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Testing and calibrating empirical models of cattle growth on native pastures in northern Australia

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Abstract: Models for simulating beef-cattle enterprises require valid predictions of key animal production responses, primarily liveweight change. For the investigation of climate change or alternate management scenarios, GRASP is the most commonly-used simulation model for pasture-based cattle production in northern Australia, and is used in association with HerdEcon and Enterprise for much of the work within the Northern Grazing Systems initiative. Whilst the pasture growth components are quite detailed and widely tested, by comparison the animal production modules of GRASP are quite rudimentary. For tropical native pastures, an annual liveweight change (LWC) model in GRASP was developed using data from Mt Bambling (south-eastern Qld), Galloway Plains (central coastal Qld) and Kangaroo Hills (north-eastern Qld).

The primary aim of this research is testing, extending and improving the predictions of the biological rates for beef cattle in northern Australia. Recent grazing trials across key agro-climatic regions were identified, and relevant data are currently being sourced. GRASP is to be parameterised for each of these trials, and simulated animal growth rates will be compared with actual data. In the first case-study, namely Mt Sanford in the Northern Territory, the preliminary liveweight data provided good agreement with the annual liveweight change model of GRASP. As further data sets are processed, however, it is expected that further model development and/or the identification of alternate predictive variables may be required, to address the many complexities and issues in northern Australian grazing systems such as temporal and spatial variability in the quality, quantity, utilisation and management of pasture and other vegetation, and management of animal nutrition, health and genotype.

To address the issue of extrapolating the annual LWC model across landtypes and climatic zones, a wide range of expert opinions regarding ‘typical’ turnoff weights and rates has been obtained during the Northern Grazing Systems Project and other workshops. Compared to the number of land-types and seasonal conditions in existing data sets, these expert-opinion estimates cover a much wider range of combinations. The key coefficients fitted to these estimated weight changes appear reasonable and consistent, and also match well with those in GRASP. They can thus be used to match with existing land types, or to extrapolate to new conditions, when using GRASP for the simulation of rangeland management options.

Whilst the accurate estimation of annual liveweight change is a necessary key step, in the real world tactical management decisions are typically made on a finer time-basis. These decisions include the use of forage crops, agistment or supplementation of the whole or parts of the herd, and rotational paddock grazing systems, etc. To incorporate these into an overall system model, a model for daily liveweight change is needed. The relevant logic and equations for the development of this model are listed, along with the coefficients as fitted using Solver in Microsoft Excel. Regarding liveweight changes, an acceptable degree of agreement was achieved across the base-data from native tropical pastures (887 average weights of cohorts of animals, across locations, management treatments and years). For ‘annual’ (> 10 month) liveweight changes the mean absolute error was 16 kg with an R^2 of 72%. Further model developments to be investigated will include the extension to sown pastures and other important beef production regions and land types. Aspects of animal performance to also be investigated include the estimation of supplementation and water-medication effects, the possible effect of age, and the extension of GRASP’s ‘growing steers’ models to other components of beef cattle herds (e.g. heifers and cows).

Keywords: *Grazing systems, GRASP, liveweight change, growth index*

1. INTRODUCTION

To be most useful, models of beef-cattle enterprises require simple but realistic predictions of key animal production responses such as liveweight change (LWC). GRASP (GRASs Production, McKeon et al., 2000) is the most commonly applied simulation model for pasture-based cattle production in northern Australia, and along with BreedCow/Dynama (Holmes, 1995), HerdEcon (Foran et al., 1990) and ENTERPRISE (MacLeod and Ash, 2001), underpins much of the work within the Northern Grazing Systems Initiative (a series of producer workshops, run by state and territory governments in collaboration with Meat and Livestock Australia). GRASP is primarily a soil moisture/pasture growth model for grazing systems in northern Australia. The liveweight change models in GRASP were well developed and tested with respect to the simulation of pasture growth for tropical and sub-tropical native pastures in Queensland dominated by black speargrass (*Heteropogon contortus*). The empirical animal production relationships used in GRASP have remained largely unchanged since 1995, and have not been tested against more recent grazing trials undertaken on different pasture communities in northern Australia.

