS researchers reported a range of views, based on feedback from graziers, on the use of supplements and the impacts on animal production.

Research developments over the last ten years in parallel projects provide the basis for a new combined approach, linking models and data sources from recent research in the fields of pasture science, grazing trials, diet selection (NIRS), and animal production. These combined potential future approaches are described as follows:

1. This project (B.NBP.0641) reviewed and identified potential improvements in the component of whole herd and property modelling. Several algorithms used in the ENTERPRISE model could be improved (e.g. steer growth to turn off age, breeder reproduction and mortality). This review also found that there was a need to develop and integrate models of the impact of supplementation on animal performance, and hence allow the development of recommendations using the ENTERPRISE model on the most efficient use of supplements to improve animal nutrition.
2. This project also identified major historical and current sources of research data (Appendix 1) that are yet to be fully analysed from the perspective of improving the GRASP model and developing parameters for new locations. These data sources involved detailed data collection, including pasture yields, pasture composition, land and resource attributes, NIRS, and monthly/seasonal measurements of liveweight. The analysis of these data sources would further contribute to industry and government agency applications by improving components of the GRASP model.
3. GRASP simulates a reasonable proportion of seasonal and annual climate-related variability (e.g. 60-70%) in liveweight gain using simple indices of plant growth (e.g. pasture growth index, 'green' days). Some models of diet selection (green material, diet %N) have been developed for cattle at one location (Brian Pastures: Hendricksen *et al.* 1982) and for sheep in western Queensland (Hall 1996). However, these sub-models are not available in the current operational versions of GRASP. Nevertheless,

these sub-models could be 'resurrected' (i.e. re-coded) and parameterised with NIRS data now available for different pasture communities. In addition, sub-models of 'forbs and browse' could be developed from the GRASP pasture production database, grazing trials and NIRS data.

4. A component of new animal nutrition models would be better estimates of pasture consumption (i.e. animal intake), and hence, better estimates of natural resource impacts from changes in grazing pressure as a result of better management of animal nutrition. For example, GRASP, and its spatial implementation as AussieGRASS, have the capability of simulating the impacts of grazing management options on resource attributes such as pasture composition, surface soil cover, perennial grass basal area, soil carbon, fire frequency, and encroachment of weeds and woody plants. Downstream implications can also be estimated in terms of relative indices of soil loss and stream sediment concentration.
5. Faecal NIRS data (R. Dixon; current research) now provides a comprehensive database of diet selection in terms of crude protein, digestibility, proportion of green material, and C_3 content (e.g. forbs, browse). The NIRS database contains information on the impact of different sources of variability such as regional, land type and temporal (i.e. climate-related) features of the grazed landscape. Previous studies have shown that GRASP provides a likely tool to explore and 'parameterise' (i.e. simulate) this variability.
6. Models of animal production have been evaluated using combinations of tropical pasture/forages and a variety of supplements (S. McLennan; current MLA project). Improved animal production models based on a known intake of energy and crude protein are now being developed, which would allow calculation of the most efficient and tactical use of supplements in feeding cattle in northern Australia.

7 Success in achieving objectives

1. Review and evaluate existing empirical models for predicting animal production currently within the GRASP, HerdEcon and ENTERPRISE models.

Completed. The underlying relationships in these models were described, and found to mostly have a common basis. The respective coefficients representing the key effects were compared and contrasted.

2. Review and document alternative or complementary approaches to prediction of key animal production measures and identified input variables which improve prediction accuracy by better explaining influences of pasture (quality, quantity and utilisation), climate, soil fertility and animal genotype.

Completed. Our results from locations across northern Australia show that the simplest way of extending the GRASP LWG model (which was based on black speargrass pastures) to other pasture and land types is to retune the model coefficients, using existing or estimated data. Model improvements, which are yet to be fully tested, include incorporating the effect of N in the sward (see Section 5.1) and the development and tuning of a daily liveweight gain model (see Appendix 2).

3. Use a short list of these approaches to develop and/or refine predictive relationships, using data from selected grazing trials (including Wambiana, Mt Sanford and Pigeon Hole projects).

Completed. The range of study locations were used to show how different parameter values can be used to cater for different pasture communities and land types. The daily liveweight gain model (useful for investigating within-year options) was developed and tuned, using some of these existing data sets.

4. Test the predictive relationships against an independent data set.

Completed. The daily liveweight gain model was validated against an independent data set, namely four paddocks at Wambiana over twelve years. Whilst the degree of fit was lower than for the original data (the mean average errors for liveweight changes were 24 and 16 kg respectively), at least some of this was due to a couple of outlier years in the Wambiana data set. Research into this is ongoing.

5. Recommend the most pragmatic approach for improving the capacity of GRASP and ENTERPRISE to realistically and reliably predict animal production.

Despite considerable and commendable efforts by our research team members (see Acknowledgements for this list), some uncertainties remain regarding the overall applicability of the GRASP models. The recommendations (see below) identify separate tasks which would build towards the goal of users having good confidence in both the absolute and relative predictions from these models.

In fulfilling the ***communication and dissemination of information requirements*** in the original proposal, this project delivered:

- A technical paper (Mayer *et al.* 2011), outlining the reviews and research from this project, was presented at the International Congress on Modelling and Simulation, Perth, in December 2011.
- A final meeting for the project was held in Brisbane on 21st March 2012, with 14 participants attending.
- A brief non-technical article in MLA's Feedback magazine, which was originally set down as due one month after the final report, is yet to be done.

8 Impact on meat and livestock industry – Now and in five years time

8.1 Now

This project has assisted in identifying scenarios where the modelled biological rates (in particular, liveweight gains) are likely to be accurate, and where the models do not currently work. For pasture communities and land types where adequate data sets and model parameterisations do not exist, approximate methods have been outlined. The studies collated in this report should give GRASP users an appreciation of the complexities involved, and an understanding of the issues involved in gaining the confidence to use these models for their particular system.

8.2 In five years time

Assuming the continuation of government and external support for this project, and completion of the recommended tasks, in five years we should have arrived at improved models which have been validated and verified across a range of environments. Potential users, from individual producers investigating on-property options to national bodies considering climate variability and change at the catchment or national level, all need to have confidence that the models are giving realistic predictions.

9 Recommendations

This review documents a number of limitations to the approaches used in GRASP to simulate beef cattle liveweight gain. These limitations were: 1) the lack of suitable models to simulate daily liveweight gain; 2) the lack of datasets of parameters for GRASP users to cover comprehensively northern Australia grazing systems (including landtypes and different forage/feeding systems); and 3) an inadequate measurement base available in modelling format.

As a result of the project, we recommend that the following tasks are required to improve GRASP's capability to model animal production and support GRASP users across northern Australia.

Task 1: Establish datasets documenting liveweight gain on commercial properties for landtypes and forage/feeding systems across northern Australia.

Over the past 30 years, there have been several attempts to establish datasets that comprehensively describe animal production for different pasture communities and forage systems across northern Australia. These estimates have been derived from expert opinion and producer surveys. For example, in 1985 E. Weston reported in estimates of annual liveweight gain for each of his 14 pasture communities. In 1998, T. Rudder (Beef Cattle Husbandry Officer, QDPI) provided G. McKeon et al. (DAQ139 *Evaluation of the impact of climate change on northern Australian grazing industries*) with estimates of turnoff weight, and by derivation, annual liveweight gain for the 10 regions used by P. O'Rourke et al. in their 1990 survey of northern Australian Beef Producers. Based on a survey conducted in the early 1990s, Bortolussi et al. (2005) published annual liveweight gains for 14 regions across northern Australia, calculated from turnoff liveweight and age. Different values were given for the range of landtypes and forage/feeding systems within each region. The Bortolussi et al. (2005) survey represents the most comprehensive estimates of annual liveweight gain available at present, but is limited in time to the early 1990s. Thus, it is recommended that a major study be carried out with GRASP to parameterise the annual liveweight gain model to match these estimates for the different landtypes and forage systems at the time they were established. This parameterisation would also require estimates of how animals access different landtypes throughout the year, (e.g. red soil country in the wet season and black soil country during the dry season).

Task 2: Datasets from grazing trials.

Over the last 30 years, liveweight gains have been measured in major grazing trials and producer demonstration sites. These trials provide more intensive (i.e. monthly/seasonal) measurements of liveweight gain than are estimated from survey information of turnoff weights (as described in Task 1). A major issue in simulating and parameterising grazing trials is the organisation of stock management records (including stocking rate, liveweight, supplementation), so that daily animal grazing pressure can be accurately simulated. Most grazing trials also have reasonable soil and tree density descriptions. However, the collation of daily rainfall data remains a difficult issue given the paucity of records, particularly in terms of spatial coverage across the trial. Where pasture standing dry matter has been measured, it is possible to parameterise the pasture growth component of GRASP. Pasture growth, in combination with estimates of stocking rate and animal intake, allow pasture utilisation to be calculated. Thus, the relationships in GRASP between liveweight gain, intake and utilisation can be improved. The databases developed in Task 1 would provide, to some extent, a test of these new relationships. A well-recognised limitation of grazing trials is their small scale (i.e. small fenced paddocks compared to extensively grazed systems in northern Australia). In addition, newer data sets based on daily automated weighing should be included into GRASP model formats, allowing issues such as variation in gut fill to be addressed.

Task 3: Collation of estimates of animal intake.

A range of estimates of animal intake have been used in different regions of northern Australia. Datasets should be assembled documenting these estimates and where possible, comparing these with observed values measured in pens or controlled grazed situations. The intake relationships in GRASP were developed in 1984, and hence should be evaluated and updated.

Task 4: Parameterise existing annual liveweight gain model.

The datasets and relationships assembled/developed in Task 1 and Task 2 can be used to parameterise the existing multiple regression model that simulates annual liveweight gain in GRASP. The derived parameters should be added to the existing set of parameters developed by J. Scanlan and colleagues in the Northern Grazing Systems Project (NGS, "Enhancing adoption of improved grazing and fire management practices in northern Australia: Bio-economic analysis and regional assessment of management options; B.NBP.0578"). An issue that will need to be resolved in this task is how to derive the three parameters for the annual multiple regression from a single estimate of annual liveweight gain, such as reported by Bortolussi et al. (2005). J. Scanlan (NGS) and this review have indicated some approaches to achieving this difficult parameterisation.

Task 5: Parameterisation and changes to the existing (i.e. 1984) GRASP daily liveweight gain model.

In this review, J. Carter carried out a preliminary analysis of the performance of the existing daily liveweight gain model in GRASP, using the dataset of liveweight gain compiled by P. Hasker in the 1980s/early 1990s. The existing daily model in GRASP requires parameterisation of seasonal potential liveweight gain. The sequence of calculation is as follows: 1) potential liveweight gains are used to calculate potential animal intake; 2) actual animal intake is calculated from potential animal intake and simulated restrictions on animal intake due to high utilisation and/or standing dry matter availability; and 3) actual liveweight gain is then calculated from actual intake. This approach does not allow for year-to-year variation in potential liveweight gain, however, it does allow for the effects of stocking rate and variable pasture growth to be simulated. J. Carter's analysis (in this review) indicates improvements that could be made in this approach, in particular, the inclusion of monthly potential liveweight gains, rather than seasonal values. The additional datasets compiled in Task 1 and Task 2 will allow this simple approach to be further improved and parameter sets developed for northern Australia, including the effects of different landtypes and forage/feeding systems. Thus, users of GRASP across northern Australia will have more information available on pasture and animal parameters to facilitate its use in application studies.

Task 6: Development and parameterisation of a new daily liveweight gain model.

Our review documents the development of a new approach to simulating liveweight gain on a daily basis that allowed inclusion of year-to-year variability in potential liveweight gain. This approach is dependent on the ability to use parameter optimisation techniques to estimate daily relationships between liveweight gain and outputs of GRASP such as growth index days, standing dry matter, simulated percent nitrogen in the sward. We have demonstrated that this approach can be applied to a wide range of situations, and hence, the developments of datasets in Task 1 and Task 2 would allow a database of parameters to be developed to further support information in Task 5.

Task 7: Developing links with NIRS.
When GRASP was first developed in the early 1980s, very few data were available on diet selection and diet quality. Nevertheless, in 1982, preliminary approaches demonstrated that for one location (Brian Pastures, Gayndah) GRASP outputs could be used to simulate diet quality (percent diet nitrogen) from simulated sward age. Recent research by A. Ash and C. McDonald in the 'Northern Australia Beef Scoping Study' MLA project has indicated that this type of approach can be further developed across a range of locations and forage systems. Measurements assembled through NIRS would allow this approach to be extended and refined to a wider range of situations/locations, allowing simulation of diet quality as an output of GRASP. Where suitable models are available, these estimates of diet quality and amount could be used to simulate liveweight gain and other attributes of animal production, and provide a basis to the calculation of likely impact and value of dietary supplementation. This approach would allow GRASP to be usefully combined with current developments in animal production science to support the provision of advice for producers' decisions in terms of animal nutrition.

The application and subsequent outcomes of these seven tasks that link the approaches and models would be:

- the integration of current knowledge across the whole grazing system, including animal nutrition and natural resource sciences, allowing consideration of both production and sustainability issues;
- the combination of research findings (e.g. grazing trials) and grazier experiences (e.g. best practice) so as to extrapolate across regions, land types and climate variability/change; and
- the capability to evaluate tactical and strategic decision recommendations on grazing management and animal nutrition across northern Australia.

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11 Appendices

11.1 Appendix 1. Tabulation of further potential data sets

Whilst many potential data sets exist, most do not have existing GRASP parameterisations. GRASP has a large number of parameters (> 100), so tuning this model to any new environment is as much an art as science. Even for the data sets which had previously been studied, it was hoped that adequate parameterisations and GRASP simulations had already been conducted. However this was rarely the case, as these tended to be more focused on pasture simulations, with animal performance only of secondary (or nil) consideration.

The geographic location and spatial coverage of these targeted data sets is outlined in chapter 5.4. The details of the specific requirements for each are as follows -

Site:	Mt Sanford
General location:	Top end NT
Years:	1994-‘00
Pasture community (main type):	Mitchell grass & red country
Data custodian / key liaison:	R Cowley
Steps required (✔ = done; or nominated key person) -	
1. Find project milestone reports and establish liaison	✔
2. Collate rainfall for each paddock and climate file	✔
3. Collate paddock, pasture descr., tree density & land type	✔
4. Collate liveweight and stocking rate data	✔
5. Derive stocking rates from area grazed ('effective SR')	✔
6. Set up GRASP stock management records	
7. Set up GRASP TSDM records	
8. Parameterise soil, pasture, trees (SWIFTSYND)	
9. Estimate parameters to the individual paddocks	
10. Tune to SDM (trees, detachment)	
11. New file with steer-equivalent SR's with steer liveweight	G McKeon
12. GRASP (1994 spaghetti version) for required parameters (%GIdays & %Utilisation)	G McKeon
13. Known issues for accurate simulation	area grazed & land type ppns

Site:	Alex. Downs	Kidman Springs	Keilambette	Glentulloch
Location:	Top end NT	Top end NT	Central Qld	Central Qld
Years:				
Pastures:	Mitchell grass	Mitchell grass & red country	Aristida/ Bothriochloa	Aristida/ Bothriochloa
Liaison:	R Cowley	R Cowley	R Silcock, P Jones	T Hall, R Silcock
Steps -				
1.			✔	✔
2.			QCCCE	J Clewett
3.			QCCCE	T Hall
4.			Report	R Silcock
5.			R Silcock	T Hall
6.			G McKeon	G McKeon
7.			QCCCE	G McKeon, J Clewett, G Whish
8.			QCCCE	J Clewett
9.			QCCCE	G McKeon
10.			QCCCE	G McKeon, G Whish
11.	G McKeon	G McKeon	G McKeon	G McKeon
12.	G McKeon	G McKeon	G McKeon	G McKeon
13.	area grazed	land type & area grazed	effective tree density, soil infiltration attributes	tree density, rainfall data

Site:	Mt Bambling	EcoSAT	Narayen	Glass	Manbulloo
Location:	South-eastern Qld	North-eastern Qld	South-eastern Qld	South-eastern Qld	Top end NT
Years:	1996 - '01				
Pastures:	Black spear grass	Black spear grass	Black spear grass	Black spear grass	Tropical tall grass
Liaison:	Brian Pastures	J McIvor / C McDonald	J McIvor / C McDonald	C McDonald	C McDonald
Steps -					
1.					
2.					
3.					
4.					
5.					
6.					
7.					
8.					
9.					
10.					
11.	G McKeon				
12.	G McKeon				
13.	change in animal type				

11.2 Appendix 2. Derivation and validation of a daily liveweight change model

Where a single paddock is grazed by a draft of animals for 12 months, GRASP's ALWG Model 2 can been applied. However, the ALWG model is not applicable to situations where multiple paddocks are grazed by a draft of animals e.g. seasonal pasture spelling and/or the use of multiple forage systems. Utilisation Model 1, whilst designed for multiple paddock situations, does not easily represent year-to-year or seasonal climatic variation in potential LWG. An investigation was therefore conducted to combine the attributes of Models 1 and 2. The three original GRASP data sets, plus the Mt Sanford utilisation trial, contributed 875 measurements (average liveweights for cohorts of animals), with at least two observations (not including starting liveweight) per year for each location. We will refer to the combined data of the four grazing trials as '4GT' data set. The independent data set used for validation comes from Wambiana (see below).

The 4GT data set provides a wide range of climates, year-to-year rainfall variability and utilisation. Nevertheless, the good agreement achieved across the data set by the ALWG Model 2 demonstrated consistent responses to utilisation and %GIdays. Thus the combined data set provides a sound basis for developing a DLWG Model

The following section describes the development of a new daily LWG model for GRASP, combining the capabilities of Utilisation Model 1 and ALWG Model 2, namely:

- Model 1 calculated DLWG as a function of seasonal potential LWG and restrictions on intake; and
- Model 2 calculated annual LWG as a function of %utilisation of pasture growth and annual %GIdays.

Thus a logical combination of these two approaches is to:

1. calculate daily potential LWG as a function of the pasture growth index;
2. calculate a daily potential intake from potential LWG;
3. calculate actual daily intake considering restriction intake as a function of:
   a) utilisation of pasture growth since the start of the growing season; and
   b) available pasture SDM; and
4. calculate actual DLWG from actual intake.

In the following analysis we address a number of uncertainties:

a. variable start to the growing season, for calculation of the utilisation term, and
b. seasonal effects on the relationship between pasture growth index and potential LWG.

The formation of the DLWG is given below.

Terminology –

actIntake	actual dry matter intake (kg/animal/day)
dlwc	daily liveweight change of animals (kg)
pot_dlwc	potential daily liveweight change
ptIntake	potential dry matter intake (kg/animal/day)
actIntake	actual dry matter intake (kg/animal/day)
gix	growth index from GRASP
tscon	accumulated animal intake (kg/ha) since growing season started
tsdm	total standing dry matter (kg/ha)
tsdm0	total standing dry matter at start of growing season (e.g. 1st Dec)
tsgrowth	accumulated pasture growth (kg/ha) since growing season started

utilisation = (accumulated intake per ha since start of growing season e.g. 1st Dec) / (accumulated pasture growth since start of growing season)

Equations –

slope = (cf2 – cf1) / cf3

pot_dlwc = min (cf2, cf1 + slope * gix)

utilisation = tscon /(tsgrowth+cf7*tsdm0)

ptIntake = (pot_dlwc + 1.058) / 0.304 (following McKeon and Rickert, 1984)

Restrictions on intake are calculated as a function of utilisation (R1) and tsdm (R2):
R1 = min (1.0, cf4 + cf5 * utilisation)
R2 = min (1.0, tsdm / cf6)

actIntake = ptIntake * min (R1, R2)

dlwc = 0.304 * actIntake – 1.058

Fitting model parameters/coefficients -

The parameters for this daily liveweight change model, as listed in Table 1, were optimised using Solver in Microsoft Excel. The usual statistical method of minimising the sum of the squared residuals (observed minus fitted liveweight) was adopted.

Table 1. Optimal parameter values for the validation and recalibrated models.

Coefficient	Coefficient description	Optimal values for 4GT data set (used for Stage 3.2 validation)	Optimal values when model is recalibrated (to the Wambiana data set)
cf1	DLWG at gix = 0 (average over year)	-0.184	-0.405
cf2	DLWG at gix ≥ threshold (avg. over yr.)	0.722	0.641
cf3	gix threshold (average over year)	0.198	0.181
cf4	intercept (utilisation relationship)	1	1
cf5	slope (utilisation relationship)	-0.188	-0.240
cf6	TSDM threshold (for restricted intake)	21.6	0.2
cf7	% TSDM carried over each season	1.23	1.99
	gix threshold (‘break’ → ‘growing’)	0.483	0.478
	gix threshold (‘growing’ → ‘dry’)	0.230	0.066
	gix threshold (‘dry’ → ‘break’)	0.330	0.345

This DLWC model 3 was sequentially developed, with the overall degree of fit, estimated coefficients, and distributions of the residuals being checked at each step. Model development was carried out in three stages, as described below and summarised in Table 2. Preliminary investigation indicated that coefficient 'cf4' was always close to 1.0 and hence to facilitate optimisation, coefficient 'cf4' was set to 1.0.