The current version of GRASP includes two models of steer LWC. In Model 1 (McKeon and Rickert, 1984), daily LWC is calculated as a function of seasonal (91 days) potential LWC, and restrictions on animal intake calculated from pasture availability, expressed as pasture standing dry matter (SDM) and/or utilisation since the start of summer (e.g.1st December). In Model 1, seasonal potential LWCs are held constant and hence the effects of varying stocking rates and temporal climatic variability are only represented through variations in utilisation and pasture availability. The main use of Model 1 in GRASP is to simulate stocking rate effects by calculating daily pasture intake and subsequent effects on LWC, pasture yield and composition. The use of Model 1 in calculating daily LWC is described in detail in Section 3.

In GRASP LWC Model 2, annual LWC for black spear grass pastures (Hall et al., 1998) is estimated, using data from Mt Bambling (Brian Pastures Research Station, south-eastern Qld), Galloway Plains (central coastal Qld) and Kangaroo Hills (north-eastern Qld). Model 2 is –

$$\text{LWC (kg/head/day)} = 0.0603 + 0.00483 * \text{green-days} - 0.00206 * \text{utilisation} \quad (1)$$

where green-days is the % of the year when GRASP's growth index (GI) > 0.05, and
utilisation is the annual % utilisation of new growth by the simulated herd.

This relationship is modified in certain circumstances, for example when feed deficits occur (defined as SDM less than a specified quantity, typically 300 kg/ha for black spear grass communities), or when the pasture is burnt (here LWC is increased by a constant amount of 15 kg/head/year for black spear grass). As described later, the empirical coefficients in Model 2 can be calibrated for different grazing systems, wherever relevant annual liveweight gain data are available or can be estimated.

The other two key biological rates driving herd dynamics, namely fertility and mortality rates, fall outside the scope of GRASP. Past researchers in this field have used a range of methods to simulate biological rates for grazing scenarios. Gillard and Monypenny's (1988) early IFPS model assumed fixed values (dependent on the management strategy) for branding and mortality rates. Similarly, Foran et al. (1990) and Buxton and Stafford-Smith (1996) use lookup tables for the biological rates, with the values in these tables being largely based on expert opinion. The McIvor and Monypenny (1995) model for the Charters Towers region, based on earlier work of McCown et al. (1981), specifies empirical models for liveweight gain, and % branding and mortality. Importantly, these relationships are primarily based on 'green weeks' and '% utilisation', which are effectively the same parameters as used in the empirical relationships of GRASP. ENTERPRISE is a suitable economics and herd dynamics model which is typically run in conjunction with GRASP, and covers these aspects of simulated animal production. ENTERPRISE takes predicted LWC from the GRASP model, and uses LWC as the independent variable in empirical equations for fertility and mortality rates (MacLeod and Ash, 2001). Hence the accurate estimation of LWC within GRASP is most important for simulation studies in northern Australia.

A daily diet selection model was initially developed for GRASP at one paddock / location (Brian Pastures) to simulate daily diet nitrogen, intake and LWC. However, there were insufficient data to allow extrapolation to other locations and pasture types. The recent increasing availability of NIRS data will allow this more mechanistic approach to be renewed. Nevertheless there is an existing need for readily parameterized empirical models of LWC. To this end, our paper reports current studies on:

1) testing Model 2 for grazing trials at location/pasture types which were very different from coastal Queensland black spear grass zone;
2) parameterising Model 2 for application to other location/land/pasture types; and

3) developing a new daily LWC model from the biological understanding represented in Models 1 & 2.

2. TESTING THE ANNUAL LIVEWEIGHT CHANGE MODEL

2.1. Comparisons with Research Trials

Much effort has been (and will continue to be) put into experimental investigations of liveweight change at different locations under a range of managerial treatments. Whilst an initial project stakeholders' meeting identified many potential animal production data sets, most did not have existing GRASP parameterisations of soil moisture and pasture growth/SDM. Calibrating GRASP to any new situation requires either measurement or estimates of a large number of soil moisture and pasture parameters (>100). Sensitivity studies have indicated that, for LWC Model 2, key outputs from GRASP such as green-days are strongly influenced by the accuracy of daily rainfall records and parameterisation of available soil moisture ranges and tree densities. We report below the results from Mt Sanford grazing trial (north-western NT) involving 5-6 stocking rate treatments over five years. Parameterisation of GRASP was derived from measurements of paddock pasture SDM and soil moisture/pasture growth in pasture exclosures. Thus the calibration of GRASP was independent of LWC measurements.