Stage 1: Optimising utilisation model components -

Stage 1 concentrated on the utilisation component of the model by holding seasonal potential LWG constant. The coefficients (cf1 to cf6) for the DLWG model were fitted (stage 1.1) to be consistent with Utilisation Model 1 (described earlier in this report) and hence 'cf7' was set to zero. Seasonal potential LWGs were optimised considering the 4GT data set as a whole. Mean absolute error (MAE) for the base (Stage 1.1) calibration was 22 kg/hd. The variation between seasons in potential LWG was greater than used in previous studies (summer 84 kg/hd, autumn 68 kg/hd, winter -8 kg/hd, and spring 21 kg/hd). Similarly, the slope of utilisation (cf5, -0.176) and SDM restricting intake (62 kg/ha) were smaller than default values derived from previous studies (McKeon and Rickert 1984; McKeon et al. 2000). These new values will now be investigated as alternative default parameters in the general use of GRASP.

Solving for the start of the growing season (Stage 1.2) indicated 10th Dec as a better date than 1st Dec. Replacing seasonal potential LWG with monthly potential LWG (Stage 1.3) reduced MAE only slightly.

Investigation of the possible role of carryover SDM at the start of the growing season (cf7), indicated that only a small amount (i.e. 1%) was necessary to include in the calculation of utilisation.

Stage 2: Varying the start of the pasture growing season -

Seasonal rainfall distribution varies greatly from south east Queensland (with both winter and summer components) to the top end of the Northern Territory, with distinct wet/dry seasons. Similarly, year-to-year variation can result in a wide range of winter/dry season severity and variation in the start of the pasture growing season.

To investigate the value of modelling seasonal components of LWG, the year was classified into three periods:

1. summer growing season;
2. dry season; and
3. break of season.

The change from season to season was determined by the pasture growth index averaged over a moving 30 day-window. The variable start of the growing season was used to commence the accumulation of pasture growth for use in the utilisation restriction calculation. However, there was little improvement in MAE (22 kg/hd) with potential LWG optimised at either the seasonal (Stage 2.1) or monthly (Stage 2.2) timescales.

Stage 3: Year-to-year variation in potential daily LWG

The successful application of the ALWG Model 2 suggested that potential daily LWG was likely to vary with the pasture growth index. When potential daily LWG was calculated as a function of the 30 day average pasture growth index and combined with the utilisation calculation developed in Stage 2, there was a substantial improvement in the variation explained and MAE was reduced from 21 to 18 kg/hd (Stage 3.1). In this simulation (Stage 3.1), constant values of cf1,cf2 and cf3 were used throughout the whole year: potential LWG at zero growth index was -0.16; maximum LWG was 0.83; and the growth index for maximum LWG was 0.31.

Table 2. Developmental stages of the DLWC model – relative fit, and optimised parameters (the column headings in italics).

Stage	Description / improvement	MAE (kg)	R-sq.	% improv.	*Slope (util.)*	*No-restr. yield*	*Reset time*		
1.1	Seasonal PotDLWGs	21.67	88.78		-0.18	61.8	1 Dec.		
1.2	Accum. date re-set (prev. 1 Dec.)	21.48	89.01	2.0	-0.22	67.1	10 Dec.		
1.3	1.2 + Monthly PotDLWGs	21.17	89.23	2.0	-0.23	9.0	10 Dec.		
							3to1 GIX	*1to2 GIX*	*2to3 GIX*
2.1	Reset date ~ f (30-d. avg. GIX)	22.36	88.10	-8.3	-0.35	3.1	0.493	0.229	0.310
2.2	Monthly PotDLWGs	22.25	88.31	1.8	-0.34	9.8	0.493	0.229	0.322
3.1	(3.2 but no cyclic components)	18.05	92.60	36.7	-0.14	41.2	0.483	0.230	0.330
3.2	PotDLWGs ~f(30-d. GIX)	16.12	94.30	23.0	-0.19	21.6	0.483	0.230	0.330
3.3	PotDLWGs ~f(daily GIX)	16.38	94.11	-3.3	-0.17	46.6	0.784	0.318	0.335
3.4	PotDLWGs ~f(30-d. ppn GIX > 0.05)	16.29	94.28	-0.4	-0.22	51.9	0.735	0.198	0.431
3.5	3.4 + varying the ppnGIX th'hold (optimal=0.095)	16.21	94.30	0.3	-0.18	51.5	0.606	0.174	0.423

We then investigated how the relationship between growth index and potential LWG varied throughout the year. To achieve this, sinusoidal functions were fitted for cf1,cf2 and cf3, as follows :

cf =(Intercept + Magnitude * COS (2 * PI * (Year_ppn + Time-shift))), where
Year_ppn is the proportion of the year, = (day – 1) / 365

When coefficients cf1-3 were allowed to vary through the year (Figure 1, Stage 3.2), there was further improvement with MAE reducing from 18 to 16 kg/d. Figure 2 shows the average fitted relationships between pasture growth index and potential DLWG for each season. When the pasture growth index is near zero, potential daily LWG (cf1) is much lower in winter/dry season (-0.44 kg/hd/day) than in summer (0.08 kg/hd/day). Similarly, the maximum potential daily LWG (cf2) is higher in summer (0.88 kg/hd/day) than in winter (0.57 kg/hd/day).

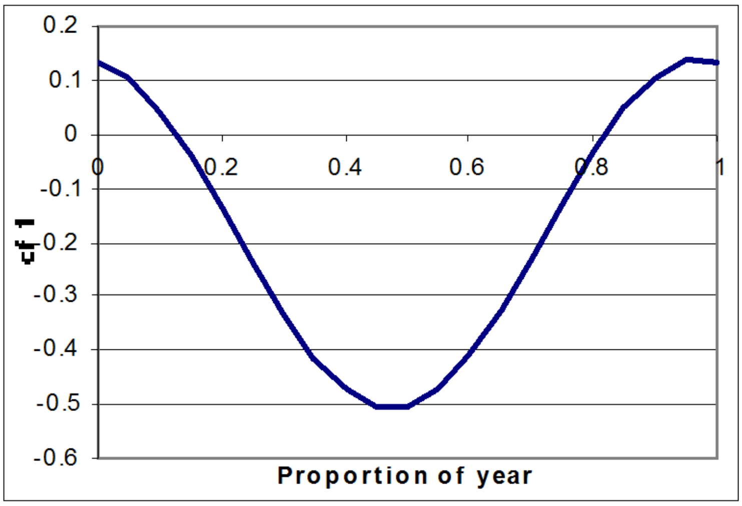


Figure 1a. Annual cycle for DLWC coefficient 1 (cf1) – liveweight change (kg/hd/d) when 30-day average GIX is zero.

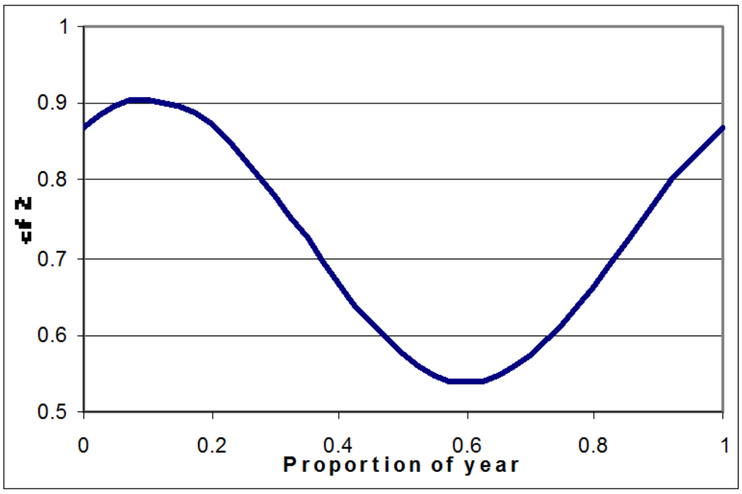


Figure 1b. Annual cycle for DLWC coefficient 2 (cf2) – liveweight change (kg/hd/d) when 30-day average GIX is greater than the GIX threshold.

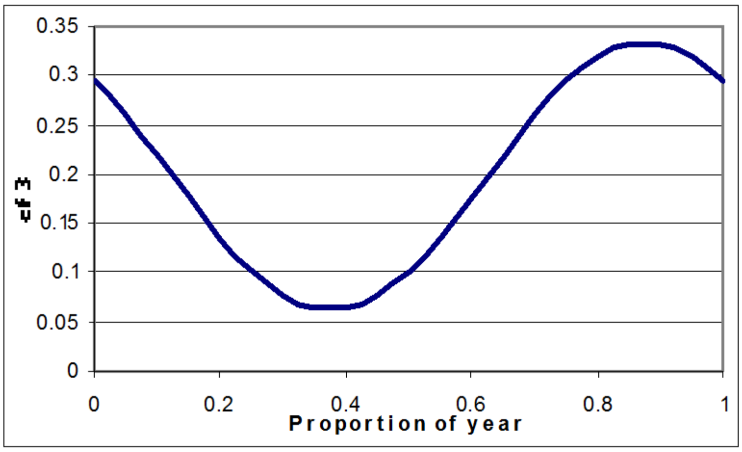


Figure 1c. Annual cycle for DLWC coefficient 3 (cf3) – the GIX threshold.

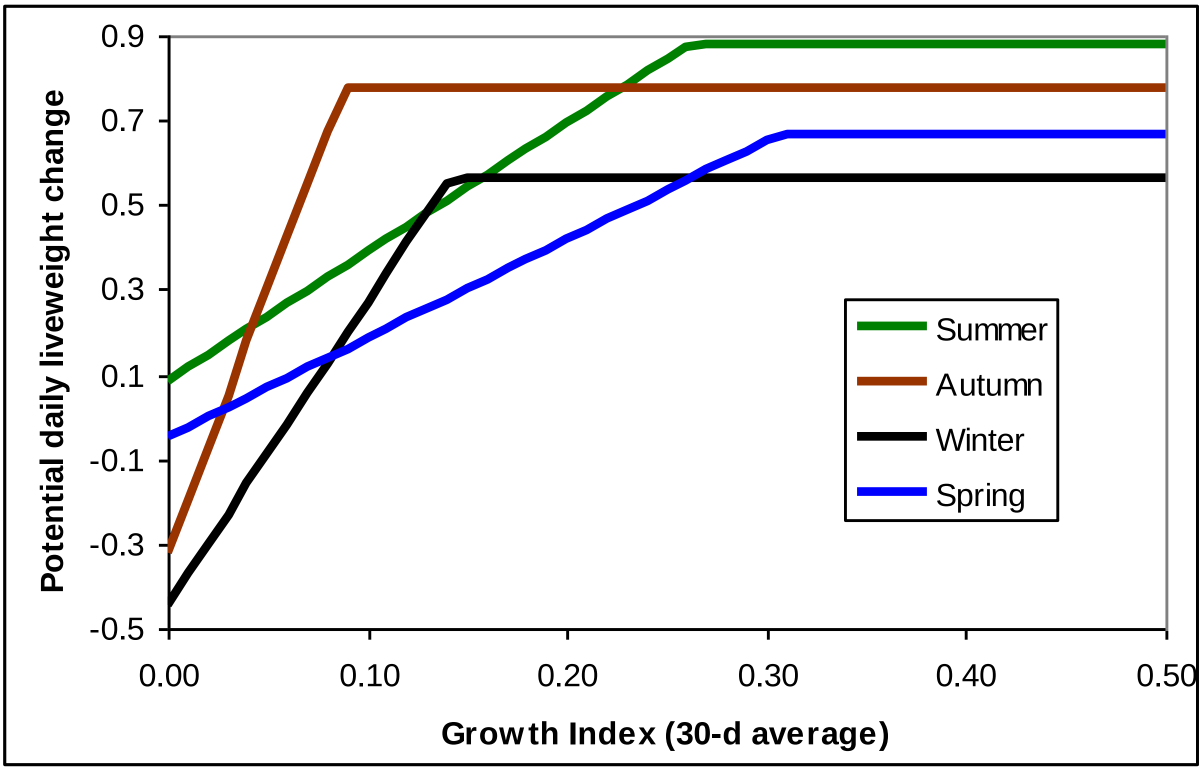


Figure 2. Potential DLWC vs. growth index, averaged across the seasons.

The pasture growth index at which maximum potential daily LWG occurs (cf3) was lower for autumn and winter, indicating greater positive impact on animal nutrition of favourable growing conditions at these times of year.

The derived relationships (between pasture growth index and potential LWG) are consistent with previous analyses of varying seasonal relationships between pasture growth index and LWG (e.g. McCown et al.1980, McKeon et al. 1980).

Alternative approaches in representing the pasture growth index term were also investigated. The approaches were:

a. Stage 3.3 – use of daily pasture growth index in contrast to a 30 day moving average;
b. Stage 3.4 – % of 30 days with pasture growth index greater than a threshold value of 0.05 (similar to the approach used in ALWG Model 2 above); and
c. Stage 3.5 – same as Stage 3.4, but with the growth index threshold value (0.095) derived from the optimisation procedure.

These results showed little difference in MAE (≈16 kg/hd) indicating that the approach of varying through the year the relationship between a pasture growth index term and DLWG was robust across a range of different representations of the pasture growth index term. Figure 3 shows the fit for the model (Stage 3.2) over time for one of the stocking rates at Galloway Plains.

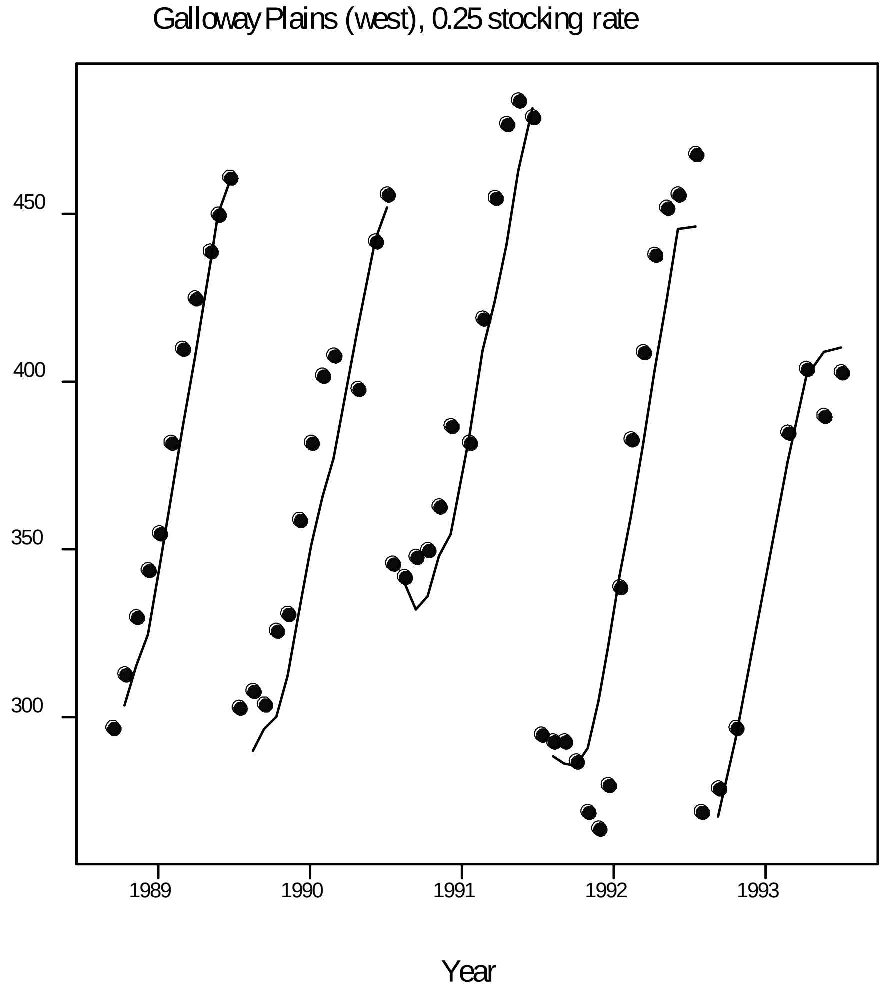


Figure 3. Observed (dots) and predicted (lines) weights over time.

Summary of model performance -

Over all (875) observations of liveweight, the lowest MAE (16.1 kg/hd) was achieved with Stage 3.2. For all average daily gains (ADG, calculated as LWG between weights divided by days), the fitted model accounted for 65% of the variation, with an MAE of 0.11 kg/hd/day compared to a mean ADG of 0.20 kg/hd/day. This relatively high error is consistent with the high variability of short term (monthly to seasonal) measurements of LWG (and liveweight losses) compared longer annual periods. The data set included 186 observations of near-annual (>10 month) LWGs. The DLWG model accounted for 77% of the variability, with an MAE (0.045 kg/hd/day) being 13% of near- annual LWG (average of 186 values was 0.35 kg/hd/day). Expressed as annual LWGs (i.e. multiplied by 365 days) average LWG was 130 kg/hd/year with an MAE of 16 kg/hd/year. Thus the fitted daily LWG model retained the features of the ALWG Model 2 (described previously), whilst providing more flexibility in simulating shorter term (monthly-seasonal) LWG. However, the error in ADG for shorter periods is relatively large (0.11 kg/hd/day) and requires more investigation than was possible in this scoping study.

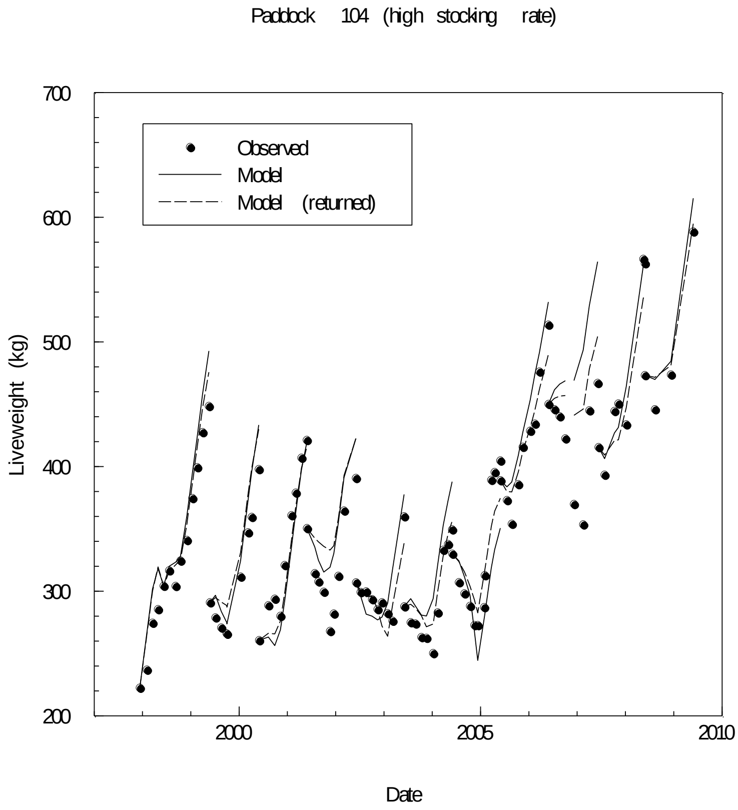
Preliminary independent test of new daily model -

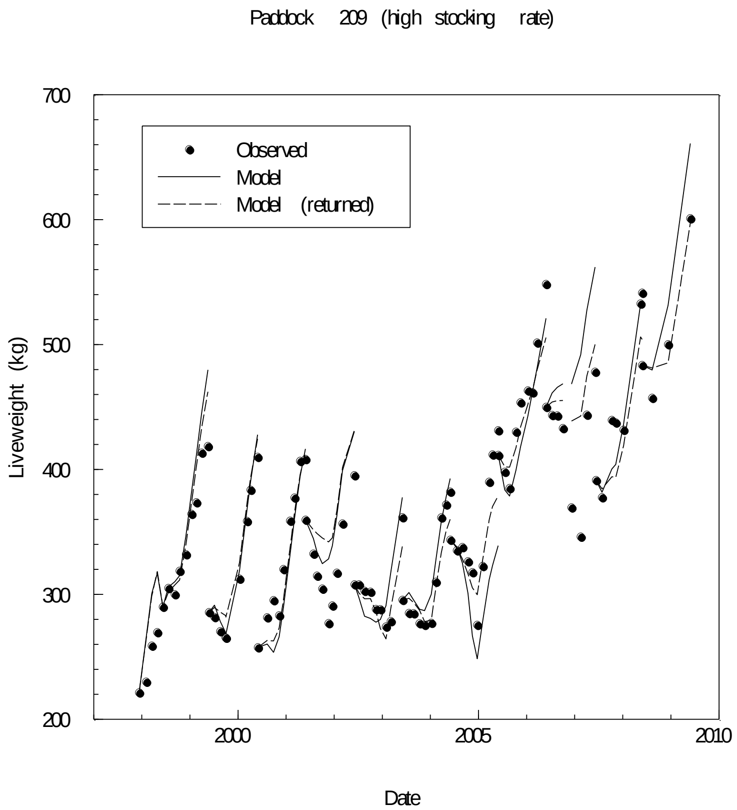
A preliminary test was developed with an independent data set for 4 paddocks from the Wambiana grazing trial (O'Reagain et al. 2009). The test is regarded as preliminary at this time (December 2012), as uncertainties regarding stock management during drought periods, pasture parameterisation, and rainfall files for each paddock are yet to be resolved. The 4 paddocks were the replicates of the Moderate and High stocking rate treatments, with liveweight measurements available over 12 years duration (341 observations; i.e. approximately 7 per paddock per year). Table 3 lists the model performance over years, and Figure 4 shows the actual data along with the model predictions. For the Moderate stocking rate paddocks, MAE was 20 kg/hd compared with 16 kg/hd for the 4GT data set described above. For the High stocking rate paddocks, MAE was higher (27 kg/hd). Over the 4 paddocks, MAE was 24 kg/hd for the 341 observations. In 3 years (2004/05, 2006/07 and 2008/09), there were major outliers with MAE of 40 kg/hd, whilst in the other 9 years, MAE was 20 kg/hd, ranging from 12 to 32 kg/hd for individual years. The years 2004/05 and 2006/07 had been previously identified as outliers by Scanlan et al. (in press). These years included periods of large liveweight losses during their respective dry seasons. We are uncertain whether the simulation for the High Stocking rate paddocks correctly represents stock and paddock management in these years.

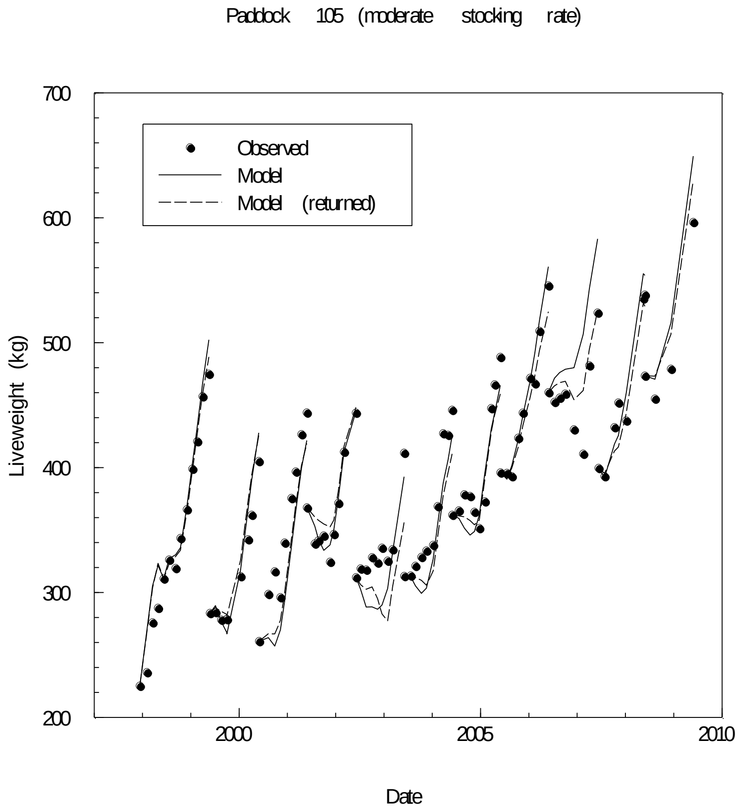
Table 3. Mean absolute error of weight changes (kg) by years, for the validation (Stage 3.2 parameters) and recalibrated models, and for all observed data as well as the 'annual' (> 10 month) weight changes only.

Season	All data –		'Annual' (> 10 months) –	
	Validation	Recalibrated	Validation	Recalibrated
1997/98	32.1	31.6	–	–
1998/99	15.5	10.6	41.4	25.9
1999/00	11.9	14.2	19.1	18.9
2000/01	29.1	24.3	17.1	16.7
2001/02	20.4	26.8	19.7	19.9
2002/03	19.9	19.2	14.0	35.1
2003/04	17.1	15.1	17.8	19.9
2004/05	28.8	18.8	46.9	31.2
2005/06	16.8	11.7	24.1	22.0
2006/07	58.5	28.9	76.8	22.5
2007/08	15.6	19.0	11.6	18.4
2008/09	32.7	20.3	51.1	21.4
'Outlier' years[#]	40.0	22.7	58.3	25.0
Others	19.8	19.2	20.6	22.1

[#] (2004/05, 2006/07 and 2008/09)


Paddock 104 (high stocking rate)
Observed
Model
Model (returned)
Liveweight (kg)
700
600
500
400
300
200
2000
2005
2010
Date


Paddock 209 (high stocking rate)
Observed
Model
Model (returned)
Liveweight (kg)
700
600
500
400
300
200
2000
2005
2010
Date



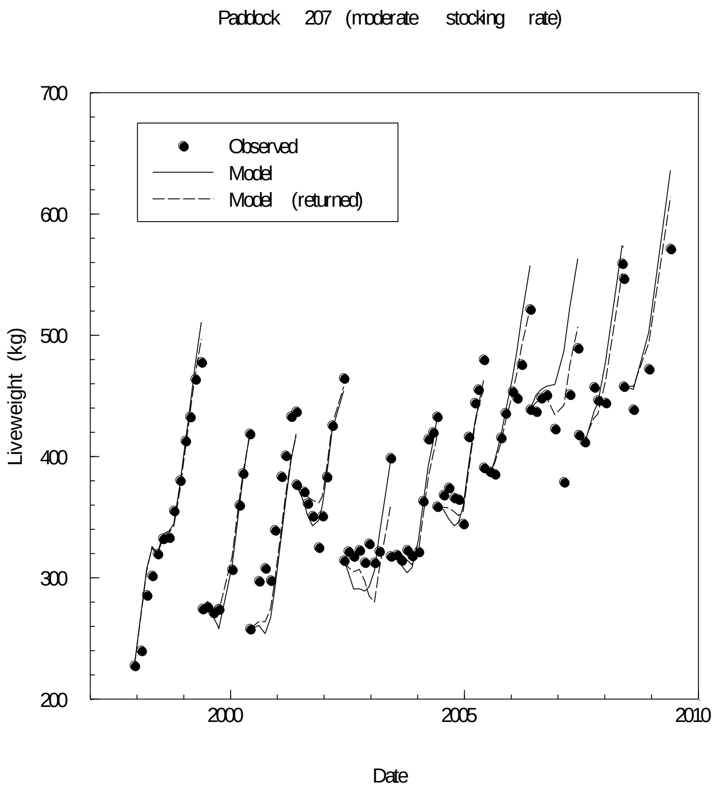


Figure 4. Observed weights and model predictions (validation and recalibrated models) over time, separately for each Wambiana paddock.

Uncertainties regarding stock management in the outlier not withstanding, recalibration of coefficients for the Wambiana data set indicated that substantial improvement was possible in the simulation of observed liveweight with the overall MAE reduced from 24 to 19 kg/hd. Recalibrated coefficients showed that the Wambiana data indicated greater liveweight losses when the pasture growth index was near zero (-0.405 kg/hd/day compared with -0.18 kg/hd/day for the 4GT data set, Stage 3.2). The recalibrated daily model substantially improved the simulation of the outlier years identified above (MAE of 23 kg/hd compared with 40 kg/hd using Stage 3.2 parameters). There was also a slight improvement in the other 9 years (MAE of 19 kg/hd compared with 20 kg/hd using Stage 3.2 parameters).

Although the preliminary independent test was only partially successful (i.e. in 9 of the 12 years), the recalibration of model coefficients indicated that substantial improvement could be achieved by allowing for greater liveweight loss during severe dry seasons. The need for more general models of the coefficients in the DLWG (Stage 3.2) will be further investigated when rainfall, pasture parameterisations and paddock and stock management in response to feed shortages have been revisited.

Discussion

The above analyses show that a daily LWG model was successfully developed, combining the features of existing GRASP LWG models (namely Utilisation Model 1 and ALWG Model 2 described previously). However, the DLWG model is yet to be more fully tested with regard to simulation of grazing management strategies (e.g. Wambiana – all treatments, and Pigeon Hole), and in forage systems where pastures are grazed only in selected seasons (e.g. McKeon and Rickert 1984). A potential limitation of the DLWG model is the difficulty of representing issues such as seasonal supplementation, legume augmentation, changes in gut contents, and compensatory gain. More sophisticated models of animal growth considering lifetime growth patterns will be required to address some of these issues. Nevertheless, the DLWG model provides an approach to representing some of the sources of variability derived from climate and utilisation, and providing the flexibility of simulating LWG at shorter timescales (e.g. seasonal).

References

(see this report's Bibliography)

11.3 Appendix 3. Grazing trials for liveweight gain analyses

(study conducted by Grant Stone and Greg McKeon)

Introduction

Purpose of using grazing trials for modelling liveweight gain with GRASP

Grazing trials conducted by DEEDI/QDPI and CSIRO over the past ≈fifty years have generally been designed for a particular purpose (e.g. stocking rate analysis or pasture-type suitability). Trials represent a considerable investment to Government and industry organisations, however, once completed and results are published, the data are seldom used again. Projects such as this review (B.NBP.0641) demonstrate that there is potential for these trials to contribute beyond the purpose for which they were originally conducted. Data collected from trials at great expense can be considered as a reservoir of information that can be further utilised for future analyses. These data include pasture yields, liveweight, runoff, rainfall, animal breed and age, and stock management/husbandry records.

The GRASP model was developed to extrapolate the knowledge gained in grazing trials. To achieve this goal, GRASP has to be calibrated (i.e. parameterised) for the specific soil, pasture and animal attributes of the trial. Before the process of calibration can occur, grazing trial data has to be organised in a form that allow repeated simulations of individual paddocks within the trial. These files known as management record files (e.g. *.mrx) describe the detailed management of individual paddocks, including:

1. dates of stock entry and departure, as well as stocking rate, liveweight, age, breed and stock type and supplementation; and
2. dates of pasture management such as pasture burning/removal, pasture cutting (i.e. for growth studies).

The files also include dates of soil, pasture and animal measurements, which allow rapid and repeated comparison of simulated and observed variables. The procedure known as model calibration, allows key soil, pasture and animal parameters (e.g. potential nitrogen uptake) to be calculated in order to simulate each paddock in the trial as accurately as possible. These parameters are the key to extrapolation of trials to other locations and management options. The following section describes issues that arise in data preparation, organisation and calibration.

The purpose of using grazing trials for this review project has been to extract animal liveweight, pasture data and associated information (e.g. pasture and stock management), to derive and test new relationships in the GRASP Model. It is important to have a thorough understanding of the treatments imposed in the trial, management employed (e.g. pasture type, supplementation, burning) as well as soil and land type effects that are present in the trial area to make the best inference of the results and trial data. Other sources of variability that influence pasture growth and animal liveweight gain include spatial and temporal distribution of rainfall and animal age and therefore need to be identified and quantified.

Existing grazing trials
Grazing trials that have been conducted by DEEDI/QDPI and N.T. Dept of Resources (DoR) were considered to be primary data sources for liveweight gain analysis for northern Australia. From initial assessment for northern Australia, those having the most potential include:

- Swans Lagoon – NQ.
- Mt. Bambling – SQ.
- Galloway Plains – CQ.
- Glentulloch – CQ.
- Keilambete – CQ.
- Wambiana – NQ.
- Brigalow – CQ.
- Pigeon Hole – N.T. DoR
- Mt Sanford – N.T. DoR
- Springmount – NQ.

Other grazing trials that are likely to be useful as data sources (but as yet have not been investigated in detail) include: Rosebank (DEEDI; western Qld), Narayen and Glenwood (CSIRO; southern Qld.), the cell grazing project (DEEDI; multiple Qld sites), Hasker data collation (DEEDI, multiple northern Australia sites), Manbulloo (CSIRO), Kidman Springs (N.T. DoR). Chapter 5 of this report has mapped locations of previously analysed grazing trials as well as sites with further potential to be investigated.

The following sections will cover the approach of preparing and analysing grazing trial data and assessing aspects of concern for modelling, using examples in particular grazing trials. These sections do not repeat the findings from previous project reports, however, some findings here have not been previously reported. These important aspects of variability are highlighted for the purpose of reducing errors in further analyses and indicating likely issues in modelling the trials. The following sections include:

- Data organisation process;
- Sources of variability;
- Galloway Plains grazing trial – case study;
- Wambiana grazing trial – case study;
- Intake calculation comparison; and a
- Utilisation calculation using QuikIntake and GRASP

Data organisation process

Data organisation from grazing trials as input for the GRASP model is a painstaking process and requires exacting organisation. Grazing trials usually include many different data types (e.g. rainfall, pasture, animal). In addition, the sequence of stock management including drought feeding and destocking has to be accurately recorded. It is a worthwhile investment, however, as once the organisation process is completed, files may be used for multiple purposes with the knowledge that the data content has been prepared to a high standard.

To organise data from grazing trials, there is a need to know a trial intimately. Knowledge of grazing trial is best gained from the relevant investigators and technical staff. To aid interpretation, it is advisable to obtain interim and final reports and publications to assemble the main results from the trial, as well as necessary detail of the trial management that may not be included in other published material (e.g. conference and journal articles). As trial information is gathered on data sources and management, it should be recorded to provide an insight for future data users – this reduces time-utilisation and repetition on future investigation.

Each set of trial data may be held in a different format including text files, spreadsheets, databases or hardcopy. The setting out of the data may also vary, with samplings, weighings etc. consistently expressed in columns and rows, or a variation of styles, due to the change of the recording officer. It is desirable that data are recorded clearly, logically and consistently for the purpose of extraction, collation and manipulation.

Missing or erroneous data are a contentious issue. While it is accepted that field data will contain some degree of error, larger errors (e.g. typos, logger errors) can lead to poor data quality, though it is debatable how much single entry errors may contribute to overall data error. Although it is an additional task, care should be taken to identify missing or erroneous data values and to ascertain from the trial operatives whether they can verify the values. If the anomalous values cannot be verified, then ‘best estimate’ proxy values should be entered with comments attached in the spreadsheet and GRASP management files. Checking for anomalous values in rainfall data, pasture samplings and animal liveweights have the most relevance for this review project, however, the list should include any data collected.

Sources of variability

In addition to actual errors in data collected, there are sources of variability which impact on data quality. Modellers and other users of trial data need to know to know the sources of variability prior to analysis to account for the variability in parameterisation. The process of modelling parameterisation also identifies ‘outliers’ in the data, which require further investigation before further model calibration. Sources of variation found in grazing trial data include:

- rainfall variation in distribution across paddocks
- soil and land type
- pasture type variability
- treatment effect
- fasted compared to unfasted animal weights
- animal age
- animal source

Examples of these sources of variability will be discussed in further detail in the following 'case study' sections.

Galloway Plains Trial – case study
Introduction
The Galloway Plains grazing trial was initiated to better understand the interaction of stocking rates (steers) with pasture dynamics, legume augmentation, burning and supplementation in the sub-coastal zone of central Queensland. The complexity of analysis for Galloway Plains trial increases due to the heterogeneous nature of soils, pasture species and animal aspects inherent in the trial site, which are described in further detail in this case study. The results of the Galloway Plains grazing trial have been described comprehensively in the following refereed publication (Orr and Burrows 2011). Key details of the trial are given below.

- Location: Calliope (central Qld).
- Established 1988 – discontinued 2001.
- Dominant species: *Hetreropogon contortus* (Black speargrass) – East replicate, *Bothriochloa bladhii* (Forest bluegrass) west replicate.
- Timber species: Silver leaf ironbark (East replicate); box and bluegum (west replicate)
- Stocking rate trial – steers (mainly annual drafts).
- Treatments: Native Pasture, Legumes + Burn treatments.
- Replicated (east/west), however, major difference in soil types (duplex; East rep) (clay/alluvial; west rep) exist between the replicates.
- Data: Pasture, liveweight, rainfall, runoff.
- Calibration – several attempts since 1995 (needs to be re-done).
- Management record status: 28 paddocks x 13 years converted to 4400 individual management and observation records which is contained in a management file known as a "mrx stack".

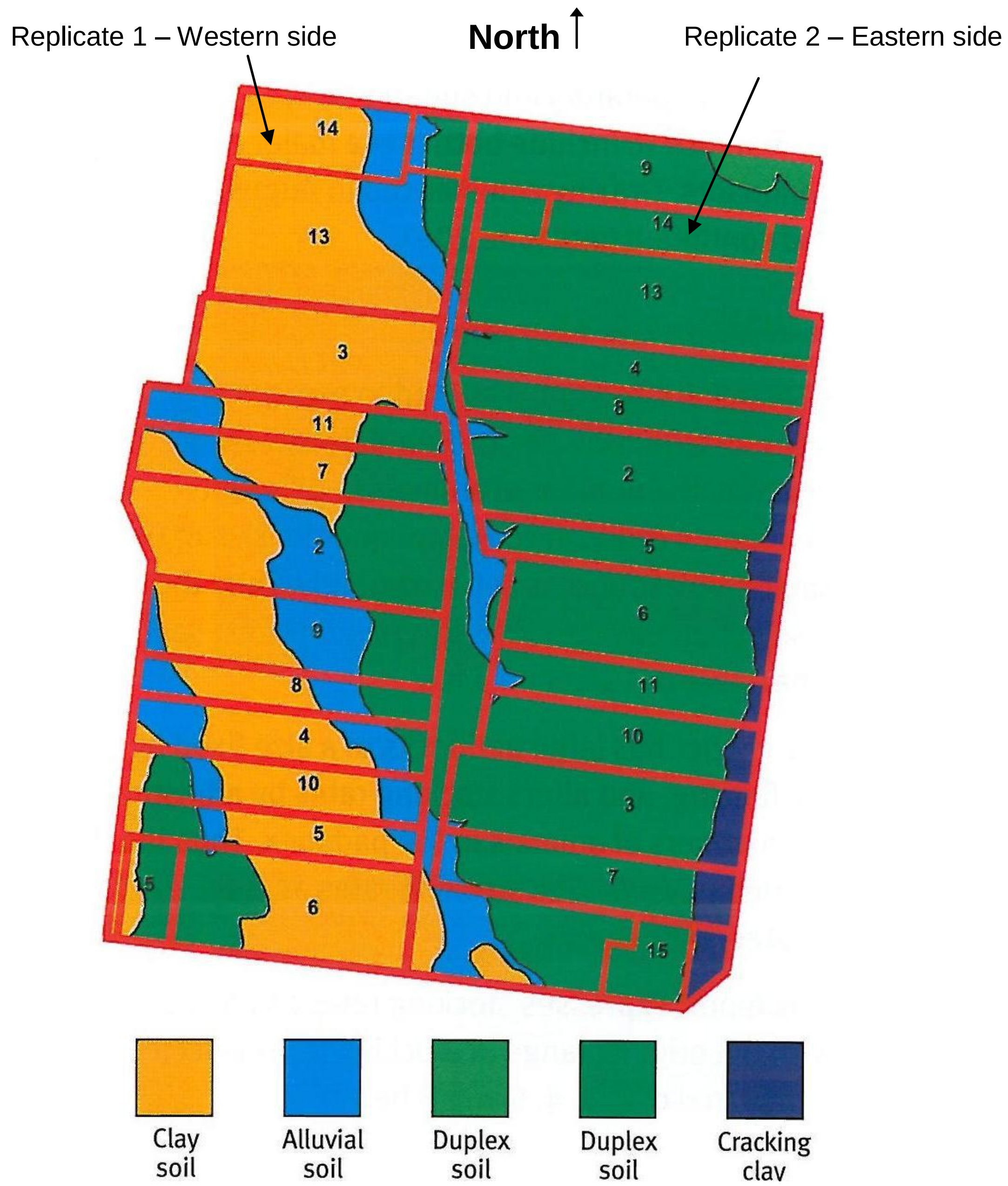
Output includes:

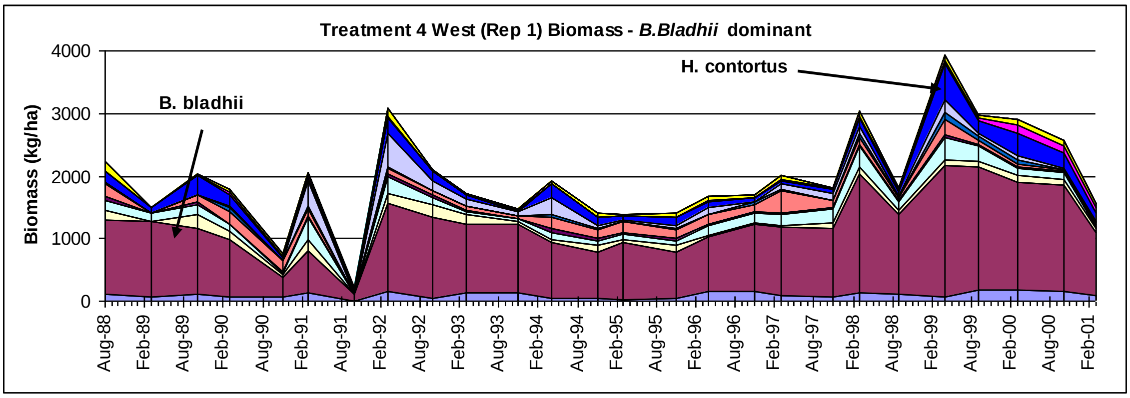
- pasture growth, composition, runoff, liveweight analysis and utilisation calculation
- Commercial property (Voewood) comparison data.
- Reports, papers, analyses to date.
- Issues: soil type variability, species variability, replicate consistency, rainfall distribution/accuracy, animal age.