Table 1 lists the regression parameters for the three sites which formed GRASP's original 'black speargrass' model (Model 1), plus the pooled regression. Also shown in Table 1 are the regression parameters for the independent Mt Sanford site.

Table 1. Parameters for the original three, plus one independent, sites

Site	Number of cohorts	R^2 (%)	Regn. coefficients for – utilisation	green days
Mt Bambling	16	32.6	–0.0012 $^-$	0.0064 $^+$
Galloway Plains	20	73.8	–0.0024 *	0.0018 $^-$
Kangaroo Hills	40	73.6	–0.0024 *	0.0042 *
'GRASP model' (3 sites)	*76*	*70.9*	*–0.0021* *	*0.0048* *
Mt Sanford	26	71.5	–0.0020 *	0.0049 *

* $P < 0.01$; $^+$ $0.05 < P < 0.10$; $^-$ $P > 0.10$

There is good consistency in the fitted slopes. The occasional non-significant and low values are not necessarily of concern, as they are more indicative of a lack of 'signal' in the data from that site. In particular, the smallest observed range in utilisation was at Mt Bambling, and similarly at Galloway Plains for green days. Statistically, the pooled test of the interactions between locations and the independent terms (utilisation and green days) was non-significant ($F_{12,162} = 1.34$; $P = 0.20$), indicating consistent responses at these locations. This will be an important test to be conducted as other targeted data sets become available.

The GRASP annual LWC model was formally tested against preliminary data from the Mt Sanford grazing trial, as shown in Figure 1. The fitted line is very close to, and not significantly different from, the y=x line. As expected, an analysis of the residuals (actual minus predicted weight changes) showed that there was no significant bias for the three sites which were used to formulate the original model, with mean biases of –3.4, +8.9 and –3.1 kg/year for Mt Bambling, Galloway Plains and Kangaroo Hills respectively. The data from Mt Sanford also matched the GRASP LWC model well, with a mean bias of +3.6 kg/year. Further data sets are currently being parameterised for GRASP. These data sets will include both the pasture communities that were used in

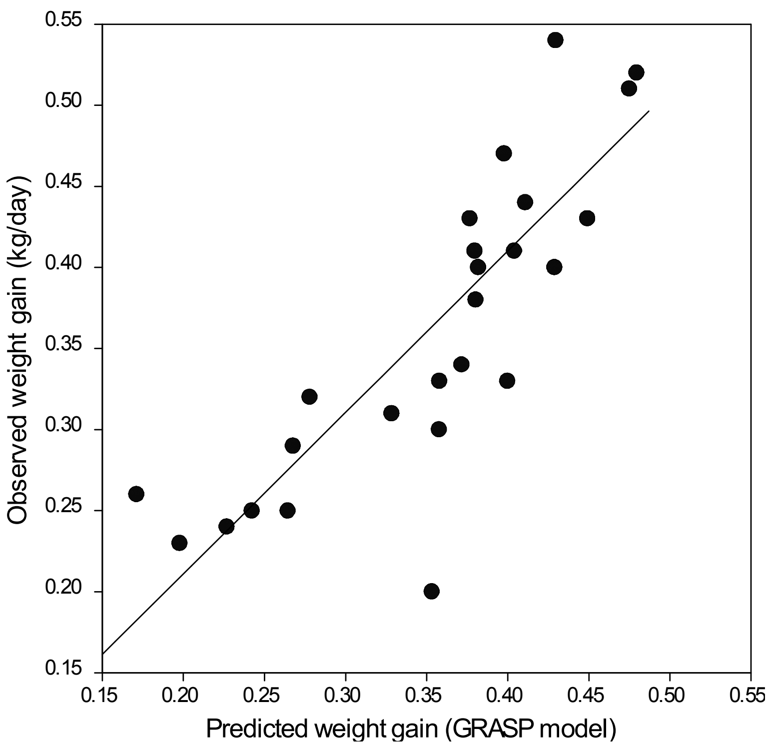

Figure 1. Annual gains and the fitted line for the Mt Sanford data.

the development of the GRASP LWC Model 2, as well as some other land and pasture types.

The combined effects of the coefficients in equation (1) confirm the importance of the availability of new plant growth (particularly green leaf) for diet selection and hence animal nutrition in native tropical pastures (e.g. McCown et al., 1981; McCaskill and McIvor, 1993). This is especially true in situations where the nutritional quality of old or senesced plant material is low, for example, during the dry and/or winter seasons in tropical and subtropical native grassland pastures. Hence equation (1) would not be expected to apply to situations where senesced plant material is of high quality (e.g., low rainfall, sown pastures) and/or when other sources of nutrition are available (such as pasture legumes, edible shrubs and trees). Preliminary analyses were conducted for an introduced buffel grass (*Cenchrus ciliaris*) pasture in small (approx 100ha) experimental paddocks at Alice Springs (central Australia), grazed at generally low utilisation rates of pasture growth (3.5 to 12% except for the driest year, when 107%) over five years. Annual rainfall (ranging from 87 to 671 mm) and green days (4.6 to 64.4%) were generally low compared to the more coastal regions. However, annual liveweight gains were remarkably high (ranging from 147 to 214 kg/hd/yr), indicating the availability of high-quality pastures even under these arid conditions.

Similarly, there is an obvious need for a model of LWC for annual forage crops and improved perennial pastures. These grazing systems generally have fertilizers applied or use increased legume composition, for increased productivity and better quality pastures. In recent times, many graziers with mixed enterprises such as cropping and beef production also tend to increasingly relying on high quality annual forage crops such as forage sorghum, forage oats, forage lablab for backgrounding and finishing cattle. High quality perennial legume-grass based pastures, such as butterflypea-grass, and leucaena-grass pastures are also becoming increasingly attractive, particularly in the Fitzroy basin. None of the currently available models have the capacity to predict dry matter productivity or LWC from these annual forages or perennial grass-legume mixed pastures in the northern region of Australia.

This issue is currently being addressed with collaborative activities involving the MLA-funded ‘High Output Forages’ project, and DEEDI-funded ‘Climate Q’. Field scale grazing trials have been set up to collect comprehensive data sets on these annual forages and perennial legume-grass pastures in central and southern Queensland. These data sets, along with some previous data, will be used to validate the predictive capacity of available models, in particular GRASP. The LWC component of GRASP (Model 1) is also currently being tested within APSIM, a well tested dynamic plant production model with various validated forage crops modules. The purpose of this exercise is to assess various available models and to develop a reliable LWC model which can be used for annual forage crops in the Queensland region.

2.2. Using Expert Opinion

For many of the targeted and important land types, no real-world data on LWC exist. Here, the coefficients for equation (1) can be derived from estimated liveweight changes, as provided by the combined opinions of experts. For most land types, experienced extension officers and land managers will have a good knowledge of the typical age of turnoff and weight of steers. These values provide one estimate of annual LWC for near-normal conditions: in this case, average utilisation which would be near to safe utilisation at near-average green days. They would also have an estimate of the range of turnoff weights during a dry period and a wet period. These estimates would 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 LWC 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. 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 LWC 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. However, with few degrees of freedom in the regression, small differences in estimates of green days or utilisation rates can lead to substantial differences in coefficients.

Another related method is to estimate the differences expected for a particular land type compared with the ‘average native pasture’ liveweight change model 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 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 be sensitive to runoff being well represented. Currently, the GRASP model uses an approach to runoff that was developed in particular land types in north-eastern Queensland. Improvements to this approach have been suggested by Owens et al. (2003), and Silburn et al. (2011) has published parameter values for an alternate approach for simulating runoff in grazing lands in Queensland.

Overall, this 'expert-opinion' approach appears worthwhile. As part of the Northern Grazing Systems and other workshops, weight changes were estimated for 22 different land-types. The fitted parameters are summarised in Table 2, and show some interesting trends, along with good agreement with the original research-data based GRASP coefficients. Overall, the equivalent of equation (1) fitted to these expert-estimated liveweight change data only resulted in an R^2 of 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 2. Regression parameters for models based on 'expert opinion' estimated LWCs