Issues of variability for liveweight gain at Galloway Plains
Soil type variability
The Galloway Plains trial site is shown in Figure 1. The western side of the trial (Replicate 1) has a combination of soil types including alluvial, clay and duplex that vary in proportion from north to south. There are also varying numbers of box and bluegum tree species across the replicate. In contrast, the eastern side of the trial (Replicate 2) has one dominant soil type (duplex), which is associated with silverleaf ironbark tree species. Figure 2 shows that replicate 1 (west) was *Bothriochloa bladhii* dominant, while replicate 2 (east) was *Heteropogon contortus* dominant. While both species are considered 3P grasses for animal production (perennial, palatable, productive), this difference has an impact on LWG of animals as *B. bladhii* is an inferior pasture grass compared to *H. contortus,* since it has the capacity to dilute its nitrogen content to very low levels (e.g. 0.3%). The effect of this

nitrogen dilution is a grass that is coarser, stalkier, lower in protein and digestibility and is likely to produce lower LWG compared to *H. contortus*. As a result the two replicates should be treated as separate entities in model calibration, due to different soil/pasture conditions.

Figure 1. The Galloway Plains trial site. The western side of the trial (Replicate 1) has a combination of soil types including alluvial, clay and duplex that vary in proportion from North to south. The eastern side of the trial (Replicate 2) has one dominant soil type (i.e. two variants of duplex).





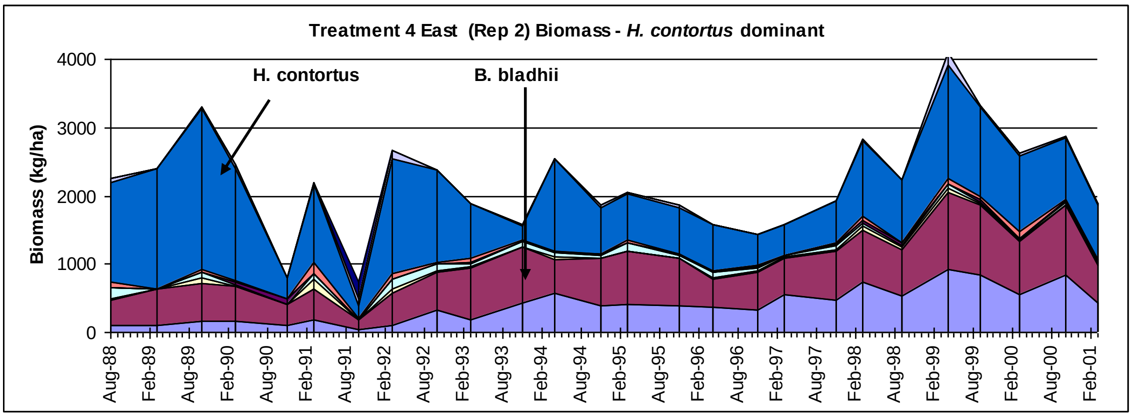


Figure 2. Pasture biomass (kg/ha) for Galloway Plains treatment 4 (0.375 beasts/ha). Replicate 1 (west) is *Bothriochloa bladhii* dominant, while replicate 2 (east) is *Heteropogon contortus* dominant.

Treatment and pasture species variability

To add to the complexity for modelling calibration, the paddocks of the western side of the trial (Rep 1) need to be parameterised individually. This is due to the variation in soil type proportion occurring throughout the replicate that can be seen in figure 1, which, as a consequence has produced variation in the proportion of the two dominant pasture species grown (i.e. *B. bladhii* and *H. contortus*).

For the western replicate, figure 3 shows the %yield of *B. bladhii* and *H. contortus* for paddocks at the start and finish of the trial, ordered from the north to the south. At the start of the trial, the proportion of *H. contortus* declined from ≈30% at the northern end down to ≈5% at the southern end of the replicate. In contrast, the proportion of *B. bladhii* increased from ≈30% at the northern end, to 40-60% in the centre and southern end of the replicate. These general effects are apparent at the start and finish of the trial.

As explained above, *B. bladhii* and *H. contortus* are both considered 3P grasses, but the differences in the proportion available to animals will have an impact on LWG, therefore confounding the treatment effects.

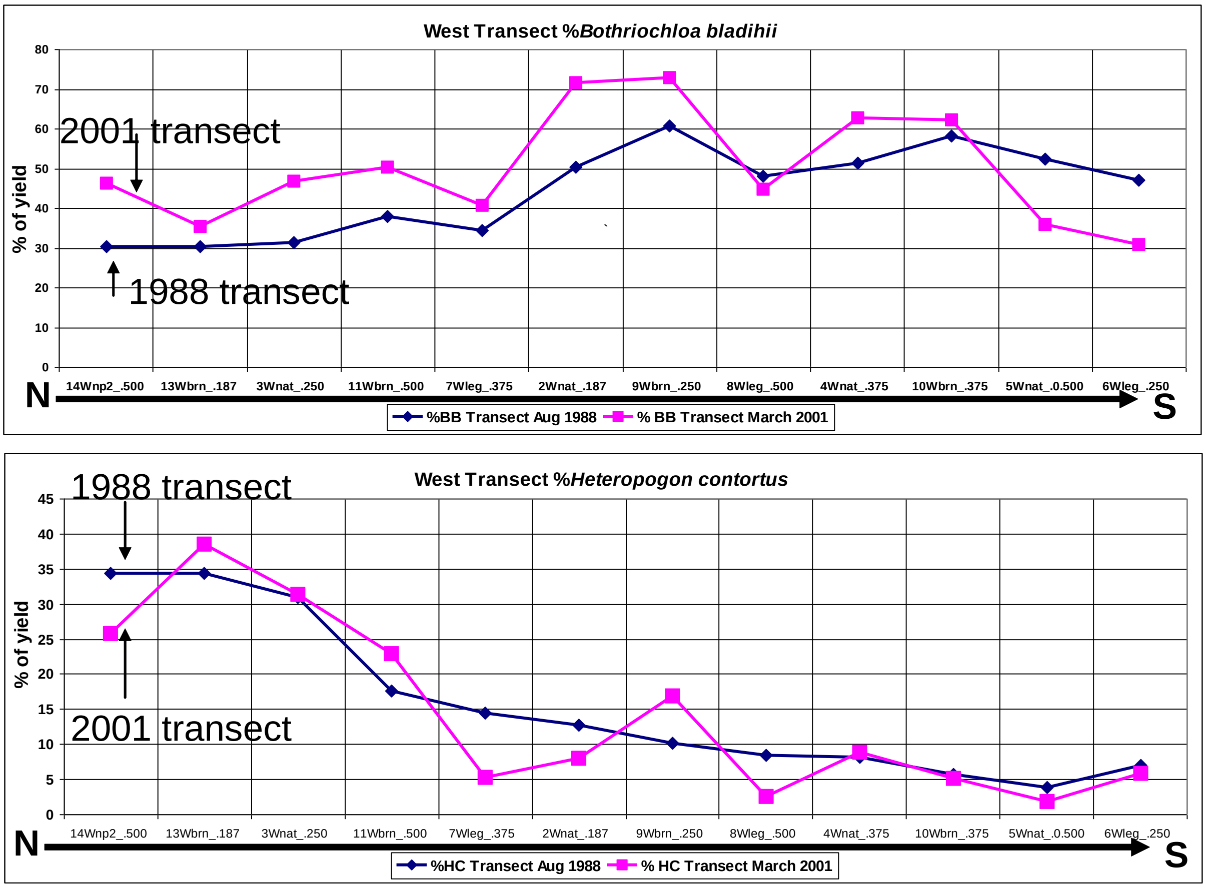


Figure 3. Percentage yield for *B. bladhii* and *H. contortus* for western side (Rep 1) at initial (1988) and final (2001) stages of the trial. It shows the variation in proportion of the two species moving from the north (left side of graph) to the south (to right side of graph) of the replicate.

Rainfall variability

Variation in rainfall across a grazing trial site can be an issue for modelling purposes, depending on the size of the trial, the number of gauges at the trial site and the reliability of the gauges. In the Galloway Plains trial, a daily rainfall file (*.dr2) was prepared to accompany the management record file to be used as input for the GRASP model. The rainfall file was assembled by G. Stone from various automatic and manual gauges placed across the site, as no one gauge registered rainfall consistently over the trial duration, in fact some rainfall periods had to be apportioned from manual gauges and patched using the daily data from the closest reporting rainfall station (Calliope Station).

The daily rainfall file prepared Galloway Plains was thought to be the closest to the actual rainfall that was received at the trial site. However, recent pasture modelling attempts by G. McKeon show some anomalous results that may indicate that either the daily rainfall file has errors or that spatially, one file is not sufficient for the entire site – or it is possible that other modelling factors need to be assessed.

Animal variability issues

Modelling data issues resulting from the animal aspect of trials include: animal age, gender, breed and location source; and animal management/husbandry – such as fasted and unfasted weighing, supplementation and drought feeding. Fasting of animals influence liveweight measurement and consistency of LWG calculations within and between cohorts (drafts). For example, on a cohort basis, were the animals dry or wet fasted; was it an overnight fast; was it a 12-hour fast; were the animals trucked or walked from a property close by; or sourced from a saleyard or distant property where the animals had been mustered, drafted and transported. Information is required on what time of day unfasted weights were taken, time, distance and difficulty with mustering and whether this occurred consistently for the animals.

Variability in animal age is known to have an impact on animal intake and also liveweight gain (Burrows *et al.* 2010, Jones 1997, Jones and Coates 1992), as will breeding animals (accounting for conceptus and lactation) compared to dry animals. Older (and larger animals) tend to lose more weight in dry times, but will generally recover in the wet season due to compensatory growth. In addition, if a draft is only partially destocked (i.e. a number of animals are retained), then a number of behaviour dynamics occur when new animals are added, which will cause variability in liveweight gain, as the retained animals are more settled than the newcomers, and introductions result in establishment of a new pecking order.

The Galloway Plains trial used steers that were ≈15-18 months old with variable initial weights which ranged from 172kg to 329kg per cohort. Generally, there was an annual cohort of animals known as a “draft” (e.g. draft 1, 2, 3 etc.), though the period of residence ranged from 35–58 weeks. Fasted weights were taken on entry and exit of each draft of animals. Unfasted weights were taken at intervals which varied from 4-weekly to 6-weekly weighings for the period of residence.

From 1992/93 a portion of the cohort for each treatment (the lightest animals) was held over for a further 12 months. New animals were introduced, but at the younger starting weight (12 months younger). However, it was not possible to analyse the different liveweight gains between the two ages for this review, as age ‘tag’ information was not available. As a result, this analysis on age effect was performed for the Wambiana grazing trial and is presented in the case study below.

A consensus should be reached whether fasted or unfasted liveweight should be used for LWG analysis, as variability exists in both measures. As explained above, there are issues with which fasting method is employed. Additionally unfasted weighings can have a degree of variation. Unfasted liveweights are usually collected at a time of day when there is less variation in aspects of the animals behaviour (e.g. drinking, feeding, defecating). For example, it is desirable that the animals are removed from each paddock before they set out to graze, but have had access to water (e.g. in the morning). However, it is possible that not all animals have actually had a drink, which is then reflected if the daily liveweight gains per head are calculated.

As an example, figure 4 shows that the liveweight change of one animal (animal #20 - pink line and square) was affected twice by gutfill changes (i.e. out of synchrony with other animals’ liveweight change) in one draft period. In the first instance (start of period), the animal appeared to have had a drink (which can amount to 20-30kg) when the other animals appeared to have not had a drink, which gives the impression that the animal has gained more weight per day. The second instance (end of period) shows the opposite effect, when the one animal appears to have missed out on a drink before being mustered for weighing. The example demonstrates that there can substantial variation when using the initial and final unfasted liveweights. The knowledge that such variability exists influencing LWG measurements reduces the expected variation that can be explained by model calibration.

An issue also exists with the effect that animal temperament may have on liveweights (fasted or unfasted). If there is difficulty in yarding highly-strung animals (particularly high-grade *Bos indicus* animals), then more emptying of gut contents will occur, with less liveweight gain in contrast to the more passive animals in the group. Care should be taken to select animals with even temperament and low ‘flight distance’ characteristics.

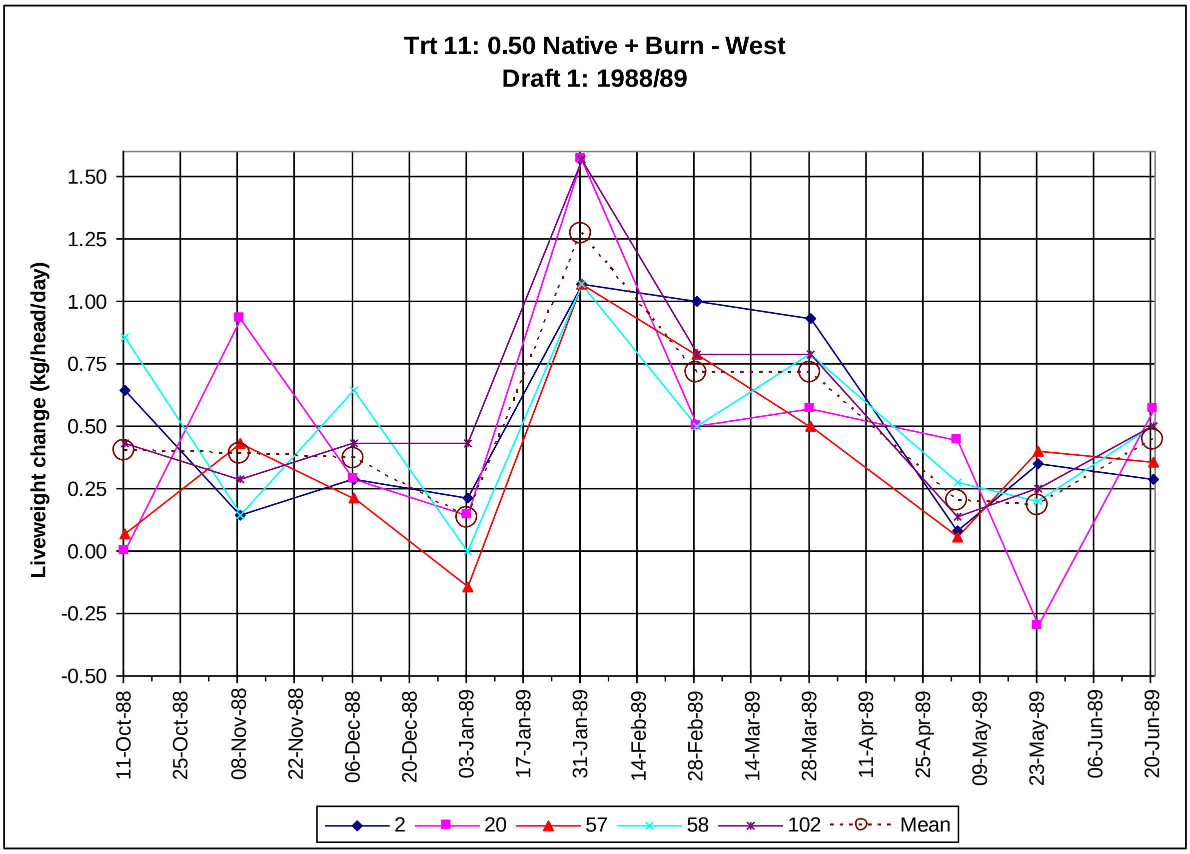


Figure 4. Unfasted liveweight gain per day (kg/hd/day) calculated from 4-6 weekly weighing intervals.

Generally, fasted liveweight gain is used for analysing animal performance in grazing trials, but is there a difference between the fasted and unfasted liveweight gain over the trial draft-periods? Mean fasted and unfasted liveweight gains were compared for all treatment groups that took part in the Galloway Plains trial. There was a difference (i.e. unfasted – fasted) of 10kg in liveweight gain (i.e. unfasted animals had gained more weight), which represented a 7.5% difference between the two groups (Figure 5). The difference in LWG (between fasted and unfasted) ranged from 52kg/treatment group to -12kg/treatment group. The same analysis was performed in the following case study for the Wambiana trial.

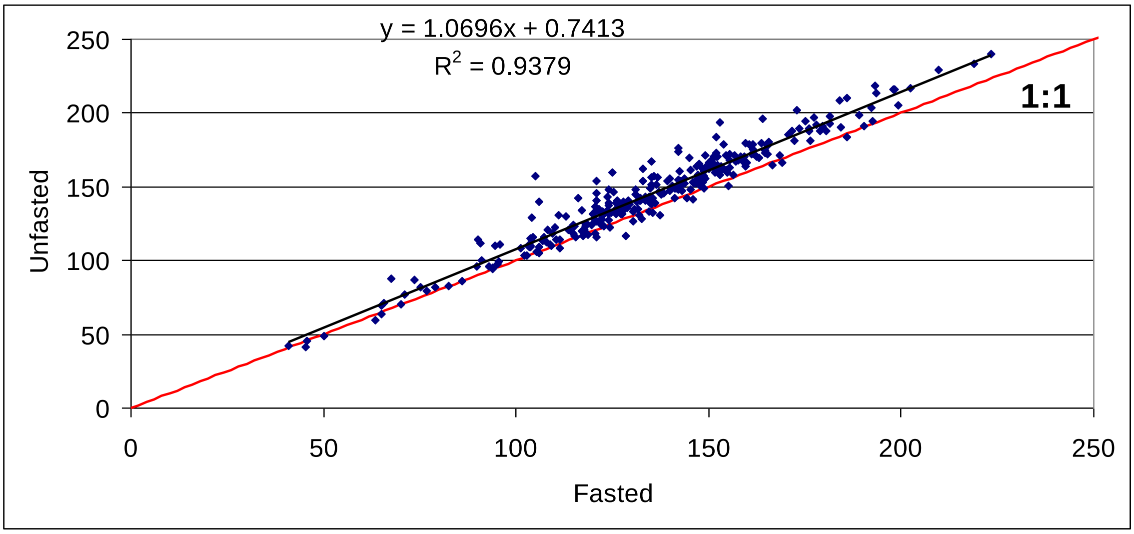


Figure 5. Comparison of fasted LWG and unfasted LWG for animals at the Galloway Plains trial.

Conclusion on Galloway Plains data analysis

The Galloway Plains trial data has been reviewed with the following observations and recommendations. Substantial pasture and soil variation exists between the replicates and therefore they need to be treated as separate entities in model calibration. The western replicate of the trial requires individual paddock parameterisation to account for species and land type differences. An investigation is required to assess the impact of mixing of animal ages that occurred in the latter stages of the trial. Further investigation is required to resolve rainfall data variability across the trial site. Discussion of previous calibration studies is required (e.g. with Ken Day) to improve parameterisation approaches reported in this initial study.

Wambiana Grazing Trial – Case Study

Introduction

The Wambiana grazing trial has been described comprehensively in the following publication (O'Reagain *et al.* 2012), in which patterns of rainfall, pasture growth, liveweight gain and management strategies are detailed. Brief details of the Wambiana trial at are given below:

- Location: 70km south-west of Charters Towers (north Qld)
- Commenced 1997 – still in operation
- Native Pastures: *H. contortus, B. ewartiana, T. triandra, Aristida & Eriachne* spp.;
- Land types: Box, Ironbark, Brigalow
- Data collected: Pasture biomass, animal liveweight, rainfall, runoff, faecal NIRS (DMD)
- GRASP *mrx status: 2009
- Modelled output: pasture growth, runoff, liveweight, utilisation analyses,
- Issues: tree basal area and canopy, *Carissa*, land types, animal age, fasting, drought feeding, supplementation

Issues of variability for liveweight gain at Wambiana

The Wambiana grazing trial has ten paddocks consisting of five treatments, with two replicates. The paddocks have a mixture of soil types dispersed throughout each paddock (see Figure 6). Generally the two dominant land types are Box on texture contrast soils (sodosols) in the north of paddocks, and Ironbark on yellow-brown soils (kandosols) in the southern end of paddocks. There are also smaller proportions of Brigalow on heavy clay soils (vertosols) in each paddock. The pasture most dominant in the Box country is desert bluegrass (*Bothriochloa erwartiana*), a 3P grass, which supports most of the grazing activity, while the Ironbark country produces less biomass with more inferior grass species (e.g. *Eriachne spp.* and *Aristida spp.*). The proportion of 3P grasses has increased in all treatments except the SOI and high-stocked treatments, with less productive grass species increasing in the high-stocked treatments.