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

3. DEVELOPMENT OF AN EMPIRICAL DAILY LIVEWEIGHT CHANGE MODEL

For managerial systems where a single paddock is grazed by a draft of animals for 12 months, Model 2 has been applied, for example in assessments of the impact of climate variability. However, it is limited in that it cannot be applied 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. Model 1, whilst designed for multiple paddock situations, does not easily represent year-to-year or seasonal climatic variation in potential LWC. A preliminary investigation was therefore conducted to combine the attributes of Models 1 and 2. The four studies described in Section 2.1 included 887 measurements (average liveweights for cohorts of animals), with at least three per year for each location. The new daily LWC model (Model 3) was formulated as follows:

ptLWC = min (cf2, cf1 + cf3 * GI) (2)

where cf2 is maximum possible LWC (e.g. 1.0 kg/day), cf1 is LWC when GI is zero (e.g. –0.2 kg/day), cf3 is daily GI required for maximum LWC (e.g. 0.30), ptLWC is potential LWC(kg/day), and GI is the daily pasture growth index (0–1) calculated by GRASP.

Following McKeon and Rickert (1984),
ptIntake = (ptLWC + 1.058) / 0.304 (3)

where ptIntake is daily dry matter intake (kg/day).

Restrictions on intake are calculated as a function of utilization (R1) and SDM (R2):

R1 = min (1.0, cf4 + cf5 * utilisation) (4)

where utilisation = (accumulated intake per ha since start of growing season e.g. 1st Dec) / (accumulated pasture growth since start of growing season) (5)

R2 = min (1.0, SDM / cf6) (6)

LWC = 0.304 * ptIntake * min (R1, R2) – 1.058 (7)

Daily intake per ha, pasture growth, SDM and GI were simulated by GRASP using Model 1 with typical values for cf4, cf5 and cf6 of 1.05, –0.30 and 300 kg/ha respectively. When the annual Model 2 is expressed in the general form of Model 3 (Equation 4), cf5 was found to be –0.145. Model 3 parameters were optimised using Solver in Microsoft Excel, adopting the usual statistical method of minimising the sum of the squared residuals (observed minus fitted liveweight). Model 3 was sequentially developed, with the overall degree of fit, estimated coefficients, and distributions of the residuals being checked at each step.

Firstly, seasonal patterns were investigated for cf1-6, and cyclic (cos) functions were adopted for cf1 and cf3. Next, the overall constant start of the growing season (across all years) was varied, with an optimal date of 11th December. Then, heuristic rules were developed to divide each year into three discrete periods representing the main seasonal effects on LWC in tropical and sub-tropical pastures – nominally the main pasture growing season, the dry or winter season, and the break (of dry/winter) season. The rules for changing seasons were based on the 30-day running mean of GI, with the cutoffs (again) being optimised using Solver. The dry season changes to break when mean GI climbs past 0.33, and then into the growing season when it exceeds 0.48. The growing season then changes back to 'dry' when the mean GI drops below 0.23.

The fitted values for cf2, cf4, cf5 and cf6 were 0.84, 1.0, –0.20, and 23, respectively. The cyclic-curve values varied across the year between –0.51 and 0.23 for cf1, and 0.07 to 0.50 for cf3. The combined effects of these parameters on estimated LWC are shown in Figure 2. This indicates, not unexpectedly, that daily LWC has generally low sensitivity to daily variation in the pasture growth index during the main growing season, unless GI is unusually low. In contrast, there is greater sensitivity to variation in the growth index during winter and spring. This is when senesced tissue is likely to be of low nutritional value, and indicates that small amounts of new pasture growth have larger impacts on animal production during this time. Further model development will evaluate the extent that other parameters such as maximum LWC (cf2) vary with time of year, or a representation of seasonality (i.e. growing, dry and break seasons) based on calculated pasture growth index.

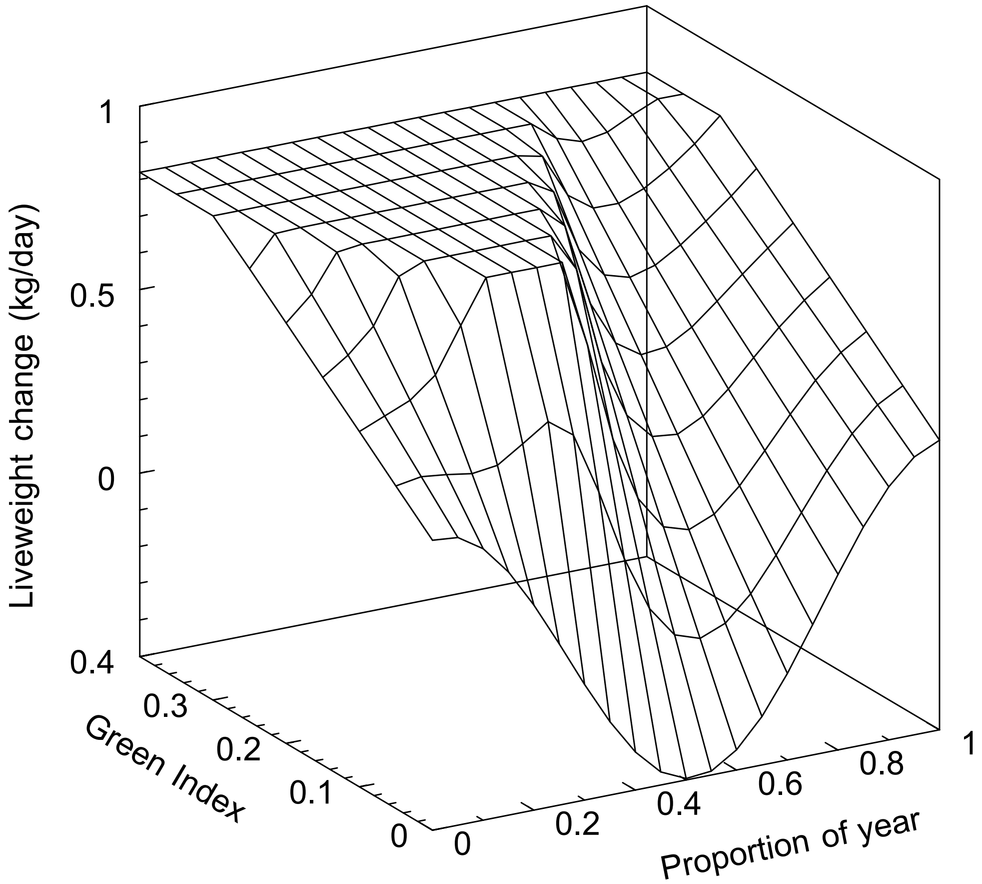

Figure 2. Predicted daily liveweight change *vs* time of the year (0 = 1st January) and GRASP's growth (green) index.

The adopted LWC model fitted the observed liveweight data quite well. The mean absolute error (weighted by the numbers of animals in each cohort) for all 887 observations was 16.2 kg. Interestingly, for the 186 'annual' (> 10 month) weight gains, the mean absolute error was 15.8 kg (which is 13% of the average 'annual' weight gain of 121 kg), and the degree of fit (R^2) against the observed weight changes was 72%. This level of accuracy would appear useful for model use, however this daily LWC model is yet to be tested against independent data sets.

Fundamental to the development of empirical animal production models is, of course, recognition that the sources of variation in liveweight gain are yet to be comprehensively documented. Some progress has been made (Hall et al., 1998) but there remains a major task of documenting expert opinion and producer experience to parameterise general models that include climatic, land type and managerial factors. Further animal aspects to be investigated in our research include the estimation of supplementation and water-medication effects, the possible effect of age, and the extension of GRASP's 'growing steers' models to heifers and cows.

4. DISCUSSION AND CONCLUSIONS

This research suggests that a high proportion of annual variation in LWC from tropical and subtropical native pastures can be accounted for by empirical models representing climatic and managerial effects. However, extrapolation to drier environments such as central Australia may require different approaches to represent the higher nutritional value of senesced SDM. The general form of the annual model was parameterised for different locations and land types using expert opinion. This approach may also allow the inclusion of other sources of variation in annual LWC (e.g. pasture burning, supplementation).

The results suggest that a general daily LWC model (Model 3) could now be implemented in GRASP, combining the attributes of existing Models 1 and 2. Model 3 was parameterised for a wide range of climate zones and managerial treatments – cleared and uncleared native pastures, and a wide range of pasture utilisation rates. Further developments will involve the application to other important beef production regions, including the low rainfall zones of central Australia, productive fertile landtypes such as the Mitchell grasslands, and sown/naturalised pastures such as buffel grass.

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