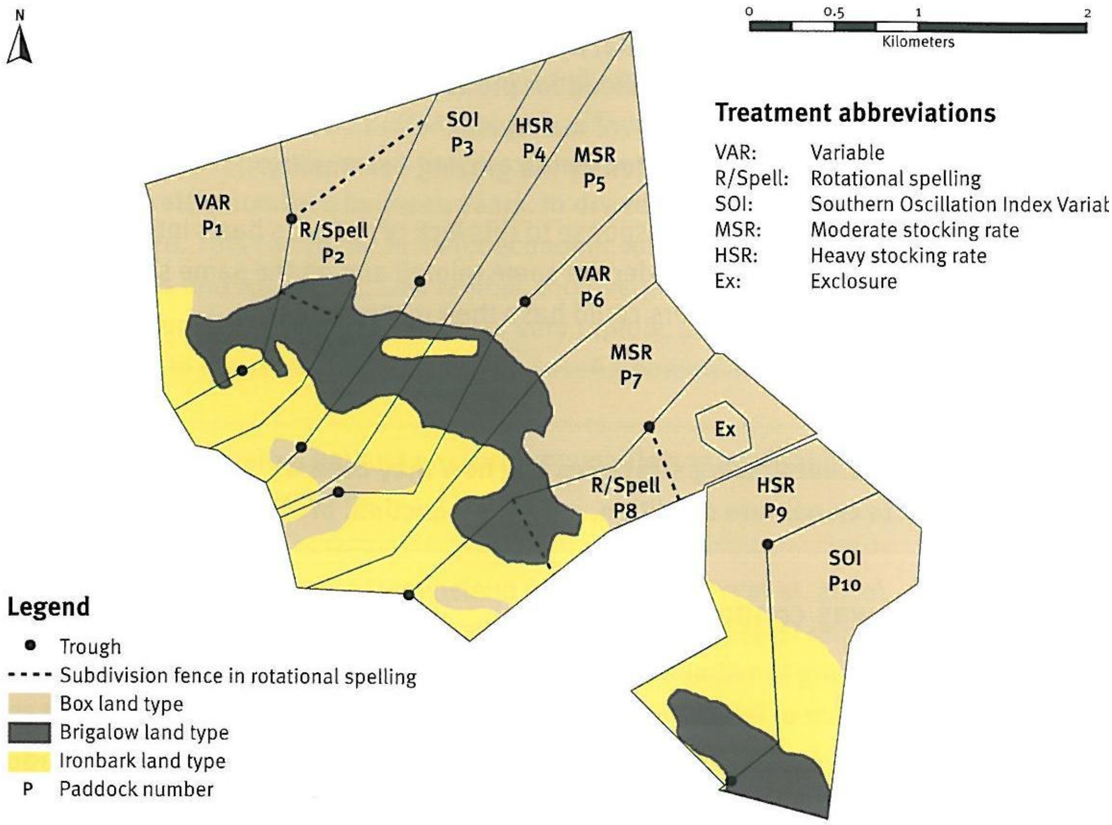


Figure 6. The Wambiana grazing trial site with site features, land type classification, paddocks and allocated treatments.

Tree basal area and shrub issue

The Box land type (see figure 6 and 7) has a total tree basal area 6-8m^2/ha live and dead) and the impact on pasture growth has proved difficult to model (G. Fraser *pers comm.*). Firstly, only a portion of the trees seen in figure 7 are live (≈40%) and so care must be taken to accurately represent the presence of only live trees. Secondly, the canopies of the Box trees are small compared to the stem diameter, consequently, the trees do not impact as heavily on pasture growth as tree species elsewhere, which has proved difficult to represent in modelling simulations.

Carissa ovata (currant bush) is another issue for modelling pasture growth as this shrub forms thickets and precludes pasture growth, predominately in the Box land type. The density has varied over the life of the trial and was been controlled by fire, but rapidly returned. Currently (2012) it is reported that *C. ovata* covers 25-30% of the box country at the trial site.

Figure 7. Example of Box country at the Wambiana grazing trial (moderate grazing treatment) in 2001. Only ≈40% of the standing trees are live. The dominant pasture species present are a mixture of *Bothriochloa ewartiana* and *Heteropogon contortus*, which are considered 3P grasses (i.e. palatable, productive and perennial).

Land type utilisation

Cattle are reported to graze in all land types, though not evenly. They tend to spend most of their time grazing the Box country and in dry times when pasture availability reduces, grazing pressure is applied to the Ironbark country, which is less resilient to heavy grazing. Figure 8 shows the trend in dry season cover from 1999-2004, where it can be seen that cover decreased for High stocking treatment paddocks and to a lesser extent in the Moderate stocking treatment paddocks coinciding with grazing pressure and land type.

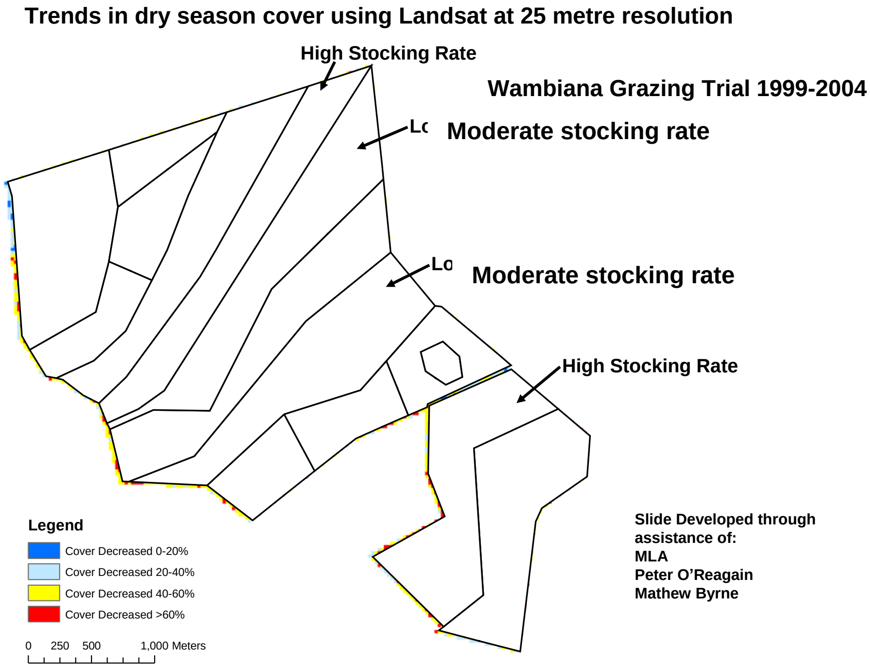


Figure 8. The Wambiana grazing trial site assessed for trends in dry season cover (1999-2004).

A reduction of 3P grasses on a particular land type will force animals to access other land types with inferior grasses such as *Erichachne spp. or Aristida spp.* which will affect the liveweight gain of those animals. Photographs below taken in late 2004 show the difference between the Ironbark country of a moderate grazing treatment (figure 9) and (the neighbouring higher grazed treatment (figure 10). It is also most likely that the rate of pasture recovery will be different for differing land types with varying grazing pressure and result in different animal responses in terms of liveweight gain.

Figure 9. Example of Ironbark country at the Wambiana grazing trial (moderate stocking rate) in November 2004. The pasture species in the foreground is *Eriachne mucronata* has not been grazed, due to sufficient 3P grasses in other areas of the paddock.

Figure 10. Example of Ironbark country at the Wambiana grazing trial (high stocking rate) in November 2004. The pasture species in the foreground (*Eriachne mucronata*) has been grazed heavily, due to low supply of 3P grasses in other areas of the paddock.

Rainfall variability

Some variability in rainfall has been observed across the Wambiana trial site (O'Reagain *et al.* 2009). Using a single rainfall file for modelling pasture growth and LWG is problematic and there have been some issues with matching simulated pasture growth and total biomass with observed biomass in certain paddocks. More importantly O'Reagain *et al.* (2009; p95) identified that a rainfall event in 2003-04 which resulted in LWG effects that lasted the whole year. We quote verbatim below to preserve the context:

> The lack of significance in 2003–04 is surprising but reflects the sometimes patchy distribution of storms across the trial site; in December 2003 an early storm delivered 70 mm to the second replicate of the HSR but only 35 mm fell in the first. This apparently small difference in rainfall resulted in a longer growing season in the former paddock and, consequently, a much greater LWG/ha (31 *v.* 17 kg/ha).

Animal variability issues

The annual cycle of grazed cohorts and drafts at Wambiana were similar to that described for the Galloway Plains trial, with periods ranging from 180 days (1997/98) to 377 days (1999/2000) with an average duration of 346 days. Fasted weights were taken on entry and exit to the trial, with unfasted weights taken at semi-regular intervals (5-8 weekly) for their duration at the trial. The difference (i.e. unfasted – fasted) in LWG between the two fasting regimes was 7kg (6.2%; figure 11), with a range of 46kg/treatment group to a minimum of -12kg/treatment group. These values are similar to those reported earlier for the Galloway Plains trial analysis.

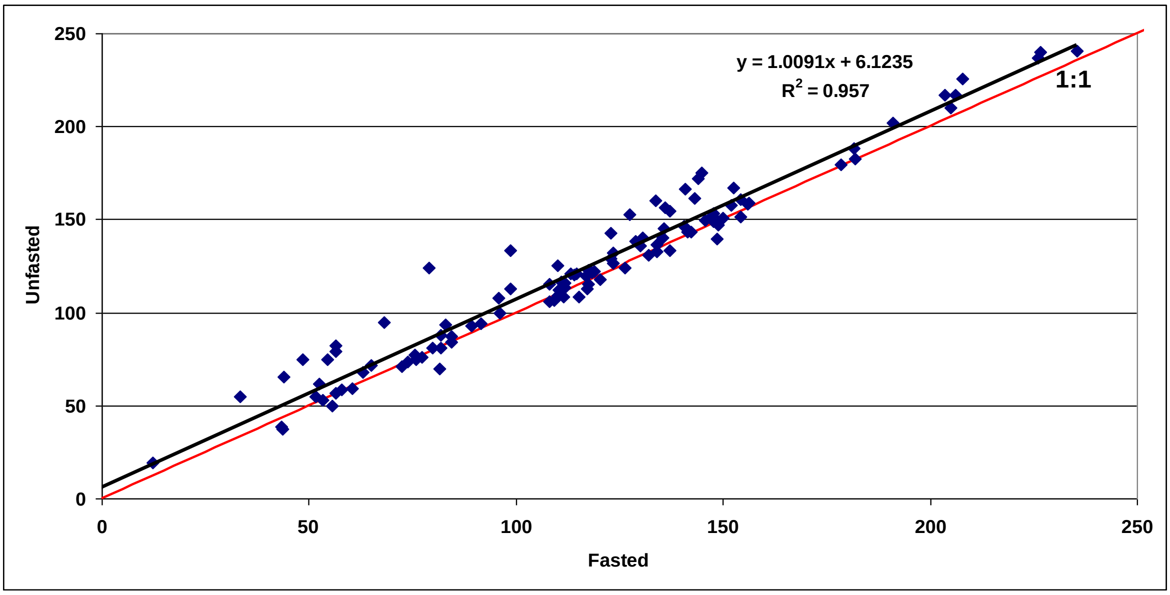


Figure 11. Comparison of fasted LWG and unfasted LWG for animals at the Wambiana grazing trial

Animals were accessed from various sources including Swans Lagoon (Millaroo, 3/4 Brahman), Fletcheview (Charters Towers, 7/8 Brahman), Wambiana station-bred high-grade Brahman steers and one other local consignment. From 2001, at the end of the annual cycle (May/June), a portion of animals were retained and the replacement animals were usually 12 months younger (i.e. 24 mths old, but has varied also). The comparison between older (retained) and younger (introduced) steers is shown in figure 12. There is a difference of 7kg/treatment group (younger animals gained more weight) which equates to 8% of liveweight gain, with a range in difference in LWG between ages of 60kg to -52kg per treatment group.

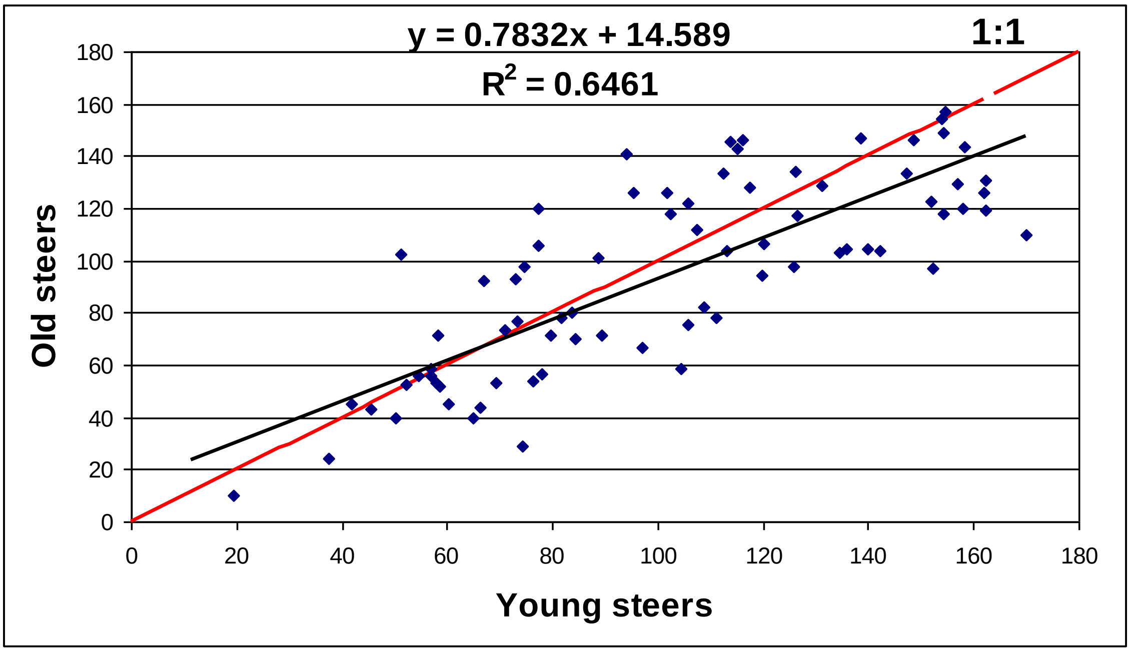


Figure 12. Comparison of LWG of older steers compared to younger steers at the Wambiana grazing trial.

Miscellaneous issues
'One-off' issues that affect pasture modelling and liveweight gain analysis at Wambiana included burning and destocking (e.g. October 1999), army worm infestation (March 2003), growth promotant application (now ongoing), drought feeding (2003/4–2006/7) and destocking (Nov 2004).

Conclusion of Wambiana utilisation analysis
From the viewpoint of model calibration and testing, the Wambiana grazing trial data has been reviewed with the following observations and recommendations. Land use by animals is dependent upon pasture availability within land types. If animals denude the 3P grasses within a land type, then they are left with no option but to graze lesser productive grasses (e.g. *Erichachne spp. or Aristida spp.*), which will affect the liveweight gain of animals and derived response to increasing utilisation. When using data from this trial for liveweight gain analysis, care should be taken to use liveweight values of similar ages with individual drafts.

In addition, further investigation is required to assess whether a rainfall gradient or spatial variability exists across the trial. If it is a significant issue, then it may require an additional rainfall file to be created to more accurately model pasture growth and growth index for liveweight gain. It is also important to have knowledge of 'one-off' situations that can cause outliers in the data and anomalies to accepted trends.

Intake calculation comparison

Background
Estimates of dry matter intake (DMI) are fundamental to the calculation of pasture utilisation (i.e. the ratio of animal intake to pasture growth) and have varied considerably between different extension and research reports. Different approaches were evaluated for estimating DMI, including: simple daily estimates based on metabolic body weight; the intake equation of Minson and McDonald (1987) using liveweight gain and liveweight; a spreadsheet model (QuikIntake, McLennan and Poppi 2004) using inputs of digestibility, liveweight gain and liveweight based on equations from SCA (1990); and intake estimates adapted from

GRASP, based on converting animals to weaner equivalents based on the intake equation of Siebert and Hunter (1977).

Introduction
In order to make estimates of pasture utilisation for the following case study (i.e. 'Utilisation calculation using QuikIntake and GRASP') a robust estimate of animal intake was required. It was proposed to use the QuickIntake model rather than the intake generated from the GRASP model, as it included a higher degree of relevant input (e.g. age, current liveweight, liveweight change per day, dry matter digestibility and distance walked) that would affect animal intake. However, there had been no comparison of these two estimates, nor had other methods been considered for comparison. Therefore, it was proposed to compare four estimates of animal intake in calculating pasture utilisation for all treatments/paddocks of the Wambiana grazing trial to ascertain differences.

Method
The following equations were used to calculate animal intake:

- GRASP-like equation – McKeon and Rickert (1984), from Siebert and Hunter (1977)
  - ((LWG+1.058)/0.304)*(LW^0.75)/(200^0.75)
- Minson and McDonald (1987) equation
  - (1.185+0.0045LW-0.0000026LW+0.31LWG)^2
- Common metabolic intake equation
  - (LW^0.75/450^0.75)*10
- QuikIntake output – McLennan & Poppi (2004, MLA) based upon SCA equations
  - Multiple inputs (LW, LWG, dry matter digestibilty, age, distance walked, terrain)

Animal liveweight data was used from the Wambiana grazing trial (1997-2009). Periodic (approx. 6-weekly) paddock liveweights were converted to daily liveweights and liveweight change as inputs to the four equations. This will be described in further detail in the following case study.

Pasture growth was simulated from GRASP, parameterised for each land type using SWIFTSYNpD-collected data at Wambiana and applied to the proportions of each land type per paddock to get an overall pasture yield, which is also described in further detail in the following case study.

Pasture utilisation was calculated for each paddock/treatment for the entire trial period (i.e. 1997-2009) by summing all daily estimated intake from each equation and all daily simulated pasture growth (on a hectare basis) and applying the values as a quotient:
i.e. %Utilisation = accumulated intake / accumulated pasture growth.

Results and Conclusion
Relative to the GRASP-like method, the other three methods estimated higher values of intake (7% for QuikIntake; 20% for Minson and McDonald; and 20% for Common metabolic intake). Figure 13 shows the estimates of pasture utilisation (%) for the Wambiana grazing trial by paddock and treatment for years 1997-2009, using the four independent intake estimates to compare the utilisation estimate.

The overall values of pasture utilisation per method of intake for all treatments of the Wambiana grazing trial (1997-2009) were: GRASP-like intake (17%); QuikIntake (18%); Minson and McDonald (20%) and Common metabolic intake (20%). This result demonstrates it is likely there is a higher degree of variability associated with other aspects of using grazing trial data (e.g. rainfall, liveweight and pasture data, model parameterisation) compared to which intake method is used to calculate pasture utilisation.

From this comparison analysis, it was decided to use the QuikIntake model for estimates of intake for the following more comprehensive utilisation analysis. QuikIntake has the advantage of including pasture digestibility in the model to account for changes in observed feed quality and liveweight which, in turn, influence estimates of DMI. In addition, it is worthwhile to use other inputs such as age, distance walked, breed and gender.

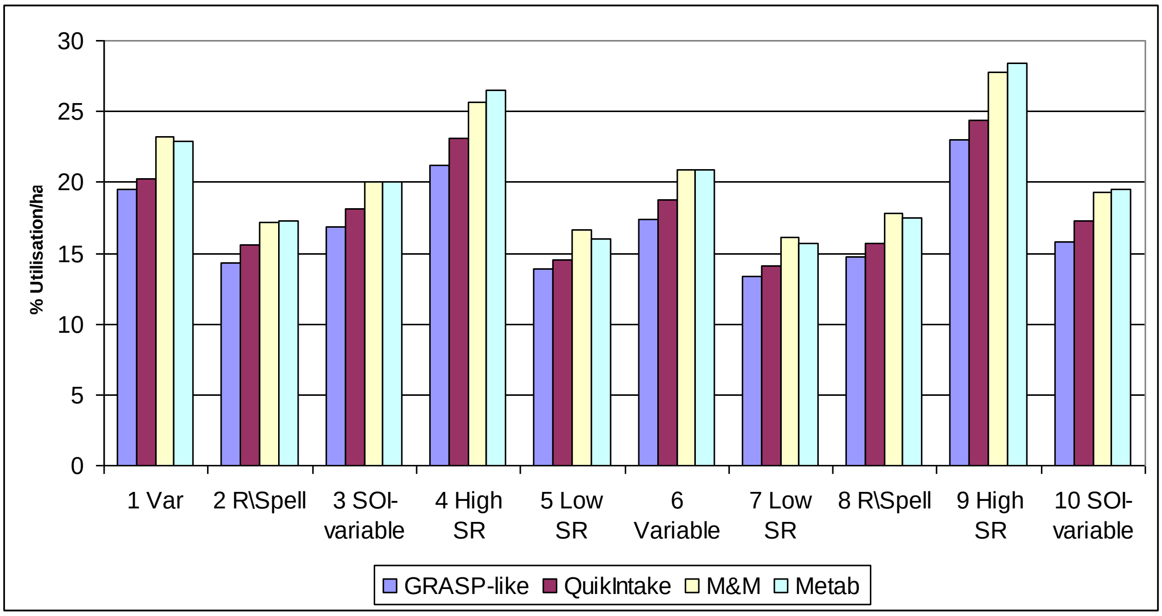


Figure 13. Estimates of pasture utilisation (%) for the Wambiana grazing trial by paddock and treatment for years 1997-2009, using four independent intake estimates for comparison.

Utilisation calculation using QuikIntake and GRASP

The calculation of utilisation of pasture growth for each experimental treatment is an important component of the analysis of grazing trials. For example the estimation of 'safe' levels of utilisation is a key to calculating safe carrying capacity for different land types. For completeness and accessibility, we repeat verbatim a section of a previously published report Stone *et al.* (2008).

Introduction

Information from the Wambiana grazing trial at Charters Towers was used to model 'potential' pasture growth, and provide estimations of animal intake and pasture utilisation. This analysis was performed on a paddock-by-paddock basis for each draft of steers (annual grazing period) from 1997 to 2007. The GRASP model was used to produce daily pasture simulations from SWIFTSYNpD data (Day and Philp 1997) collected at the trial and the QuikIntake spreadsheet model was used to calculate feed intake. Liveweight of steers and pasture dry matter digestibility (DMD) were interpolated to daily values using a linear interpolation function in an MS EXCEL spreadsheet. The resultant time-series include accumulated pasture growth, feed intake, pasture digestibility and pasture utilisation. The information presented in the time-series provides a valuable summary of management outcomes and is used to compare differing grazing strategies across land types for both production and sustainability issues.

Method

Pasture production data using SWIFTSYNpD methodology was gathered across land-types over the duration of the grazing trial. The GRASP model was parameterised with particular attention to the differences in soil fertility between land types. The parameter sets were then used to simulate pasture growth yields over the period of the grazing trial (1997 to 2007). The proportional area of each land-type (e.g. Box, Ironbark, and Brigalow) in each paddock was then used to calculate an overall daily paddock pasture growth. The simulated growth does not include the effects of grazing in terms of decline in resource condition that occurred during the trial.

As steer liveweight and pasture digestibility data from the grazing trial was provided on a ≈6-weekly basis, an interpolation process was developed to convert periodic data to daily values. Lookup tables were constructed in an MS Excel spreadsheet, which returned an incremented value per day for steer liveweight (kg) and pasture digestibility (%DMD), to establish a daily time-series of values. These values were used to estimate a daily feed intake as part of the pasture utilisation calculation.

After review (see intake comparison; previous section) it was decided to use 'QuikIntake', the MLA funded spreadsheet model produced by McLennan and Poppi (2004), to calculate DMI. QuikIntake had the advantage of including pasture digestibility algorithms in the model to account for changes in observed feed quality and liveweight which, in turn, influence estimates of DMI. Relevant information (age, current liveweight, liveweight change per day, dry matter digestibility and distance walked) was entered into the QuikIntake model to estimate DMI for each day and by paddock (i.e. ≈3500 days x 10 paddocks). Other inputs such as gender, breed, terrain and distance walked were kept constant. A 'macro' was generated in MS Excel to automate the process. Supplementation of steers has not been included in this analysis, but could be estimated in further studies to improve estimates of feed intake.

Pasture utilisation (i.e. the ratio of animal intake to pasture growth) was then calculated for each steer draft by paddock for the duration of the trial. Feed intake per steer was summed to give total feed intake per paddock using the number of steers that were present on a given day. Daily pasture growth was summed for each land type in a paddock. At the end of an annual grazing period (usually the end of May), utilisation for each draft was calculated as the sum of daily feed intake values (kg DM/paddock) divided by the sum of daily pasture growth values (kg DM/paddock) expressed in percentage terms.

Results

A time series of annual pasture utilisation for the ten paddocks of the Wambiana Grazing Trial for drafts of steers from December 1997 to June 2007 (10 draft periods) is shown in Figure 14. Draft periods varied from 180 days (1997/98) to 377 days (1999/2000) with an average duration of 346 days. Pasture utilisation across all paddocks was light for the first few drafts of the trial (e.g. 1997-2000) due to wet conditions and, in turn, high pasture growth. However, from 2000 onwards, utilisation levels were much higher due to drier conditions and lower pasture growth. The years from 2001-2005 (the millennium drought) showed a series of peaks and troughs where pasture growth was severely reduced, while steer numbers were maintained at earlier rates. The utilisation rates during this period were particularly high for the High and Variable stocking rates (HSR, VAR). With an overall reduction in stocking rates and more moderate seasons, the rates of utilisation were reduced in 2006 and 2007.

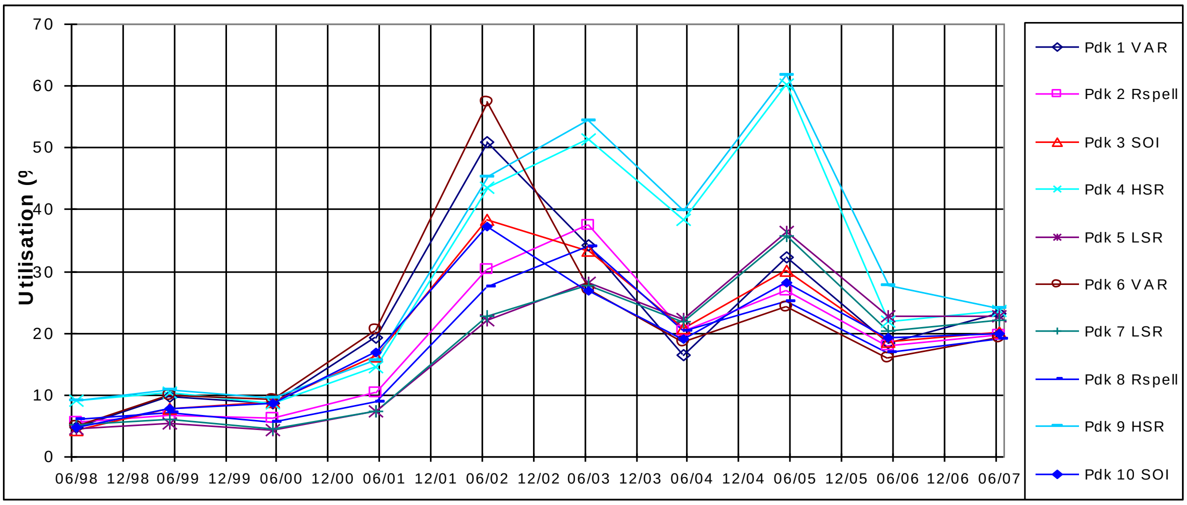


Figure 14. Time series of annual pasture utilisation for the 10 paddocks in the Wambiana grazing trial. There were 10 draft periods for the duration of the trial (December 1997 to June 2007).

While figure 14 enables comparison between paddocks, further information is required to fully interpret the results. For example, for Paddock 1 (VAR), we have graphed other information including daily values of pasture digestibility, animal numbers, pasture intake (accumulated per draft) and accumulated pasture growth (accumulated per draft). It can be seen from figure 15 that high pasture growth in the period from 1997 to 2000 combined with low steers numbers resulted in a low rate of utilisation (i.e. 5-10). Increased grazing pressure from 2000 coincided with reduced pasture growth and resulted in high utilisation. When numbers were reduced (from mid 2002), the utilisation rates remained high for year 2003 and 2005 respectively (e.g. 40 and 38%).

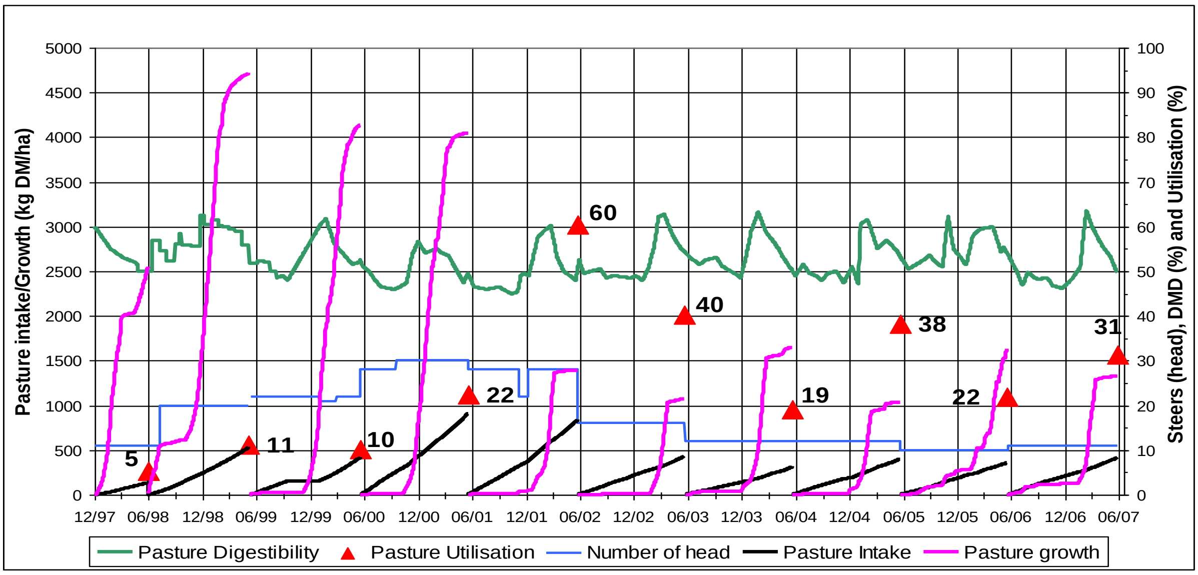


Figure 15. Grazing summary for Paddock 1 (variable stocking rate) of the Wambiana grazing trial from December 1997 to June 2007.

Conclusion of utilisation analysis

Further analysis of utilisation would involve the simulation of pasture growth including the feedback effects of grazing on the pasture resource. These effects include changes in grass basal area, species composition and infiltration attributes of the soil surface. Calculation of pasture growth using this approach would use actual paddock measurements, including measured pasture yields and pasture basal area data. Animal effects would include the use of supplementation and variation in distance walked per day to reflect variation in seasonal pasture variability, as both of these factors influence feed intake. Wet season spelling can also be incorporated to calculate the pasture utilisation on individual spelled cells. This analysis will be carried out once the pasture data have been collated and each paddock calibrated with the GRASP model.

For grazing trials that are current (e.g. Wambiana), the analysis can be added to with each year's data for calculation. The calculation of pasture utilisation outlined here has also been carried out on the Keilambete grazing trial (Rubyvale, central Qld). The process could be repeated for all grazing trials where information (as described above) can be provided. In this way, there will be a standardised approach applied to past, current and future grazing trials. For the first time the outputs from all trials can thus be assimilated and meaningfully compared using a standard process.

Summary of analysis of using grazing trials for modelling liveweight gain with GRASP

Grazing trials represent a considerable investment to organisations, however, once completed and results are published, the detailed data are seldom used again. Modelling grazing trials has a capacity to make the data more useful. The grazing trials listed earlier in this liveweight gain review that have not been further analysed have potential that has not been fully utilised. Two grazing trials (Galloway Plains and Wambiana) have been evaluated here to assess aspects of variability that need to be considered in modelling analyses.

Preparation of data files for models such as GRASP from grazing trials is a time consuming process. Nevertheless, there is a need for developing experience and expertise in the timely and accurate preparation of data files to provide a long-term accurate repository of useful scientific data for future use.

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11.4 Appendix 4. Publications from this project

[1] Mayer, D.G., Scanlan, J.C., Cowley, R.A., Singh, D. and McKeon, G.M. (2011). Testing and calibrating empirical models of cattle growth on native pastures in northern Australia. In Chan, F., Marinova, D. and Anderssen, R.S. (eds) MODSIM2011, 19th International Congress on Modelling and Simulation. Modelling and Simulation Society of Australia and New Zealand, December 2011, pp. 815-821. ISBN: 978-0-9872143-1-7.

(available at www.mssanz.org.au/modsim2011/B1/mayer.pdf)

[2] Mayer, D.G., McKeon, G.M. and Moore, A.D. (2012). Prediction of mortality and conception rates of beef breeding cattle in northern Australia. *Animal Production Science* **52,** (in press), pre-print follows -

Prediction of mortality and conception rates of beef breeding cattle in northern Australia

(Running head: Mortality and conception rates of beef cattle)

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Abstract. In current simulation packages for the management of extensive beef cattle enterprises, the relationships for the key biological rates (namely conception and mortality) are quite rudimentary. To better estimate these relationships, cohort-level data covering 17,100 cow-years from six sites across northern Australia were collated and analysed. Further validation data, from 7,200 cow-years, were then used to test these relationships. Analytical problems included incomplete and non-standardised data, considerable levels of

correlation amongst the 'independent' variables, and the close similarity of alternate possible models. In addition to formal statistical analyses of these data, the theoretical equations for predicting mortality and conception rates in the current simulation models were reviewed, and then reparameterised and recalibrated where appropriate. The final models explained up to 80% of the variation in the data. These are now proposed as more accurate and useful models to be used in the prediction of biological rates in simulation studies for northern Australia.

Additional keywords – body condition ratio, body condition score, breed, lactation status, pregnancy

Introduction

In northern Australia, the task of evaluating optimal strategies to manage extensive properties is challenging. Regardless of the criterion chosen for optimisation (usually economics or profitability), all management decisions interact with climatic and other natural features of each dynamic system (Mayer *et al*. 1998). The only realistic method of investigating these interactions is with simulation models that encompass the whole system, from rainfall and soils, to pasture production and animal intake (McKeon *et al*. 1990, Hall *et al*. 1998), herd dynamics, and through to the economics of animals turned off (Freer *et al*. 1997).

Herd dynamics models currently in use, such as BREEDCOW and DYNAMA (Holmes 1995), are generally accountancy-type packages. In these, the key biological rates covering the processes of reproduction and mortality need to be user-supplied, rather than being estimated within the model. Hence, changes in these rates from alternate managerial strategies such as stocking rate or supplementation (and the resultant effects on herd structure and profitability) cannot easily be evaluated. The GRAZPLAN ruminant biology model (Freer *et al*. 1997) was largely developed for animals grazing temperate pastures in southern Australia, and is currently being used widely in these regions. Its relationships for conception, however, rely on an assumption that all females come into oestrus each year, and its equation for mortality assumes constant death rates with age once stock are mature. Neither assumption can be expected to hold in the more tropical regions of northern Australia, where cattle are routinely subjected to long periods of nutritional stress. We therefore hypothesized that alternate or adapted relationships would be required for these areas.

This study compares predictions from current models with historical data from across northern Australia, and then develops more accurate and useful models to be used in the prediction of conception and mortality rates. Biological data from a range of beef-producing environments across northern Australia were collated and analysed. The following sections describe the data sources used, and then the model comparisons and analyses which identified improved predictive models for mortality and conception rates. Following this, further data were sourced to validate these relationships.

Data Sources

Data were collated from six sites (two each in the Northern Territory, north Queensland, and central Queensland), as summarised in Table 1. The performance of cohorts or groups of animals was targeted from each site, on a four-way interaction basis (year by breed by age by lactation status). These data were variously available from published sources and theses, unpublished summaries and internal departmental memos, and re-analyses of raw data. Across these locations, consistency of data measurements and structures remains a problem. Whilst the timing varies, all sites generally experience 'favourable' (wet) and 'unfavourable' (dry) periods each year. Mustering and data collection dates varied with site, but where possible animal weights at approximately the start and end of these two periods were obtained, also allowing estimation of average weight changes. As stage of pregnancy was recorded, all animal weights were adjusted for weight of the conceptus and products, via the method for specific breeds (O'Rourke *et al*. 1991) or earlier general relationships (Silvey and Haydock 1978). When applied in a practical sense to estimating cow weights, the differences between these methods are insignificant (P K O'Rourke, pers. comm.). The 283 observations in this data set total 17,100 cow-years, giving an average of 60 animals per cohort. Example data for some of these site/year/breed/age/lactation status cohorts are illustrated in Figure 1.

(Table 1 and Figure 1 near here).

Main effects for the Kidman Springs data were presented in Sullivan *et al.* (1992). For our study, the full interaction means were re-extracted from the raw data. This site operated under continuous mating, starting with non-pregnant animals in June of each year. Pregnancy within 12 months was defined as a 'success', but calving would be some time after this if pregnancy occurred late in the year.

All other sites were managed under controlled mating, generally coinciding with the wet period (early in the calendar year). Animals found to be pregnant then calved later that year, setting up an approximately annual cycle. The Mt Bundey data were extracted from O'Rourke (1994). The overall average weight change during the wet season was slightly negative for these data, which is a reflection of both the harsher environment and the fact that many of these animals were lactating through this period, and unable to gain weight (although their calves were gaining weight).

Data from the James Cook University Tropical Veterinary Research Station at Fletcherview were available from Anderson (1989). The available age classes were 'three year olds' and 'mature animals', with both lactating and non-lactating groups within each of these.

For Swan's Lagoon, data for the various animal classes were extracted from Anderson (1989), Holroyd *et al.* (1990a, b), Fordyce *et al*. (1993) and O'Rourke (1994). Reproductive and weight data were available on a year by breed by age/lactation status basis. Mortality data were only available for lactating animals on a year by breed basis. Previous statistical analyses of the age effects (O'Rourke 1994, p 183) had indicated few important or consistent differences between ages, so these pooled mortality rates (across ages) were used.

From Belmont, animal weights were only readily available for the drought year of 1969 (Frisch 1973), although these studies ran from 1957 to 1984 (Mackinnon *et al.* 1989). Mortality and calving rates were listed by breeds, being averaged across ages and lactation status. Pregnancy rates (which were not reported) were back-estimated from calving rates by using breed-specific differences from the comprehensive and comparable Brigalow data set.

Pregnancy rate and weight data for Brigalow are listed in O'Rourke *et al.* (1992a), by year and breed with age and lactation status pooled into four classes, namely heifers, three year old lactating, four year and older lactating and three year and older non-lactating cows.

The range of production systems across northern Australia are illustrated by the data in Table 1. Annual mortality rates in the more favourable environments averaged around 3%, but range up to 12%. At Kidman Springs, however, 11% was the average, with a much greater range. These values were also typical in the Kimberley region of Western Australia, where Pratchett and Young (1989) reported average mortalities of 19% for unweaned cows, and 10% for the weaned treatments. The Northern Territory sites also had lower conception rates, weights and weight gains (Table 1), due to harsher conditions. These trends, along with the partial confounding of sites with breeds (only *Bos indicus* at the harsher environments, and none of these at Brigalow) caused problems with analyses.

Estimation of Biological Relationships

A two-fold approach was used for the analyses of mortality and conception rates. The first was a formal statistical analysis, fitting generalised linear models (McCullagh and Nelder 1989) of both discrete factors and continuous variates to the dependent variables. Secondly, the relationships incorporated in some of the decision support packages (largely derived under southern Australian conditions) were tested. In some instances, internal parameters of these models were tuned to achieve an acceptable fit to the observed data. Both analytical methods struck some problems with correlations amongst the (assumedly) independent variates. As expected, the highest dependencies (r up to 0.92) were amongst the weight variables at different times during the year. Only one of these terms may therefore reasonably be fitted in any model. The site factor was significantly associated with a number of the predictor variables, which along with the partial confounding introduces some degree of uncertainty into interpretation. The rates of weight changes at various times of the year also tend to be reasonably correlated (r up to 0.68) with actual weights, despite having the potential to be important additional predictors of animal wellbeing and hence performance.

In all analyses, the number of observations (cow-years) in each cohort or group was used as a weighting factor. The factors investigated in these analyses were 'site', 'breed' (both as listed in Table 1), and 'age and lactation status' [four defined levels, namely: heifers (two years old), three years old lactating, 4 years and older lactating, and non-lactating cows].

To fit the GRAZPLAN models (Freer *et al*. 1997, 2009), the internal parameters of 'standard reference weight' (SRW) and 'normal weight' (N, the potential or expected body weight at any given age) need to first be determined. SRW is defined as the weight of a mature animal of average body condition. This was estimated from our data as 520 kg for the European animals, and 425 kg for other breeds. Attempts to fit these SRWs as extra parameters in nonlinear regression models were largely unsuccessful (Mayer *et al*. 1996), due to parameter correlations - other parameters in the models ended up being adjusted to compensate for any shift in SRW. Fitted models using the SRW values listed above appeared to be biologically appropriate.

The calculation of N, the expected body weight for age of animals at average condition, proved to be more problematic. Brody (1945) theorised an exponential model describing weight from birth (Wt_{birth}) to maturity, given adequate nutrition, namely:

$N = SRW - (SRW - Wt_{birth}) \exp[-k*age/(SRW^{0.27})]$ ……………….……………(eqn. 1)

Taylor (1965, 1968) further developed this equation, tabulating potential growth rates by species of animal. The tabulated value for sheep of 1.8 back-converts to a k-value (the growth rate, with age measured in days) of 0.0157, as was originally used in GRAZPLAN (Freer *et al*. 1997). However, for cattle the tabulated values convert to k-values of 0.008 to 0.01, indicating slower proportionate growth. The Brody exponential model fitted to the observed weight data of Table 1 (ignoring all other factors) estimated k as 0.0104 with a standard error 0.0006. Hence a value of 0.01 appears reasonable for these data, and was adopted for all analyses. Subsequent to this research, k for cattle in the current GRAZPLAN model (referred to in Freer *et al*. 2009 as the growth rate constant, C_{N1}) has been revised to 0.0115.

The definition of normal weight (N) for any age allows the formulation of GRAZPLAN's measure of body condition ratio (BCR), defined as the ratio of liveweight to N. BCR values of one will be obtained for animals that are at their expected weight-for-age. BCRs less than one indicate underweight animals (of poor body condition) and vice-versa. For data sets where only body condition score (BCS), on a 0 to 9 scale (NRC 1996), was recorded, Table 2 shows the conversion adopted. This was derived via expert opinion of researchers in the DroughtPlan project team. It has subsequently been validated with independent data from Alexandria Station (Savage *et al*. 2004), which had both weights and condition scores for 53 cohorts of animals. Figure 2 shows the relationship between the estimated (via Table 2) and observed condition scores. Whilst there is some degree of variability in these data, the fitted slope is very close to one.

(Table 2 and Figure 2 near here)

Analyses of Mortality Rates

Statistical Analysis

As a considerable portion of the mortality data is in the 0 to 5% range, the assumption of a normal distribution is clearly inappropriate. Generalised linear models with the binomial error distribution and logit link function (McCullagh and Nelder, 1989) were fitted using GenStat (version 12.1, VSN International Ltd., Oxford, UK). It is obvious that a range of potential predictors exist. Initial analyses showed that body condition ratio measures were superior predictors to actual weights. Using step-forward regression with the factors and quadratics for all the variates, annual average BCR was the best single predictor (R^2 = 42%). Animal age came in next, followed by weight change during the dry period (which is the critical period for mortality, P K O'Rourke pers. comm.). No further single terms gave a significant ($P < 0.05$) improvement to this three-term model. Importantly, this indicates that the key effects of site, breed, and lactation and pregnancy status are all being adequately covered by the three terms in the model. As a final step, all multiplicative and divisive interactions between BCR, age and weight change during the dry period were screened. The BCR by age interaction was the only significant ($P < 0.05$) interaction, and lifted the adjusted R^2 for this final model to 67.3%. The fitted statistical equation for mortality is:

mortality (%) = 100 / (1 + $e^{-\text{logit}}$), where
logit = –21.3 + 40.7 * BCR – 24.2 * BCR^2 + 1.05 * Age – 0.0255 * Weight change – 0.893 * Age * BCR ……………………………………………………(eqn. 2)

This model includes a complex interaction between body condition ratio and age, as shown in Figure 3. This pattern appears biologically meaningful, and agrees with researchers' expectations. Young animals do exhibit a rise in mortality rates as BCR declines, but these animals tend to be more resilient and are still capable of surviving reasonably well under poorer conditions. The older the animals get, however, the more mortality rises in these circumstances. In particular, underweight old animals appear to be highly vulnerable. For example, 7 year old cows with a BCR of 0.7 and weight change of –10 have a predicted mortality rate of 19.2%, and one such cohort of animals in the base data had an observed mortality rate of 26%. The other term in the mortality equation, namely weight change in the dry period, was also important. With observations adjusted to their mean values of BCR and age, the effect of the observed range of weight changes (back-transformed through the logit) was an extra 5.4% mortality.

(Figure 3 near here).

This mortality model was further checked using a tree-based regression analysis. This is a binary recursive technique, searching the data for discrete cutoff points which maximise the degree of discrimination for the dependent variable. This analysis also identified average BCR as the dominant independent variable affecting mortality rates, with age and weight change in the dry period also contributing significant discrimination. This analysis confirms the appropriateness of these terms in the above statistical model.

Alternate Models

The ENTERPRISE decision support package (MacLeod *et al*. 2004) has mortality as an exponential function of annual liveweight gain (LWG), with an apparently-arbitrary constant of 50 being added first. Separate functions are used for breeders and dry stock. Table 3 shows the comparison of these predictions against our observed data. In GRAZPLAN, predicted mortalities are low-level and random at 0.0118% per day (4.2% per annum), unless extra mortality is introduced when BCR falls below a defined critical limit (which is related to relative size, and hence age). For these data which generally show a saw-tooth weight gain over time, minimum weight during the year usually occurs at the end of the dry period. Given the ratio of end-of-dry weight to end-of-wet weight as an estimate of worst BCR for each cohort in each year, this was plotted against age for our data. All values were above GRAZPLAN's defined critical BCR limit, hence the predicted mortalities throughout are 4.2% per annum, as also shown in Table 3.

(Table 3 near here).

Given the general lack of agreement in Table 3, and that mortality is a function of LWG only in ENTERPRISE and BCR only in GRAZPLAN, no retuning of parameters of these models was attempted. The statistical model (equation 2), which incorporates the effects of BCR, age and weight gains during the critical dry period, and agrees with expert opinion, was therefore adopted as the best prediction equation for mortality.

Validation of Mortality Model

Data sets with the levels of detail necessary to test equation (2) were difficult to obtain. Some earlier (pre-1985) data sets were ruled out, as there was some contention as to whether the breeds and circumstances back then remain representative of the current industry. For example, one cohort of animals in 'very poor - poor' condition and going into a drought in a dry tropical environment (Fordyce *et al*. 1990) lost 54 out of 105 animals. In a commercial situation under these circumstances, managerial intervention (supplementation, agistment, sales) seems more likely than 'letting them die', so it is probable that mortality levels this high are unlikely to occur in practice.

Three independent data sets were used for validation. The first was a herd of 570 *Bos indicus* cross animals in the Gulf district of the Northern Territory (Schlink *et al*. 1994a). Of the four years presented, only 1987 had the necessary weight change data. Here the observed mortality rate was 13%, which is somewhat higher than the predicted rate of 8.2% from the mortality model. This predicted value was largely influenced by a low average BCR of 0.74, plus higher weight losses during the dry period of that year.

The remaining two data sets come from the Producer Demonstration Sites of 1989 across southern Queensland (unpublished, DEEDI). At Mundubbera, two out of 42 Brahman cross cows died, giving a mortality rate of 4.5%. With their average BCR of 0.87, the predicted mortality rate was 3.7%. Conversely, in a similar herd at Monto with an average BCR of 0.86 and a predicted mortality rate of 3.8%, none (0%) of the 103 Santa Gertrudis cows died. The random nature of mortality, particularly with cohorts of smaller numbers, obviously affects these comparisons. However it is evident that the mortality predictions are of the correct order of magnitude.

Analyses of Conception Rates

Conception and pregnancy rates are usually interchange, under a binary definition (pregnant or not) at each measurement time. Calving rates are measured much later, and will usually be somewhat lower. Initially, we analysed pregnancy rate (PR) on a percent per annum basis, as this is the usual basis for presentation. This approach identified the obvious problem of the Kidman Springs animals (being continuously mated) apparently being more fertile than those at the other seasonally-mated sites, simply because they had more opportunities (cycles) to achieve pregnancy. To standardise for this effect, for this paper we define conception rate (CR) as per 21-day cycle, calculated as:

$CR = 1-(1-PR)^{1/n}$, where n is the number of cycles ………………………………(eqn. 3)

This is a probabilistic calculation, and the discreteness of the binary response can cause problems when all animals get pregnant in the period (as occurred with 12 cohorts in our data, averaging 12 animals per cohort). Here, the calculated CR is also 100%, implying all animals get pregnant each cycle, which is unrealistic. Graphically, these CR points were far removed from the rest. Rather than delete these points (as they are valid representations of good conception rates), we nominally deleted 'a quarter of a cow' from PR for the calculation of CR. This adjustment is based on the view that the 'all pregnant' result would not have been observed if there was a higher number of animals in that cohort, and that the observed result in reality approximately covers the range from 'all animals in cohort (*n*) pregnant' to '(*n*-0.5) animals pregnant'. The half way point in this range, namely (*n*-0.25), has been adopted as its best overall representation. For example, with 12 animals in the group and three cycles, 11.75 were deemed to be pregnant, and the estimated CR is now 72%. This change shifted these values to around the top of the scatterplots, and these are a more realistic interpretation. With the low numbers of animals and hence statistical weighting of these observations, this adjustment probably had little effect on the overall degree of fit.

Statistical Analysis

With conception rates generally above 10%, the normal distribution was assumed, and general linear models were fitted to the untransformed percentage conception per cycle. The binomial distribution with the logistic link function was tried, but produced almost identical results, so the normal (which produced acceptable residual plots) was preferred for simplicity. As with the mortality models, the BCRs were better predictors than weights. Mid-mating BCR, with R^2 of 63% (Figure 4), was used as a starting point for the step-forward multiple models, as it best reflects the average during the mating period. The age/lactation status factor was the dominant and significant ($P < 0.05$) next addition, followed in a similar fashion by breed, giving a three-term model (with ten coefficients) with an adjusted R^2 of 75%. Whilst the further additions of both site and weight gain during the mating period were statistically significant ($P < 0.05$), these only had relatively low contributions (increasing the adjusted R^2 by less than 3%), so were not included. All interactions between BCR, age/lactation and breed were then screened, but none were included as the best only increased adjusted R^2 by 0.8%.

(Figure 4 near here).

Using S-Plus, a tree-based regression analysis confirmed these relativities, with the first two break-points using BCR. Further divisions involved age, breed, lactation status and weight gain. These break-points reflected biological effects, and the resultant average conception rates within each group were biologically informative, and largely as expected.

Whilst the final statistical model initially appeared appropriate, concerns regarding the functional form were identified – for example, a sigmoidal curve may be more appropriate, given the data patterns in Figure 4.

Alternate Models

The GRAZPLAN model for conception rates in cattle is based on a logistic equation (Freer *et al*. 1997):

$$CR = \left[1 + \exp\left(-\left(\frac{2(\ell n(0.95) - \ell n(0.05))}{\beta - \alpha}\right)\left(\frac{Weight}{SRW} - \frac{\alpha + \beta}{2}\right)\right)\right]^{-1}$$ ……………..(eqn. 4)

where CR is conception rate per cycle,
Weight is liveweight of the animal,
SRW is the 'standard reference weight' parameter,
α and β are empirical response parameters, corresponding to the estimated values of Weight/SRW for 5 and 95% CR respectively.

The default GRAZPLAN co-efficients for cattle produced a clearly inadequate fit to our data – for BCR of 1.0, Figure 4 shows our CRs range between 15 and 60%, averaging about 35%. Whereas Figure 16 in Freer *et al*. (2009) indicates that animals with BCRs of 1.0 should average CRs of 65% to 95%. Hence retuning of this equation was required. Initially, SRW was taken as an unknown parameter to be estimated, and this nonlinear regression problem was fitted via Genstat (version 12.1, VSN International Ltd., Oxford, UK) and a simulated annealing algorithm. However, no unique set of parameter values was found under either approach. This generally indicates an over-parameterised model, where there exists an almost infinite number of combinations of the parameters which fit the data equally well. Further investigations of the functional form proved this to be the case, as this conception rate equation can be reparameterised to remove SRW:

$$\mathrm{CR} = \left[1 + \exp\left(-\left(\frac{2(\ell \mathrm{n}(0.95) - \ell \mathrm{n}(0.05))}{\beta_1 - \alpha_1}\right)\left(\mathrm{Weight} - \frac{\alpha_1 + \beta_1}{2}\right)\right)\right]^{-1}$$ ……………..(eqn. 5)

where α_1 = SRW α, and β_1 = SRW β.

SRW must thus be *a priori* set to biologically realistic values, and then the other parameters tuned to these. The previously-listed values of SRW were adopted, namely 520 kg for European breeds and 425 kg otherwise. Based on the data patterns in Figure 4, a third parameter (representing the upper asymptote) was also added to this nonlinear regression model; however the degree of fit was disappointing, with an adjusted R^2 of 47%.

It was noted that the driving independent predictor in equation (4), namely Weight/SRW, was derived in GRAZPLAN as the product of 'body condition' (BCR, = Weight/N) by 'relative size' (Z, = N/SRW) (Freer *et al*. 1997). The statistical analyses showed BCR alone to be a reasonably good predictor of conception rate. Further statistical investigations of the effect of Z on conception rates (not presented here) showed this latter term to have little practical contribution, either in the linear or multiple models. Hence it appears that GRAZPLAN's hypothesised relationship between skeletal growth and reproduction maturity (as modelled by Weight/SRW) may not apply so well for cattle in northern Australia.

It was suggested that BCR by itself may be a better independent variate for equation (4), and this proved to be the case. Following on from the statistical results, BCR at the middle of the mating period was used, and this gave an adjusted R^2 of 64% - slightly superior to the statistical model of quadratic BCR, for the same number of parameters.

After adjusting for BCR, the statistical analysis had then identified age/lactation status and breed as important factors. These were fitted in the sigmoid by allowing each of the three constants to have a different value for each level of the factors. This raised the adjusted R^2 to 80%, again superior to the fitted statistical model. This reparameterized GRAZPLAN model was thus adopted as the prediction equation for conception rates.

Validation of conception model

As with the mortality rates validation, the first available data set was from the Gulf district of the Northern Territory (Schlink *et al*. 1994a). In this harsher environment, overall pregnancy rates were 71%, with conception rates per oestrus cycle correspondingly lower. Schlink *et al*. (1994b) reported conventional and early-weaned cohorts in 1992 at Lansdown Station near Townsville, with pregnancy rates of 47% and 76% respectively. The Producer Demostration Site at Mt Tom, Miriam Vale in 1989 (unpublished, DEEDI) also reported on late and early weaning cohorts, with pregnancy rates of 65% and 82% respectively. Finally, for the Alexandria Station 1997 - 2001 study in the Barkly Tableland region of the Northern Territory, data at the individual cohort level was obtained from the principal investigator (D. Savage, pers. comm.). This well-managed herd, in an endowed region which received above-average rainfall during the study period, generally had pregnancy rates of 90% or better. For these more recent 'tropical composite breed' animals, SRW was set at 465kg (D. Savage, pers. comm.).

In each of these validation data sets, the animals were all *Bos indicus* crosses. The comparisons of observed *vs*. predicted fertility, as listed in Table 4, are again for conception rates per oestrous cycle, which were calculated from the listed pregnancy rates accounting for the length of the mating period.

(Table 4 near here).

In this table, we have six points with good agreement, two which over-predict (although these were the cohorts with only 80 and 45 animals respectively), and one which under-predicts (171 animals). The Alexandria data, totalling 6,200 observations, showed good agreement for all animal classes.

Given the wealth of the validation data (over 7,200 cow-years, which represents 42% of the size of the original data set), it was deemed appropriate to then include these data in a combined analysis, to give an overall final model. The re-fitted simplified sigmoidal relationship, for mature lactating F_n *Bos indicus*, is thus:

$CR(\%) = a/(1+e^{(-b(BCR-c))})$, where a = 55.1, b = 6.66 and c = 0.983 ………………(eqn. 6)

For the other breeds and animal classes, each of these three coefficients is incremented by further amounts, as listed in Table 5. Figure 5 shows the fitted effect for the 'age/lactation status' factor, and the breed differences are displayed in Figure 6.

(Table 5 and Figures 5 and 6 near here).

One further suggestion from team members was that, for conception rates in heifers, actual weights were more biologically important than BCR scores. For the heifer data, with 62 cohorts containing 5,200 cow-years, this alternative gave a marginal improvement. Equation (6) was re-fitted using just the heifer portion of our data, giving a five-coefficient model (models with extra coefficients either would not converge, or gave lower adjusted R^2 values), with an adjusted R^2 of 63%. Then, BCR was replaced by weights - taken as relative to SRW (as per the original GrazPlan formulation in equation 4), to factor in the different sizes between breeds. Here the adjusted R^2 stayed the same. For completeness, this equation using liveweights (at the middle of the mating period) is:

$CR(\%) = a/(1+e^{(-b(Weight/SRW-c))})$, where a = 37.0 for *Bos indicus* and European, 43.6 for British, or 49.0 for Africander; SRW = 520 for European breeds, 465 for recent tropical composites, and 425 otherwise; b = 22.4 and c = 0.614 …..………(eqn. 7)

Figure 7 shows the predicted pregnancy rates from this equation, for heifers experiencing a twelve-week mating period.

(Figure 7 near here).

Discussion

Whilst these analyses are based on good sample numbers, which were taken from locations across the area of interest, care must still be taken in generally extrapolating these findings. The base data came from research stations and collaborative producers' properties, and these would represent 'good management'. The biological rates applicable to the 'lower end' of producers can only be speculated upon. For example, undiagnosed or untreated disease problems will have a negative effect on the animals, resulting in higher mortalities and lower conception rates. Despite these reservations, the above equations can be taken as 'targets'. They are based on expert opinion and good sample numbers, and provided that no disease or other problems exist in a herd, should provide reasonable predictions of expected biological rates. Hence they are appropriate for adoption into rangelands simulation models, to then be used when investigating alternate management scenarios and strategies.

One further possible concern is the adaptation and evolution of the composite breeds in northern Australia. Recent unpublished data from the Co-operative Research Centre for Beef Genetic Technologies (G Fordyce, pers. comm.) show average weights for mature animals of around 510kg for Brahmans, and 545kg for 'tropical composite breeds'. These weights were from animals in middle body condition, fasted, and corrected for conceptus products – this being the usual definition of standard reference weight. This apparent problem, of 'shifting' SRW, is however a separate issue to the estimation of biological rates. SRW is a key parameter in these prediction equations, as it accounts for the effect of frame sizes of different breeds. After an appropriate SRW is determined for any class of animal, the prediction equations in this paper should remain relevant, as they incorporate the key driving factors of the system (primarily, body condition ratio). Hence it will be the responsibility of future model users to determine and then specify appropriate SRWs for each herd being studied.

Overall, the improved prediction equations for mortality and conception rates are based on a sizable database across northern Australia, agree with expert opinion, and give good accuracy of predictions. These models thus appear appropriate for general use in this region.

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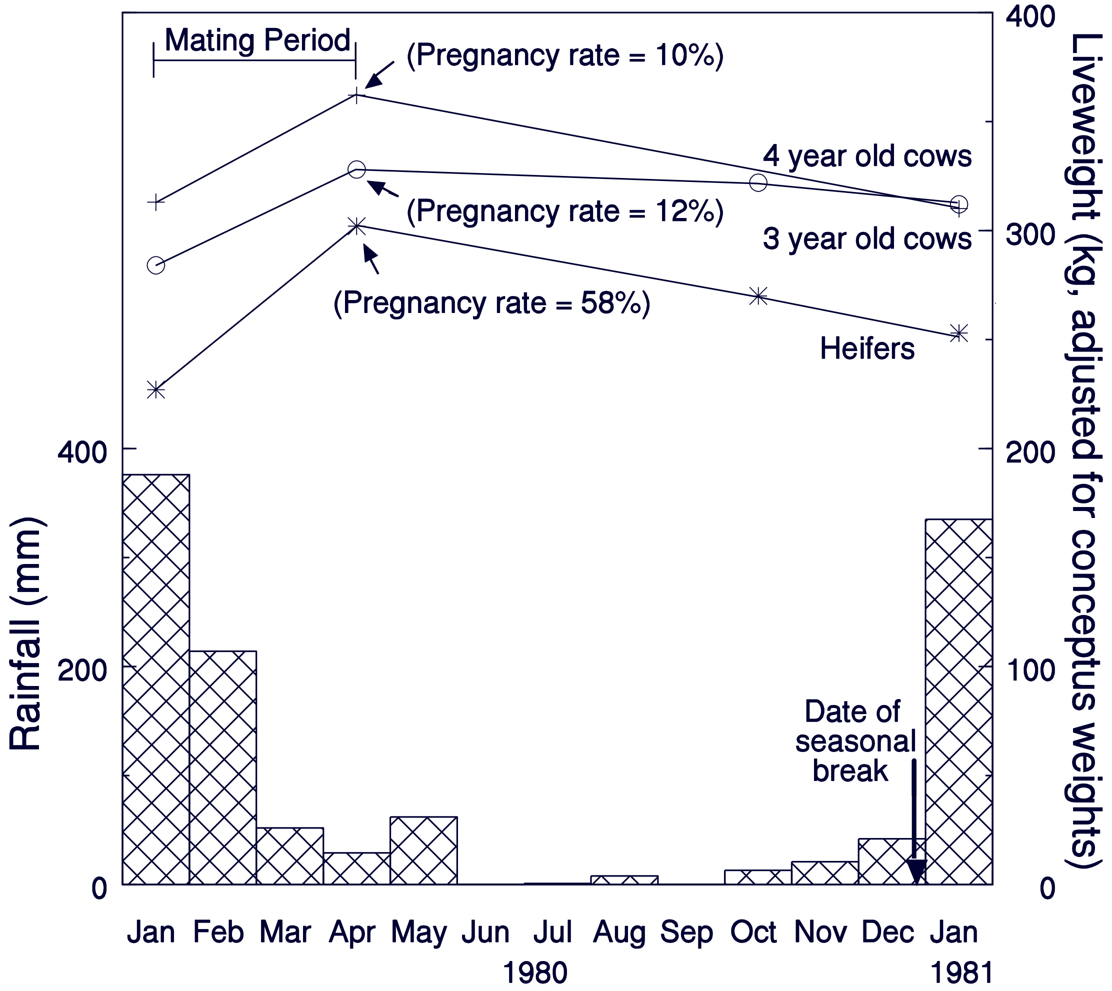

Figure 1. Rainfall (hatched bars) and liveweights (lines) for three age-cohorts of F_n *Bos indicus* crosses at Swan's Lagoon during 1980/81.

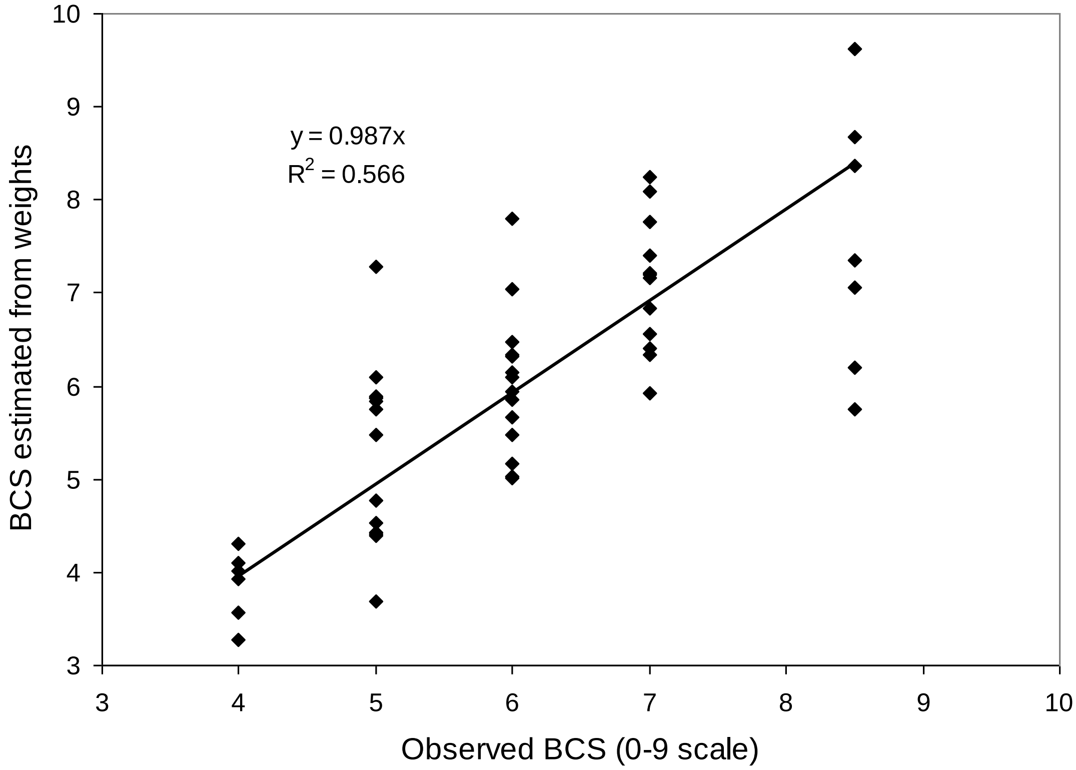

Figure 2. Validation of the relationship between observed and estimated body condition scores (BCS), for Alexandria Station data.

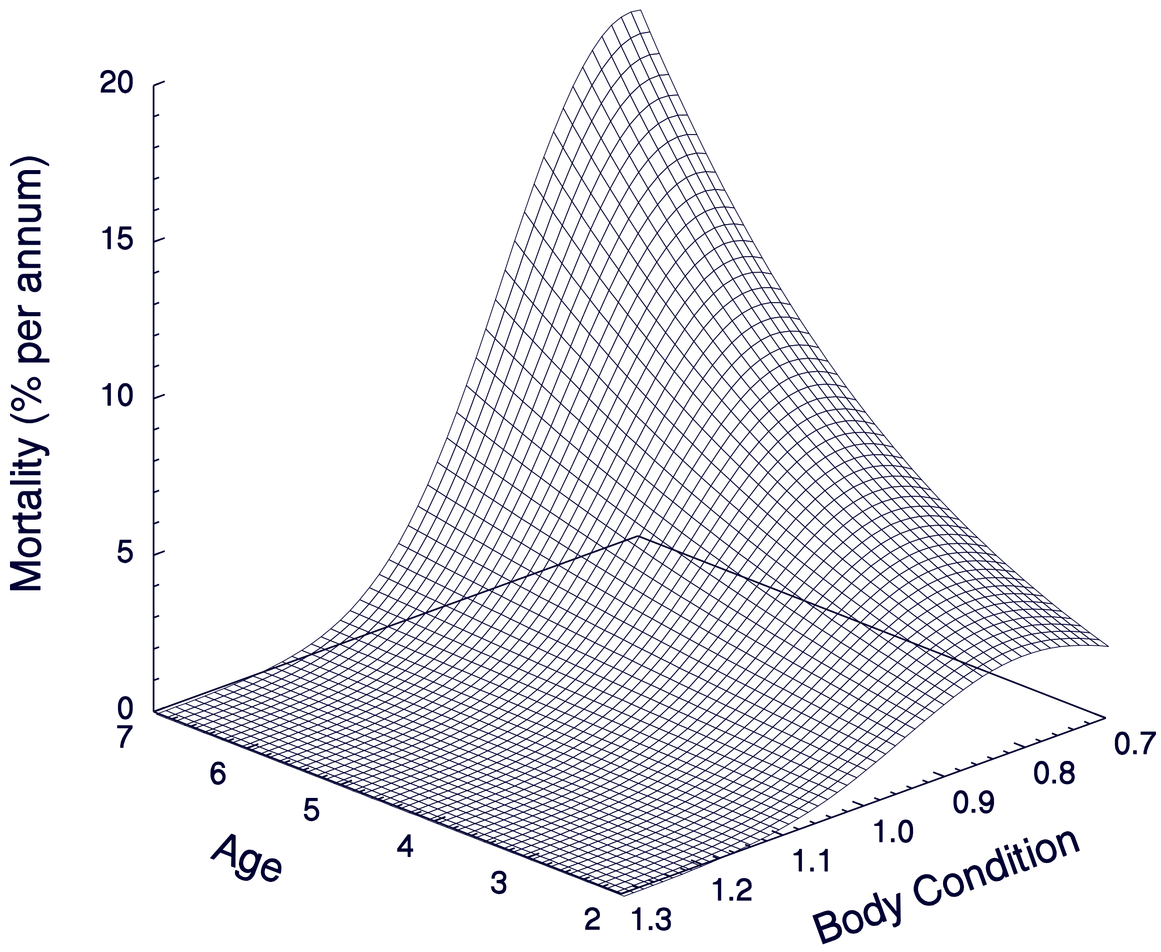

Figure 3. Fitted mortality surface for the interaction between age (years) and body condition (ratio).

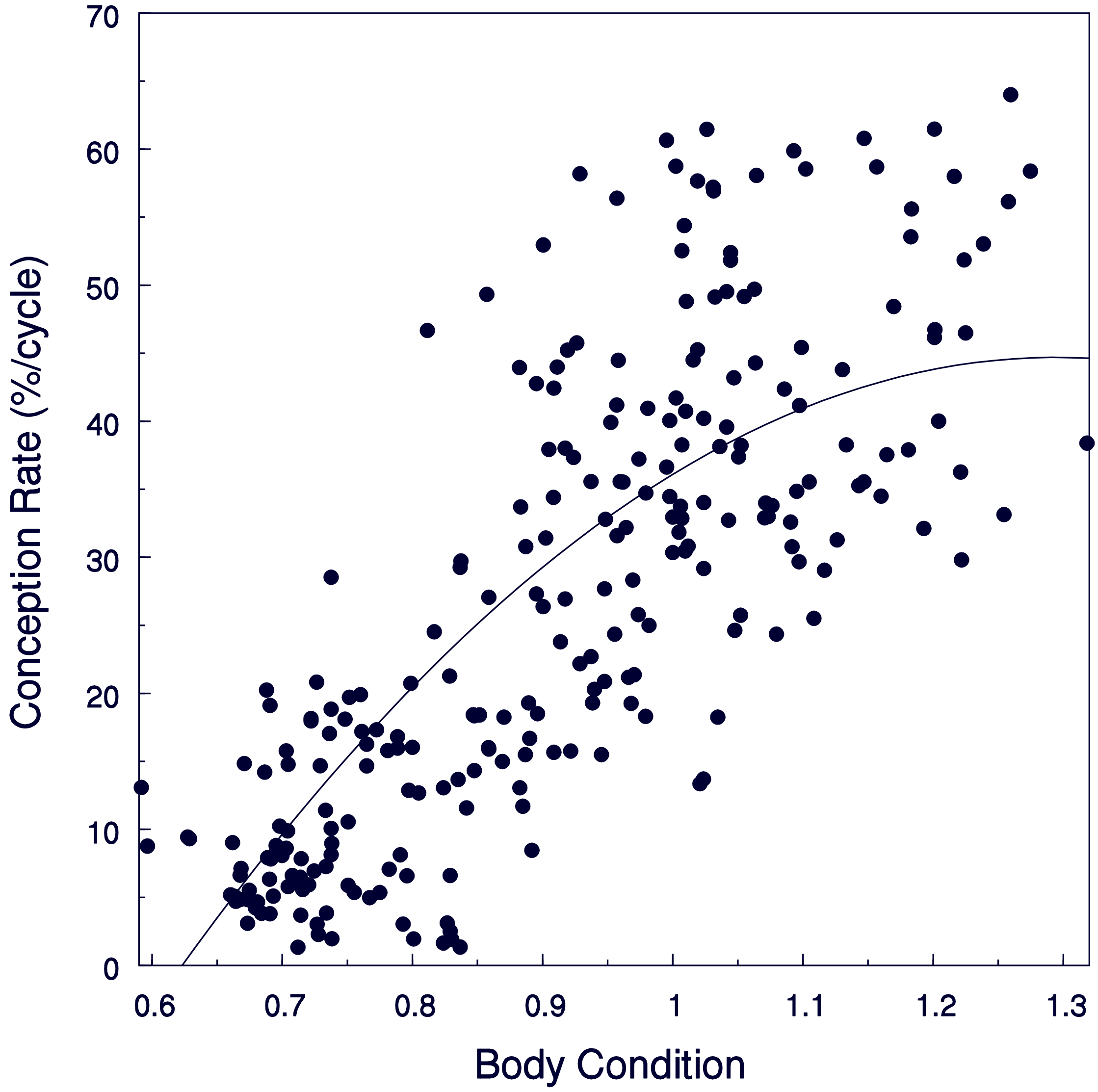

Figure 4. Fitted quadratic relationship and data for conception rate against body condition ratio.

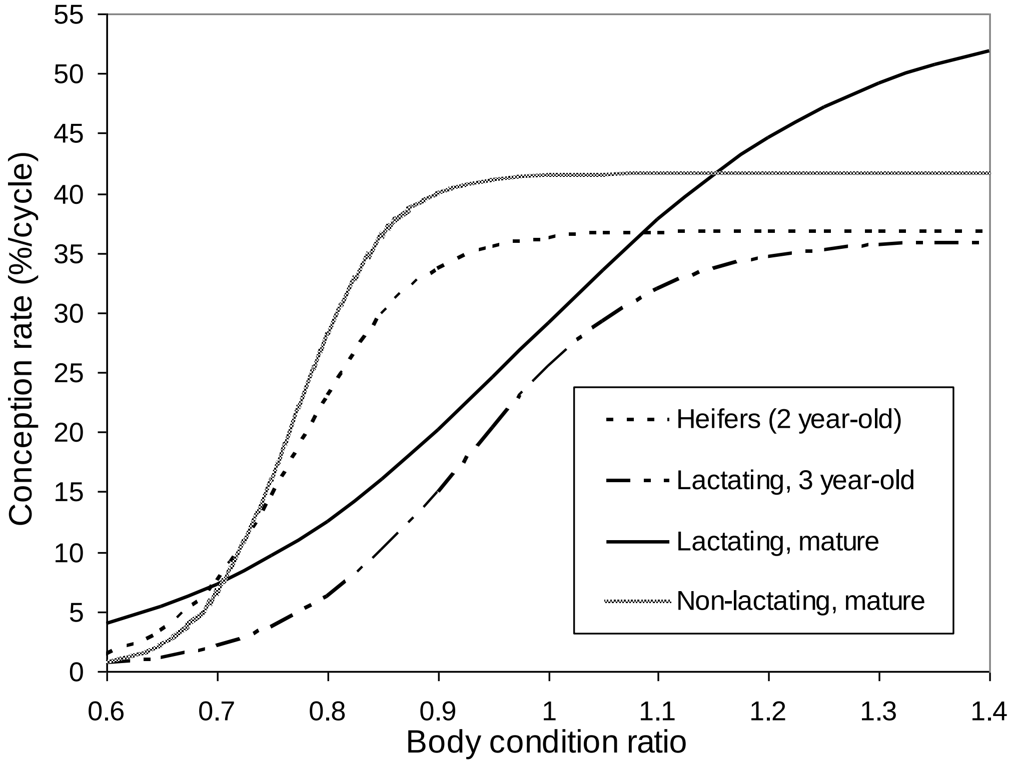

Figure 5. Fitted effects of age and lactation status on conception rates, illustrated for F_n *Bos indicus* breeds.

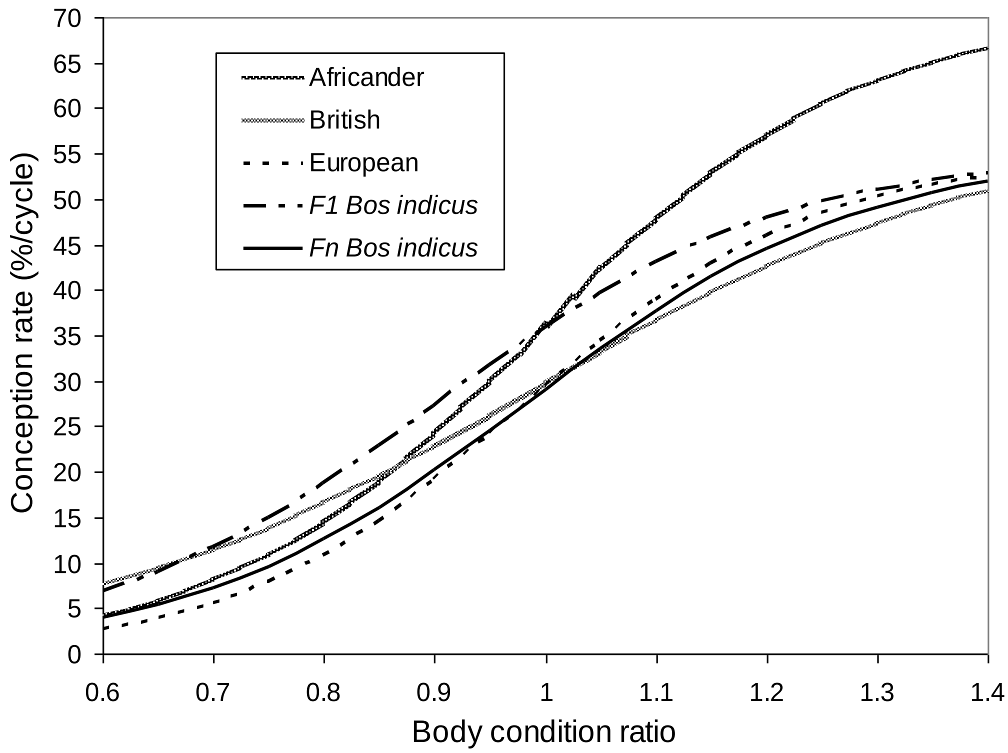

Figure 6. Fitted effects of breeds on conception rates, illustrated for lactating mature animals.

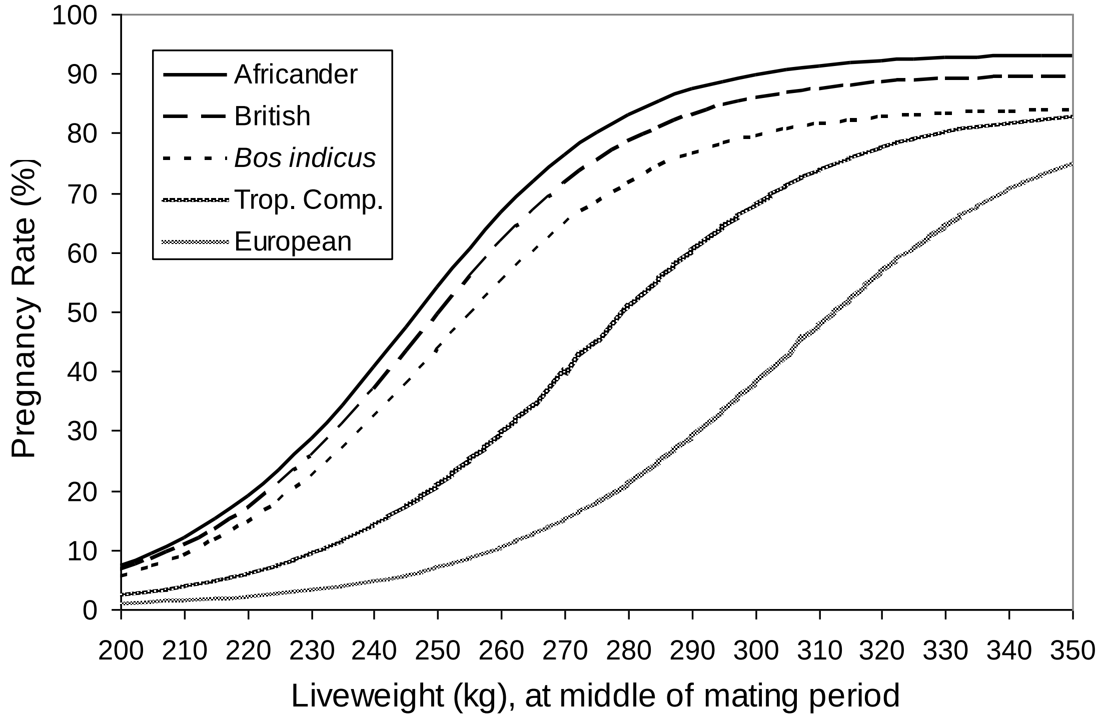

Figure 7. Effects of breeds on pregnancy rates vs. weights, for heifers under a twelve-week mating period.

Table 1. Breeder experiments - background and biological data (means and ranges).

Site	Kidman Springs	Mt Bundey	Fletcher-view	Swan's Lagoon	Belmont	Brigalow
Location	16°07'S, 130°57'E	25°02'S, 122°12'E	19°53'S, 146°11'E	20°05'S, 147°14'E	23°16'S, 150°26'E	24°50'S, 149°48'E
Years	1981-89	1980-84	1981-87	1972-86	1969	1980-85
Breeds#	I*x* (F_n)	I*x* (F_n)	I*x* (F_n)	I*x* (F_1,F_n)	I*x*,A*x*,Br	A*x*,Br,Eu
Observations (cow-years)	3,570	3,590	1,010	5,700	430	2,790
Mortality (%/yr) - ranges	11.3 0 to 25.6			2.5 0 to 6.7	3.2 1.5 to 6.0	2.3 0.3 to 11.8
Pregnancy rate (%/yr) - ranges	59 4 to 100	64 13 to 97	73 7 to 100	74 8 to 100	56 50 to 62	76 12 to 100
Conception rate (%/cycle) - ranges	10 1 to 28	20 2 to 45	32 2 to 60	31 2 to 62	30 26 to 34	38 4 to 65
Weight* (at start of year) - ranges	270 177 to 326	353 298 to 374	387 267 to 487	348 213 to 454		419 287 to 594
Weight* (end-of-wet) - ranges	319 223 to 404	333 258 to 410	437 296 to 522	393 268 to 498	435 423 to 443	459 330 to 643
Weight* (end-of-dry) - ranges	322 250 to 426			366 270 to 482	378 354 to 392	
Weight change^ ('wet') - ranges	9.1 -3.4 to 25.4	-0.1 -6.6 to 11.8	13.7 -2.3 to 27.7	18.8 0.4 to 48.8	18.8 17.2 to 19.8	17.3 -2.2 to 38.3
Weight change^ ('dry') - ranges	-5.4 -17.6 to 8.4			-0.1 -10.5 to 15.0	-7.3 -8.7 to -6.0	

I*x* = *Bos indicus* crosses, A*x* = Africander crosses, Br = British, Eu = European; F = filial generation.
* All cow weights (kg) are adjusted for conceptus products.
^Seasonal weight changes, in kg per month.

Table 2. Equivalence of body condition score (BCS) scale to body condition ratio (BCR).

Description of animal	BCS value (0-9 scale)	Nominal BCR range
Emaciated	0	0.5 - 0.6
Very poor	1	0.6 - 0.7
Poor	2	0.7 - 0.8
Backward store	3	0.8 - 0.9
Store	4	0.9 - 1.0
Forward store	5	1.0 - 1.1
Prime	6	1.1 - 1.2
Fat Prime	7	1.2 - 1.3
Fat	8	1.3 - 1.4
Over-fat	9	1.4 - 1.5

Table 3. Observed and predicted average mortality rates from alternate models, by animal classes.

Animal class	Observed mortality (%/yr)	Annual LWG (kg)	Predicted mortality (%/yr) from ENTERPRISE	Predicted mortality (%/yr) from GRAZPLAN
Heifers	2.8	34	21.4	4.2
3 year olds	2.7	19	25.1	4.2
Matures	11.2	10	34.6	4.2

Table 4. Observed and predicted conception rates (CR,%/cycle) for the validation data sets.

Source	Years	Animal class	No. animals	Obs. CR	Pred. CR
Schlink *et al*. (1994a)	1986 - 1989	Mature	570	10.1	9.3
Schlink *et al*. (1994b)	1992	Conventional	80	14.7	34.4
		Early-weaned	45	30.0	42.3
Unpub. (DEEDI)	1989	Late-weaned	195	37.0	36.7
		Early-weaned	171	52.8	31.5
Savage *et al*. (2004)	1997 - 2001	Heifers	2147	36.0	36.7
		Lactating 3-y.-o.	847	27.4	26.4
		Lact. mature	148	25.4	28.9
		Non-lact. mature	3030	40.8	41.5

Table 5. Increments to be applied to the coefficients of equation (6), for different animal classes and breeds.

	a	b	c
Animal classes - Heifers	-18.3	12.02	-0.211
Lactating three-year-olds	-19.1	5.47	-0.055
Nonlactating matures	-13.5	17.57	-0.213
Breeds – British	2.4	-1.76	0.002
Africander	15.2	0.35	0.009
F_1 *Bos indicus*	-0.10	-0.18	-0.081
European	-0.51	1.04	-0.002